M1.(a) The ratio $\frac{\text{energy given to hot space/area to be heated}}{\text{work input}}$ ✓

OR COP = Q_{IN} / W with Q_{IN} and W explained / defined ✓

It must be clear that Q_{IN} is energy delivered <u>to the area to be heated / hot space</u>. Do not accept 'heat input' or any wording that is vague

1

(b) (i) $\eta_{max} = \frac{1600 - 290}{1600}$ = 0.82 / 82% ✓

input power = $\frac{\text{output power}}{\text{efficiency}} = \frac{80}{0.82}$ = 98 kW ✓

fuel flow rate × CV = 98 kW

fuel flow rate = 98000 / (49 × 10^6) = 2.0 × 10^{-3} ✓

kg s^{-1} ✓

OR 7.2 ✓ kg h^{-1} ✓

If first 2 steps in calculation are not seen and 80 kW used for input power give 1 mark for:

fuel flow rate = 80000 / (49 × 10^6) = 1.6 × 10^{-3} ✓

The unit mark is an independent mark

4

(ii) $COP_{HP} = \frac{Q_2}{W}$

So Q_2 =16 × 2.6 = 41.6 or 42 kW ✓

Q_1 = 98 − 80 = 18 kW ✓

Total Q_1 + Q_2 = 60 kW ✓

CE for Q_1 if incorrect input power from i is used, but NOT 80 −16 or 80 − 80

3

(iii) Heat pump delivers more heat energy than the electrical energy input ✓

Reason: it <u>adds</u> energy from external source to electrical energy input ✓

Accept Q_{IN} = W + Q_{OUT} if explained correctly e.g. by diagram

2

[10]

M2.(a) (A device in which) an input of work ✓

(causes) heat to transfer from a cold space / reservoir to a hot space / reservoir ✓

2

(b) Heat transfer to hot space equals work done plus heat transfer from cold space / $Q_{IN} = W + Q_{OUT}$

Either written statement or expressed in symbols

so Q_{IN} (is always) > Q_{OUT} *reason must be seen* ✓

$$COP_{HP} = \frac{Q_{IN}}{W} \text{ and } COP_{REF} = \frac{Q_{OUT}}{W}$$

So $COP_{HP} > COP_{REF}$ ✓

The COP formulae are in formulae booklet so no marks for simply quoting them. i.e 2nd mark cannot be awarded without first mark.

OR

$Q_{IN} = W + Q_{OUT}$ ✓

$$COP_{HP} \times W = \quad + COP_{REF} \times W \text{ or } COP_{HP} = \frac{Q_{IN}}{W} = \frac{W + Q_{OUT}}{W}$$

So $COP_{HP} = 1 + COP_{REF}$

So $COP_{HP} > COP_{REF}$ ✓

2

[4]

M3. (a) (refrigerator operates between a cold space and a hot space)

Q_{out} is the energy removed from the fridge contents (or from the cold space) **(1)**

Q_{in} is the energy given to the surroundings (or to outside the fridge/hot space) **(1)**

2

(b) (i) power for cooling ice = 5.5 × (420 × 10^3)/3600 = 642 W **(1)**

P_{in} = 642/4.5 = 142 W **(1)**

or energy taken from ice in 1 hour = 5.5 × 420 × 10^3 = 2310 kJ

W_{in} = 2310/4.5 = 513 kJ **(1)**

$P_{in} = \frac{513 \times 10^3}{3600}$ = 142 W **(1)**

2

(ii) Q per s = 142 + 642

= 784 W (give CE) **(1)**

or $Q_{in} = Q_{out} + W_{in}$ = 513 kJ + 2310 kJ = 2820 kJ

Q_{in} per s = $\frac{2820 \times 10^3}{3600}$ = 784 W **(1)**

1

[5]