Loughborough University

THERMAL MODELLING AND 3D BUILDING INFORMATION MODELLING (BIM)

(21CVP310)

Semester 1 2021-22 (1b) Exam paper

This is a (1b) online examination, meaning you have a total of **2 hours plus 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 helpdesk. 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 any calculator (not just those on the University's approved list).

Answer **THREE** questions.

All questions carry equal marks.

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1 a) Tables Q1(a1) and Q1(a2), respectively, give data about a wall and the relevant climate conditions. The wall is of area 50m^2 and the values for internal and external surface thermal resistance are 0.11 and 0.045 m^2KW^{-1}, respectively. The decrement factor is 0.6 and the time lag is 7.5 hours.

i) Calculate the peak heat flow rate through the wall, and its time of occurrence. [10 marks]

ii) What would be the heat flow rate through the wall and its time of occurrence if thermal capacity effects are neglected? [7 marks]

Question 1 continues/…

Table Q1(a1): Wall Thermal Properties

Layer	Thickness (m)	Thermal Conductivity ($Wm^{-1}K^{-1}$)
Brick outer leaf	0.15	0.84
Insulation	0.10	0.025
Concrete inner leaf	0.20	0.52

Table Q1(a2): Climate Data

Variable	Value
Mean sol-air temperature	23.5°C
Peak sol-air temperature	38.0°C at 14.00 hours
Mean internal air temperature	19.5°C

b) Write a report which discusses the following three methods for building simulation: the steady-state method; the admittance method; and the finite difference method. The report should be in your own words and any quotes from other sources should be fully referenced.

Your report should include:

- A description of the three methods and their fundamental assumptions.
- An evaluation of the different approaches taken by the three methods to calculate the heat flow and energy consumption in buildings.
- The strengths and weaknesses of the three different methods for evaluating potential building design.
- A discussion of the applications which are best suited to the three different methods.

[16 marks]

Continues/…

2 a) A 0.21m thick solid concrete wall has a thermal conductivity of 1.3 $Wm^{-1}K^{-1}$, a specific heat capacity of 1.2 kJ $kg^{-1}K^{-1}$ and a density of 1800.0 kg m^{-3}. Assume three equally-spaced layers through the wall, and a time-step of 600 seconds.

i) If the wall is initially in a thermal steady state condition, with its internal face at 24°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 30°C while the external face is held at 0°C, use the finite difference technique to determine the temperature profile through the wall after 2400 seconds. [11 marks]

b) You work for a building services consultancy company and a client asks you to carry out a building simulation study for a new building design. Before you start this work, the client asks you to write a quality assurance report on your approach to building simulation.

Provide this quality assurance report here. This should include your steps and approach to ensure the model is set up correctly and that the client can have a high degree of confidence in the simulation results. Clearly describe the strengths and weaknesses inherent in your approach and any assumptions used.

The report should be in your own words and any quotes from other sources should be fully referenced. Your report could include, but is not limited to, the following factors:

- Choice of software tool
- Choice of model inputs
- Use of model assumptions
- Model validation
- Ensuring the model results are realistic
- Procedures to reduce errors
- Simulation strategy for testing design options
- Analysis of simulation results
- Communication of results

[16 marks]

Continues/…

3 a) Figure Q3 gives the model residual equations for a HVAC sub-system model in which "T" is temperature, "M" is mass flow rate and subscripts "a" and "w" relate to air and water.

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]

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

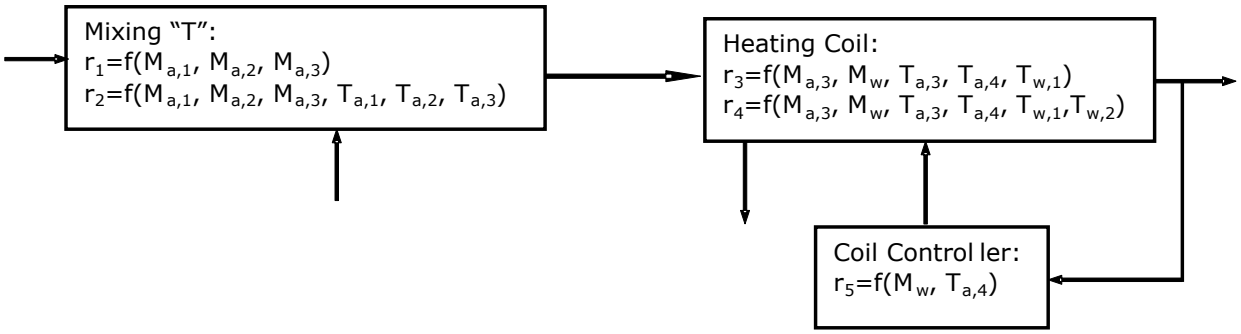

Figure Q3: HVAC System Model Residual Equations

b) Write a report on dynamic thermal models for building simulation.

The report should be in your own words and any quotes from other sources should be fully referenced. Figures and illustrations can be included to describe the key concepts.

The report should be aimed as an introductory text for the non-specialist reader and could include, but is not limited to, the following topics about dynamic thermal models:

- Their theoretical background and fundamental equations used.
- The heat transfer processes which they model.
- The key assumptions used and the potential implications of these assumptions.
- Their use and application in building design.
- Their strengths and weaknesses.
- Their implementation within the IES software and the ApacheSim calculation engine.

[16 marks]

Continues/…

4 a) A lumped parameter model can be classified as a “grey-box” model. Explain the reasons for this classification and in doing, the potential applications of lumped-parameter models. [6 marks]

b) Explain a theoretical metric that can be used to validate the potential accuracy of a lumped-parameter model. [7 marks]

c) Figure Q4, illustrates a simple lumped parameter model for the thermal response of a single building zone. ‘R’ represents thermal resistance, ‘C’ thermal capacitance, and ‘T’ temperature; ‘Q’ is a direct heat input (or loss) to the zone. Temperature subscripts ‘o’, ‘w’, and ‘a’, correspond to the outside air temperature, wall temperature, and zone temperature.

i) Use an energy balance on each node to write the difference equations for the model. [6 marks]

ii) Explain what resistance path R_3 represents and how its value can be calculated. [6 marks]

iii) Give an equation for the time constant for the change in temperature T_w resulting from a step change in temperature T_a. [4 marks]

iv) Explain, and give an equation for, the part of the model that represents the steady-state heat transfer coefficient for the wall (the “U” value for the wall). [4 marks]

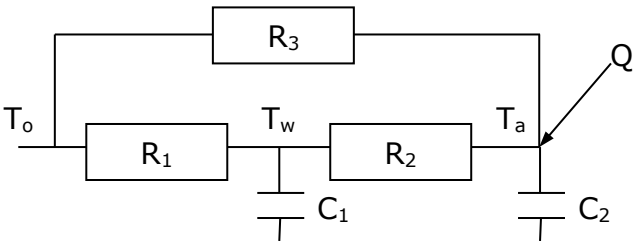

Figure Q4. Single Zone Lumped Parameter Model

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