M1.(a) $T_H = 273 + 540 = 813$ K

$T_C = 273 + 25 = 298$ K ✓

$\eta_{max} = (813 . 298) / 813 = 0.633$ or 63.3 % ✓

Both temperatures correct for 1st mark.

No CE for incorrect temperatures

If °C used η_{max} = 95.4%

2

(b) input power = $\dfrac{\text{output power}}{\eta_{max}}$

Give CE from (a) unless $\eta_{max} > 1$

$= \dfrac{48.0}{0.633} = 75.8$ MW ✓

If η_{max} = 0.95 used, input power = 50 MW

1

(c)
- Heat exchanger will not convert all (internal) energy of salts to (internal) energy of water / steam

  WTTE

  E.g. turbine to surrounding air
- (Unwanted) heat transfer losses **from** ……. **to** ……..

  Do not accept bland statements e.g. 'heat loss to surroundings', 'friction' / 'friction in steam turbine'
- Friction … in bearings of all machinery / in bearings of turbine generator / between moving parts / between moving surfaces / from viscosity of lubricants
- Power needed to drive auxiliary equipment e.g. pumps, motors
- Turbine cycle will not give max theoretical efficiency

  Do not allow: turbine generator is not 100% efficient

any 2 ✓✓

2

[5]

M2.(a) $\eta = (1450-310) / 1450 = 0.79$ / 79%✓

1

(b) Claim 1: input power = $55.5 \times 10^{6} \times 5.00 \times 10^{-3}$ = 278 kW ✓
actual claimed efficiency = 210 / 278 = 0.76 / 76% ✓

1

claim not justified because actual efficiency too close to max theoretical. ✓

1

OR claim would be justified if engine ran at max efficiency (giving 218 KW electrical power) ✓

1

Claim 2: 278 kW – 210 kW = 68 kW ✓
Judgement: claim justified because 55 kW < 68 kW ✓ (and allows for some unwanted energy loss to surroundings)

1

OR for claim 2:
any efficiency lower than 79% will give more than 68 kW of heating (WTTE) so claim justified ✓

1

[6]

M3. (a) (i) $3.2 \times 780 = 2500$ W ✓

1

(ii) $2500 - Q_{out} = 780$

$Q_{out} = 1720$ W ✓

or $3.2 = \dfrac{Q_{in}}{Q_{in} - Q_{out}} = \dfrac{2500}{2500 - Q_{out}}$

giving $Q_{out} = 1720$ W ✓

1

(b) • heat pump does deliver more energy than is input as work on the system but there must also be energy input from cold space ✓

- obeys conservation of energy because work done plus energy from cold space (or equivalent, eg ground) equals energy by heat transfer to hot space (or equivalent) ✓

- obeys second law because (reversed heat engine) operates between hot and cold spaces
  [accept 'source' and 'sink'] ✓

- work done on the system requires energy transfer (from a heat engine elsewhere) so overall result is spreading out of energy [owtte] ✓

max 3

[5]

M4. (a) $T_H = 273 + 820 = 1093$ (K), $T_C = 273 + 77 = 350$ (K) **(1)**

efficiency = $\dfrac{T_H - T_C}{T_H} = \dfrac{1093 - 350}{1093}$ = 0.68 or 68% **(1)**

2

(b) rotational speed of output shaft = $\dfrac{1800}{2 \times 60}$ = 15 rev s^{-1} **(1)**

(work output each cycle = 380 J, 2 rev ≡ 1 cycle in a 4 stroke engine)

indicated power = 15 × 190 = 5.7 kW **(1)**

2

(c) power lost (= indicated power –actual power) = 5.7 – 4.7 = 1.0 kW **(1)**
(allow C.E. for incorrect value from (b))

1

(d) energy supplied per sec (= fuel flow rate x calorific value)

$= \dfrac{2.1 \times 10^{-2}}{60} \times 45 \times 10^{6}$ = 16 kW (15.8 kW) **(1)**

1

(e) efficiency = $\frac{\text{net power output}}{\text{power input}} = \frac{4.7}{16}$ = 0.29 or 29 %

$\frac{4.7}{15.8}$ = 0.30 or 30%

(allow C.E. for value from (d))

1

[7]

M5.(a) (i) $\eta_{max} = \frac{T_H - T_C}{T_H}$ **(1)**

$= \frac{360 - 280}{360}$ = 0.22 (or 22%) **(1)**

(ii) (use of $\eta = \frac{W_{out}}{Q_{in}}$ gives) $Q_{in} = \frac{5 \times 10^6}{0.22}$ = 23 MW **(1)**

(allow C.E. for value of η_{max})

(iii) Q_{out} = (23 - 5) = 18 MW **(1)**

(allow C.E. for value of Q_{in})

4

(b) loss of heat to the atmosphere during the process **(1)**
friction between moving parts **(1)**
losses in the electrical generating system **(1)**
variation in sea temperature **(1)**
any other sensible and correct physics **(1)**

max 2

(c) no fuel transportation costs **(1)**
no cost of raw fuel **(1)**
no cost of removing / treating waste products

1

[7]