Thermal Modelling and 3D Building Information Modelling (BIM)
22CVP310

Semester 1 2022-23 Online Short-window Exam paper

This is an online short-window examination, meaning you have a total of **2 hours plus an additional 30 minutes** to complete and submit this paper. The additional 30 minutes are for downloading the paper and uploading your answers when you have finished. If you have extra time or rest breaks as part of a Reasonable Adjustment, you will have further additional time as indicated on your exam timetable.

It is your responsibility to submit your work by the deadline for this examination. You must make sure you leave yourself enough time to do so.

It is also your responsibility to check that you have submitted the correct file.

Exam Help

If you are experiencing difficulties in accessing or uploading files during the exam period, you should contact the Exam Helpline. For urgent queries please call **01509 222900**.

For other queries email examhelp@lboro.ac.uk

You may handwrite and/or word process your answers, as you see fit.

You may use a calculator for this exam.

Answer **THREE** questions.

All questions carry equal marks.

Continues/…

1) a) The one-dimensional finite difference solution to the transient conduction equation is given in the equation below where symbols have their usual meaning.

$$\theta_{m+1,n} = \theta_{m,n}(1 - 2K) + (\theta_{m,n+1} + \theta_{m,n-1})K$$

where $K = (\Delta t / \Delta x^2)(k / \rho C_p)$

A 0.24 m thick solid concrete wall has a thermal conductivity of 1.1 W/mK, a specific heat capacity of 1.5 kJ/kgK and a density of 1600.0 kg/m^3. Assume three equally-spaced layers through the wall, and a time-step of 500 seconds.

i) If the wall is initially in a thermal steady state condition, with its internal face at 15°C and its external face at 0°C, determine the initial temperature profile through the wall at each relevant position.

[6 marks]

ii) If the internal face of the wall is suddenly raised to, and held at, a temperature of 21°C while the external face is held at 0°C, use the finite difference technique to determine the temperature profile through the wall after 2000 seconds.

[10 marks]

b) Figure Q1 gives the model residual equations for a duct system with a fan speed controller. In the diagram, ‘m’ refers to mass flow rate, ‘p’ to pressure and ‘n’ to a control signal. The subscripts ‘i’ refer to inputs and ‘o’ to outputs.

i) Identify a unique set of linking variables and draw the corresponding information flow diagram.

[5 marks]

ii) State the number of residual equations, list the variables and select a viable set of boundary variables.

[4 marks]

iii) Write the adjacency matrix and check that the model is well-posed.

[5 marks]

Question 1 continues/…

iv) Identify any equations that can be solved independently of the other equations.
[3 marks]

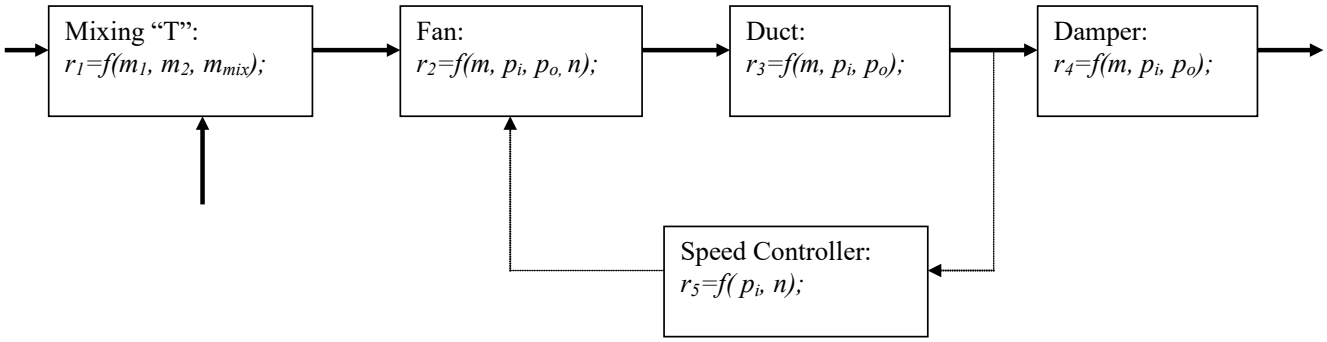

Figure Q1: HVAC System Model Residual Equations

2) a) Lumped parameter models can be classified as "grey-box" models. Explain why this is the case.
[7 marks]

b) Figure Q2(b) illustrates a lumped parameter model of a multi-layered wall construction. R_a and R_b are thermal resistances, and C the thermal capacitance. r_1, r_2, and r_3, and c_1, c_2, and c_3, are the thermal resistance and capacitance of each layer of the construction. For each scenario i) to iii) below, explain whether the temperature node T_w, would be positioned closer to surface (a) or (b).

i) $r_1 = r_3$; $r_2 \neq r_1$
$c_1 = c_3$; $c_2 \neq c_1$
[3 marks]

ii) $r_1 > r_2 > r_3$
$c_1 = c_2 = c_3$
[4 marks]

iii) $r_1 = r_2 = r_3$
$c_1 < c_2 < c_3$
[4 marks]

Question 2 continues/…

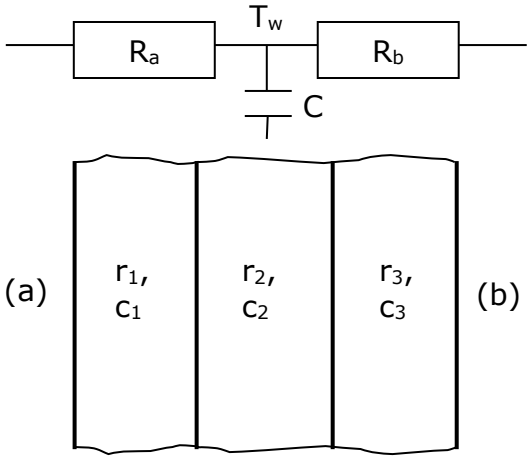

Figure Q2(b), Three Layer Wall and Lumped Parameter Model

c) The Biot number is equal to the conductive resistance divided by the surface convective resistance. Explain why this ratio can be used to test the validity of a lumped-parameter model.

[6 marks]

d) Figure Q2(d) illustrates a simple lumped parameter model for the dynamic response of an external wall and air in a room. T_o is the temperature of the external air, and T_a the temperature of the air in the room, and T_w the temperature at some point in the wall. Q is the rate of heat input directly to the air in the room. The symbols R are thermal resistances, and C thermal capacitances.

Give the difference equations for the node temperatures T_w and T_a. Marks will only be awarded when a full explanation of the principles applied in developing the equations are given.

[9 marks]

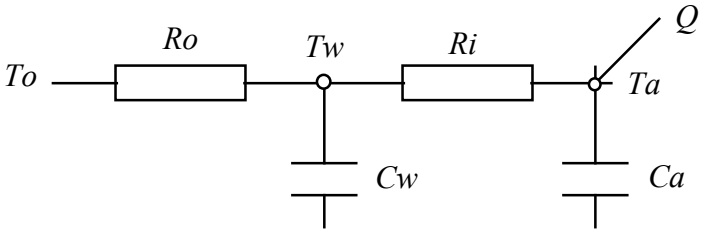

Figure Q2(d), Simple Lumped Parameter Model

Continues/…

3) a) A building has a single thermal zone measuring 10 m x 8 m x 3 m.

The thermal zone air has the following heat gains and losses:

- Convection heat gain from a radiator at a constant value of 2,000 W
- Convection heat loss to the internal surfaces at a constant value of 500 W

Given the air temperature of the thermal zone at time t = 0 is 15 °C, estimate how long it will take for the air temperature to reach 20 °C.

[8 marks]

b) A building has a single thermal zone measuring 6 m x 7 m x 2.5 m.

The zone has a single window measuring 5 m x 1.5 m with a total hemispherical solar absorptivity of 0.1 and a total hemispherical solar reflectivity of 0.1.

Given the window receives direct solar irradiance of 500 W/m^2 and diffuse solar irradiance of 100 W/m^2, estimate the solar irradiance in W/m^2 incident on the ceiling of the zone assuming an area-weighting approach is used.

[8 marks]

c) In your own words, provide a full description of the use of weather files in building simulation studies. This should include:

- A definition of a weather file.
- The typical contents and structure of a weather file.
- Why a weather file is needed for building simulation.
- The influence of external conditions on the heat flows in a building.
- The limitations of weather files.
- The choice of the weather file by the modeller.
- The sources of weather files.

[17 marks]

Continues/…

4) a) A wall has a surface temperature of 18 °C and a height of 2.5 m.

The zone adjacent to the wall's surface has an air temperature of 21 °C.

i) Calculate the convection coefficient of the wall using the Alamdari and Hammond correlation.

[6 marks]

ii) What is the percentage difference between the convection coefficient of part a) i) and the CIBSE Fixed Convection Coefficient used in the IES software?

[2 marks]

b) A wall (Wall 1) has a surface with total longwave hemispherical emissivity of 0.7, an area of 10 m^2 and a surface temperature of 19 °C.

Calculate the emitted power in Watts from the surface in the form of longwave radiation.

[4 marks]

c) A second wall (Wall 2) is located at a distance away from Wall 1. Wall 2 has the same characteristics as Wall 1 (as given in part b). The view factor between the two walls is 0.6.

Calculate the amount of longwave radiation from Wall 1 that will be absorbed by Wall 2.

[4 marks]

d) In your own words, describe the fundamental approaches to solar radiation absorption by internal surfaces, as carried out in the IES ApacheSim algorithms. This should include:

- The concepts of solar radiation
- The meteorological variables required
- The definition of any material characteristics required
- The calculation processes for solar radiation gains in buildings
- The different treatment of direct and diffuse solar radiation
- The key heat transfer processes which are impacted by solar radiation
- Any limitations and assumptions used by the software in its calculations

[17 marks]

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