Problem 1 (30/100 points)
Given: Each part of this problem is worth 10 points. There is no partial credit for each sub-problem in each part. Your answer must be placed in the box. Note the requested units for each part.

a). A power cycle operating between two reservoirs receives energy $Q_H$ by heat transfer from a high temperature reservoir at 1500 K and rejects energy $Q_L$ to a low temperature reservoir at 500 K. Please determine the following cases whether the cycle is reversible, irreversible, or impossible.

1. $Q_H = 800 \text{ kJ}, W_{cycle} = 550 \text{ kJ}$
2. $Q_H = 800 \text{ kJ}, Q_L = 350 \text{ kJ}$

\[
\eta_{max} = 1 - \frac{T_L}{T_H} = 1 - \frac{500}{1500} = \frac{2}{3}
\]

\[
\eta_1 = \frac{W_{cycle}}{Q_H} = \frac{550 \text{ kJ}}{800 \text{ kJ}} = 0.69 > \eta_{max}
\]

\[
\eta_2 = 1 - \frac{Q_c}{Q_H} = 1 - \frac{350 \text{ kJ}}{800 \text{ kJ}} = 0.56 < \eta_{max}
\]

b). A heat engine undergoing a reversible cycle takes 50 J of net heat transfer per cycle. (1) Find the work done per cycle, in J. (2) If the cycle is irreversible and the net heat transfer remains the same (50 J), does the work done per cycle become larger than, smaller than, or the same as that done with the reversible cycle?

1. $Q_{net} - W_{cycle} = \Delta E_{cycle} = 0$
   \[ W_{cycle} = Q_{net} = 50 \text{ J} \]

2. The First Law does not change for an irreversible cycle.

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**Problem 2 (35/100 points)**

Given: A small office loses 2 Btu/s heat through its building envelope but gains 0.5 Btu/s from its occupant and heated equipment. A hot air heating system is used to maintain the room at a comfortable temperature of 75°F. The air temperature from the supply is 85°F. To conserve energy, only minimum intake of outdoor air at a rate of 0.053 lbm/s is used to maintain an acceptable air quality. The outdoor air temperature is 40°F. The air pressure is 14.7 psia throughout the system. Neglect potential energy change and kinetic energy change. Assume all the ducts are well insulated. The air is ideal gas and the specific heat is constant (0.24 Btu/lbm °R). The system can also be assumed to be at steady state.

Find:

(a) The airflow rate supplied to the room, lbm/s
(b) The air temperature after the mixing at position 2, in °F
(c) The power used to heat the air by the heater, in Btu/s

**System:** (draw control volumes used)

**Assumptions:**
- SSSF
- \( \dot{Q}_{\text{duct}} = 0 \)
- \( W_{\text{cv}} = 0 \)
- \( \DeltaKE = 0, \DeltaPE = 0 \)
- \( C_p = \text{const}, \text{ Ideal gas} \)

**Basic Equations:**

\[
\frac{dm_{\text{cv}}}{dt} = \sum \dot{m}_{\text{in}} - \sum \dot{m}_{\text{out}}
\]

\[
\frac{dE_{\text{cv}}}{dt} = \dot{Q}_{\text{cv}} - W_{\text{cv}} + \sum \dot{m}_{\text{in}} (h + \frac{v^2}{2} + gZ)_{\text{in}} - \sum \dot{m}_{\text{out}} (h + \frac{v^2}{2} + gZ)_{\text{out}}
\]

**Solution:**

\( a = \dot{Q}_{\text{gain}} - \dot{Q}_{\text{loss}} + \dot{m}_3 C_p (T_3 - T_4) \)

\( \dot{m}_3 = \frac{-\dot{Q}_{\text{gain}} + \dot{Q}_{\text{loss}}}{C_p (T_3 - T_4)} = \frac{(-0.5 + 2) \text{ Btu/s}}{0.24 \text{ Btu/lbm}^\circ \text{R} (85-75) \circ \text{R}} \)

\( \dot{m}_3 = 0.625 \text{ lbm/s} \)
(b) \( \dot{m}_1 + \dot{m}_5 - \dot{m}_2 = 0 \)
\[ \dot{m}_5 = \dot{m}_2 - \dot{m}_1 = (0.625 - 0.053) \text{lbm/s} = 0.5721 \text{lbm/s} \]
\[ 0 = \dot{m}_1 h_1 + \dot{m}_5 h_5 - \dot{m}_2 h_2 \]
\[ = \dot{m}_1 h_1 + (\dot{m}_2 - \dot{m}_1) h_5 - \dot{m}_2 h_2 \]
\[ 0 = \dot{m}_1 C_p (T_1 - T_5) + \dot{m}_2 C_p (T_5 - T_2) \]
\[ T_2 = T_5 + \frac{\dot{m}_1}{\dot{m}_2} (T_1 - T_5) = 75 - \frac{0.053}{0.625} (40 - 75) \]
\[ T_2 = 72 \text{°F} \]

(c) \[ 0 = \dot{Q}_{\text{heater}} + \dot{m}_2 (h_2 - h_3) \]
\[ \dot{Q}_{\text{heater}} = \dot{m}_2 C_p (T_3 - T_2) \]
\[ = 0.625 \text{ lbm/s} \times 0.24 \frac{\text{Btu}}{\text{lbm} \cdot \text{°R}} (85 - 72) \text{°F} \]
\[ \dot{Q}_{\text{heater}} = 1.95 \frac{\text{Btu}}{\text{s}} \]
Problem 3 (35/100 points)
Given: An adiabatic, two-stage turbine operates at steady state. Steam enters at state 1 with a pressure of 20 bar, temperature of 500°C, and mass flow rate of 20 kg/sec. Some steam is extracted at state 2 from the turbine at a pressure of 4 bar and a temperature of 200°C. The remainder expands to state 3 with a pressure of 0.1 bar and a quality of 1.0 with a mass flow rate of 15 kg/sec. Kinetic and potential energy effects can be neglected.

Find: 

a). Complete the table below.

b). Show steam vapor dome and sketch the processes in p-v and T-v diagram.

c). Calculate the total power produced by the two-stage turbine, in kW.

System sketch: (Draw the control volume)

Assumptions:

\[ SS SF, \quad Q = 0 \]
\[ \Delta KE = 0, \quad \Delta PE = 0 \]

<table>
<thead>
<tr>
<th>State</th>
<th>Pressure (bars)</th>
<th>Temperature (°C)</th>
<th>Specific Volume (m³/kg)</th>
<th>Enthalpy (kJ/kg)</th>
<th>Quality or Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>500</td>
<td>0.0176</td>
<td>3468</td>
<td>SHV</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>200</td>
<td>0.534</td>
<td>2861</td>
<td>SHV</td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
<td>45.81</td>
<td>14.67</td>
<td>2584</td>
<td>1.0 (saturated vapor)</td>
</tr>
</tbody>
</table>

b)
Basic equations:

\[ \frac{dm_{cv}}{dt} = \sum \dot{m}_{in} - \sum \dot{m}_{out} \]
\[ \frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum \dot{m}_{in} (h_{ij} + \frac{v^2_{ij}}{2} + g_2)_{in} - \sum \dot{m}_{out} (h_{ij} + \frac{v^2_{ij}}{2} + g_2)_{out} \]

Solution:

(c) \( 0 = \dot{m}_1 - (\dot{m}_2 + \dot{m}_3) \)

\[ \dot{m}_2 = \dot{m}_1 - \dot{m}_3 = (20 - 15) \text{ kg/s} = 5 \text{ kg/s} \]

\[ 0 = -\dot{W}_{cv} + \dot{m}_1 h_1 - (\dot{m}_2 h_2 + \dot{m}_3 h_3) \]

\[ \dot{W}_{cv} = 20 \frac{Kg}{s} \times 3468 \frac{kJ}{Kg} \]

\[ - (5 \frac{Kg}{s} \times 2861 \frac{kJ}{Kg} + 15 \frac{Kg}{s} \times 2584 \frac{kJ}{Kg}) \]

\[ \dot{W}_{cv} = 16295 \text{ kW} \]