SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING
LRESE - Laboratory of Renewable Energy Sciences and Engineering

Renewable Energy: Solution (Geothermal)

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1. (a) The mass of the air to be heated is :
$m_{air} = V \cdot \rho_{air} = 8000m^3 \cdot 1.29$ kg/m^3 = 10320 kg
The required energy change:
$\Delta\dot{E} = m_{air} \cdot c_{air} \cdot \Delta T/\Delta t = 10320kg \cdot 1000\frac{J}{kgK} \cdot 7.3 \cdot 10^{-3}K/s = 75336J/s$
Installed heating capacity: P_n = 75.3 kW

   (b) COP of heat pump = 4.2
E = Electrical energy (for pump)
Q_n = Useful heat
Q_u = Ambient heat
$Q_n = Q_u + E$

   Coefficient of power for heat pump is defined as COP $= \frac{Q_n}{E} = \frac{P_n}{P_{el}}$
This implies electrical power P_{el} = 75.3 kW / 4.2 = 17.9 kW
Heating power of the probe corresponds to the Q_n and hence $P_n = P_u + P_{el}$ implying P_u = 75.3 kW - 17.9 kW = 57.4 kW

   (c) l is the length of the probe. Using P_u from part b we get: $l \cdot 52\frac{W}{m}$ = 57.4 kW implies l = 1104m
we also have : $\frac{Q_u}{l} = \frac{Q_n - E}{l} = \frac{Q_n - \frac{Q_n}{COP}}{l}$
Insertion of annual heating demand Q_n = 135000 kWh gives:
$\frac{Q_u}{l} = 93.2\frac{kWh}{m} < 110\frac{kWh}{m}$

   (d) $E = \frac{Q_n}{COP}$ = 32143 kWh
implies the electricity cost = 32143 kWh · 0.13 Fr./kWh = 4178.59 Fr.

   (e) Oil heating:
Annual heating demand in MJ equal to 135000 kWh = 486.10^3 MJ
Volume of oil required is $V_{oil} = \frac{486.10^3 MJ}{42.6MJ/kg \cdot 0.86kg/l}$ = 13266 litres
The price of the oil would be 13266 litres . 0.86 Fr./litre =11408.75 Fr.

(f) CO_2 emission geothermal heat pump : $E \cdot 0.13 \frac{kg}{kWh} = \frac{Q_n}{COP} \cdot 0.13 = 4179$ kg

CO_2 emission oil heating : 486. 10^3 MJ $\cdot$ 0.074 $\frac{kg}{kWh} = 35964$kg

Hence reduction in CO_2 emission is $\frac{(35964 - 4179)}{35964} = 88.4\%$

2. (a) Available heat in the geothermal source: $\dot{Q} = \dot{m} c_p (T_{in} - T_{out}) = 50 * 4180 * (190 - 85) =$ 21.945 MW

Exergy available in the geothermal source:

$$T_{logmean} = \frac{T_{h,in} - T_{h,out}}{ln \frac{T_{h,in}}{T_{h,out}}} = \frac{463 - 358}{ln \frac{463}{358}} = \frac{105}{0.2572} = 408.25\text{K}$$

$$Ex_{source} = \dot{Q} * (1 - \frac{T_a}{T_{logmean}}) = 21.945 * (1 - \frac{287}{408.25}) = 21.945 * (1 - 0.703) = 6.52\text{MW}$$

Exergy for district heating:

$$T_{logmean} = \frac{T_{h,in} - T_{h,out}}{ln \frac{T_{h,in}}{T_{h,out}}} = \frac{333 - 313}{ln \frac{333}{313}} = \frac{20}{0.06194} = 322.9\text{K}$$

$$Ex_{heating} = \dot{Q} * (1 - \frac{T_a}{T_{logmean}}) = 12 * (1 - \frac{287}{322.9}) = 12 * (1 - 0.889) = 1.334\text{MW}$$

Energy Efficiency:
- summer: 3.2 MW_e/21.945 MW =14.6%
- winter: (2.4 MW_e+12 MW_{th})/21.945 MW = 65.6%

Exergy Efficiency:
- summer: $\epsilon = \frac{Ex_{electrical} + Ex_{heating}}{Ex_{source}} = \frac{3.2 + 0}{6.52} = 49.1\%$
- winter: $\epsilon = \frac{Ex_{electrical} + Ex_{heating}}{Ex_{source}} = \frac{2.4 + 1.334}{6.52} = 57.3\%$

(b) The marginal electrical efficiency in winter is the elec. production from the residual heat (21.945 MW - 12 MW DH = 9.945 MW), thus 2.4/9.945=24.1%