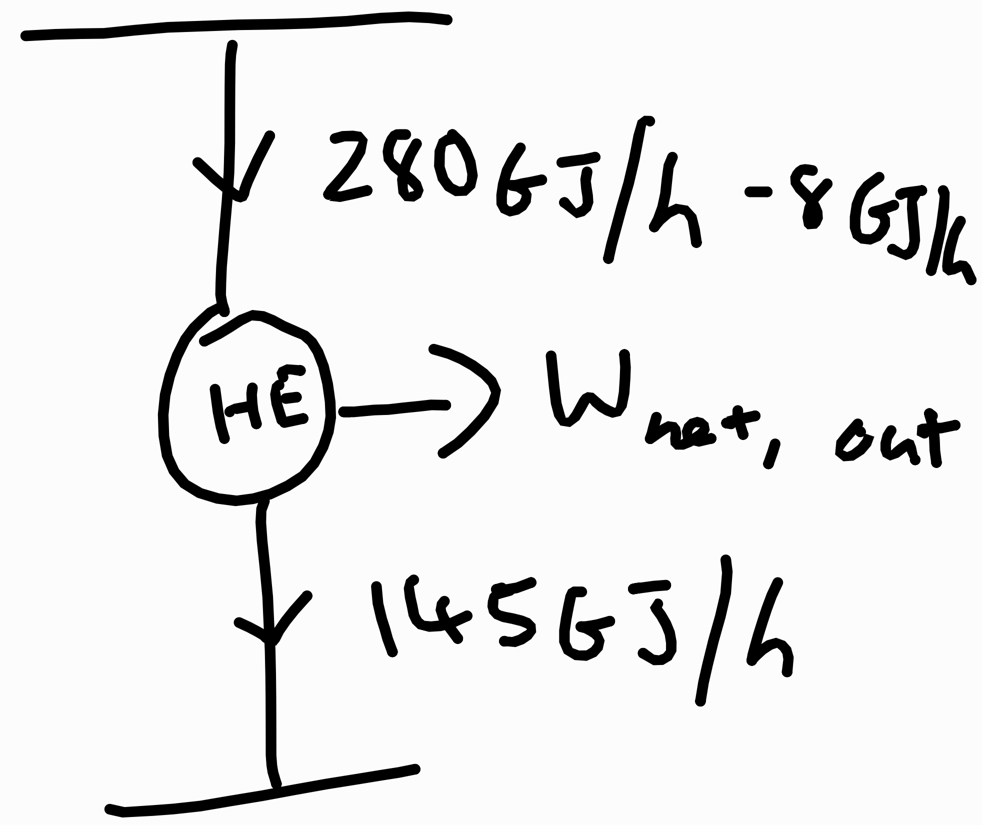
1a) $W_{net, out} = Q_H - Q_L$

$= 280 - 8 - 145$

$= 127\ GJ/h$

$= 35.3\ MW$



b) $\eta_{th} = \dfrac{\text{Net work output}}{\text{Total heat input}}$

$= \dfrac{127}{280}$

$= 45.4\%$

2a) $COP_R = \frac{\text{Desired output}}{\text{Required input}}$

$$1.5 = \frac{Q_L}{W_{in}}$$

$$1.5 W_{in} = 60$$

$$W_{in} = 40 \text{ kJ/min}$$

$$= 0.67 \text{ kW}$$

b) $Q_H - Q_L = W_{in}$

$$Q_H = W_{in} + Q_L$$

$$= 40 + 60$$

$$= 100 \text{ kJ/min}$$

3) $Q_H = 60,000 - 4,000$

$= 56,000 \, kJ/h$

$COP_{HP} = \dfrac{\text{Desired output}}{\text{Required input}}$

$2.5 = \dfrac{Q_H}{W_{in}}$

$2.5 W_{in} = 56,000$

$W_{in} = 22,400 \, kJ/h$

$= 6.22 \, kW$

4) $\eta_{th} = \frac{\text{Desired output}}{\text{Required input}}$

$$= \frac{Q_H - Q_L}{Q_H}$$

$$= 1 - \frac{Q_L}{Q_H}$$

$$= 1 - \frac{T_L}{T_H}$$

$$= 1 - \frac{20+273}{140+273}$$

$$= 29.1\%$$

When the temperature is $500°C$,

$$\eta_{th} = 1 - \frac{20+273}{500+273}$$

$$= 62.1\%$$

4) When environment temperature drops to 0°C

$$\eta_{th} = 1 - \frac{0+273}{140+273}$$

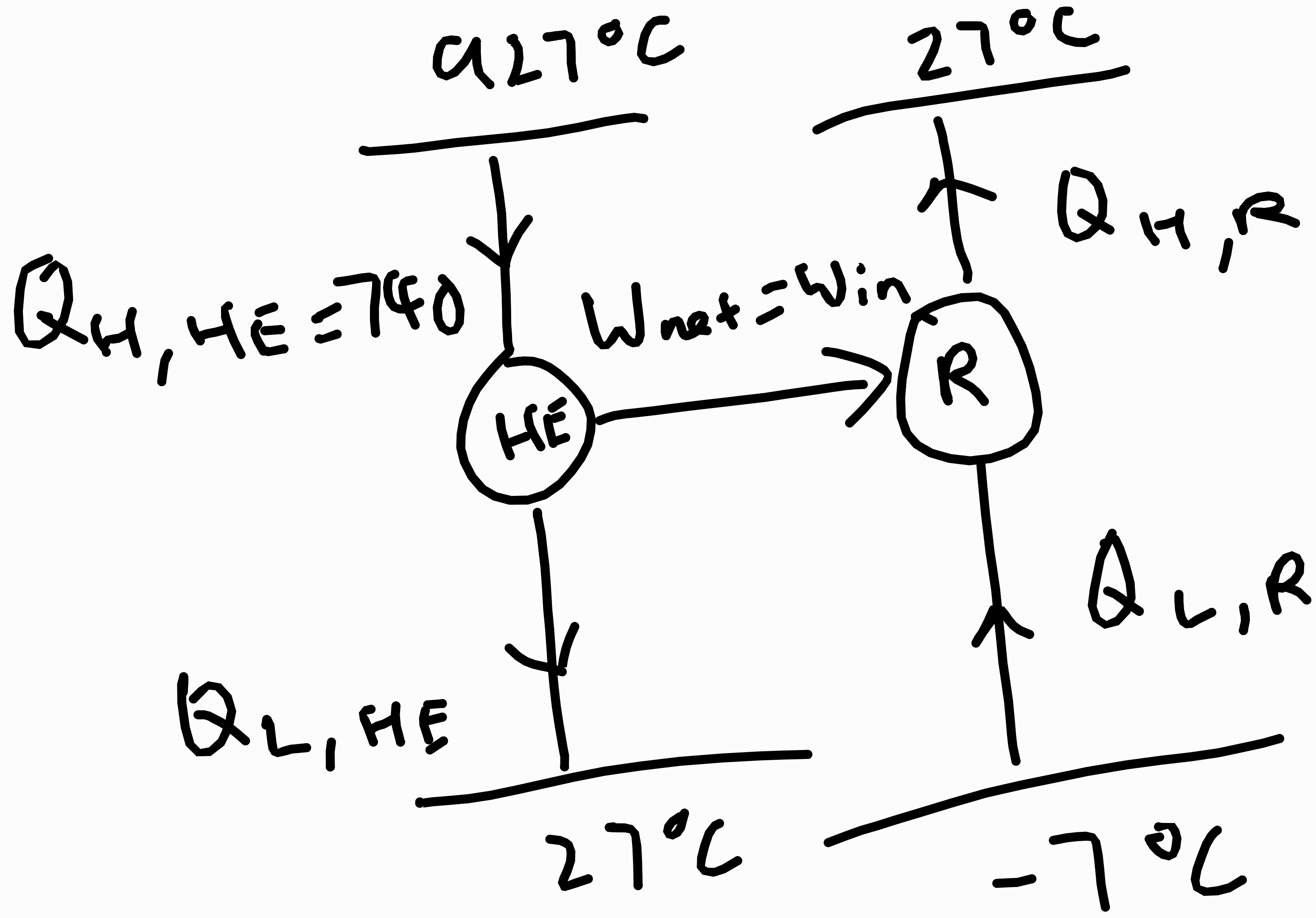
$$= 33.9\%$$

When environment temperature increases to 40°C

$$\eta_{th} = 1 - \frac{40+273}{140+273}$$

$$= 24.2\%$$

5a)



$$COP_{R,rev} = \frac{Q_{L,R}}{W_{in}}$$

$$= \frac{Q_{L,R}}{Q_{H,R} - Q_{L,R}}$$

$$= \frac{1}{\frac{Q_{H,R}}{Q_{L,R}} - 1}$$

$$= \frac{1}{\frac{T_{H,R}}{T_{L,R}} - 1}$$

$$= \frac{1}{\frac{27+273}{-7+273} - 1}$$

$$= \frac{133}{17}$$

5a) $\eta_{th} = 1 - \frac{T_{L,HE}}{T_{H,HE}}$

$$\frac{W_{out}}{Q_{H,HE}} = 1 - \frac{27+273}{927+273}$$

$$W_{out} = \frac{3}{4}(740)$$

$$W_{out} = 555 kJ/min$$

$$COP_{R,rev} = \frac{Q_{L,R}}{W_{in}}$$

$$Q_{L,R} = \frac{133}{17}(555)$$

$$= 4342 kJ/min$$

5b) $COP_{R,rev} = \dfrac{Q_{L,R}}{Q_{H,R} - Q_{L,R}}$

$$\frac{133}{17} = \frac{4342}{Q_{H,R} - 4342}$$

$$Q_{H,R} - 4342 = 555$$

$$Q_{H,R} = 4897 \text{ kJ/min}$$

$$\frac{Q_{L,HE}}{Q_{H,HE}} = \frac{T_{L,HE}}{T_{H,HE}}$$

$$Q_{L,HE} = \frac{27+273}{927+273}(740)$$

$$= 185 \text{ kJ/min}$$

Total rate of heat rejection $= Q_{L,HE} + Q_{H,R}$

$$= 185 + 4897$$

$$= 5082 \text{ kJ/min}$$