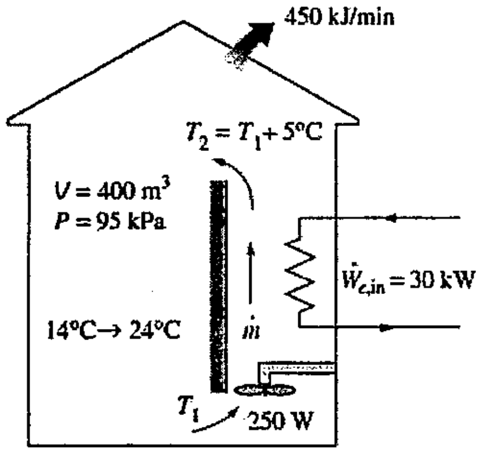
#1 A building (as shown below) with an internal volume of 400 m^3 is to be heated by a 30 kW electric resistance heater placed in the duct inside the building. Initially, the air in the building is at 14°C, and the local atmospheric pressure is 95 kPa. The building is losing heat to the surroundings at a steady rate of 450 KJ/min. Air is forced to flow through the duct and the heater steadily by a 250 W fan, and it experiences a temperature rise of 5°C each time it passes through the duct, which may be assumed to be adiabatic. Here the specific heat of air at constant pressure can be taken as 1.005 kJ/kg/K, and the ideal gas law, $P = \rho RT$, can be assumed for air, with P the pressure, T the absolute temperature, and R = 286.9 J/kg/K.

(a) How long will it take for the air inside the building to reach an average temperature of 24°C? (15%)

(b) Determine the average mass flow rate of air through the duct. (10%)



#2 A mass of liquid water, m = 10kg, initially in thermal equilibrium with the atmosphere at 25°C, is cooled at constant pressure to 15°C by mean of heat pumps operating between the mass of water and the atmosphere. What is the minimum work required? The specific heat of water at constant pressure can be taken as 4.182 kJ/kg/K. Hint: The minimum work is required if the process is reversible, and we can imagine a series of reversible heat pumps operating so as to remove the heat from the water at various temperature levels as the water cools from 25°C to 15°C. (25%)

#3 The ideal Otto cycle consists of four internally reversible processes: isentropic compression, constant-volume heat addition, isentropic expansion, and constant-volume heat rejection.

(a) Draw the P-v (pressure-volume) and T-s (temperature-entropy) diagrams for these processes. (10%)

(b) Consider an ideal Otto cycle with a compression ratio of 8. At the beginning of the compression process, air is at 100 kPa and 17 °C, and 800 kJ/kg of heat is transferred to air during the heat-addition process. Accounting for the variation of specific heats of air with temperature, determine the maximum temperature and pressure that occur during the cycle, the net work output, the thermal efficiency, and the mean effective pressure for the cycle. [Use the specific internal energy u=206.91 kJ/kg and the relative specific volume v_r=676.1 at T=290 K.] (15%)

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#4 (a) The equations that relate the partial derivatives of properties P, v, T, and s of a simple compressible system to each other are called the Maxwell relations. Starting from the Gibbs relations (the total differentials of specific internal energy and enthalpy expressed by the thermodynamic properties), derive the four Maxwell relations. You need to define two functions: the Helmholtz function a and the Gibbs function g. (15%)

$$\left(\frac{\partial T}{\partial v}\right)_s = -\left(\frac{\partial P}{\partial s}\right)_v$$

$$\left(\frac{\partial T}{\partial P}\right)_s = \left(\frac{\partial v}{\partial s}\right)_P$$

$$\left(\frac{\partial s}{\partial v}\right)_T = \left(\frac{\partial P}{\partial T}\right)_v$$

$$\left(\frac{\partial s}{\partial P}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_P$$

(b) A corollary of the Maxwell equations is the Clapeyron equation that can be used to calculate the enthalpy change associated with a phase transition at constant pressure and temperature (e.g. vaporization h_{fg}). Starting from the Maxwell equations, derive the Clapeyron equation. (10%)

$$\left(\frac{dP}{dT}\right)_{sat} = \frac{h_{fg}}{Tv_{fg}}$$

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