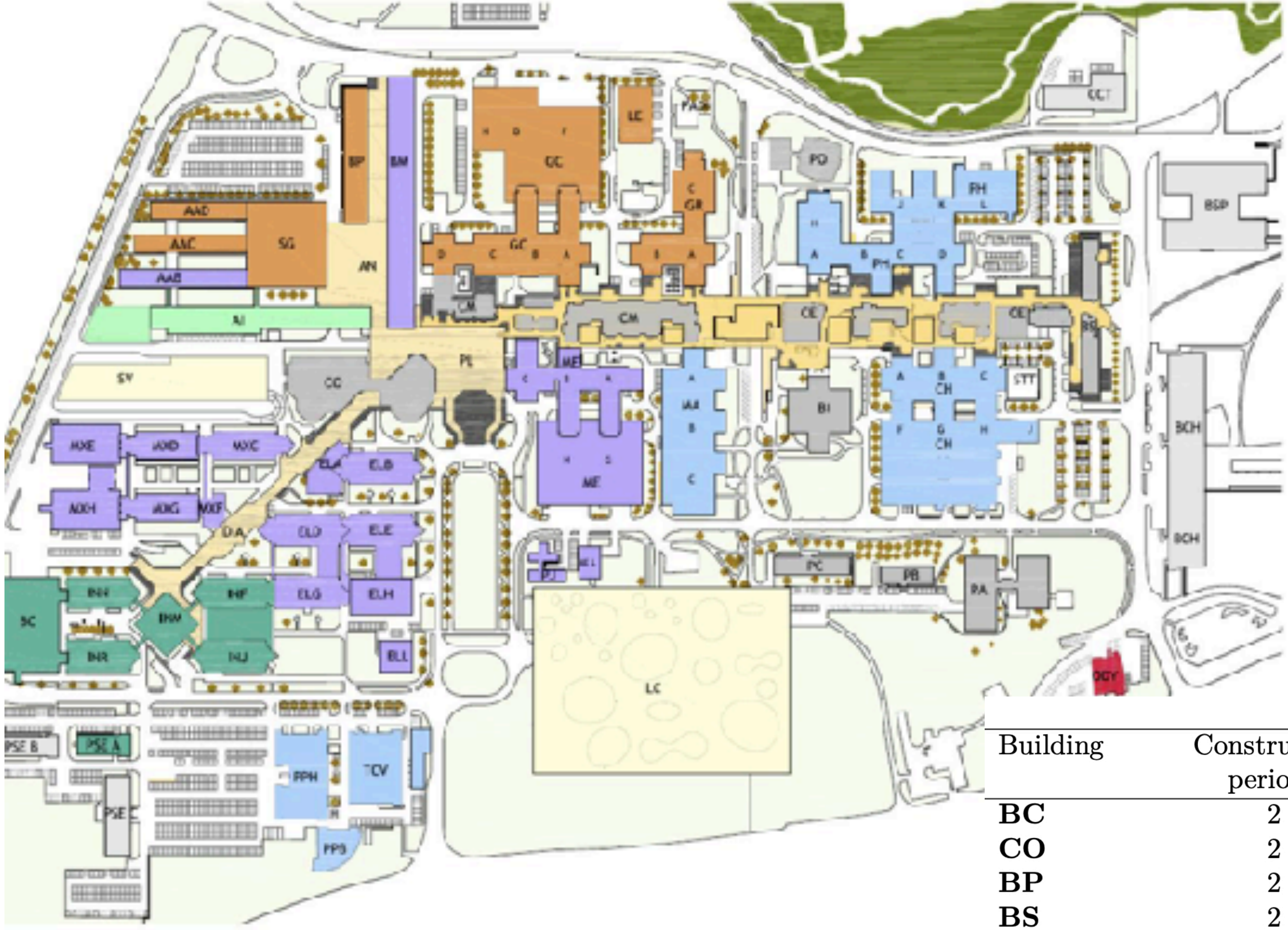
The Energy Supply System

Prof François Marechal

IPESE
Industrial Process
and Energy Systems
Engineering

Part1 : defining the building needs

Buildings stock

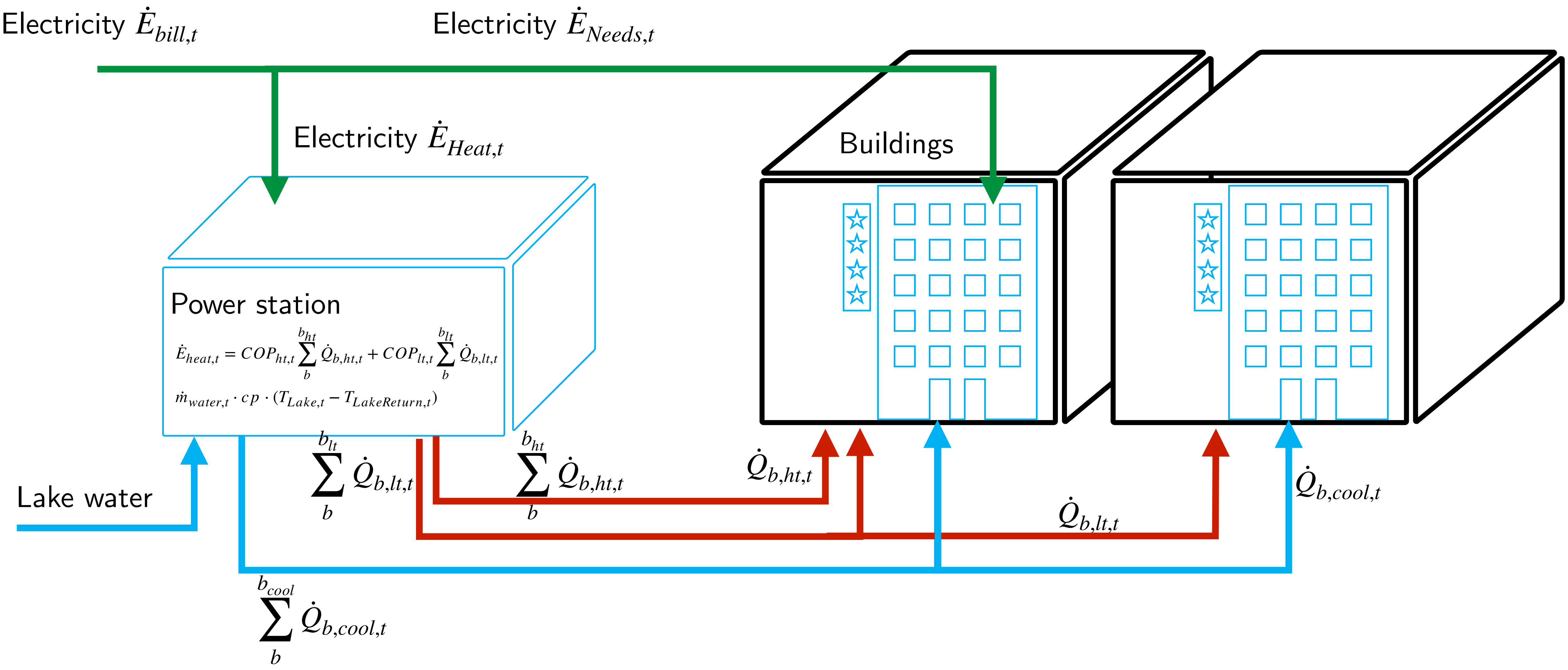


Measures

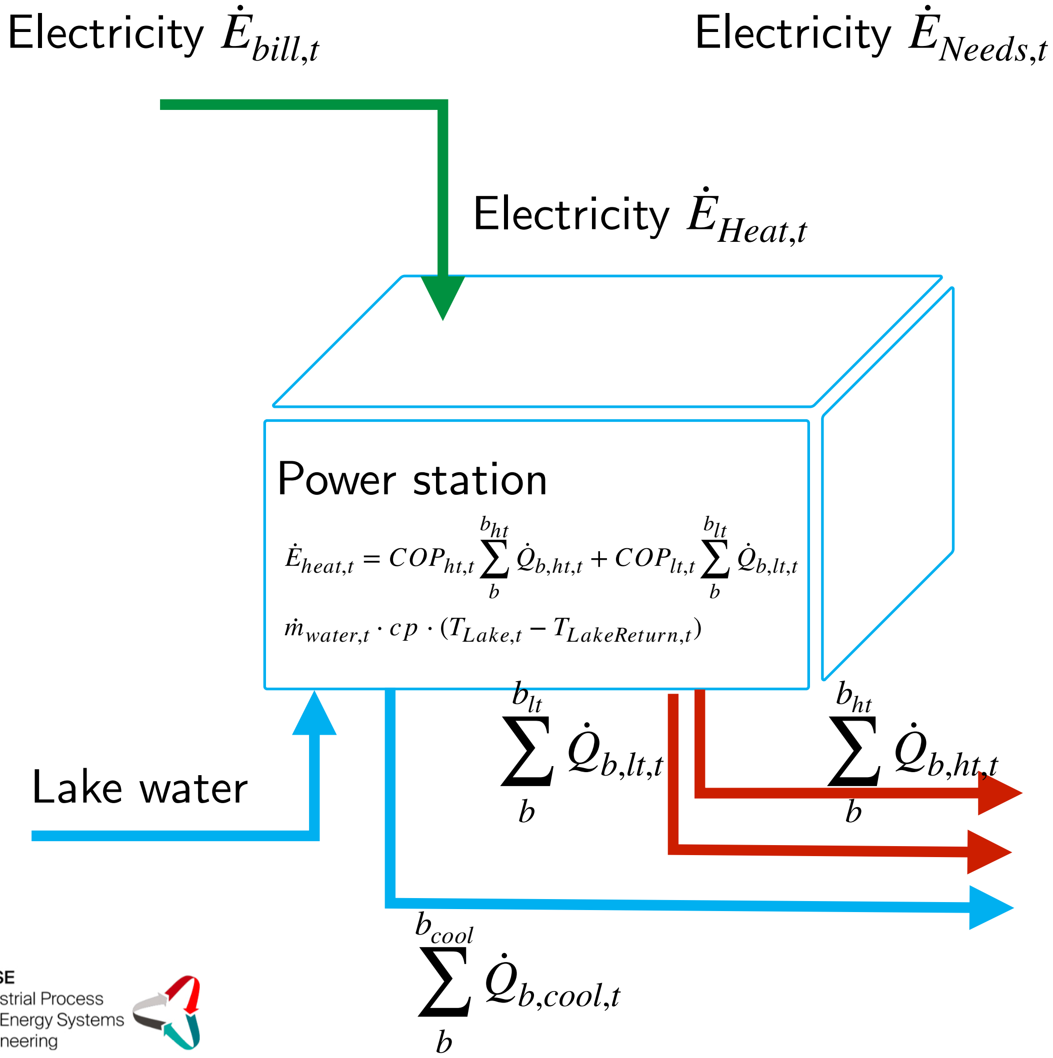
Table 1.1: EPFL Buildings

Building	Construction period[a]	Heated surface A_{th} [m^2]	Annual heat demand Q_{th} [kWh]	Annual electricity demand Q_{el} [kWh]
BC	2	17480	418,491	1,603,596
CO	2	11901	477,008	943,653
BP	2	10442	457,861	691,031
BS	2	10267	509,183	350,860
TCV	2	6095	318,209	2,067,675

The energy system of EPFL



The energy conversion system



- For each distribution system d (e.g. ht)
  - Demand : $\dot{Q}_{d,t} = \sum_{b}^{n_b} \dot{Q}_{b,d,t} \quad \forall t \in lifetime$
- For each unit u (e.g. heat pump}
  - Supply by unit u : $\sum_{u=1}^{n_u} \dot{Q}_{u,d,t} = \dot{Q}_{d,t} \quad \forall t \in lifetime$
  - and $\dot{Q}_{u,t} = \sum_{d}^{n_d} \dot{Q}_{u,d,t}$
- Cost of the supply
  - Size of the conversion equipment :
    $\sum_{u=1}^{n_u} \max_{t \in lifetime} (\dot{Q}_{u,d,t}) = \max_{t \in lifetime} (\dot{Q}_{d,t})$
  - $\dot{Q}_{u,max} = \max_{t \in lifetime} (\dot{Q}_{u,t})$
  - Buy the resources : $\sum_{r=1}^{n_{res}} \sum_{u}^{n_u} \left(\int_{t_0}^{lifetime} c_{r,t} \cdot m_{r,u,t} \cdot \dot{Q}_{u,t} \cdot dt \right)$

Energy conversion OPEX

$$\sum_{r=1}^{n_{res}} \sum_{u}^{n_u} \left(\int_{t_0}^{lifetime} c_{r,t} \cdot m_{r,u,t} \cdot \dot{Q}_{u,t} \cdot dt \right) \quad [CHF/lifetime]$$

- $c_{r,t}$ $[CHF/unit_r]$ cost of one unit of resource r at time t
  - e.g. kg of water, kg of fuel, kJ of fuel or kWh of electricity
  - $c_{r,t} \leq 0$ for products (e.g. electricity production)
- $m_{r,u,t}$ $[unit_r/kJ_{th}]$ unit of resource r used to deliver one $[kJ_{th}]$ of heat by unit u at time t
- $\dot{Q}_{u,t}$ $[kW]$ heat delivered by unit u at time t
- $lifetime$ $[s]$ expected lifetime of the project

OPEX in [CHF/year]

- OPerating EXpenditure (we assume a typical year of operation) :

Cost of resources $\sum_{r=1}^{n_{res}} \sum_{u}^{n_u} \left(\int_{t_0}^{year} c_{r,t} \cdot m_{r,u,t} \cdot \dot{Q}_{u,t} \cdot dt \right) \quad [CHF/year]$

+ Maintenance [CHF/year]

+ Men Power [CHF/year]

+ Taxes [CHF/year] :

fixed : e.g. based on installed power

proportional : $\sum_{r=1}^{n_{res}} \sum_{u}^{n_u} \left(\int_{t_0}^{year} t_{r,t} \cdot m_{r,u,t} \cdot \dot{Q}_{u,t} \cdot dt \right) \quad [CHF/year]$

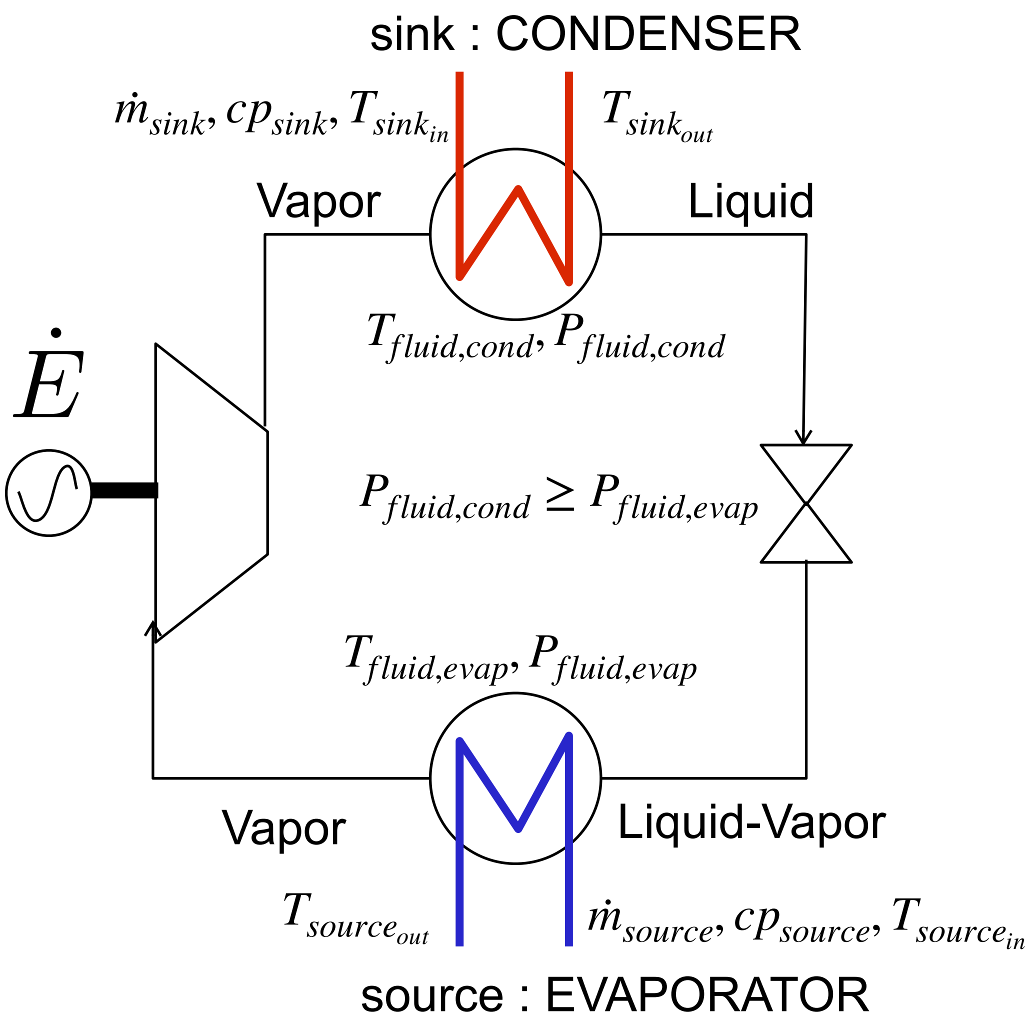
with $t_{r,t} \quad [CHF/unit_r]$ tax per unit of r

e.g. $t_{r,t} = \tau_{CO_2}[CHF/kg_{CO_2}] \cdot m_{CO_2,r}[kg_{CO_2}/unit_r]$

Calculating $m_{r,u,t} \quad [unit_r/kJ_{th}]$ for a Cogeneration unit

- Assumptions
  - Thermal efficiency : $\eta_{th,u} = \dfrac{\dot{Q}_{th,u}}{\dot{m}_{r,u}} \quad [kJ_{th}/kJ_r]$
  - Electrical efficiency : $\eta_{e,u} = \dfrac{\dot{E}_u}{\dot{m}_{r,u}} \quad [kJ_e/kJ_r]$
- $m_{r,u,t} = \dfrac{1}{\eta_{th,u}} \quad [kJ_r/kJ_{th}]$
- $\dot{E}_{u,t} = \dfrac{\eta_{e,u}}{\eta_{th,u}} \cdot \dot{Q}_{u,t}$

Calculating $m_{r,u,t}$ $[kJ_e/kJ_{th}]$ for a heat pump : approximation



$$\dot{Q}_{sink} = \dot{Q}_{u,t} = \dot{m}_{sink,t} \cdot cp_{sink} \cdot (T_{sink_{out,t}} - T_{sink_{in,t}})$$

$$\dot{E}_{u,t} = \frac{\dot{Q}_{u,t}}{COP_{u,t}}$$

$$COP_{u,t} = \eta_{COP} \cdot COP_{th,u,t}$$

$$\eta_{COP} = 50\,\%$$

$$COP_{th,u,t} = \frac{\tilde{T}_{sink,t}}{\tilde{T}_{sink,t} - \tilde{T}_{source,t}}$$

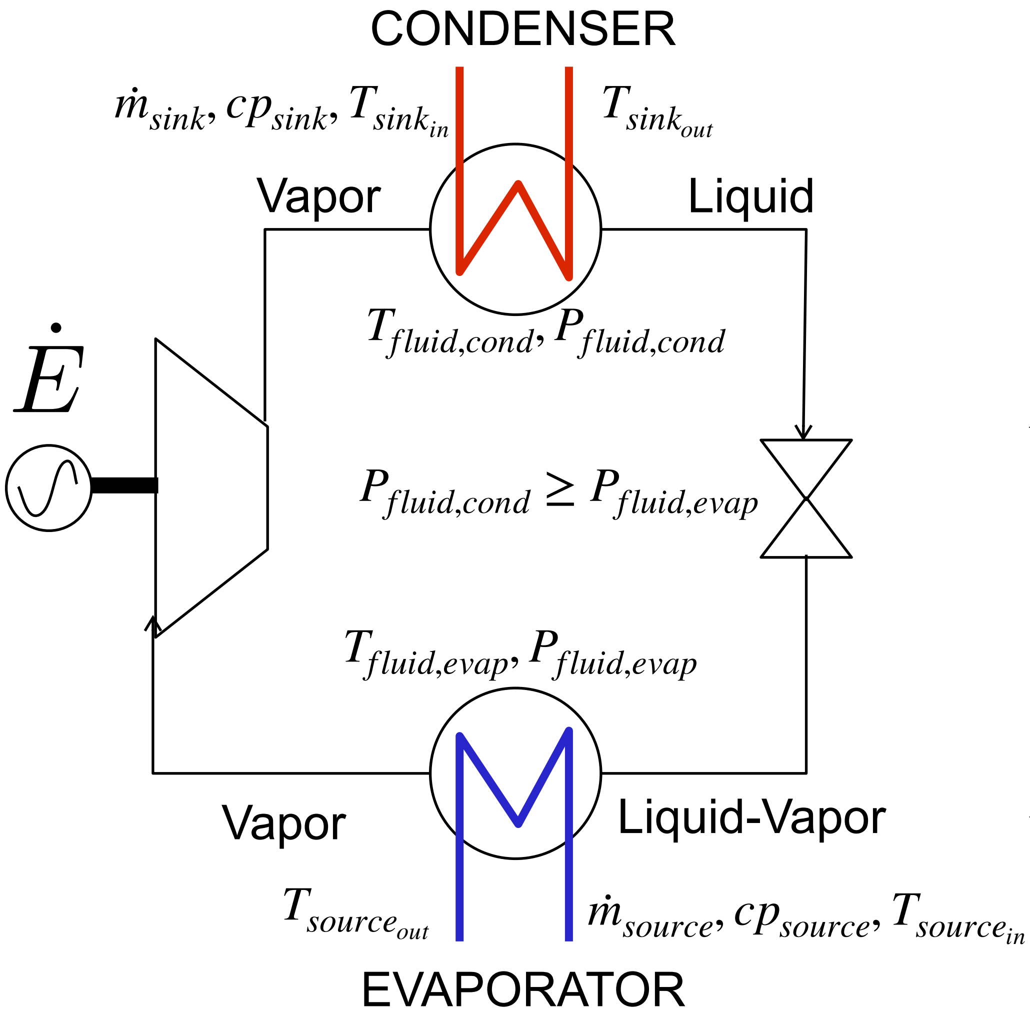
$$\tilde{T}_{sink,t} = \frac{T_{sink_{out,t}} - T_{sink_{in,t}}}{ln(T_{sink_{out,t}}) - ln(T_{sink_{in,t}})}$$

$$\tilde{T}_{source,t} = \frac{T_{source_{out,t}} - T_{source_{in,t}}}{ln(T_{source_{out,t}}) - ln(T_{source_{in,t}})}$$

$$\dot{Q}_{source,t} = \dot{m}_{source,t} \cdot cp_{source} \cdot (T_{source_{in,t}} - T_{source_{out,t}})$$

$$\dot{Q}_{source,t} = \dot{Q}_{u,t} - \dot{E}_{u,t}$$

Calculating $i_{u_{\dot{Q}_{u,max}}}$ $[CHF/kW]$ for a heat pump



Sizing : condenser, evaporator & compressor

$$\dot{Q}_{u,t} = \dot{Q}_{sink,t} = \dot{m}_{sink,t} \cdot cp_{sink} \cdot (T_{sink_{out},t} - T_{sink_{in},t})$$

$$\dot{Q}_{sink,t} = \dot{m}_{fluid,t} \cdot (h(T_{fluid,cond_{in},t}, P_{fluid,cond_{in},t} - h(T_{fluid,cond_{out},t}, P_{fluid,cond_{out},t})$$

$$A_{condenser} = \max_{t \in lifetime} \left(\left(\frac{1}{u_{sink}} + \frac{1}{u_{fluid,cond}} \right) \frac{\dot{Q}_{sink,t}}{\frac{(T_{fluid,cond,t} - T_{sink_{in},t}) - (T_{fluid,cond,t} - T_{sink_{out},t})}{ln(T_{fluid,cond,t} - T_{sink_{in},t}) - ln(T_{fluid,cond,t} - T_{sink_{out},t})}} \right)$$

$$\dot{E}_{max} = \max_{t \in lifetime} \left(\frac{\dot{Q}_{u,t}}{COP_{u,t}} \right)$$

$$A_{evaporator} = \max_{t \in lifetime} \left(\left(\frac{1}{u_{source}} + \frac{1}{u_{fluid,evap}} \right) \frac{\dot{Q}_{source,t}}{\frac{(T_{source_{out},t} - T_{fluid,evap,t} - (T_{source_{in},t} - (T_{fluid,evap,t})}{ln(T_{source_{out},t} - T_{fluid,evap,t}) - ln(T_{source_{in},t} - T_{fluid,evap,t})}} \right)$$

$$\dot{Q}_{source,t} = \dot{m}_{source,t} \cdot cp_{source} \cdot (T_{source_{in},t} - T_{source_{out},t})$$

$$\dot{Q}_{source,t} = \dot{m}_{fluid,t} \cdot (h(T_{fluid,evap_{out},t}, P_{fluid,evap_{out},t} - h(T_{fluid,evap_{in},t}, P_{fluid,evap_{in},t})$$

$$\dot{Q}_{source,t} = \dot{Q}_{sink,t} - \dot{E}_{u,t}$$

CAPEX energy conversion system [CHF/year]

- CAPital EXpenditure

$$CAPEX \quad [CHF/year] = \sum_{u=1}^{n_u} \frac{1}{\tau_u} \cdot i_{u_{\dot{Q}_{u,max}}} \cdot \dot{Q}_{u,max}$$

  - $i_{u_{\dot{Q}_{u,max}}} \quad [CHF/kW]$ specific investment of unit u for size $\dot{Q}_{u,max}$
    - $\dot{Q}_{u,max} = \max_{t \in lifetime} (\dot{Q}_{u,t})$ [kW] size of unit u
  - $\dfrac{1}{\tau_u} = \dfrac{1}{\tau(i, lifetime_u)} \quad [year^{-1}]$: annualisation factor of unit u

Total Cost (TOTEX in [CHF/year])

- TOTal EXpenditure :

$$TOTEX \quad [CHF/year] = OPEX \quad [CHF/year] + CAPEX \quad [CHF/year]$$

it assumes that the unit will be operated with the same power profile over the lifetime of the equipment

We assume a mean year and the associated costs as being representative of the lifetime of the project