EPFL

Typical Operating Conditions

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Industrial Process and Energy Systems Engineering

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 OPEX in [CHF/year]

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

Options 1 : typical year representing 220000 hours of lifetime by 8760 hours

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

$$\Delta t = 3600 \quad [s/year] = 1[hour/year]$$

$year \quad [hours/year]$: 8760 [hours/year]

Option 2 : representing 220000 hours by N_p periods

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

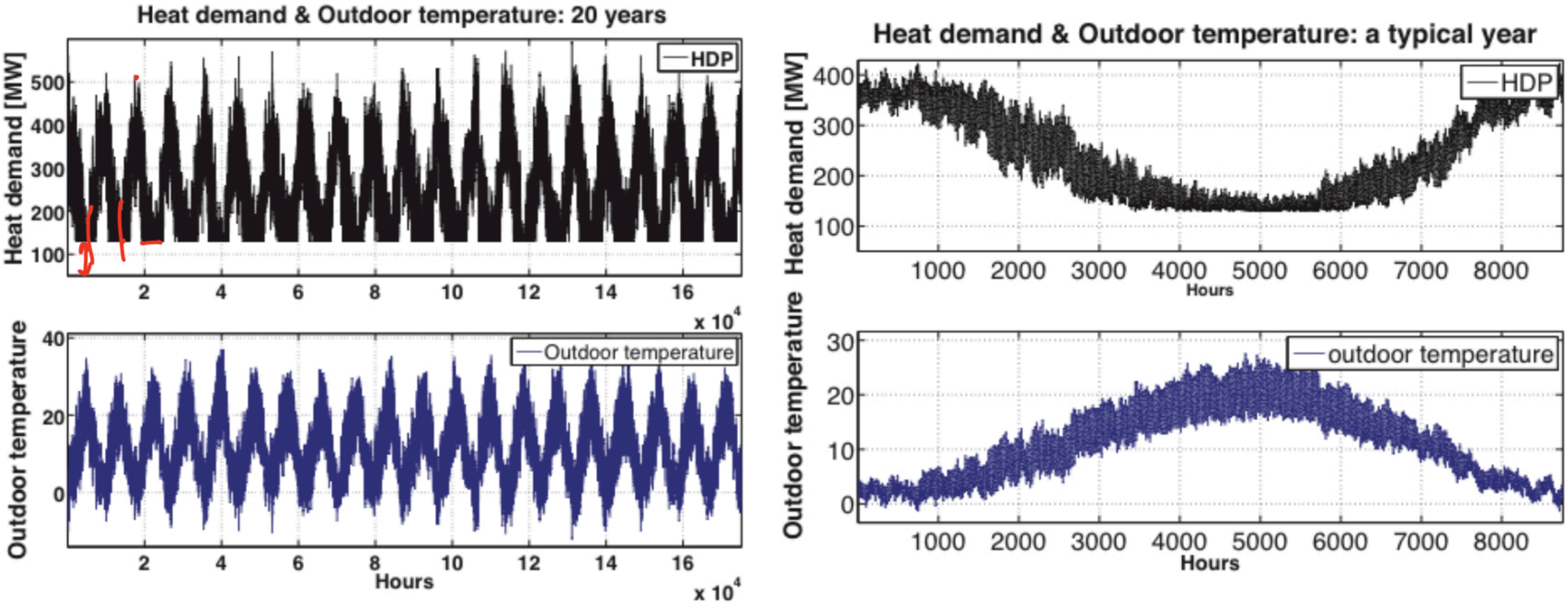
$\Delta t_p \quad [hours/year]$: number of hours per year where $\dot{Q}_{u,t_p}$ is expected

N_p : nb of periods used to represent operations during a typical year of the lifetime

Clustering methods

Clustering methods

The goal is to represent the 20 coming years with a limited number of time step in the sum.



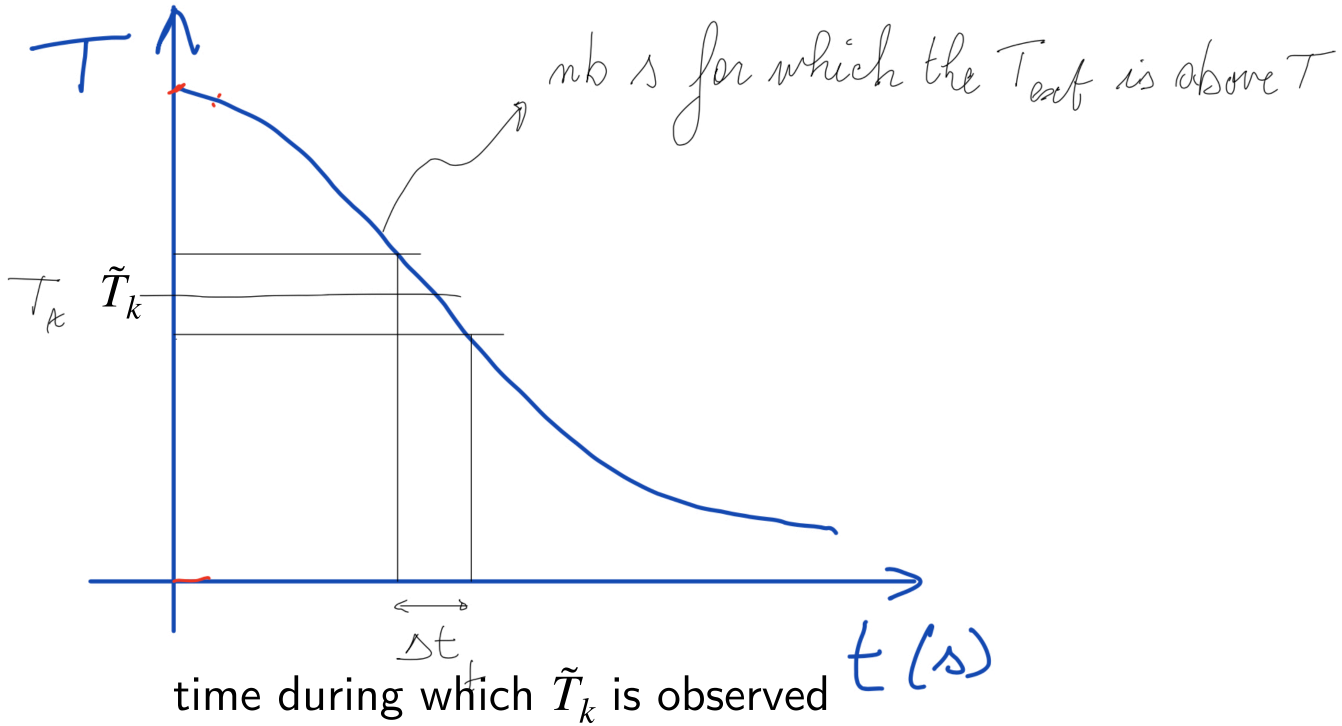
Fazlollahi, S.; Bungener, S. L.; Mandel, P.; Becker, G.; Maréchal, F. Multi-Objectives, Multi-Period Optimization of District Energy Systems: I. Selection of Typical Operating Periods. *Computers & Chemical Engineering* **2014**, *65*, 54–66. https://doi.org/10/f5zmkk.

Temperature distribution curve : mean days

$$\Delta t_t = [s/year]$$

Probability of appearance of conditions t during a year

TEMPERATURE DISTRIBUTION CURVE



Clustering one mean day per month:

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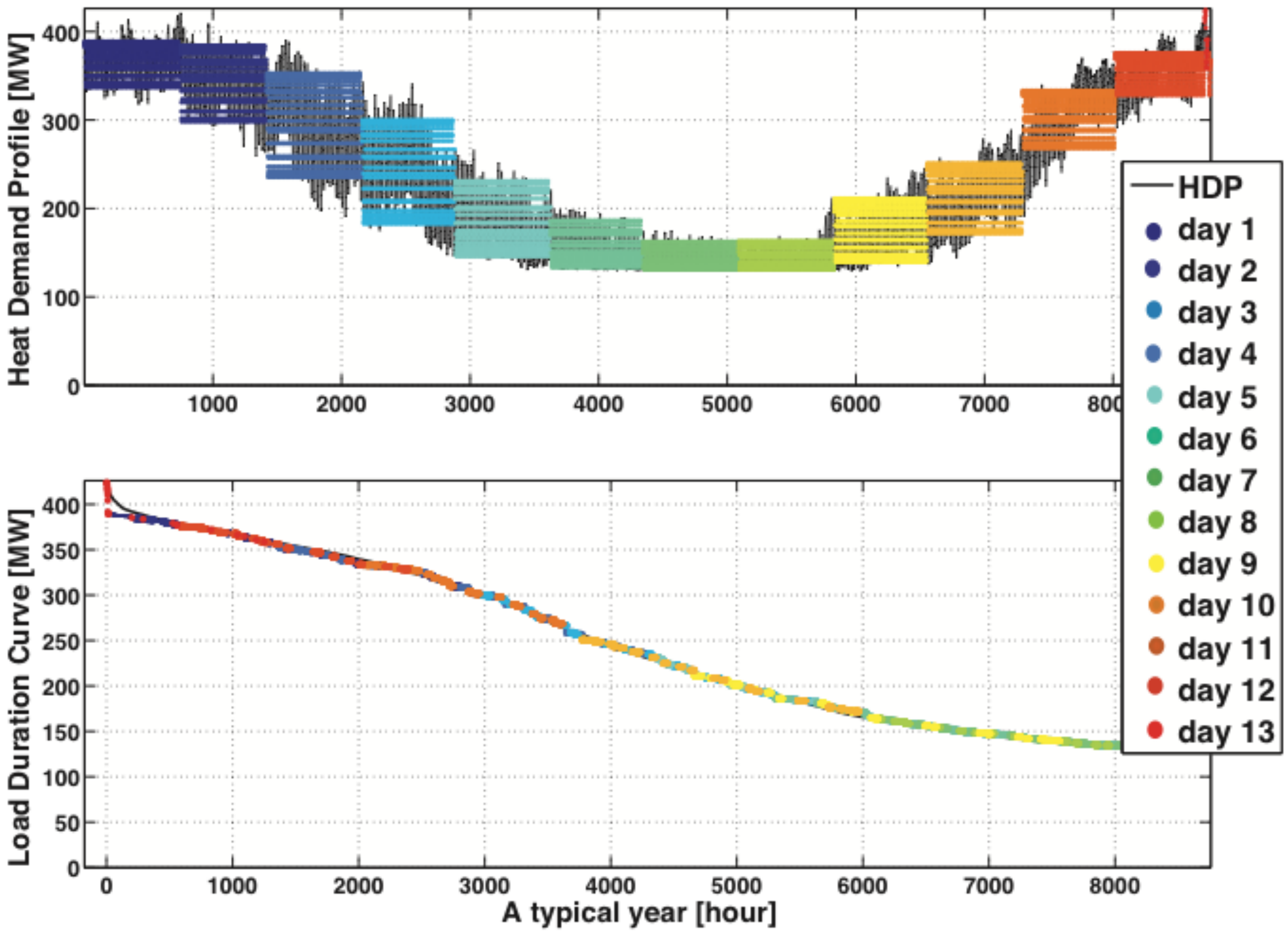


Typical days definition

Using optimisation method (greedy algorithm)

Choose : a set of features i

Calculate the value of $z_{i,k}$:

- the feature $i \in N_i$
- the cluster representative $k \in N_k$

Method :

- K-mean
  - $z_{i,k}$ is a mean value
- K-medioid
  - $z_{i,k}$ is member of the set x_i

Criteria

k-means is a **greedy** optimization algorithm, which minimizes the squared error over all N_k clusters (Eq. (1)):

$$\min \left[\sum_{k=1}^{N_k} \sum_{i=1}^{N_i} d(\hat{\mu}_k, \hat{x}_i) \times z_{i,k} \right] \tag{1}$$

$$\sum_{k=1}^{N_k} z_{i,k} = 1, \quad \forall i \tag{2}$$

$$d(\hat{\mu}_k, \hat{x}_i) = \sum_{a=1}^{N_a} \sum_{g=1}^{N_g} (\hat{\mu}_{k,a,g} - \hat{x}_{i,a,g})^2 \quad \forall k, i \tag{3}$$

$$\hat{x}_{i,a,g} = \frac{x_{i,a,g} - \min\{x_{i,a,g} \quad \forall i, \forall g\}}{\max\{x_{i,a,g} \quad \forall i, \forall g\} - \min\{x_{i,a,g} \quad \forall i, \forall g\}} \quad \forall i, a, g \tag{4}$$

Performance of the clustering as a function Nb of clusters

Deviation from load curve

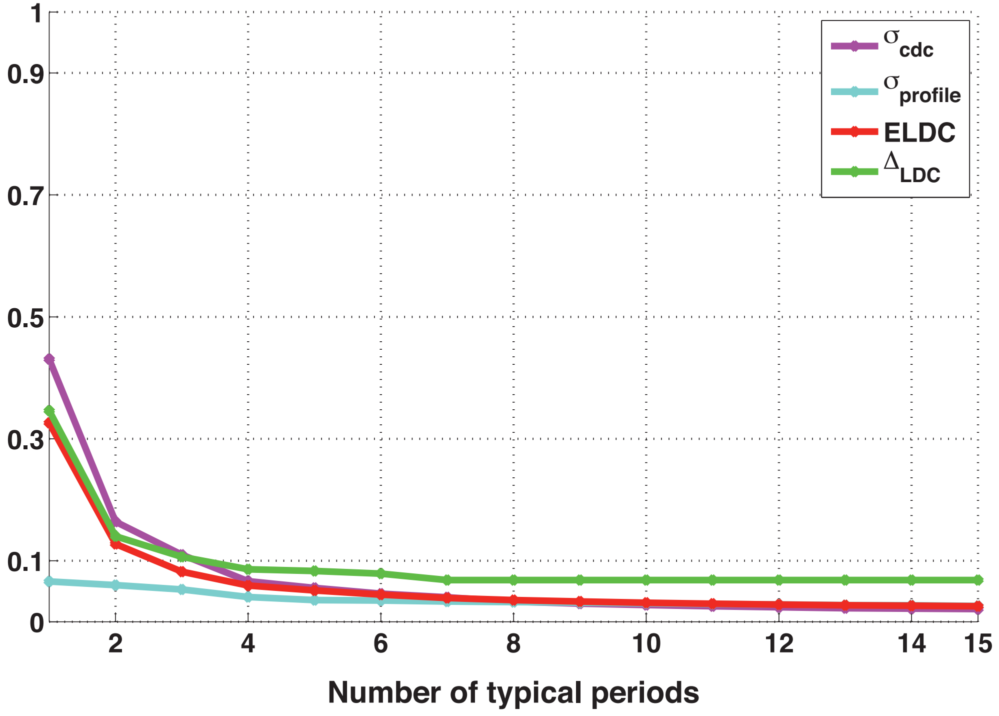
$$\sigma^{a}_{cdc,N_k} = \left[\frac{1}{N_i} \sum_{k=1}^{N_k} \sum_{i=1}^{N_i} z_{i,k} \times \left(\frac{\overline{x}_{i,a} - \overline{\mu}_{k,a}}{\overline{x}_{i,a}} \right)^2 \right]^{1/2} , \quad \forall a$$

ELDC : error in load curve duration

$$ELDC^{a}_{N_k} = \frac{\sum_{p=1}^{N_i \times N_g} |LDC^{a}_{o}(p) - LDC^{a}_{e,N_k}(p)|}{\sum_{p=1}^{N_i \times N_g} LDC^{a}_{o}(p)} \quad \forall a$$

Profile deviation

$$\sigma^{a}_{profile,N_k} = \left[\frac{1}{N_i \times N_g} \sum_{k=1}^{N_k} \sum_{i=1}^{N_i} \sum_{g=1}^{N_g} z_{i,k} \times \left[\frac{(x_{i,a,g} - \overline{x}_{i,a}) - (\mu_{k,a,g} - \overline{\mu}_{k,a})}{\overline{x}_{a}} \right]^2 \right]^{1/2} , \quad \forall a$$



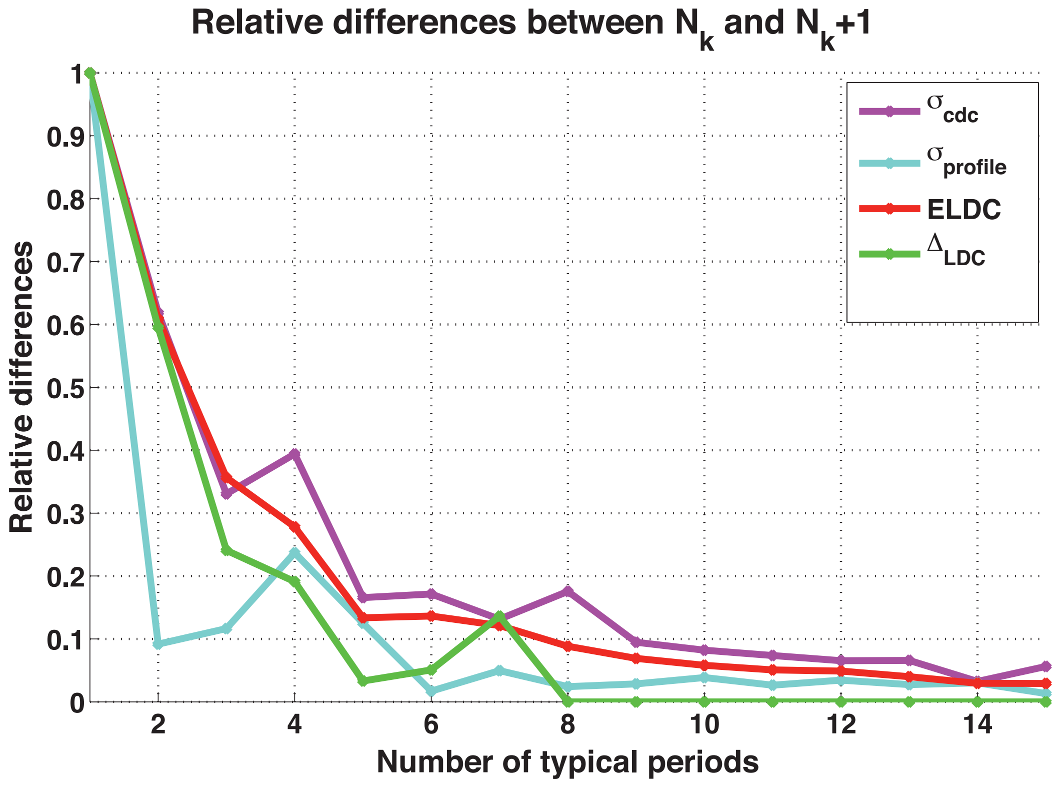


Fig. 5. Pareto frontiers of typical periods' normalized performance indicators using the mean typical year data: case study 1. (1)

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Choosing typical days with days in segments

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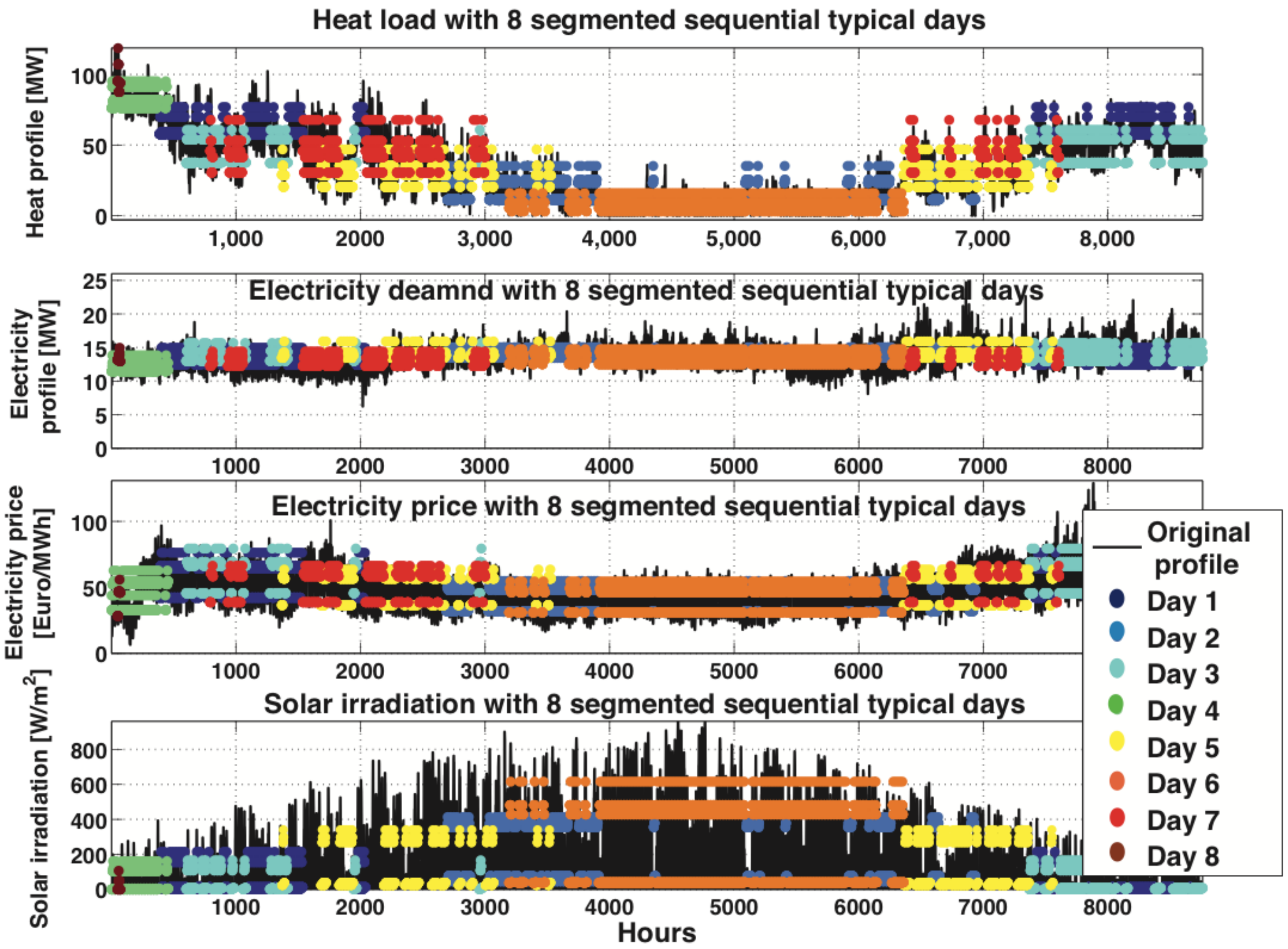
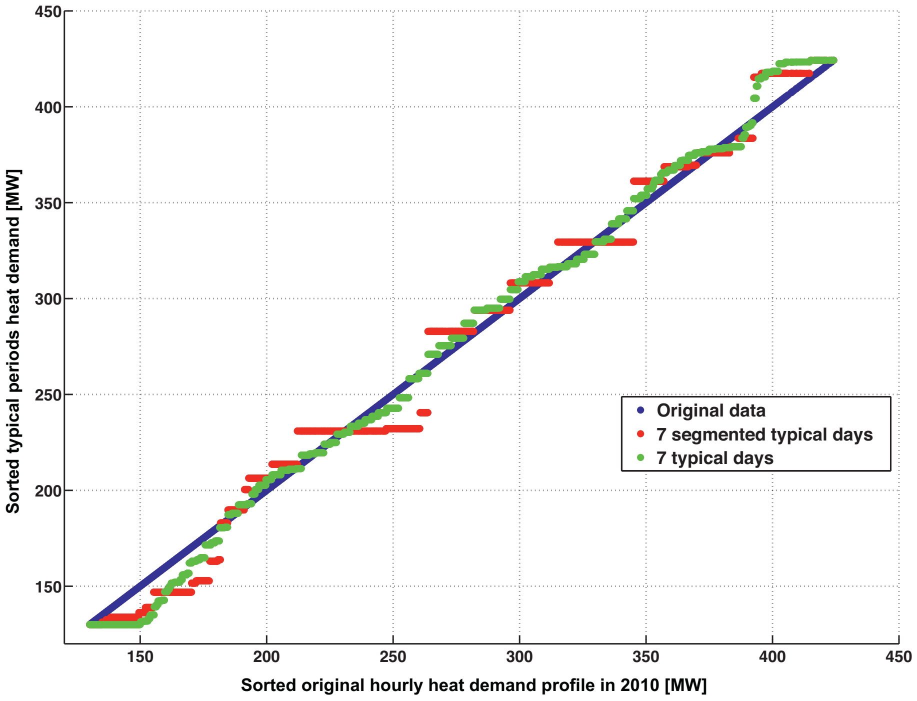


Parity plot : observation vs model



Gains in problem size

- NB Variables : from 200 (20 years) to 7 (1 year) to 1 (typical day)
- Time of resolution : 120 (20 years) to 4 (1 year) to 1 (typical days)
- Total cost error : vs 20 years : 2% (1 year) to 0.2% (typical days)

Table 5
The comparison between the reference case and the optimization results from 2010 to 2012 with regards to the size of the peak boiler, the fuel consumption and the operating costs.

	Ref. case	13 Empirical periods	7 typical periods using	
			The typical year	The 20 years
Municipal waste [GWh]	7415	7570 (−2.1%)[a]	7593 (−2.4%)	7489 (−1.0%)
Biomass [GWh]	663	638 (+3.8%)	654 (+1.4%)	659 (+0.6%)
Coal [GWh]	1992	2032 (−2.0%)	2006 (−0.7%)	1989 (+0.15%)
Natural gas [GWh]	112	8.9 (+92%)	6.72 (+94%)	85 (+24.0%)
Peak gas boiler [MW_{th}]	175	34 (+80%)	34 (+80%)	200 (−14%)
Under estimated periods[b]	0	4	4	0
Operating costs [M€]	119.7	117.5 (1.8%)	117 (2.3%)	119.4 (0.2%)
Resolution time [s]	2700	85	23	23
No. constraint	183×10^4	65320	7427	7427
No. variables	152×10^4	54423	6225	6225
No. integer variables	11×10^4	3756	432	432

[a] The relative differences between the reference case and the typical periods optimization.
[b] Number of time steps from 2010 to 2012 when the maximum original heat demands are higher than the maximum typical values.

Typical operating conditions

- We aim to represent the conditions under which the system will be operated in the future by a limited set of n_p typical operating conditions p that have a certain probability $d_p[s/lifetime]$ to occur.
- The integral of the operating expenditures can then be replaced by a weighted sum

$$OPEX = \sum_{p=1}^{n_p} OPEX_p \cdot d_p$$