

# The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 3 MODULE, AUTUMN SEMESTER 2015-2016

## **ENERGY EFFICIENCY FOR SUSTAINABILITY 2**

Time allowed ONE Hour THIRTY Minutes

---

*Candidates may complete the front cover of their answer book and sign their desk card but must NOT write anything else until the start of the examination period is announced*

### **Answer question ONE and TWO other questions**

*Only silent, self contained calculators with a Single-Line Display or Dual-Line Display are permitted in this examination.*

*Dictionaries are not allowed with one exception. Those whose first language is not English may use a standard translation dictionary to translate between that language and English provided that neither language is the subject of this examination. Subject specific translation dictionaries are not permitted.*

*No electronic devices capable of storing and retrieving text, including electronic dictionaries, may be used.*

### **DO NOT turn examination paper over until instructed to do so**

***In this examination candidates are required to answer Question ONE and TWO other questions. If a candidate answers more than the required number of questions, all questions will be marked and the highest marks will be used in the final examination mark.***

**ADDITIONAL MATERIAL:**      Formula Sheet  
  Enthalpy – Entropy Chart for Steam  
  Tables of Properties of Fluids

### **INFORMATION FOR INVIGILATORS:**

Question papers should be collected in at the end of the exam – do not allow candidates to take copies from the exam room.

1. Answer each part of this question. Each part carries the same mark.

*It should not be necessary to write more than about two or three sentences in answer to any part of this question.*

- (a) List the three sources of energy used most widely in the world.
- (b) State two ways in which oxides of nitrogen may be formed during combustion.
- (c) State two means by which tidal energy can be extracted.
- (d) State two reasons why it is better to use natural gas rather than coal for large scale electricity generation.
- (e) In a heat exchanger state two ways in which the thermal resistance to heat transfer between the two fluids may be reduced.
- (f) List three sources of energy loss from a combustion plant in which complete combustion takes place.
- (g) What is the minimum rate of electrical power input required for a heat pump to give a heat output of 15 kW at a temperature of 40 °C, when the heat source is a 6°C?
- (h) Define exergy.
- (i) What is the rate of exergy input needed to maintain a refrigerated room at a temperature of -10°C when the environment temperature is 25°C, if 9 kW of heat must be removed from the room to maintain the temperature of -10°C.
- (j) Figure Q1(j) shows the heat transfer between two fluids in a heat exchanger. Estimate the capacity ratio.

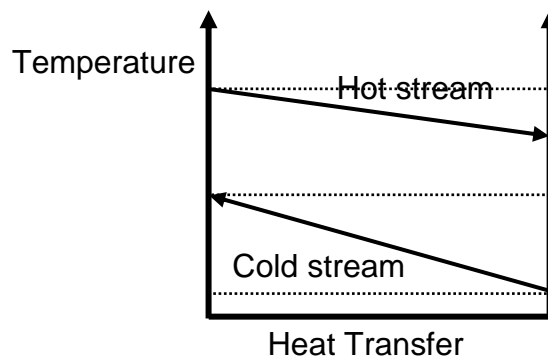


Figure Q1(j)

[Total 30 marks]

2. (a) What is an energy audit? [6 marks]

An oil-fired boiler (Figure Q2) produces hot water to heat an office. The cool water returning to the boiler is first preheated by heat from the flue gases in a heat exchanger before passing into the boiler.

- (b) Describe measurements that you would take in order to identify all of the energy flows in the boiler system. [11 marks]

- (c) Describe calculations that you would do to determine the energy flows and efficiency of the boiler system from the measured data. [11 marks]

- (d) Draw a Sankey Diagram that you would expect to represent, approximately, the energy flows in the boiler system. [7 marks]

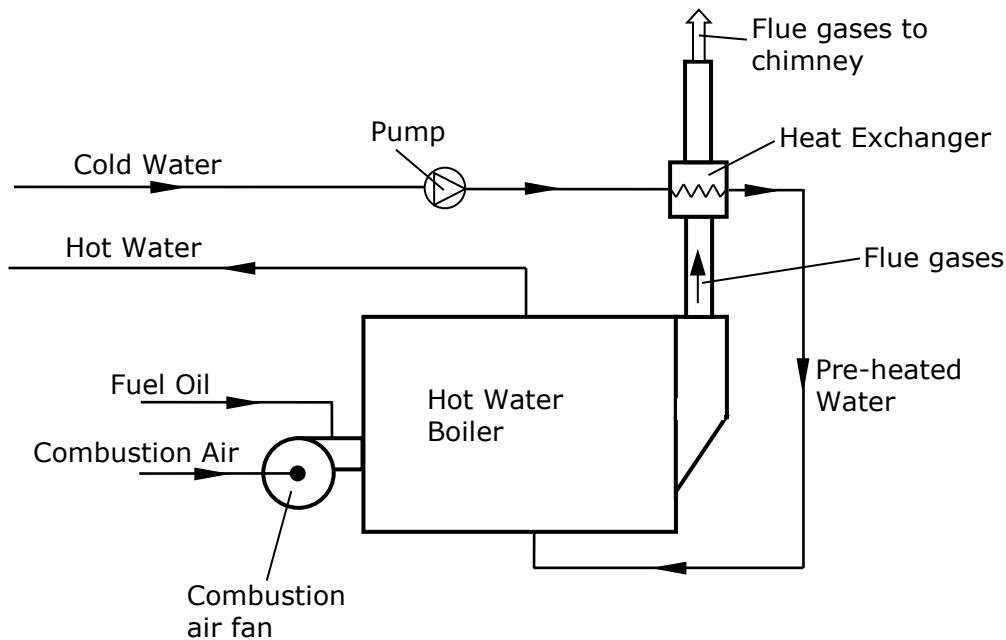


Figure Q2

*Turn over*

3. A central heating boiler furnace is fuelled by natural gas (assume it is methane  $\text{CH}_4$ ). The pressure in the boiler is 1 bar absolute. For every kg of methane gas consumed the following kg of products of combustion are formed:

Carbon dioxide ( $\text{CO}_2$ )	1 kmol
Water vapour ( $\text{H}_2\text{O}$ )	2 kmol
Oxygen ( $\text{O}_2$ )	0.8 kmol
Nitrogen ( $\text{N}_2$ )	10.53 kmol

- (a) Calculate the boiler efficiency if the flue gases leave the boiler at  $100^\circ\text{C}$ . Ignore the heat loss from the boiler structure. The gross calorific value of the gas is  $53.4 \text{ MJ/kg}$ . The fuel and air enter the boiler at  $20^\circ\text{C}$ .

[18 marks]

- (b) An additional heat exchanger is installed in the boiler to cool the flue gases from the boiler down to  $40^\circ\text{C}$ . Calculate the new efficiency of the boiler. Account for the condensation of water vapour from the flue gases in your calculations.

[17 marks]

In all calculations assume the following specific heat capacities ( $c_p$ ) for the following gases:

$c_p$ carbon dioxide =	0.871 kJ/kgK
$c_p$ oxygen =	0.923 kJ/kgK
$c_p$ nitrogen =	1.040 kJ/kgK

4. A heat pump as shown in Figure Q4 is used to provide heating for a house. The outside air temperature is  $7^{\circ}\text{C}$  and the temperature inside the house is  $19^{\circ}\text{C}$ . The heat pump operates with working fluid R134a. The saturation temperature in the evaporator is  $0^{\circ}\text{C}$  and the saturation temperature in the condenser is  $40^{\circ}\text{C}$ . At the outlet from the evaporator the fluid is a dry saturated vapour. At the outlet from the compressor the fluid vapour has 20K of superheat. At the outlet from the condenser the fluid is a saturated liquid. The electric motor has an efficiency of 90%.

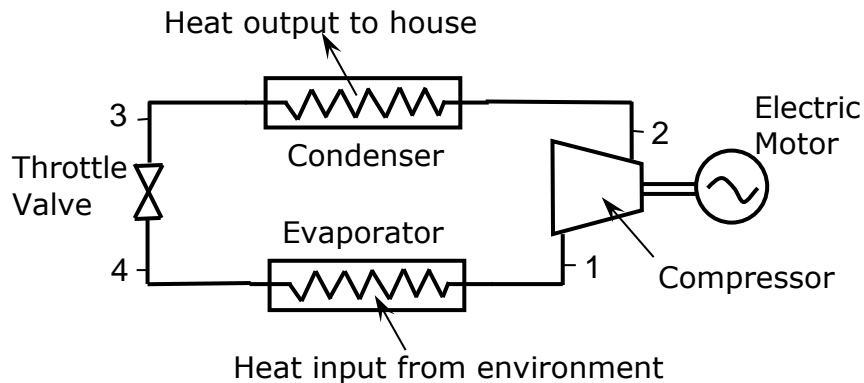


Figure Q4.

The enthalpy and entropy at each point around the cycle is as shown below:

	Pressure Bar	Temperature $^{\circ}\text{C}$	State	Enthalpy kJ/kg	Entropy kJ/kgK
1.	2.928	0.0	Sat vapour	398.43	1.7264
2.	10.163	60.0	S/H vapour	441.32	1.7788
3.	10.163	40.0	Sat liquid	256.38	1.1903
4.	2.928	0.0	Wet vapour	256.38	1.2063

At the environment temperature of  $7^{\circ}\text{C}$  and pressure of 1 atmosphere, the working fluid is normally a superheated vapour with an enthalpy of  $409.2\text{ kJ/kg}$  and entropy of  $1.845\text{ kJ/kgK}$ . (*This point is not given in the tables*)

If the rate of heat input to the house is  $11\text{ kW}$ , calculate:

- The Coefficient of Performance of the heat pump and the overall rational efficiency of the heat pump in providing heat for the house. [15 marks]
- The rate of irreversibility in the evaporator, compressor, electric motor, condenser and throttle. [15 marks]
- Describe ways in which the performance of the heat pump may be improved. [5 marks]

Turn over

5. An industrial site has installed a gas fuelled internal combustion engine combined heat and power (CHP) plant. Details of the engine are:

Electricity output	350 kW
Electrical generation efficiency	35.4%
Exhaust gas flow rate	0.68 kg/s
Exhaust gas temperature	450°C
Specific heat capacity of exhaust gas	1.07 kJ/kgK
Rate of heat rejection to the water cooling system	245 kW

The exhaust gases are fed through a heat exchanger to produce hot water for an industrial process and the exhaust gases leave at 97 °C. The heat rejected from the engine water cooling system can also be used by the industrial process.

The engine can only be operated at full output when running.

The electricity demand of the site is in excess of the output generated by the CHP plant at all times. The demand for heat at the site is 600 kW during weekdays (day and night) but reduces to 265 kW during weekends (day and night). There are 48 working weeks at the industrial site per year.

- (a) Calculate the annual cost savings for operating the CHP plant.

[28 marks]

- (b) Discuss the economic operation of the CHP system and suggest potential ways of improving the annual savings.

[7 marks]

Assume the following cost and efficiency data

Purchase price of electricity during the day (17 hours)	£25/GJ
Purchase price of electricity during the night (7 hours)	£12/GJ
Price of fuel for CHP plant and alternative boilers	£5/GJ
Maintenance cost of the CHP plant is	2.0p/kWh of electricity generated
Efficiency of alternative boilers for producing hot water is	85%

All efficiencies and fuel prices are based on gross calorific value.  
Electricity and fuel prices do not vary during the year.

**END**