2nd International Conference on Smart Energy Systems and 4th Generation District Heating
Aalborg, 27-28 September 2016

Exergy Meters in District Heating Systems

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What is Exergy

- Exergy is defined as the theoretical maximum work which can be obtained from an energy system.
  - High grade energy (work or electricity)
  - Low grade energy (Heat)

- A simple example:
  - 1 MWh of electricity can give 1 MWh of heat.
  - 1 MWh of heat always gives less than 1 MWh of electricity because of the notion of irreversibility and the concept of entropy.

Exergy Background

- Nicolas Leonard Sadi **Carnot** in 1824 proposed a theoretical thermodynamic cycle providing an upper limit on the efficiency that any engine can achieve during the conversion of heat into work.
- Josiah Williard **Gibbs** (1839 – 1903) was accredited with the availability of energy concept by indicating that the environment plays an important part.
- Zoran **Randt** (1904 – 1972) proposed in 1956 the exergy term that quantifies in a coherent way the quantity and the quality of different forms of energy.

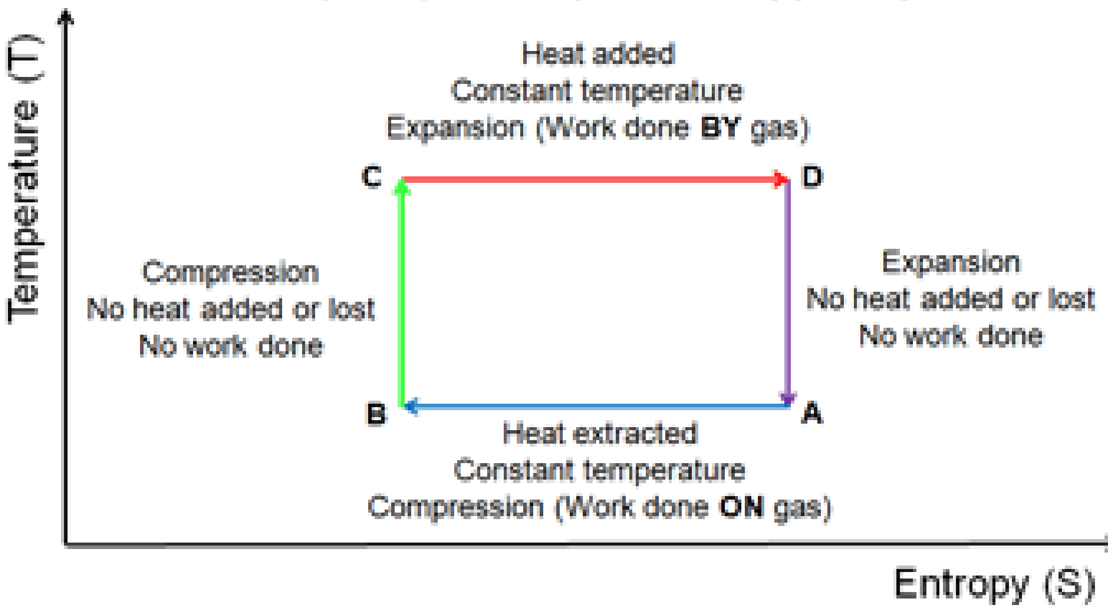
Carnot Factor

The maximum work that can be supplied by a reversible machine only depends on the temperature of the internal energy considered.

The Carnot factor or the maximum efficiency possible for any engine is:

$$\Theta = 1 - \frac{T_c}{T_h}$$

Carnot (Ideal) Heat Cycle Entropy Diagram



Heat Exergy

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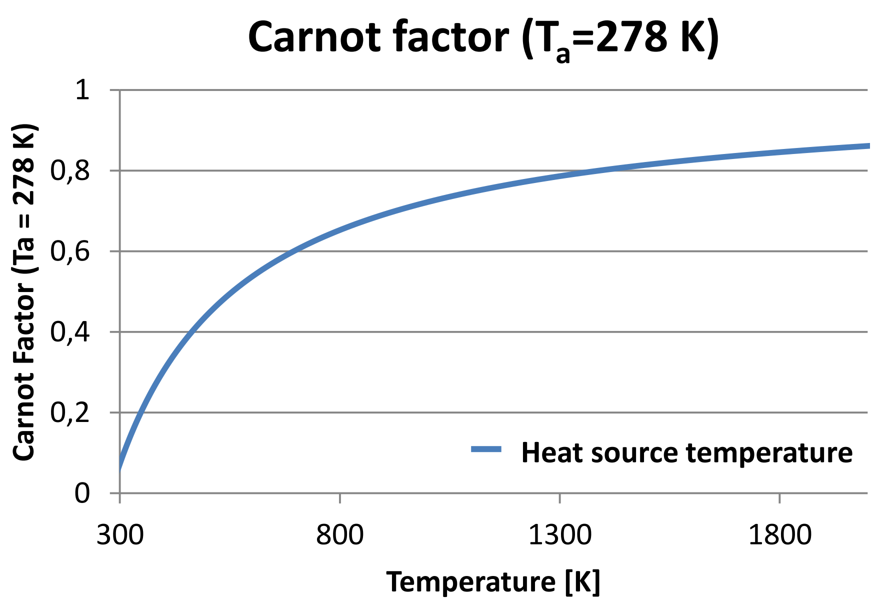
Heat exergy is the maximum work that can be obtained from a heat source by means of a reversible cycle operating between the temperatures T_i of the heat source and T_a of the atmosphere.

$$\dot{E}_q = \Theta * \dot{Q}_i = \left(1 - \frac{T_a}{T_i}\right) * \dot{Q}_i$$

Θ: Carnot factor

$\dot{Q}_i$: Heat



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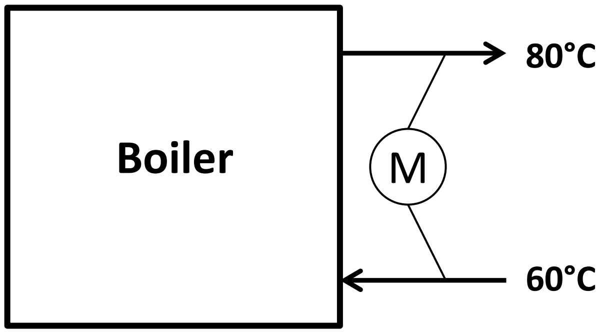
Exergy Meters



The exergy meter would monitor the transformation exergy $\dot{E}_y$ cumulated on the flow leaving a heat exchanger.

$$\dot{\boldsymbol{E}}_{\boldsymbol{y}} = \dot{\boldsymbol{Q}}^{+} * (\mathbf{1} - \frac{\boldsymbol{T}_{\boldsymbol{a}}}{\widehat{\boldsymbol{T}}_{\boldsymbol{ln\,fluid}}}) \qquad \widehat{T}_{\ln fluid} = \frac{T_{out} - T_{in}}{\ln\left(\frac{T_{out}}{T_{in}}\right)}$$

If 10 MWh of cumulated heat is metered from the (M) heat meter, 1.9 MWh of Exergy would instead have been monitored by an exergy meter with an outside temperature of 5°C.

$$\dot{E}_y = 10 * \left(1 - 278 * \frac{\ln\left(\frac{353}{333}\right)}{353 - 333}\right) = 1.9\ MWh$$

Heat Pump Performance

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Heating coefficient of performance (COP) – (Heating effectiveness)

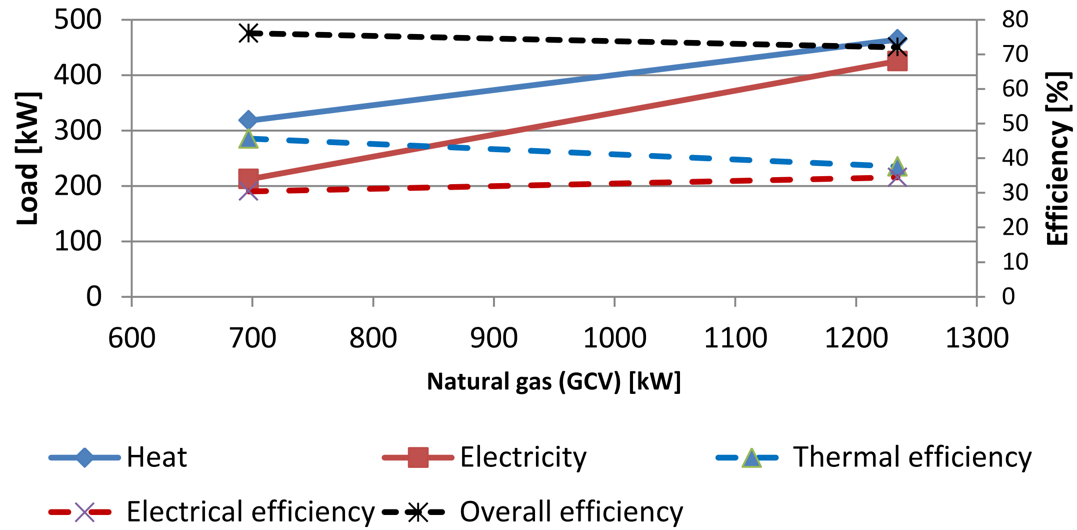
$$\varepsilon_h = \frac{Heat\ generated}{Electricity\ consumption} > 1$$

Exergy efficiency (Includes all consumptions and generation)

$$\eta = \frac{Heat\ exergy\ generated}{Electricity\ consumption\ (exergy)} < 1$$

Please note that the heat exergy consumed to evaporate the heat pump refrigerant equals zero.

CHP engines Performance (E-425)



Overall energy efficiency (HHV)

Part load: $\varepsilon = 45.6\% + 30.4\% = 76.1\ \%$

Full load: $\varepsilon = 37.6\% + 34.4\% = 72.0\ \%$

(Heat exergy + Electricity exergy)

Exergy efficiency (T_a = 5°C)

Part load: $\eta = 10.8\% + 32.3\% = 43.2\ \%$

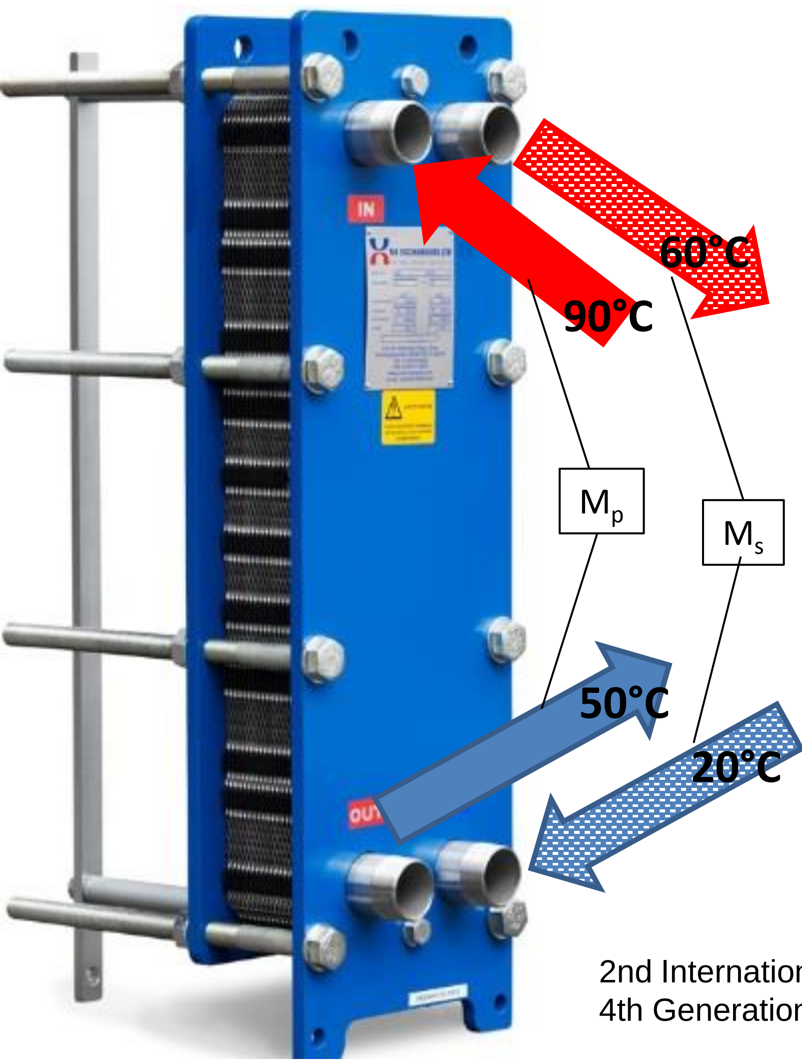
Full load: $\eta = 8.9\% + 36.6\% = 45.5\ \%$

(Heat exergy + Electricity exergy)

1) The overall energy efficiency reduces with an increasing load.

2) The exergy efficiency increases with an increasing load.

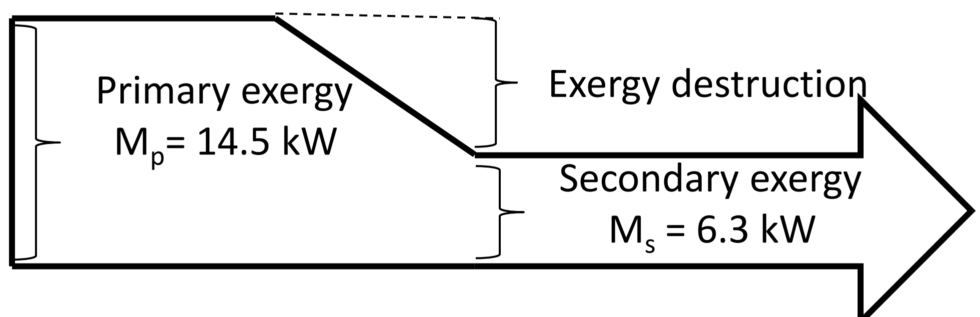
Plate heat exchanger and exergy destruction @ T_a = 20°C



- 100 kW of heat from the primary flow gives 100 kW of heat on the secondary side.
- M_p: 100 kW of heat equals to 14.5 kW of exergy-heat on the primary side.
- M_S: 100 kW of heat equals to 6.3 kW of exergy-heat on the secondary side.

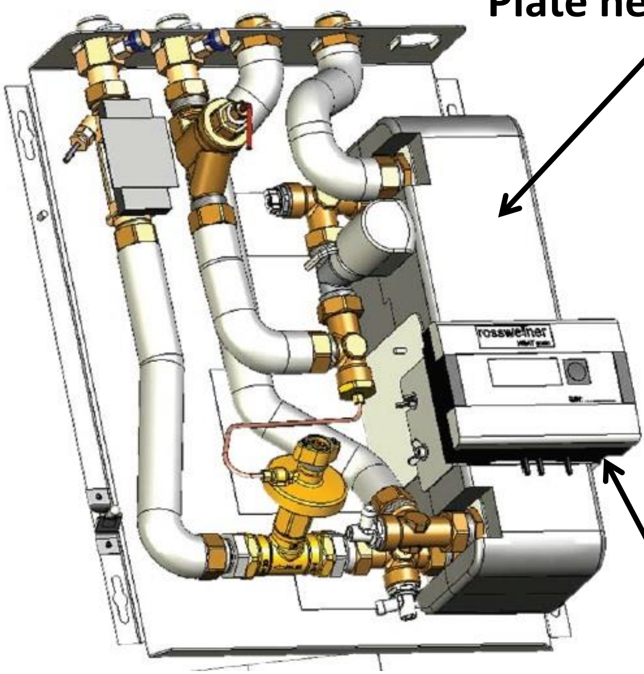
$$\dot{E}_y = \dot{Q}^+ * (1 - \frac{T_a}{\hat{T}_{\ln fluid}})$$

$$\hat{T}_{\ln fluid} = \frac{T_{out} - T_{in}}{\ln\left(\frac{T_{out}}{T_{in}}\right)}$$



Useable Heat and Heat Meter Location

Plate heat exchanger



ESCo sell useable heat which can vary in quality. To heat a building at 21°C, the DH flow temperature must be above that temperature. However, a space would heat up sooner if the heat is supplied at a higher temperature than 21°C. Hence, heat at 70°C could be more expensive than heat at 21°C.

Heat meter : It calculates the heat consumed on the primary side. Thus, it measures the flow rate and the supply and return temperatures of the primary side.

End User

Underfloor heating

T_{sup} = 45°C
T_{ret} = 30°C

Radiator

T_{sup} = 60°C
T_{ret} = 45°C

Pimlico District Heating Undertaking
50,000 MWh of heat per year

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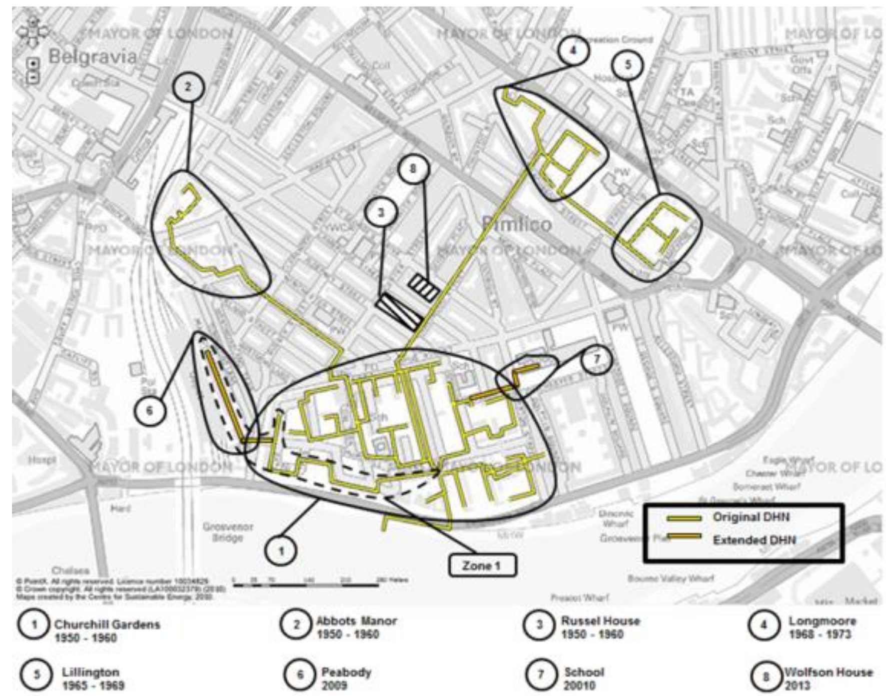

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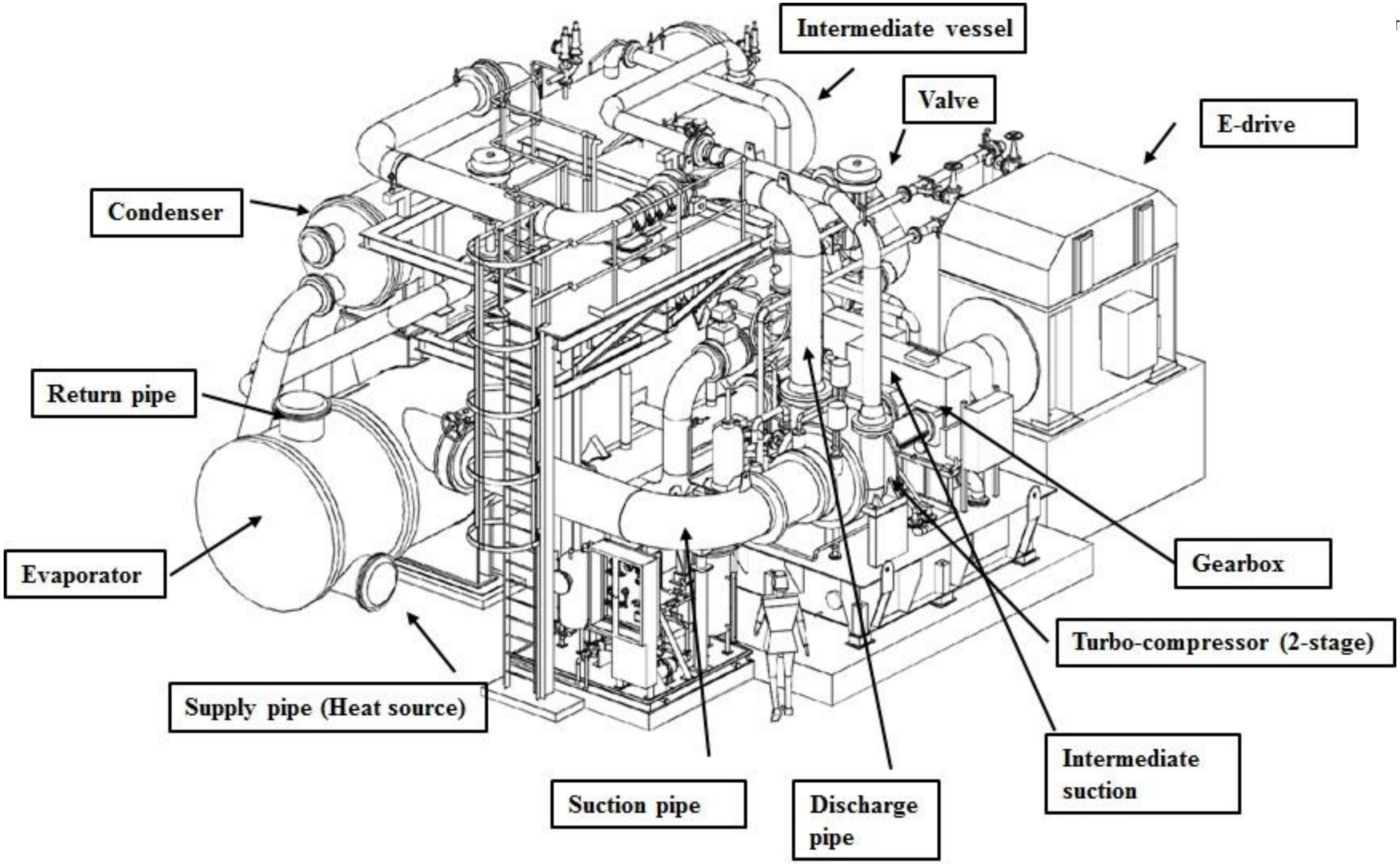
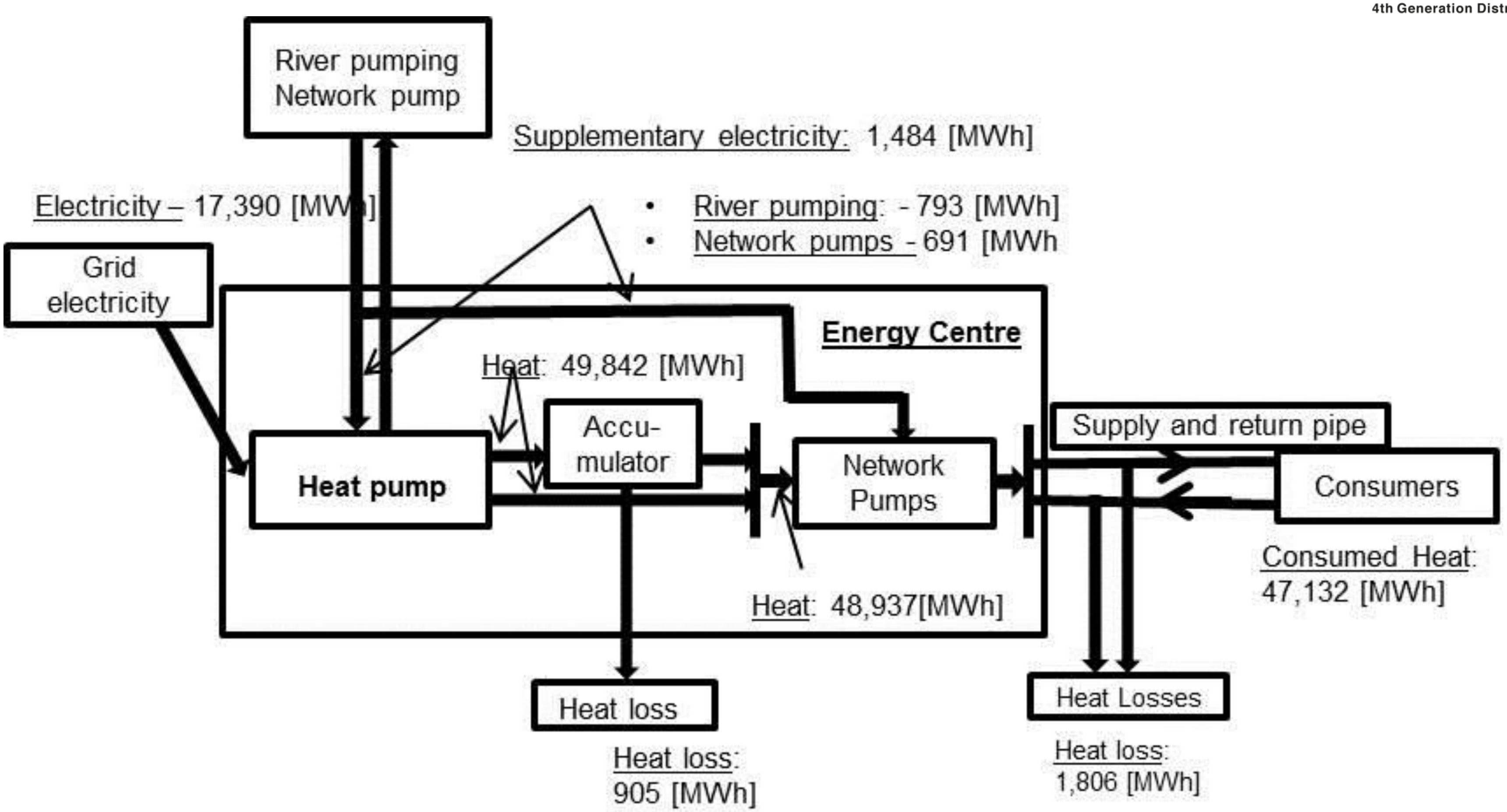
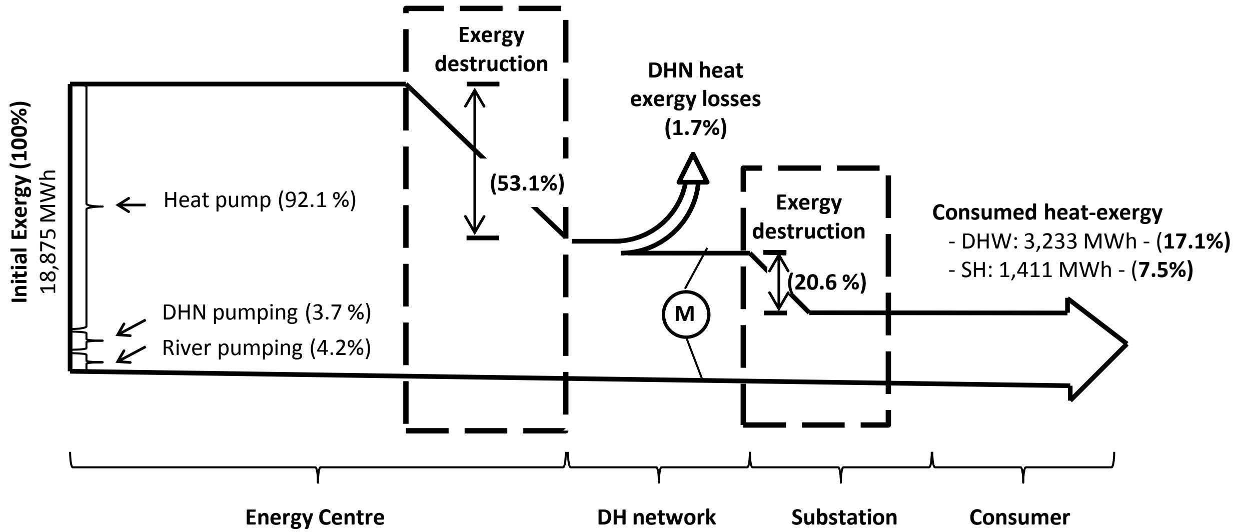
Open Loop Heat Pump



Sankey Diagram



Grassman Diagram



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In Conclusion

Exergy meters would encourage consumers to reduce their heating cost by requiring a lower flow temperature and cooling it further. This would simultaneously improve the performance of a district heating system by:

- Reducing the electricity consumption for Pumping;
- Flattening the heating load;
- Reducing the heat losses in the DH network.

Questions

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