Solutions

2.1

- $q_L = h_1 - h_4 = 240.0 - 100.0 = \mathbf{140.0}$ kJ/kg.
- $w_{in} = h_2 - h_1 = 290.0 - 240.0 = \mathbf{50.0}$ kJ/kg; $\mathrm{COP}_R = 140.0/50.0 = \mathbf{2.80}$.

2.2

- $q_H = h_2 - h_3 = 290.0 - 100.0 = \mathbf{190.0}$ kJ/kg.
- $\mathrm{COP}_{HP} = 190.0/50.0 = \mathbf{3.80}$; identity: $q_H/w - q_L/w = (q_L + w_{in})/w - q_L/w = 1$, and $2.80 + 1 = 3.80$ ✓.

2.3

- Ceiling $= 268.2/(303.2 - 268.2) = 268.2/35.0 = \mathbf{7.66}$.
- The machine's 2.80 sits well below 7.66, so it is viable - the ceiling forbids only COPs above it.

2.4

- The expansion spans a wet two-phase flow where a tiny turbine is not worth building; a throttle is cheap, isenthalpic and destroys only a few kJ/kg, which the compressor simply re-pays.
- The bound comes from Carnot ratios of absolute temperatures: $T_{cold}/(T_{hot} - T_{cold})$ with kelvin; using differences of Celsius readings changes the ratio and misprices the ceiling.

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