Thermal Modelling and 3D Building Information Modelling (BIM)
23CVP310

Semester 1 2023-24 | 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) Draw an illustrative diagram of the significant heat transfer and mass transfer processes in buildings. The diagram should include a single room with a window and include 11 significant heat transfer processes and 4 significant mass transfer processes. Include heat and mass transfer processes that occur inside and outside the building, and through the building envelope.

[11 marks]

b) In building simulation, thermal zones are created which represent portions of the building. A thermal zone can be a single room or multiple rooms combined together.

List five criteria that are recommended when grouping volumes of a building into thermal zones.

[5 marks]

c) A building has a single thermal zone which has a floor area of 10 m x 10 m and has walls which are 3 m high.

There is a single window in one wall of the building. The window has an area of 5 m^2, a total hemispherical solar transmissivity of 0.9 and a total hemispherical solar reflectivity of 0.05.

For an instance when the window receives direct solar irradiance of 700 W/m^2 and diffuse solar irradiance of 200 W/m^2, calculate:

i) The amount of solar radiation (in Watts) absorbed by the window.

[4 marks]

ii) The total solar radiation (in Watts) falling on the inside surface of the wall which contains the window, assuming an area-weighted approach is used for the distribution of direct and diffuse solar irradiance.

[5 marks]

d) A thermal zone has an internal air temperature of 21 °C and one of the internal wall surfaces of the zone has a temperature of 16 °C. The wall has a height of 2.5 m and a width of 10 m.

i) Calculate the heat convection coefficient of the internal surface, using the equation by Alamdari and Hammond below, where symbols have their usual meaning.

$$h_{conv,i} = \left\{ \left[1.5 \cdot \left(\frac{|T_z - T_i|}{H} \right)^{1/4} \right]^6 + \left[1.23 \cdot \left| T_z - T_i \right|^{1/3} \right]^6 \right\}^{1/6}$$

[4 marks]

ii) Calculate the heat transfer from the zone air to the internal surface.

[4 marks]

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2. a) There are three generic categories of model, forward-models, inverse-models, and grey-box models. Discuss the differences between each category and explain the categorisation and potential use of lumped-parameter models.

[6 marks]

b) Define the Biot number and explain its use in evaluating the assumptions made in formulating a lumped parameter model.

[7 marks]

c) Figure Q2, 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.

[8 marks]

ii) Explain what resistance path R3 represents and how its value can be calculated.

[8 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]

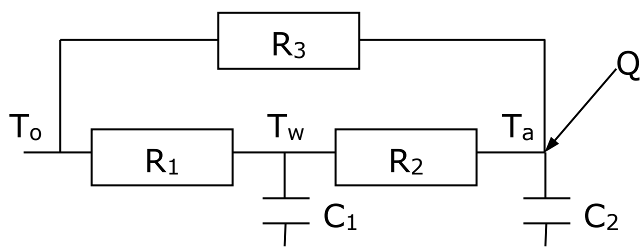

Figure Q2. Single Zone Lumped Parameter Model

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3. a) A building has a thermal zone with a number of internal heat sources including people, lights and appliances.

   i) Describe the heat transfer mechanisms of heat gains from the internal sources to the internal air and the internal surfaces of the zone.

   [3 marks]

   ii) Describe the inputs required to represent the internal heat sources in building simulation software, and where suitable input values might be sourced from.

   [3 marks]

b) List five common approaches used in building performance simulation for establishing the transfer of air between zones. For each approach give your view on the strengths and weaknesses of the technique.

[10 marks]

c) The influence of external environmental conditions on a building simulation model can be described in terms of the following five processes:

- Solar absorption
- Air infiltration
- Surface convection
- Longwave radiation
- Ground heat transfer

For each of these processes:

i) Describe the effect of the process on the mass and energy balances of the building.

[5 marks]

ii) State the influencing external conditions, typically found in weather files, of the process and describe how the external conditions impact on the process.

[12 marks]

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4. a) For heat conduction transfer in opaque assemblies, a numerical approximation of the heat diffusion equation can be derived as:

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

Based on this equation:

- State the meaning of the symbols and subscripts in this equation.
- State the units of all variables used.
- Provide an illustrative diagram in your answer to aid in the description of the symbols.
- State the key assumptions upon which the derivation of this equation is based.

[17 marks]

b) HVAC system models can be classified as being ‘first principle’ models, ‘empirical’ models or ‘semi-empirical’ models. Give a definition and example application for each class.

[6 marks]

c) In dynamic thermal simulation of buildings, HVAC system simulation can be carried out either dynamically or using steady-state methods. State why this is the case and give reasons for using each method.

[4 marks]

d) Components in HVAC simulation can be linked using either ‘menu-based’ or ‘component-based’ simulations. Describe each of these methods including the advantages and disadvantages of each.

[6 marks]

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