nano-tera.ch
swiss scientific initiative in health / security / environment systems

HeatReserves RTD 2013

FNSNF

Energy management of the NEST demonstrator building

M. Hohmann[1], R. Evins[1], J. Carmeliet[2], J. Lygeros[3]

[1]Urban Energy Systems Laboratory, Empa, 8600 Dübendorf; [2]Chair of Building Physics, ETH Zürich, 8093 Zürich; [3]Automatic Control Laboratory, ETH Zürich, 8092 Zürich

Empa Materials Science and Technology

ETH zürich

Introduction

Increasing the efficiency of energy systems, a crucial climate change mitigation measure, and the decentralization of energy systems are two objectives that do not necessarily align.

The NEST energy hub provides researchers with an advanced automation platform to investigate novel control and dispatch schemes that lead to stable and efficient decentralized multi-energy systems.

In its final state, NEST emulates a city district with a diverse set of users (residential, office, gym etc.).
In the following, we present the modelling of the NEST demonstrator building and its systems. Two computationally efficient energy system coordination approaches based on non-convex optimization are outlined and described that increase the efficiency of decentralized energy systems.

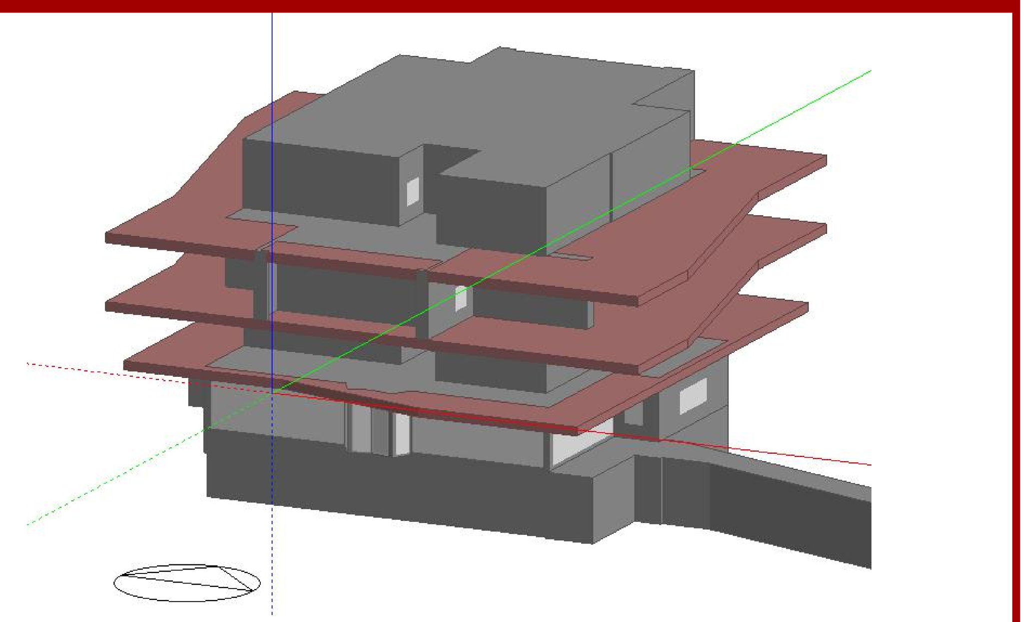


Figure 1. EnergyPlus building model of NEST

NEST building and systems modelling

The NEST building consists of a backbone structure (Figure 1) and research units in which specific building technologies are tested and demonstrated. The NEST backbone was modelled in EnergyPlus. Using the building model, demand data can be calculated or simpler controller-compatible representations can be generated.
The principal energy systems of the NEST energy hub are heat pumps.

Heat pumps pose the following modelling challenges:

- Coupling of electricity and heat
- Efficiency (COP) depends on load factor and temperature lift
- Internal controllers are IP-protected

A model with internal controllers was created in Simulink. Advanced controller schemes can be validated by combining the building and systems models. Additionally, an extremum-seeking controller is tested to increase the COP.

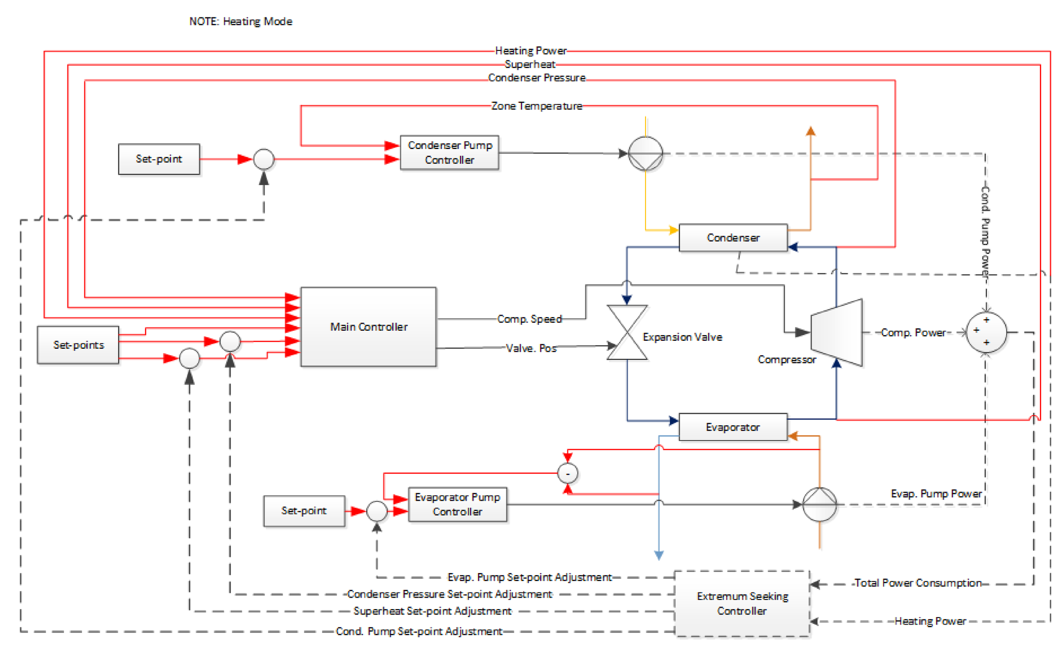


Figure 2. Control scheme of the NEST heat pump

Real-time coordination of energy conversion and storage systems

The efficiency of continuously controllable energy systems varies over the operating range (Figure 4(a)). Only some combinations of systems of multi-carrier energy network lead to a optimal efficiency, depending on the load conditions. The best combination can be found with mathematical programming.

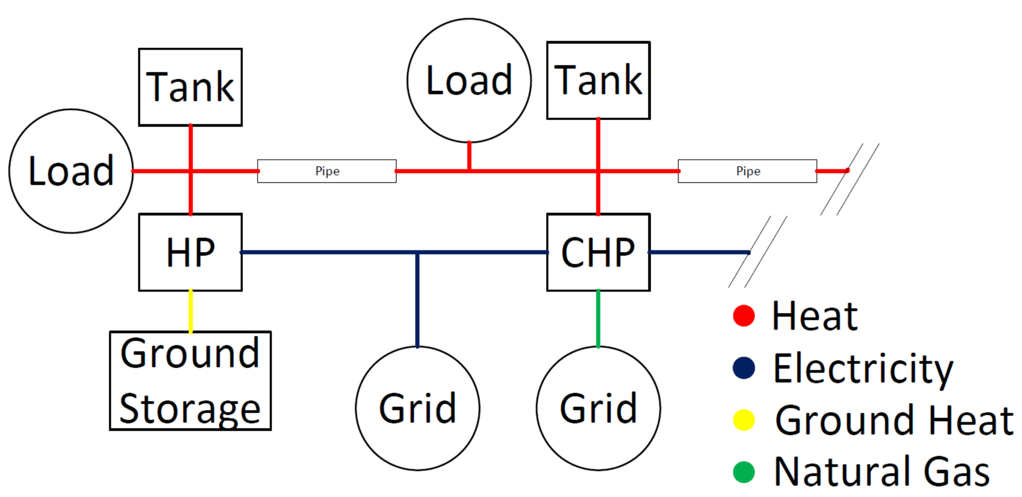


Figure 3. Example of a multi-carrier energy systems with heat pumps (HP) and combined heat and power plants (CHP). Only parts of the network are shown.

An increasing efficiency can only be handled in the framework of non-convex optimization. Standard mixed-integer programming may not satisfy the real-time conditions. Hence, two novel approaches are proposed.

Standard formulation of energy conversion processes:

$$f_i(p_{in}) = a_i\, p_{in} + b_i, \underline{p}_i \leq p_{in} \leq \overline{p}_i \quad \forall i = \{1, ..., n\} \tag{1a}$$

$$f_i(\overline{p}_i) = f_{i+1}(\underline{p}_{i+1}) \quad \forall i = \{1, ..., n-1\} \tag{1b}$$

with $a, b, \underline{p}, \overline{p} \in \mathbb{R}^n$.

Mixed-integer linear programming formulation (MILP):

$$p_{out} = f(p_{in}) = a^T\, p + b\, d \tag{2a}$$

$$0 \leq p_{out} \leq p_{max}\, d \tag{2b}$$

$$p_{in} = \sum_{i=1}^{n} p_i \tag{2c}$$

$$0 \leq p_i \leq c_i\, d \tag{2d}$$

$$a_i \geq a_{i+1} \tag{2e}$$

where $d \in \{0, 1\}$, $p \in \mathbb{R}^n$, $a^T, c \in \mathbb{R}^n, b \in \mathbb{R}$.

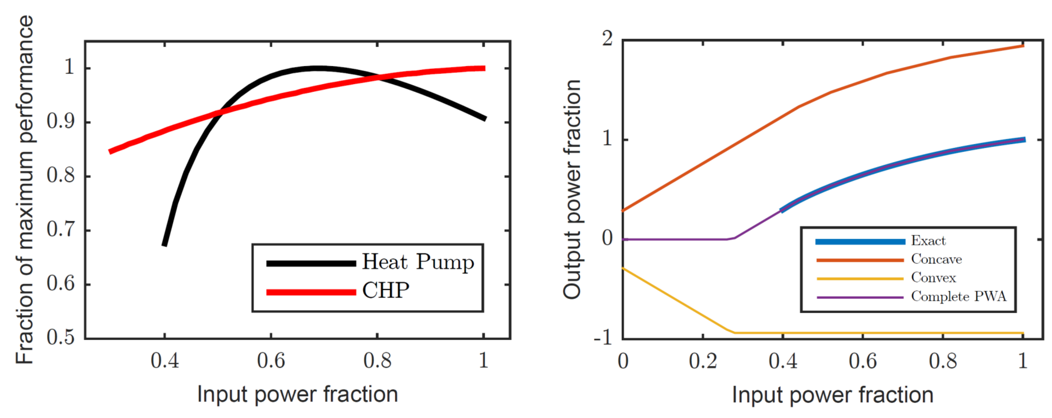
Inverse parametric optimization formulation (IPO):

$$g = y + z \tag{3a}$$

$$0 = y - (a_\psi\, p_{in} + b_\psi) - \sum_{i=1}^{n_\psi} \lambda_i \tag{3b}$$

$$0 \leq y - (a_{y,i}\, p_{in} + b_{y,i}) \perp \lambda_i \geq 0 \quad \forall i \in \{1, ..., n_\psi\} \tag{3c}$$

$$z \leq a_{z,j}\, p_{in} + b_{z,j} \quad \forall j \in \{1, ..., n_\phi\} \tag{3d}$$



(a) (b)

Figure 4. (a) Efficiency curves of energy conversion systems. Note the economies of scale. (b) Decomposition of energy conversion functions into a convex and concave curve.

COMPUTATION TIME AND SUBOPTIMALITY

Case	Loads	CHP/HP	MILP(a)	MILP(b)	IPO
Case 1	10	2/2	6.08s	202.9%	0.05%/0.65s
Case 2	20	3/3	19.3s	1.70%	0.31%/3.00s
Case 3	30	4/4	34.5s	5.00%	0.55%/8.39s
Case 4	40	4/10	26.36s	1.40%	1.51%/5.06s
Case 5	50	5/10	19s	303.86%	1.6%/4.57s

Table 1. Comparison of mixed-integer linear programming approach and inverse parametric optimization for different scales of energy systems. Computation time in [s]. Optimality gap in [%].

Conclusions and References

- Characteristics of energy conversion processes should not be ignored.
- An improved formulation of energy conversion processes can reduce the computational load significantly.
- Large multi-energy systems must be coordinated to increase efficiency.

M. Hohmann, R. Evins, J. Lygeros; Optimal dispatch of large multi-carrier energy networks considering energy conversion functions; IEEE CDC 16 (submitted)