Loughborough University

# Building Energy Supply Systems and District Energy Networks
## 23CVP306

Semester 2 2024 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.

Continues/…

1. a) Compare and describe the operation of a vapour compression and a lithium bromide absorption refrigeration system using schematics and heat balance equations.
[17 marks]

b) A Refrigerant R134a refrigeration plant has a constant condenser pressure of 12 bar and a constant evaporator pressure of 2 bar to meet a cooling load of 50 kW. The vapour leaving the evaporator is superheated by 10 $^{o}$C and the liquid leaving the condenser is sub-cooled by 5 $^{o}$C. If the compressor has an isentropic efficiency of 80%, determine:

i) The rate at which heat is rejected at the condenser.
[6 marks]

ii) The mass flow rate of the refrigerant.
[3 marks]

iii) The actual COP.
[3 marks]

iv) The Carnot COP.
[2 marks]

Compare the two COP results for (iii) and (iv) and comments on the above results.
[2 marks]

You may use the pressure-enthalpy chart given in Figure Q1.

2. a) An office building is three storeys high. Each storey is the same rectangular shape and measures 30 m by 20 m. The annual fuel consumption of the building is 50 kWh/m2 for heating and 70 kWh/m2 for electricity. Mackay (2008) describes a series of assumptions for annual energy generation from the solar resource, photosynthesis and the wind resource, as well as assumptions for the efficiency of renewable energy systems.

These include:
- The average power on a south-facing roof in the UK is 110 W/m2
- Photosynthesis performance per land area is 0.5 W/m2
- Solar thermal average efficiency is 50%
- Solar PV average efficiency is 20%
- Biomass assumed efficiency is 66%
- Onshore wind power per unit area is 2 W/m2

Question 2 continues/…

Using these assumptions, calculate:

i) The potential annual heat generation available from a roof-mounted solar thermal system.

[2 marks]

ii) The potential annual electricity generation available from a roof-mounted solar PV system.

[2 marks]

iii) The approximate land area required to meet the building's annual heat demand using biomass.

[2 marks]

iv) The approximate land area required to meet the building's annual electricity demand using wind power.

[2 marks]

b) Describe four benefits and four limitations of biomass heating systems.

[4 marks]

c) Name four emissions, in the form of combustion gases, which arise from burning biomass. In each case describe the polluting effect of the emissions.

[4 marks]

d) Describe the second law of thermodynamics and the two corollaries associated to this law.

[6 marks]

e) Derive the equation for Carnot efficiency and draw the Carnot cycle on a T-S diagram together with the areas of heat, and work on separate T-S diagrams.

[6 marks]

f) A heat engine operating on the Carnot cycle uses solar energy as the source of high-temperature heat input. The solar irradiation, averaged over the day, has a value of 0.81 kW/m$^2$. This provides energy to the cycle at a uniform temperature of 200$^o$C, and the cycle rejects heat to the environment at a temperature of 100$^o$C. The engine produces 2000 kW of power. Calculate the minimum area needed to provide this power.

[5 marks]

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3. a) With the aid of a suitable sketch illustrate the optical and heat transfer mechanisms that occur in a single glazed solar flat plate water heating collector.

[7 marks]

b) List the different design factors that affect the thermal losses from a solar water heating collector and indicate the steps that can be taken to minimise them.

[6 marks]

c) A solar collector has a maximum efficiency of 65%. Calculate the collector loss coefficient if the stagnation temperature is 100ºC when the radiation is 400W/m2 and the ambient temperature is 5ºC. The value of $F_R$ can be taken to be 0.85.

[7 marks]

d) Three solar collector systems have been shortlisted for a new solar collector installation. The collector performance characteristics are summarised below in Table Q3.

Table Q3 Collector performance characteristics

| | $F_R$ | τα | $U_L$ |
|---|---|---|---|
| Collector A | 0.92 | 0.80 | 3.4 |
| Collector B | 0.90 | 0.89 | 5.5 |
| Collector C | 0.75 | 0.72 | 1.2 |

Determine which system will have the highest efficiency when the incident radiation is 400Wm$^{-2}$, the ambient temperature is 15°C and

i) the inlet temperature is 40°C,
ii) the inlet temperature is 80°C.

Indicate which collector should be selected for each inlet temperature.

[7 marks]

e) Given that the mass flow rate of water, (Cp = 4200Jkg-1K-1 ) through the collector is 0.03kgs-1 and the collector area is 6m2, calculate the increase in temperature that you will obtain through the selected collectors for inlet temperatures of 40 and 80 °C and thus the outlet temperatures.

[6 marks]

The following two equations are provided:

$$\frac{Q_u}{AI} = \eta$$

$$\eta = F_r\left[\tau\alpha - U_L\frac{(T_i - T_a)}{I}\right]$$

Continues/…

4. a) Considering a domestic, or boiler for a small commercial building, discuss the factors affect the load throughout the heating season and sketch and describe how you might expect boiler efficiency to vary as a function of load, identifying and discussing any key features.

[12 marks]

b) On a larger boiler installation, discuss the use of multiple boilers as a strategy to maximise part load efficiency while delivering a required capacity of 800kW.

[8 marks]

c) State the primary function of the boiler plant and discuss the tasks facing the designer when selecting a suitable boiler plant for a building. Comment on the key factors affecting boiler selection.

[13 marks]

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P Eames
S Firth
R Buswell

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