Part 1 : defining the heating needs of a building stock

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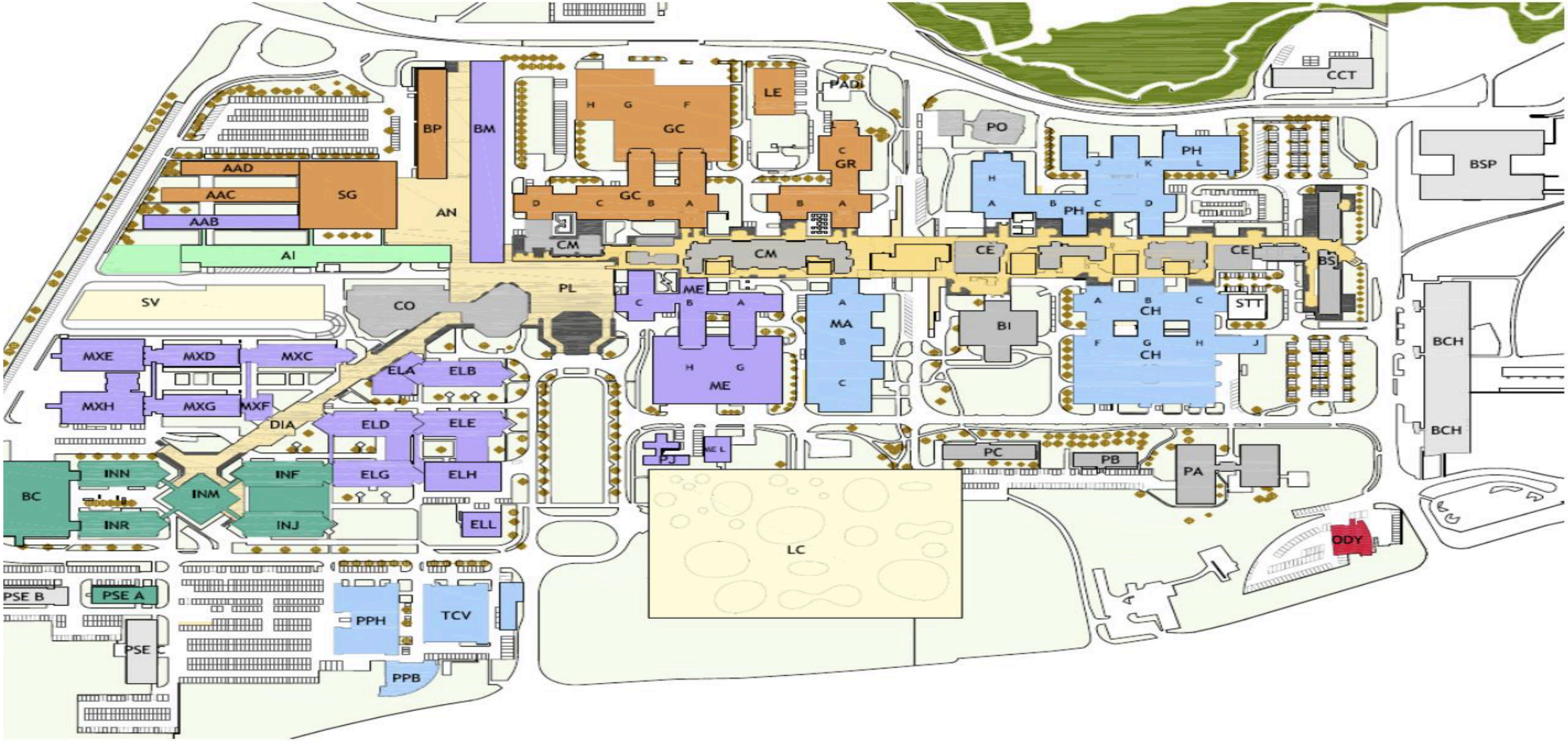
Industrial Process and Energy Systems Engineering

Part1 : defining the building needs

EPFL Buildings stock



AGIR : the methodology of a task

Analyse

- **What we want ?**
  - define variables (x_i) : give a textual description
  - define physical units : e.g. $[kJ_e/kJ_{th}]$
  - define order of magnitude of expected value of x_i : $x_{i_{min}} \leq x_i \leq x_{i_{max}}$
- **What we know : Write equations defining your knowledge !**
  - write the knowledge as a set of equations $f_k(x_i, \pi_{k,j}) = 0$
  - $\pi_{k,j}$ are parameters of equation k
- **What we have : collect the data :**
  - values of $\pi_{k,j}$ => reference, [physical units], comments
  - add assumptions : $f_a(x_i, \pi_{a,j}) = 0$ so that $\#k + \#a = \#i$

Generate

- Find numerical value of x_i by solving the set of equations : $f_e(x_i, \pi_{e,j}) = 0$, with $x_{i_{min}} \leq x_i \leq x_{i_{max}}$ and $f_e = \{f_k, f_a\}$
  - define the solving method
  - define the convergence criteria

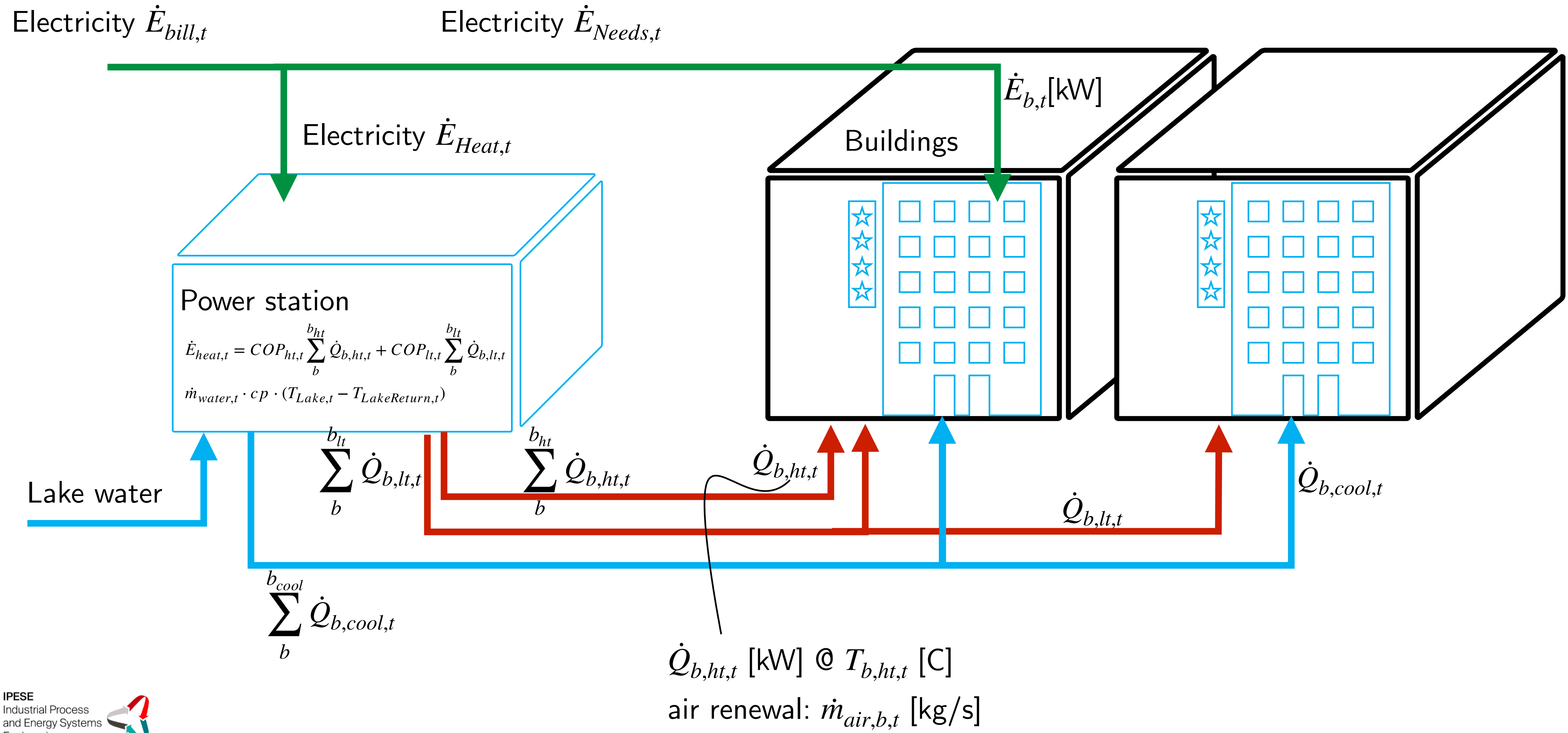
Interpret

- Verify that the value of x_i is meaningful for the application

Report

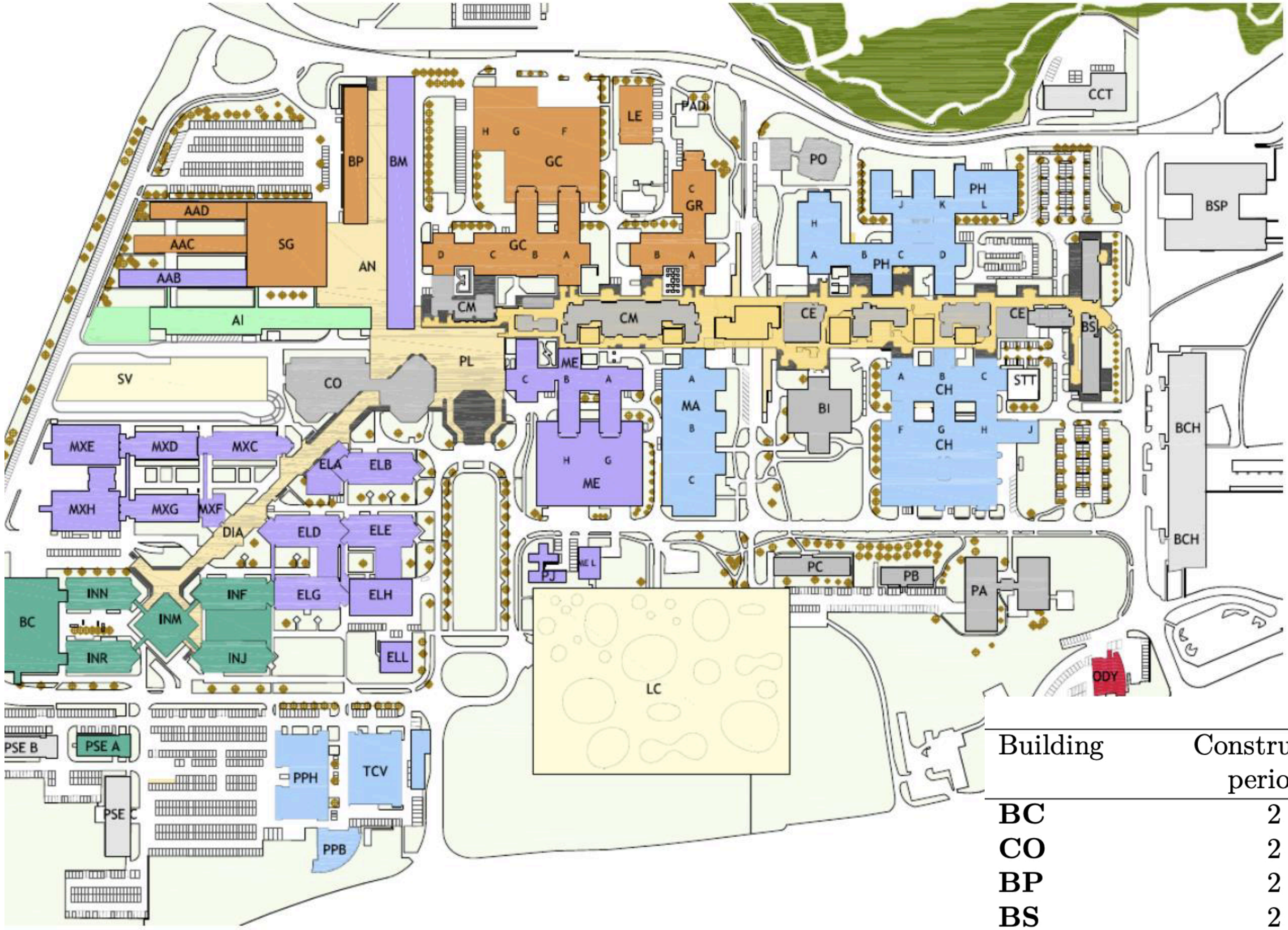
- Report the values (plots, tables, validity check)

What are the needs ?



Part1 : defining the building needs

Buildings stock



Heating needs are defined by :

- $\dot{Q}_{b,t} \quad \forall b \in \{1..n_b\}$ [kW]

  heat required by building b

  at time t of the year
- $T^{supply}_{b,t} \quad \forall b \in \{1..n_b\}$ [°C]

  Minimum temperature

  of the heat supply of building b

  at time t of the year

Available :

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

What we want ?

- $\dot{Q}_{b,t}[kW]$: Heat load of building b at time t of its life time

What do we have ?

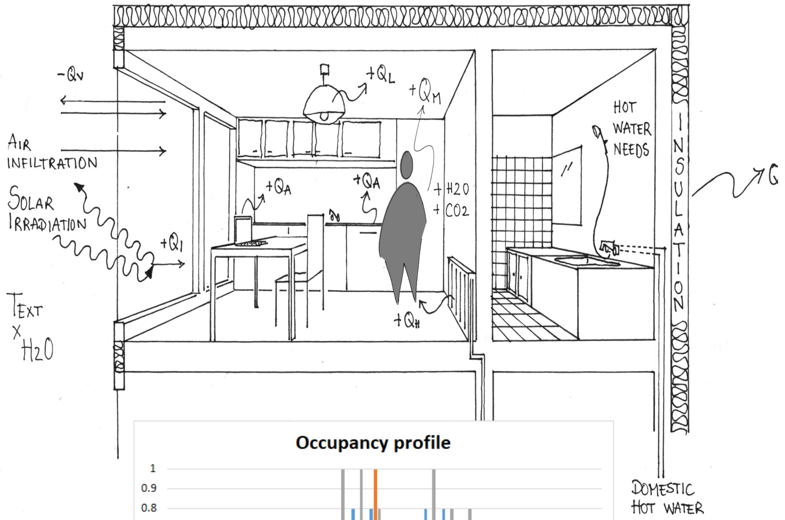
Building enveloppe

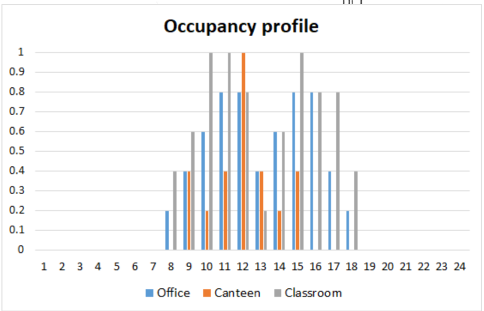
S [m2]

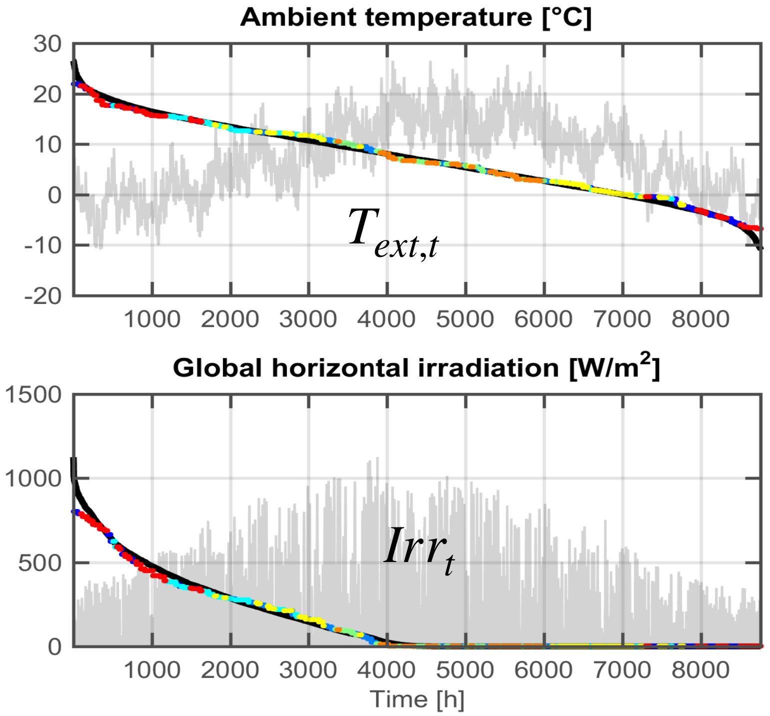
h [m]

People presence cap_t

Comfort Temperature $T_{comfort,t}$







Measurement

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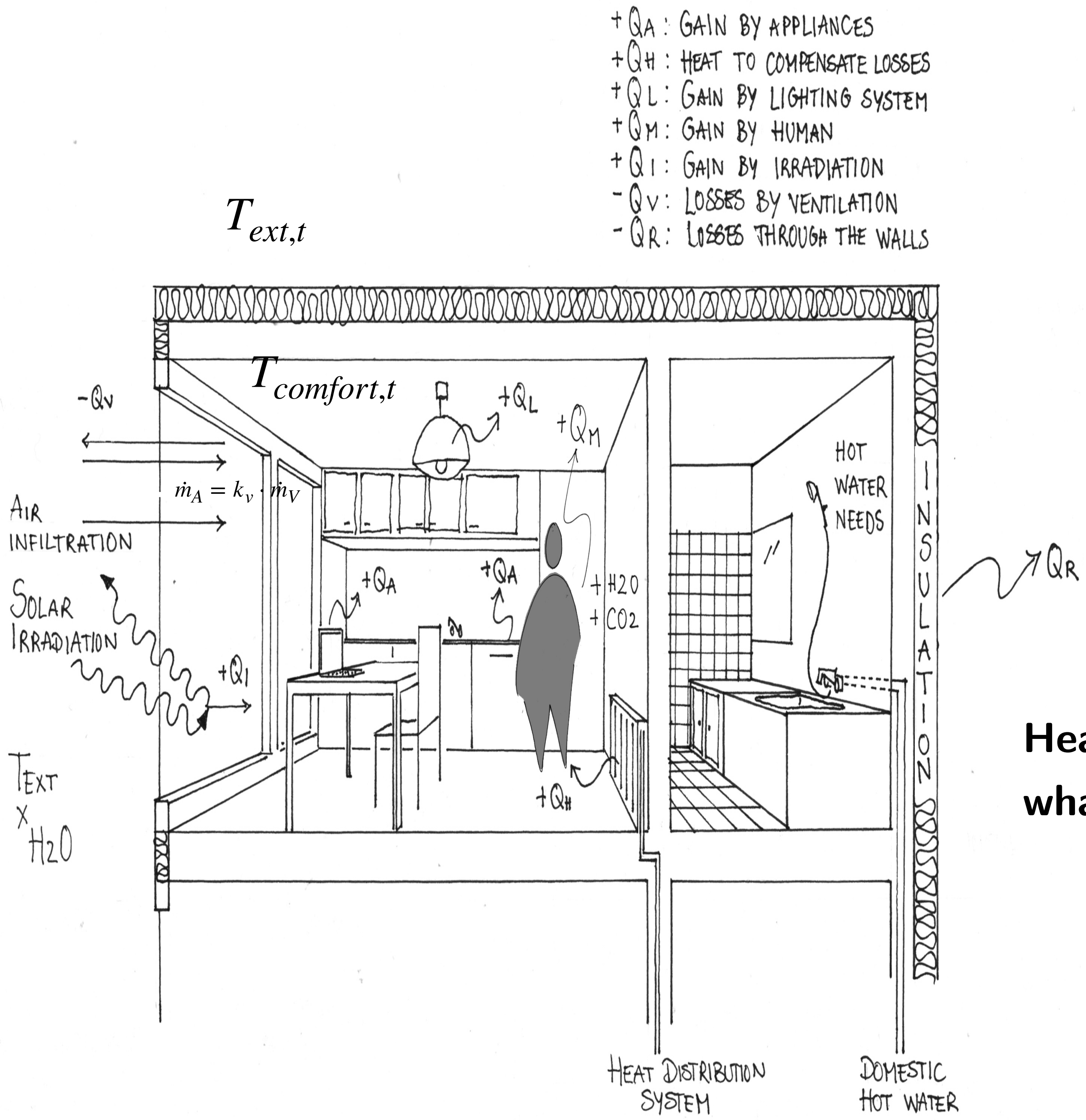
What do we know ?



Our knowledge :

The model of the building envelop heat balance

$$\dot{Q}_{A,t}[kW] = \dot{E}_{A,t}$$
$$\dot{Q}_{L,t}[kW] = \dot{E}_{L,t}$$
$$\dot{Q}_{M,t}[kW] = \dot{q}_{cap} \cdot \sum_{cap} cap_t$$

$\rightarrow \dot{Q}_{gain,t}$ **Gains**

$$\dot{Q}_{I,t}[kW] = \dot{Irr}_t \cdot k_{sun}$$
$$\dot{Q}_{V,t}[kW] = \dot{m}_V \cdot cp_{air} \cdot (T_{comfort,t} - T_{ext,t})$$
$$\dot{Q}_{R,t}[kW] = \sum_{wall} k_{wall} \cdot S_{wall} \cdot (T_{comfort,t} - T_{ext,t})$$

Losses

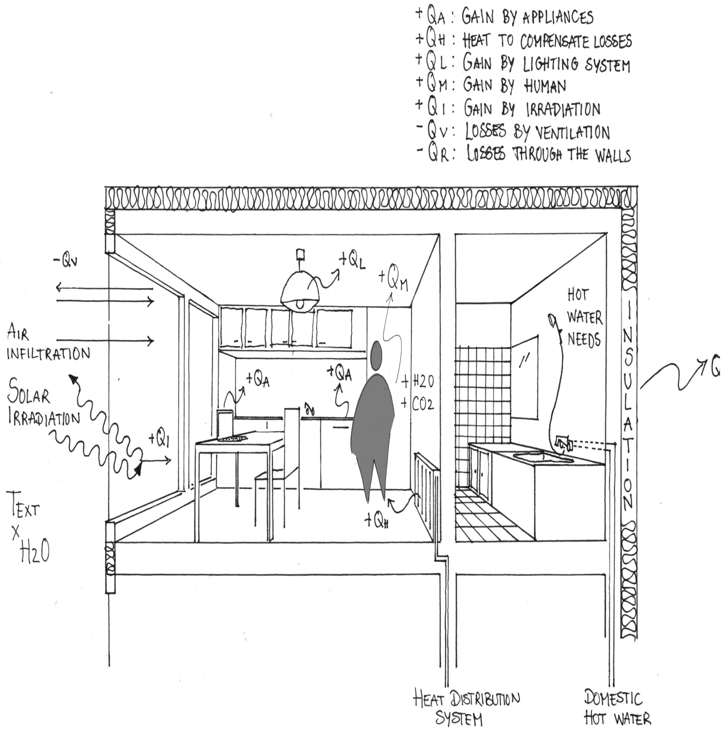
$$\dot{Q}_{V,t} + \dot{Q}_{R,t} = k_{th}(T_{comfort,t} - T_{ext,t})$$

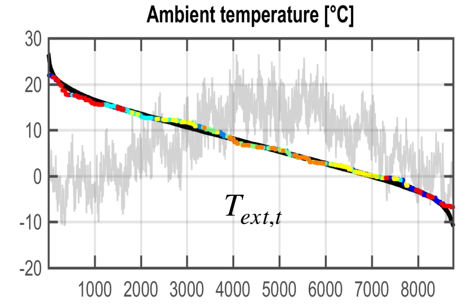
Heat balance :

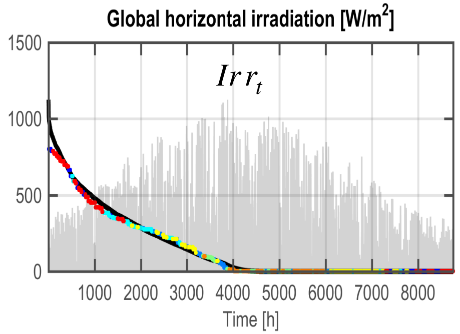
what is the load to maintain the comfort temperature ?

$$\dot{Q}_{H,t}[kW] = max(0, \dot{Q}_{V,t} + \dot{Q}_{R,t} - (\dot{Q}_{A,t} + \dot{Q}_{L,t} + \dot{Q}_{M,t} + \dot{Q}_{I,t}))$$

What we want : $\dot{Q}_b(t)[kW] = \dot{Q}_H(t)$







$$\dot{Q}_{A,t} = \dot{E}_{A,t}$$

$$\dot{Q}_{L,t} = \dot{E}_{L,t}$$

$$\dot{Q}_{M,t} = \dot{q}_{cap} \cdot \sum_{cap} cap_t$$

$$\dot{Q}_{I,t} = \dot{Irr}_t \cdot k_{sun}$$

$$\dot{Q}_{V,t} = \dot{m}_V \cdot cp_{air} \cdot (T_{comfort,t} - T_{ext,t})$$

$$\dot{Q}_{R,t} = \sum_{wall} k_{wall} \cdot S_{wall} \cdot (T_{comfort,t} - T_{ext,t})$$

$$\dot{Q}_{H,t} = max(0, \dot{Q}_{V,t} + \dot{Q}_{R,t} - (\dot{Q}_{A,t} + \dot{Q}_{L,t} + \dot{Q}_{M,t} + \dot{Q}_{I,t}))$$

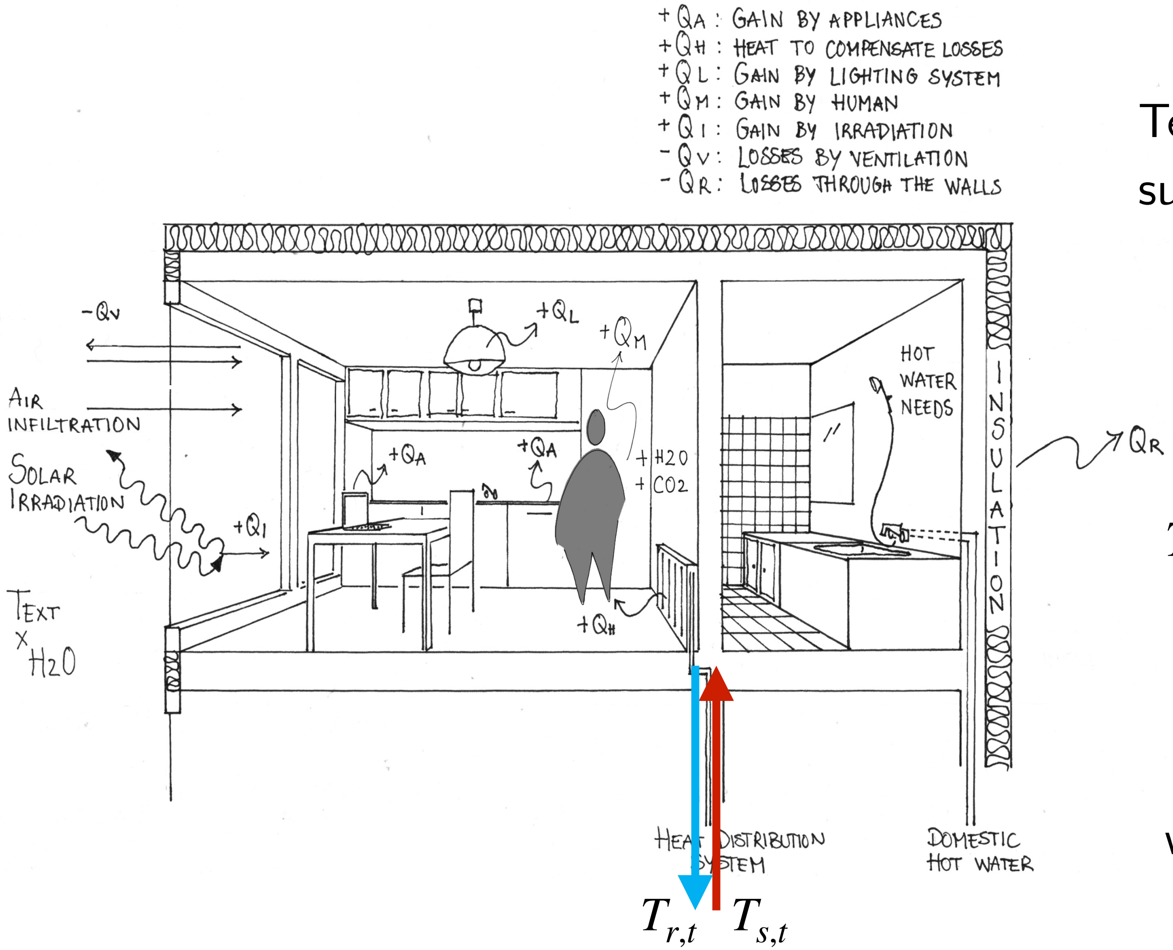
$$\dot{Q}_H(t) = max(0, k_{th} \cdot (T_{comfort,t} - T_{ext,t}) - k_{sun} \cdot \dot{Irr}_t - \dot{Q}_{gain,t})$$

$$Q_H(t_0, t_{end}) = \int_{t_0}^{t_{end}} \dot{Q}_{H,t} \cdot dt = \int_{t_0}^{t_{end}} max(0, k_{th} \cdot (T_{comfort,t} - T_{ext,t}) - k_{sun} \cdot \dot{Irr}_t - \dot{Q}_{gain,t}) \cdot dt$$

Typical formulation of the needs

- $Need_{k,t} = f(\pi_k, x_{k,i,t})$
  - π_k : parameters for calculation the need k
    - assumptions & knowledge
      - from the description of the Physical/Chemical phenomena
    - observations => parameter fitting
  - $x_{i,k,t}$: variables defining the environment applying to the need k
    - observations

Temperature of the heat supply



Temperatures of the heat distribution (hd) system: supply $T_{s,t}$ and return $T_{r,t}$ can be calculated

$$\dot{Q}_{H,t} = \dot{m}_{hd,t} \cdot cp_{hd} \cdot (T_{s,t} - T_{r,t})$$

$$T_{r,t} = T_{s,t} - \frac{\dot{Q}_{H,t}}{\dot{m}_{hd,t} \cdot cp_{hd}}$$

$T_{s,t}$ is calculated by solving

$$\dot{Q}_{H,t} = UA_{hd} \frac{(T_{s,t} - T_{r,t})}{ln(T_{s,t} - T_{comfort,t}) - ln(T_{r,t} - T_{comfort,t})}$$

with UA_{hd} calculated from the design conditions

$$UA_{hd} = \dot{Q}_{H,design} \cdot \frac{ln(T_{s,design} - T_{comfort,design}) - ln(T_{r,design} - T_{comfort,design})}{(T_{s,design} - T_{r,design})}$$

For each building and each time will obtain the minimum supply and return temperatures of the building.

State the problem to be solved : what needs to be calculated

$$Q_H(t_0, t_{end}) = \int_{t_0}^{t_{end}} \dot{Q}_{H,t} \cdot dt = \int_{t_0}^{t_{end}} max(0, k_{th} \cdot (T_{comfort,t} - T_{ext,t}) - k_{sun} \cdot \dot{Irr}_t - \dot{Q}_{gain,t}) \cdot dt$$

Calculate k_{sun} and k_{th} if

$$Q^1 = Q_H(January, December)$$

and

$$Q^2 = Q_H(February, March)$$

$$Q_H(January, December)(k_{sun}, k_{th}) - Q^1 = 0$$

$$Q_H(February, March)(k_{sun}, k_{th}) - Q^2 = 0$$

2 equations and 2 unknowns : k_{sun}, k_{th}

Activate your knowledge :

Solve a set of equations

F(X)=0