EPFL

Project – Introduction to Part 1

Lecture ME 454

Modeling and Optimization of Energy Systems

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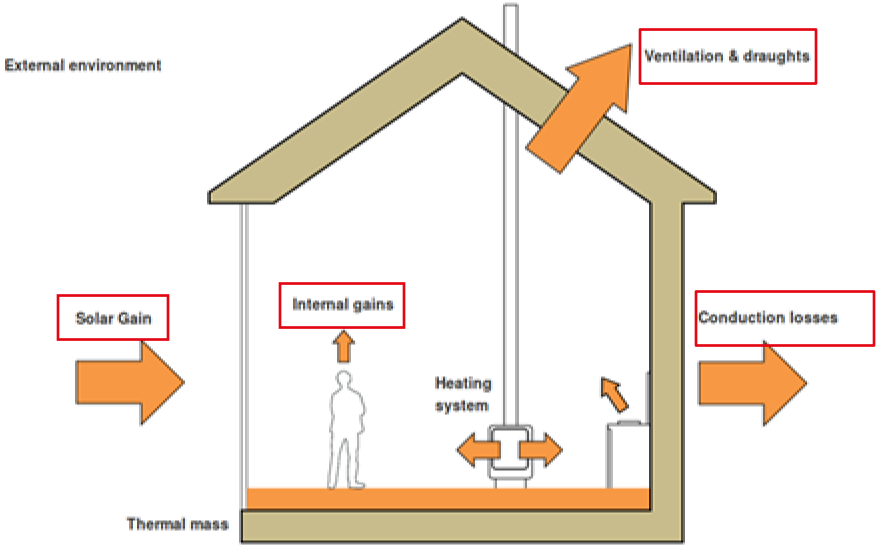
Hourly demand profiles

Estimation of heat gains/losses

Conduction & Ventilation — Solar gain — Internal gains

$$\dot{Q}_{th}(t) = A_{th}\{k_{th}(T_{int} - T_{ext}(t)) - k_{sun}\dot{i}(t) - \dot{q}_{pl}(t)\} - f_{el}\dot{Q}_{el}(t)$$



Calculation of building properties

Estimation of heat gains/losses

Conduction & Ventilation

Solar gain

Internal gains

$$\dot{Q}_{th}(t) = A_{th}\{k_{th}(T_{int} - T_{ext}(t)) - k_{sun}\,\dot{i}(t) - \dot{q}_{pl}(t)\} - f_{el}\dot{Q}_{el}(t)$$

k_{th}: thermal losses and ventilation coefficient

k_{sun}: solar radiation coefficient

Unknown

Outline Part 1

Identification of typical heat and electricity demand per building

- Task 1: Estimation of heat gains
- Task 2: Calculation of building envelope properties
- Task 3: Calculation of the hourly demand
- Task 4: Analysis on impact of renovation
- Task 5: Clustering of typical days

Calculation of building thermal properties

Unknowns

- *Heat transfer coefficients*
  - k_{th} *: thermal losses of the building*
  - k_{sun} *: thermal gains by radiation*

- *Thermal load of building*
  - $\dot{Q}_{th} = f(k_{th}, k_{sun,}, T_{int}, T_{ext}, \dot{q}_{people}, \dot{Q}_{elec})$

Equations

- *Yearly heating demand*
  - Hourly heating demand
  - Switching the heating system on

- *Mean heat gains*
  - Switching off the heating system

Attention: Properly identify the conditions when the heating system is on/off

↳ Implement Newton-Raphson to numerically solve for k_{th}, k_{sun}

EPFL

Yearly heating (equation 1)

Table 1.1: EPFL Buildings

Building	Construction period*	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
IN	2	24073	1,260,041	1,889,430
GC	1	26586	1,465,755	1,978,120
CE	1	16655	1,003,313	1,200,598
ODY	2	4092	253,199	81,410
MA	1	14018	889,271	5,531,370
GR	1	9997	649,081	813,804
ME	2	17151	1,126,830	3,118,001
CM	1	18663	1,251,411	1,354,652
AA + SG	2	18389	1,306,603	1,231,934
				413,651
				1,447,090
				94,326
				1,608,750
				2,832,408
				2,411,721
				4,717,985
				-
				4,433,829
				3,898,106

low temperature demand

- Hourly heating demand :

$$Q_{\text{th}}(t) = \Delta t \left\{ A_{\text{th}} \cdot \left(k_{\text{th}} \cdot (T_{\text{int}} - T_{\text{ext}}(t)) - k_{\text{sun}} \cdot \dot{i}(t) - \dot{q}_{\text{people}}(t) \right) - f_{el} \cdot \dot{Q}_{\text{el}}(t) \right\}$$

$$\forall t, \quad \text{if } T_{\text{ext}} \leq T_{\text{cut-off}} \qquad (1.3)$$

$$\text{if } Q_{\text{th}} \leq 0, \ \text{cooling}$$

$$\text{if } Q_{\text{th}} \geq 0, \ \text{heating}$$

- Keep only the positive values, remember, we are designing a heating system :

$$Q^{+}_{\text{th}}(t) = \begin{cases} Q_{\text{th}}(t), & \text{if } Q_{\text{th}}(t) \geq 0. \\ 0, & \text{otherwise.} \end{cases} \qquad (1.4)$$

You only may need heating during the time people are in the building, which is only from Mondays to Fridays and between 7AM and 9 PM.

- You will have 8760 hourly entries (zero and/or non-zero). Add them all together to get the yearly demand :

$$Q^{+}_{\text{th,year}} = \sum_{p=1}^{N_p} Q^{+}_{\text{th}}(t) \qquad (1.5)$$

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Project description

Mean heat (equation 2)

- For this equation to work, you will need to compute the mean heat gains (solar, people and electric) of the values **only when** the outside temperature is between 15ºC and 17ºC (16ºC ± 1ºC).

$$0 = A_{\text{th}} \cdot \left(k_{\text{th}} \cdot (T_{\text{int}} - T_{\text{cut}}) - k_{\text{sun}} \cdot \dot{i}_{mean} - \dot{q}_{\text{people,mean}}\right) - f_{el} \cdot \dot{Q}_{\text{el,mean}} \quad (1.6)$$

- This will give you the second equation to solve for.

Solving the equation

To find the k-values of each building we will use such that F(x) = 0, we will use the Newton-Raphson method.

Newton's method for a multivariable problem next iteration is defined as :

$$\mathbf{X}_{k+1} = \mathbf{X}_k - \left[J^{-1}(\mathbf{f}(\mathbf{X}_k)) \cdot \mathbf{f}(\mathbf{X})\right]$$

It is up to you to choose the initial value of $\mathbf{X}_0$ and do the code implementation.

Remember, the Jacobian is defined as :

$$J = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \cdots & \frac{\partial f_1}{\partial x_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial f_n}{\partial x_1} & \cdots & \frac{\partial f_n}{\partial x_n} \end{bmatrix}$$

Debugging

- Verify that your implementation of Newton-Raphson works with a simple equation.
- Check units and signs.
- Use different starting values.
- Print or save your iterations to understand how your code is performing.

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Task 1: Estimation of heat gains

Task 2: Calculation of building envelope properties

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Task 4: Analysis on impact of renovation

Task 5: Clustering of typical days

Calculation of the hourly profiles

$$\dot{Q}_{th}(t) = A_{th}\{k_{th}(T_{int} - T_{ext}(t)) - k_{sun}i(t) - \dot{q}_{pl}(t)\} - f_{el}\dot{Q}_{el}(t)$$

Everything on the right-hand side is now known !

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Impact of renovation

- Discussion of the impact of renovation on the building heating demand.
- In which direction is it beneficial to vary the heat transfer coefficients ?
- How can k_{th} be varied ? What about k_{sun} ?
- Reminding that $k_{th} = \underbrace{U_{env} + \dot{m_{air}} \cdot c_{p,air}}_{\text{Conduction + Ventilation}}$ is there some limit on k_{th} value ?

- Propose a brief quantitative analysis and present insightful graphical results.

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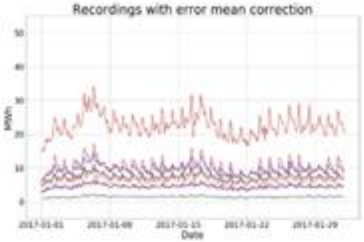
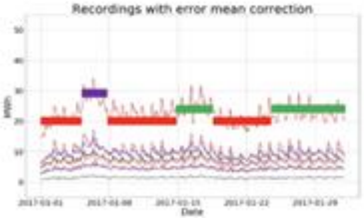
Clustering of typical days

Context



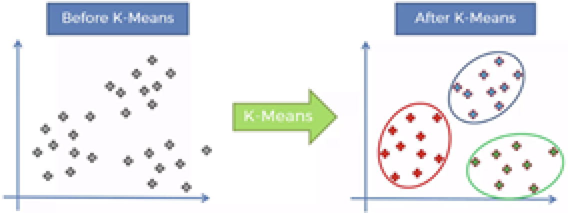
Hourly data is **computationally heavy**



Define typical days
- how many ?
- which accuracy ?

Objective

- Clustering the weather data
- Try different methods and evaluate their accuracy
  - monthly approach: 1 typical day per month ?
  - seasonal approach: 1 typical day per season ?
  - k-means approach ? k-medoids ?



For your information