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Assignment 2 Primary Energy Factors (Date: 09.02.2014)

general calculations

- total area $28\,000 m^2$
- design heating load $75 W/m^2$
- coincidence factor 0.8
- heating demand full load $3000 h$
- total annual heat extraction $30\,000 kWh$

maximum design heating load: $75 W/m^2 \cdot 28\,000 m^2 = 2\,100 kW$
total heat consumption in DH system: $2\,100 \cdot 0.8 \cdot 3000 h = 5040 GWh$

Assignment 2a

- efficiency of the heating network: $\eta_{hn} = 0.9$
- power to heat ratio: $\sigma = 0.5$
- $f_{p,el} = 2.8$
- $Q_{del} = 30GWh \cdot 20\% = 6GWh$
- total annual power production

$$E_{el} = \sigma \cdot 30\,000MWh = 15\,000MWh$$

- net power loss due to DH system

$$\frac{delivered}{total} \cdot (power\ loss\ of\ plant)$$

$$\frac{6\,000}{30\,000} \cdot (15\,000 * 0.2) = 600MWh/year$$

- primary energy factor

$$f_{p,dh} = \frac{\sum_i E_{f,i} \cdot f_{p,F,i} - E_{el,chp} \cdot f_{p,el}}{\sum_j Q_{del,j}}$$

$$f_{p,dh} = \frac{2.8 \cdot (net\ power\ loss\ due\ to\ DH\ system)}{0.9 \cdot (total\ heat\ consumption\ in\ DH\ system)}$$

$$f_{p,dh} = \frac{2.8 \cdot 600}{0.9 \cdot 5040} = 0.37$$

Assignment 2b

- boiler
  - maximum power $P_{max,boiler} = 1.4MW$
  - fuel efficiency $\eta_{T,gen} = 0.85$
  - full load time $1000h$
- CHP
  - heat to power factor $\sigma = 0.95$
  - total efficiency $\eta_{chp} = 0.72$
- heating net efficiency $\eta_{hn} = 0.75$
- $f_{p,el} = 3.31$
- $f_{p,gas} = f_{p,T,gen} = 1.3$
- $Q_{del} = 5\,040MWh$

total amount of generated heating energy Q

$$Q = Q_{chp} + Q_{gas}$$
$$Q = 1\,411MWh + 1\,400MWh = 2\,811MWh$$

amount of generated heating energy by gas boiler Q_{gas}

$$Q_{gas} = P_{max,boiler} \cdot duration$$
$$Q_{gas} = 1.4MW \cdot 1\,000h = 1\,400MWh$$

amount of heat delivered by CHP Q_{chp}

$$P_{max_{chp}} = \frac{0.28 \cdot 5\,040MW}{2\,000h} = 0.706MW$$
$$Q_{chp} = P_{max_{chp}} \cdot duration$$
$$Q_{chp} = 0.706MW \cdot 2\,000h = 1\,411MWh$$

ratio of CHP produced heat and total produced heat

$$\beta = \frac{1.4MW \cdot 1\,000h}{5\,040MWh} = 0.28$$

amount of fuel energy delivered to the CHP Q_B

$$Q_B = \frac{E_{el,chp} + Q_{chp}}{\eta_{tot}}$$
$$Q_B = \frac{1\,340.6MWh + 1\,411MWh}{0.72} = 3822MWh$$

total annual electricity production by the CHP E_{el}

$$E_{el} = Q_{chp} \cdot \sigma$$
$$E_{el} = 1\,411MWh \cdot 0.95 = 1\,340.6MWh$$

elecricity efficiency of the CHP η_{el}

$$\eta_{el} = \frac{E_{el}}{Q_B}$$

$$\eta_{el} = \frac{1\,340.6MWh}{3\,822MWh} = 0.35$$

primary energy factor f_p

$$f_{p,dh} = \frac{(1+\sigma)\cdot\beta}{\eta_{hn}\eta_{chp}} \cdot f_{p,chp} + \frac{1-\beta}{\eta_{hn}\eta_{T,gen}} \cdot f_{p,T,gen} - \frac{\sigma\beta}{\eta_{hn}} \cdot f_{p,el}$$

$$f_{p,dh} = \frac{(1+0.95)\cdot 0.28}{0.75\cdot 0.72} \cdot 1.3 + \frac{1-0.28}{0.75\cdot 0.85} \cdot 1.3 - \frac{0.95\cdot 0.28}{0.75} \cdot 3.31$$

$$f_{p,dh} = 1.609 \approx 1.61$$

Assignment 2c

- $\sigma = 0.95$
- $\eta_{chp} = 0.75$
- $\eta_{hn} = 0.75$
- $f_{p,el} = 3.31$
- $f_{p,gas} = f_{p,chp} = 1.3$

all energy is produced by the CHP, so the ratio β of CHP produced heat to total produced heat is 1

$$P_{max,chp} = \frac{5\,040MWh}{3\,000h} = 1.68MW$$

total amount of generated heating energy Q_{chp}

$$Q_{chp} = P_{max,chp} \cdot duration$$

$$1.86MW \cdot 3\,000h = 5\,040MWh$$

amount of heat delivered by the CHP Q_{del}

$$Q_{chp} = 5\,040MWh$$

total amount of fuel energy delivered Q_B

$$Q_B = \frac{E_{el,chp} + Q_{chp}}{\eta_{tot}}$$

$$Q_B = \frac{4\,788MWh + 5\,040MWh}{0.75} = 13\,104MWh$$

total annual electricity production E_{el}

$$E_{el} = Q_{chp} \cdot \sigma$$

$$E_{el} = 5\,040MWh \cdot 0.95 = 4\,788MWh$$

electricity efficiency η_{el}

$$\eta_{el} = \frac{E_{el}}{Q_B}$$

$$\eta_{el} = \frac{4\,788MWh}{13\,104MWh} = 0.37$$

primary energy factor f_p

$$f_{p,dh} = \frac{(1+\sigma) \cdot \beta}{\eta_{hn}\eta_{chp}} \cdot f_{p,chp} - \frac{\sigma\beta}{\eta_{hn}} \cdot f_{p,el}$$

$$f_{p,dh} = \frac{(1+0.95)}{0.75 \cdot 0.75} \cdot 1.3 - \frac{0.95}{0.75} \cdot 3.31$$

$$f_{p,dh} \approx 0.31$$

Assignment 2d

- $P_{max} = 1.4MW$
- $\eta_{T,gen} = 1.1$
- $f_{p,gas} = f_{p,gen} = 1.3$
- $\eta_{hn} = 0.75$

$$\beta = \frac{1.4MW \cdot 3\,000h}{5\,040MWh} = 0.83$$

total amount of generated heating energy Q_{gas}

$$Q_{gas} = P_{max,gas} \cdot duration$$
$$Q_{gas} = 1.4MW \cdot 3\,000h = 4\,200MWh$$

amount of heat delivered Q_{del}

$$Q_{del} = Q_{gas} \cdot \eta_{hn}$$
$$Q_{del} = 4\,200MWh \cdot 0.75 = 3\,150MWh$$

primary energy factor

$$f_{p,dh} = \frac{1-\beta}{\eta_{hn}\eta_{T,gen}} \cdot f_{p,T,gen}$$
$$f_{p,dh} = \frac{1-0.83}{0.75 \cdot 1.1} \cdot 1.3$$
$$f_{p,dh} \approx 0.26$$

Assignment 2e

The example in 2d gives the lowest energy factor. This is because of a high net calorific efficiency and a placement within the district heating boundaries. A good possibility to decrease primary energy factors is to deliver produced energy to the power grid. These terms are subtracted from the primary energy factor, and so this is getting lower. To decrease the primary energy factor one possibility could be to measure the heat which is not used and flow back to the power plant, get environmental factors like CO_2 and the geographical position of the plant, as well as the climatic data of the region.