Loughborough University

# Thermal Modelling and 3D Building Information Modelling (BIM)
## 24CVP310

Semester 1 2024-25 In-Person Exam Paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Answer **THREE** questions.

All questions carry equal marks.

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1) a) Write a description of dynamic thermal models for building simulation.

Figures and illustrations can be included to describe the key concepts.

The description 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]

b) Draw an illustrative diagram of the heat transfer processes which form the energy balance for the internal surfaces of buildings. The diagram should include a wall with an internal surface and include six thermal exchange processes.

Also state the equation which links these six heat transfer processes.

[8 marks]

c) The following equation states the zone energy balance for buildings, where the symbols have their usual meaning.

$$\left[m_a c'_P\right]_z \cdot \frac{dT_z}{dt} = \sum q_{conv,i\rightarrow z} + \sum q_{conv,source\rightarrow z} + \sum \left(\dot{m}_a \cdot c'_P\right)_{inf} \cdot (T_{oa} - T_z) + \sum \left(\dot{m}_a \cdot c'_P\right)_{t\text{–}in} \cdot (T_{t\text{–}in} - T_z) + \left(\dot{m}_a \cdot c'_P\right)_{SA} \cdot (T_{SA} - T_z)$$

State the meaning of each variable in the equation, providing a full definition and the associated units.

Also state the key assumptions that are made when forming this equation.

[9 marks]

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

[7 marks]

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

[8 marks]

c) i) Figure Q2(c) 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 from internal heat gains and the HVAC system. 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.

[13 marks]

ii) Redraw figure Q2(c) to include a resistance that represents the energy transfer due to infiltration and ventilation air flow.

[5 marks]

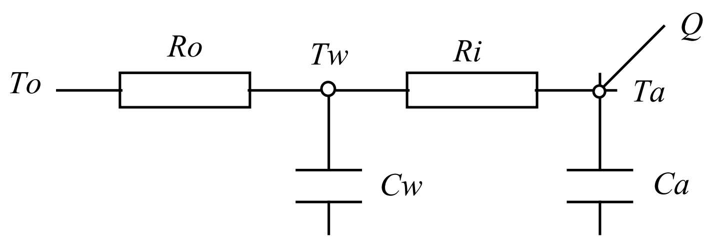


**Figure Q2(c), Simple Lumped Parameter Model**

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3) a) Describe the four common approaches for determining convection coefficients used by building performance simulation programs.

[8 marks]

b) i) The equation for the total emissive power of a blackbody is given by the equation below (where symbols have their usual meaning):

$$E_b = \sigma \cdot T^4$$

where the Stefan-Boltzmann constant has a value of 5.67 x $10^{-8}$ $W/m^2K^4$.

A wall (Wall 1) has a surface with total longwave hemispherical emissivity of 0.8, an area of 100 $m^2$ and a surface temperature of 18 °C.

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

[4 marks]

ii) 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)i). The view factor between the two walls is 0.7.

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

[4 marks]

c) The three methods of modelling airflow in buildings are CFD, single-zone models and network airflow models.

Give a description of each of these methods including their strengths and limitations, the key assumptions made and the appropriate situations where they should be used.

Provide illustrative diagrams where appropriate.

[17 marks]

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4) a) Draw an illustrative diagram of the significant heat transfer process for the external surfaces of buildings. The diagram should include a wall with an internal surface and include five heat transfer processes.

Also state the equation which links these five heat transfer processes.

[7 marks]

b) Weather files are used by building simulation software programs as part of their calculation procedures.

Write a short report on weather files. In your answer include a background description, the main variables provided, typical sources of weather data and the key assumptions made.

[10 marks]

c) For heat conduction transfer in opaque assemblies, a numerical approximation of the heat diffusion equation can be derived as below (where symbols have their usual meaning):

$$\frac{(\rho c_P)_P}{\Delta t} \cdot \left(T_P - T_P^{t-\Delta t}\right) = \left(\frac{k_P + k_E}{2 \cdot \Delta x \cdot \Delta x_{east}}\right) \cdot \left(T_E^{t-\Delta t} - T_P^{t-\Delta t}\right) - \left(\frac{k_P + k_W}{2 \cdot \Delta x \cdot \Delta x_{west}}\right) \cdot \left(T_P^{t-\Delta t} - T_W^{t-\Delta t}\right)$$

A 0.3 m thick solid concrete wall has a thermal conductivity of 1.3 W/mK, a specific heat capacity of 1.4 kJ/kgK and a density of 1500 kg/m3. Assume three equally-spaced layers through the wall and a time-step of 300 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 5°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 20°C while the external face is held at 5°C, use the finite difference technique to determine the temperature profile through the wall after 1200 seconds.

[10 marks]

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