Support material permitted: attached collection of formulas.

Write on each and every page:
Code and name of the course
Name and student number
Department and date
Return this text together with your solutions and the collection of formulas.

1.

a) Explain why, if 1-dim steady heat transfer occurs, the temperature profile inside a wall is linear. Use the appropriate formulas and physical principles.
How does the temperature profile change in a transient process, what is the role of the Fourier number?

b) During winters, freezing of water in underground pipes is a major concern. Fortunately, the soil remains relatively warm thus protecting the water from subfreezing temperatures.
Now, a pipe design task: The temperature of the ground surface 15°C suddenly drops to -10°C, and stays constant for a very long period. Determine the freezing depth as a function of time for

- 10 days
- 30 days
- 60 days

so that the minimum burial depth can be determined to prevent the pipe from freezing (0°C).
The average soil properties are $k = 0.4\ w/m°\text{C}$ and $\alpha = 0.15 \times 10^{-6}\ m^2/s$, $T_i = 15°C$.

2.

a) Dry air with inlet temperature T_{in} =7°C is flowing inside a circular aluminum air duct of length L=12m and diameter d=50cm. The surface temperature of the pipe T_s =45°C is constant and uniform, and we neglect its thickness for simplicity.
How much should the mean velocity V_m of the air be, in order to obtain an outlet temperature T_{out} =20°C? Choose the material properties by using approximated T values, and assume full turbulence.

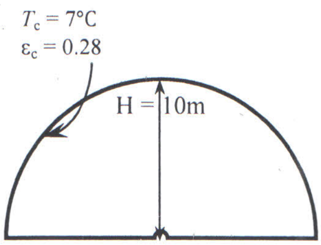
b) The heat transferred between room air and the surface of an internal wall by natural convection can be large.
Compute this amount for 24h, if the room wall is 2.5m high and 5m long, in two cases:

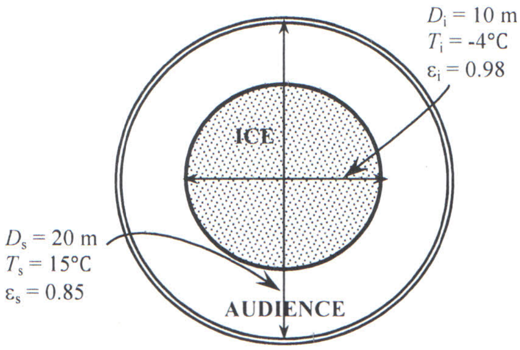
- surface temperature $T_1 = 35°\text{C}$ and room temperature $T_{in_1} = 25°\text{C}$
- $T_2 = 10°\text{C}$ with room temperature $T_{in_2} = 20°\text{C}$.

3.

a) List *all* the (thermo)physical processes to which a double pane window of our department is subjected, both inside its structure and on the external surfaces. Comment on the effect of internal ventilation, external wind and glass glazing.

b) Design problem: study radiation heat transfer in an ice hall during night time, i.e. when the lights are switched off.





Assume that the ceiling is dome-shaped, with emissivity $\varepsilon_c = 0.28$, height H=10m and average temperature $T_c = 7°C$. The circular ice rink has diameter $D_i = 10$m, $T_i = -4°C$ and $\varepsilon_i = 0.98$.
The audience's sitting area, between the rink's edge and the dome's walls, corresponds to $D_s =$ 20m, $T_s = 15°C$ and $\varepsilon_s = 0.85$.

Compute the <u>net</u> heat rates between
i) the dome and the ice rink
ii) the dome and the sitting area
Hint: use the properties of the view factor. The surface of a circle is $A_c = \pi r^2$ and that of a sphere is $A_s = 4\pi r^2$.

4.

a) Discuss briefly the analogy between heat and mass transfer by commenting on the relevant formulas.
b) A multi-layered roof is designed as in the Table below, where dimensions and material values are listed.
Determine if the structure has <u>condensation risk</u> under the following conditions:
Indoor T_{in}=20°C, RH_{in}=65% and $h_{in} = 6\ W/m^2K$; outdoor T_{out}= -8°C, RH_{out}=50% and $h_{out} = 32\ W/m^2K$.

Material	Thickness (cm)	k (W/mK)	R_v (sm^2Pa/ng)
Outdoor			0
Reinforced concrete	3	1.7	0.19
Cement mortar	1	0.9	0.012
Concrete	45	0.2	0.03
Cement mortar	2	0.9	0.02
Gypsum	1	0.17	0.70
Indoor			0

5.

a) Define the *implicit* and *explicit* numerical methods for studying time-dependent heat transfer, comparing them from the viewpoint of stability. How can we increase the precision?

b) Consider steady two-dimensional heat transfer in a long solid bar of square cross section in which heat is generated uniformly at a rate $\dot{q} = 5\ W/m^3$. The size of the bar is 0.4m x 0.4m, and its thermal conductivity is $k = 5\ W/mK$. All four sides of the bar are subjected to convection with the ambient air at T_∞= 25°C with heat transfer coefficient $h = 7\ W/m^2K$.

Using the finite difference method with a mesh size $\Delta x = \Delta y = 0.2m$, find the temperatures at all the nine nodes. Exploiting the evident *symmetry* of the system will simplify your task enormously.