

# Typical Operating Conditions

Prof François Marechal

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

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

with  $m_{r,u,t}$   $[kg/kJ_{th}]$  mass of resource  $r$  to supply heat ( $\dot{Q}$ ) at time  $t$ .

+ Maintenance [CHF/year]

+ Men Power [CHF/year]

+ Taxes [CHF/year] :

fixed : e.g. based on installed power

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

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

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

# EPFL 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

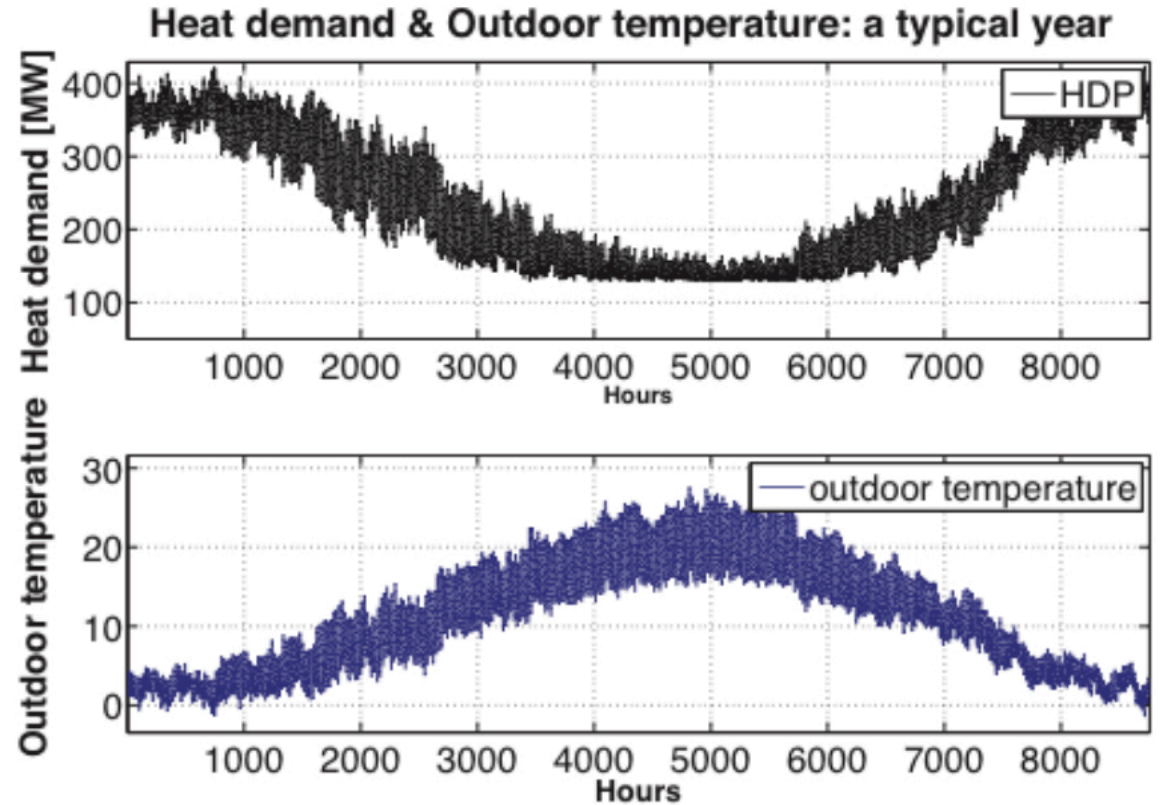
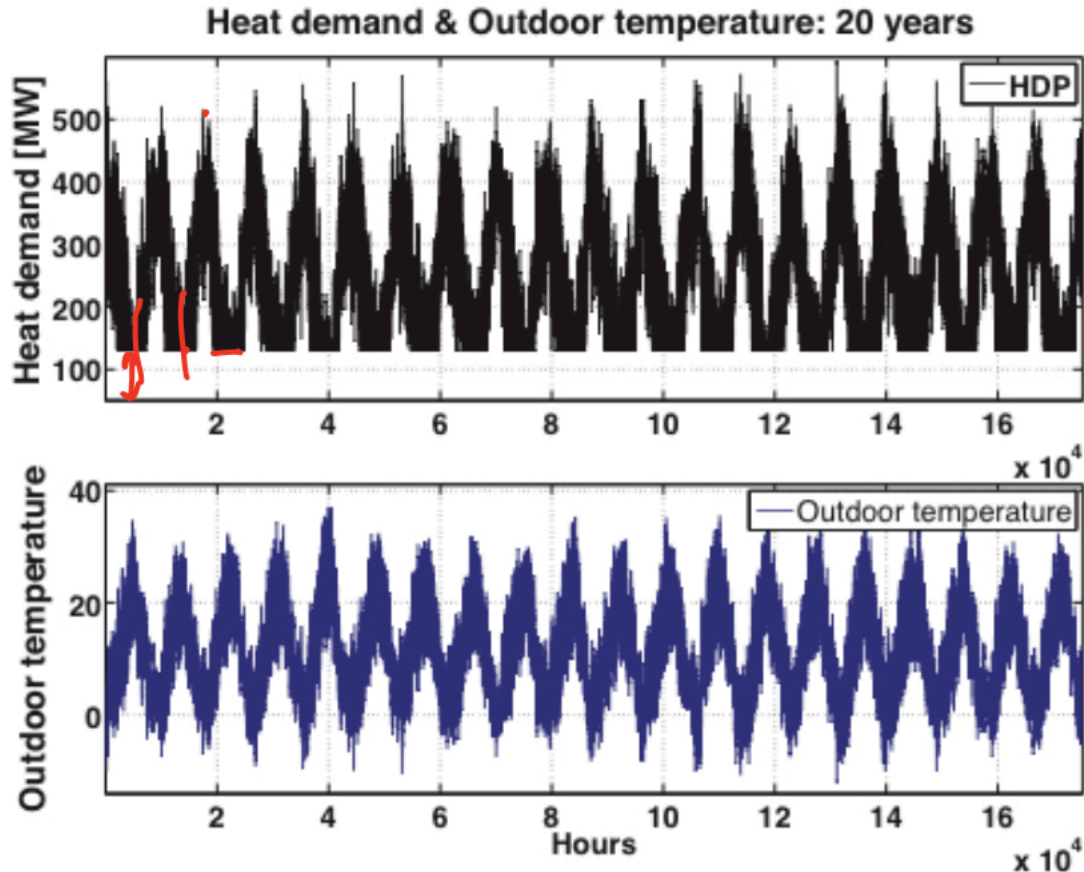
$$\text{Cost of resources} = \sum_{r=1}^{n_{res}} \sum_{u=1}^{n_u} \left( \sum_p^{N_p} c_{r,t} \cdot m_{r,u,t_p} \cdot \dot{Q}_{u,t_p} \cdot \Delta t_p \right) \quad [CHF/year]$$

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

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



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

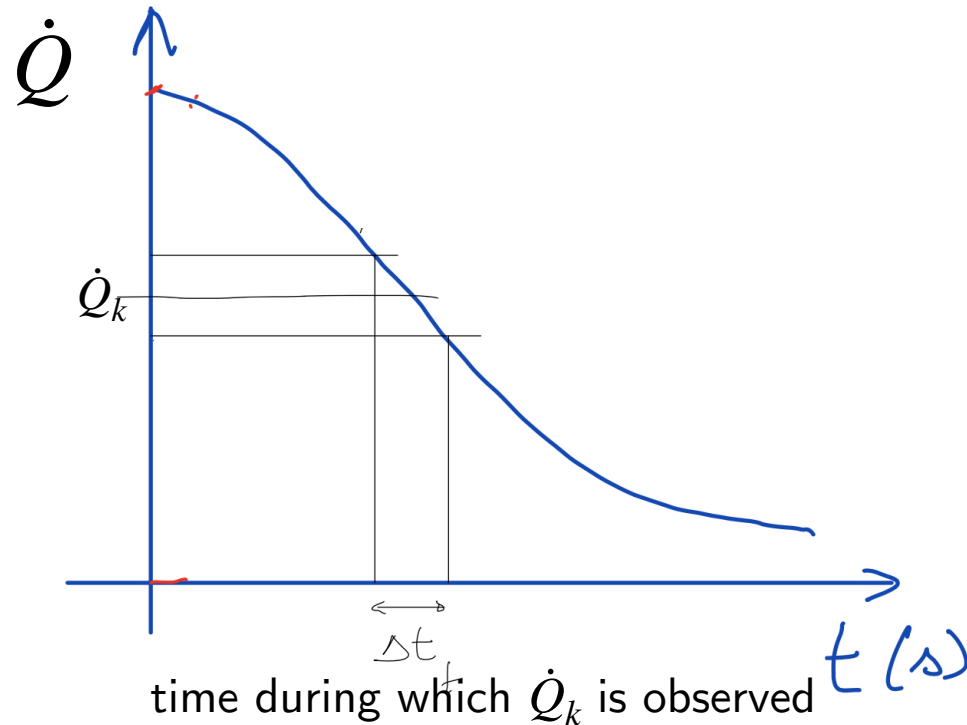


Fazlollahi, S.; Bungener, S. L.; Mandel, P.; Becker, G.; Maréchal, F. Multi-Objectives, Multi-Period Optimization of District Energy Systems: I. Selection of Typical Operating Periods. *Computers & Chemical Engineering* **2014**, *65*, 54–66. <https://doi.org/10/f5zmkk>.

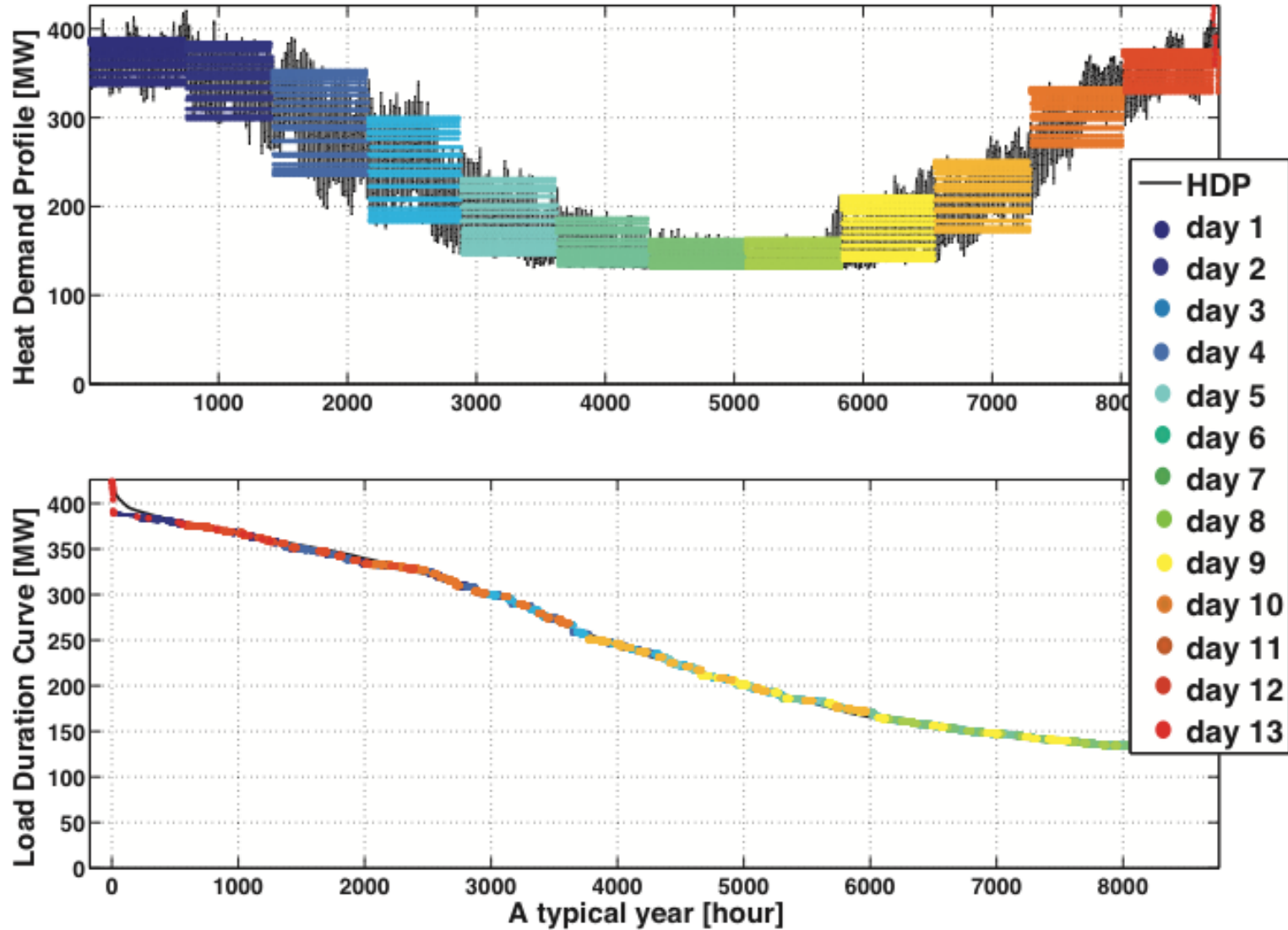
$$\Delta t_f = [\text{s/year}]$$

Probability of appearance of conditions  $t$  during a year

Heat load distribution curve



S. Fazlollahi et al. / Computers and Chemical Engineering 65 (2014) 54–66



Typical days definition

## Criteria

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  $x_i$

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

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

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

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

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

Deviation from load curve

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

Profile deviation

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

ELDC : error in load curve duration

$$ELDC_{N_k}^a = \frac{\sum_{p=1}^{N_i \times N_g} |LDC_o^a(p) - LDC_{e, N_k}^a(p)|}{\sum_{p=1}^{N_i \times N_g} LDC_o^a(p)} \quad \forall a$$

Relative differences between  $N_k$  and  $N_k+1$

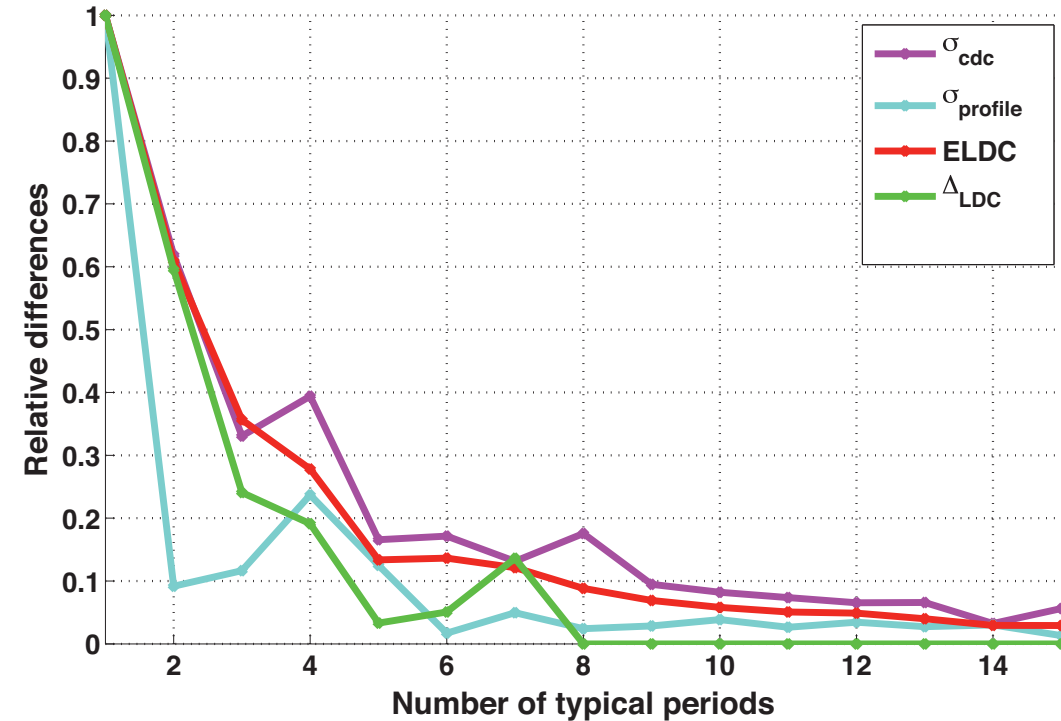
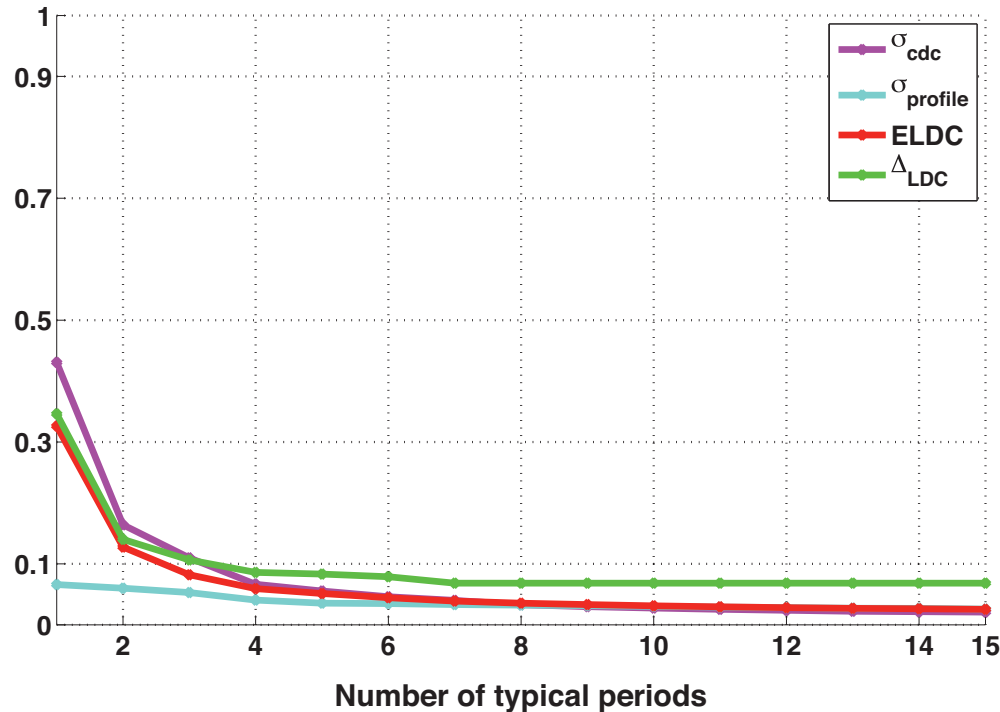
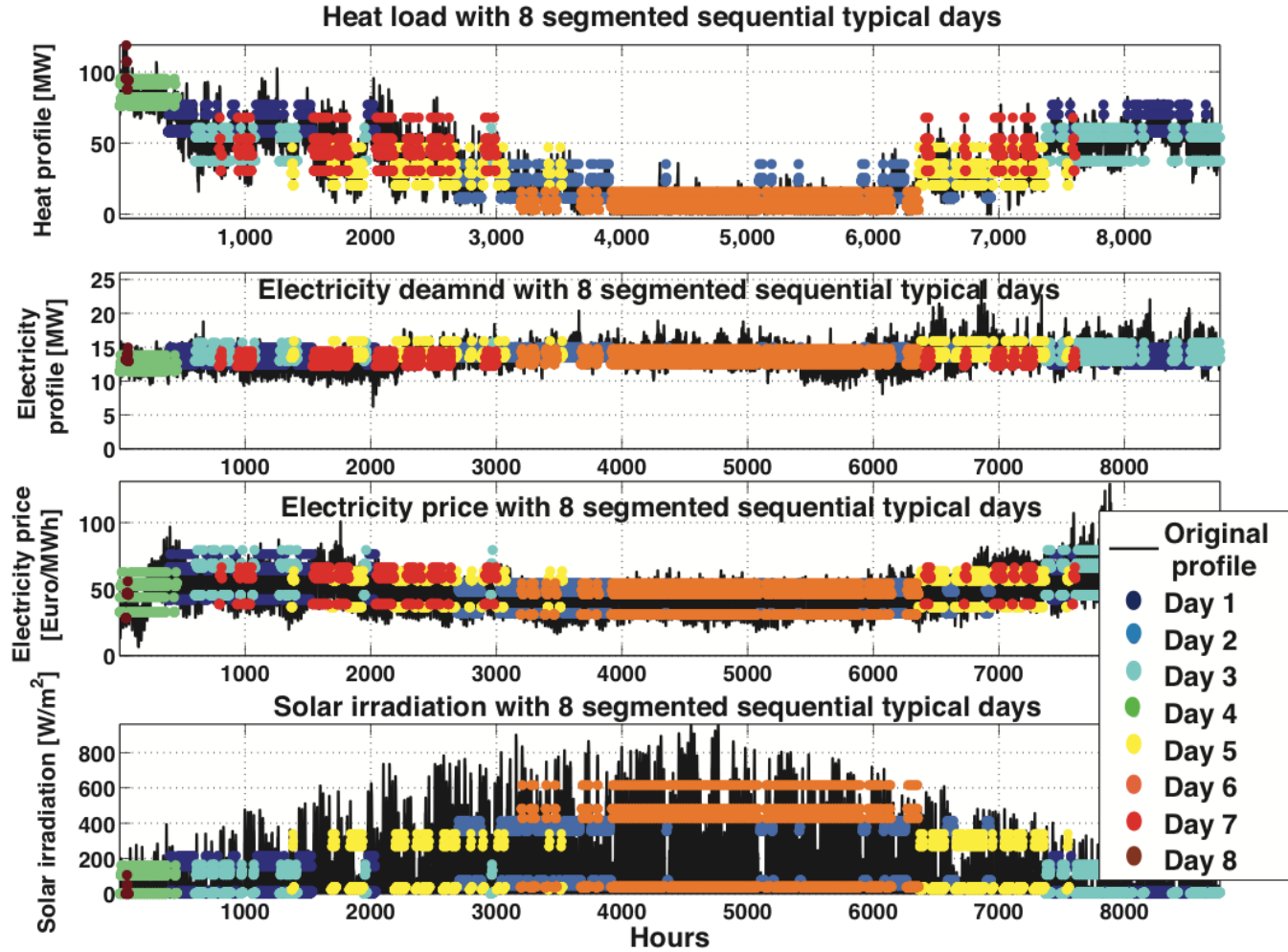
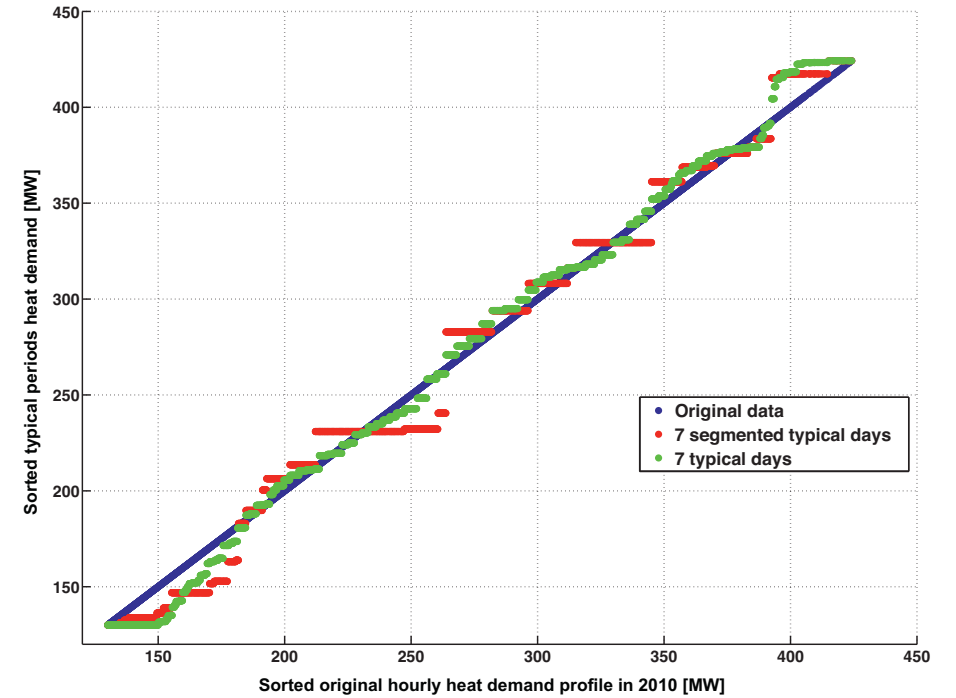


Fig. 5. Pareto frontiers of typical periods' normalized performance indicators using the mean typical year data: case study 1. (1)

S. Fazlollahi et al. / Computers and Chemical Engineering 65 (2014) 54–66



Parity plot : observation vs model



- # 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%) <sup>a</sup>	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 <sub>th</sub> ]	175	34 (+80%)	34 (+80%)	200 (-14%)
Under estimated periods <sup>b</sup>	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 <sup>4</sup>	65320	7427	7427
No. variables	152 × 10 <sup>4</sup>	54423	6225	6225
No. integer variables	11 × 10 <sup>4</sup>	3756	432	432

<sup>a</sup> The relative differences between the reference case and the typical periods optimization.

<sup>b</sup> Number of time steps from 2010 to 2012 when the maximum original heat demands are higher than the maximum typical values.