



a) $\eta_{th}^{HE} = 1 - \frac{T_2}{T_1}$, 1st law: $0 = Q_1 - Q_2 - W$
 $\eta_{th}^{HE} = 1 - \frac{Q_2}{Q_1}$, $W = Q_1 - Q_2$
 so $\eta_{th}^{HE} = 0.5$, $Q_1 = 200 \text{ kJ}$

get: $W = \eta_{th}^{HE} Q_2$ $W = 100 \text{ kJ}$

b) $Q_1 = 200 \text{ kJ}$ (see above)

c) $COP_R = \frac{Q_5}{W}$, 1st law: $0 = Q_5 - Q_6 + W/2$
 $Q_5 = Q_6 - W/2 = 100 \text{ kJ}$

$COP_R = \frac{2Q_5}{W} = 2$

d) $Q_5 = 100 \text{ kJ}$ (see above) and $\frac{Q_5}{T_5} = \frac{Q_6}{T_6}$ so $T_5 = \frac{Q_5}{Q_6} T_6$

$T_5 = 200 \text{ K}$

e) $COP_{HP} = \frac{Q_4}{W}$, 1st law: $0 = Q_3 - Q_4 + W/2$
 $Q_4 = Q_3 + W/2 = 150 \text{ kJ}$

$COP_{HP} = \frac{2Q_4}{W} = 3$

f) $Q_4 = 150 \text{ kJ}$ (see above) and $\frac{Q_4}{T_4} = \frac{Q_3}{T_3}$ so $T_4 = \frac{Q_4}{Q_3} T_3$

$T_4 = 450 \text{ K}$