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Poster Abstract: Sector Coupling with Optimization: A comparison between single buildings and combined quarters.

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Abstract

The combination of building technologies with renewable energies, storage systems and low carbon technologies, like Combined Heat and Power (CHP) and heat pumps, demands to consider different energy networks, i.e. sector coupling, in their building energy management systems (BEMS). This and the observation that energy equipment in buildings is often oversized and seldom used to its full potential during the most time of the year calls for a holistic approach to establish sustainable multi-energy neighbourhoods. In this work, we introduce a model for a district energy system with sector coupling that integrates BEMS and compare the results of this model for the optimized operation of single buildings and the integrated solution to quantify the possible saving potential.

Keywords: Sector Coupling; Multi-Energy Prosumers; Optimization and Model Predictive Control; Building Energy Management Systems; Quarters and Energy

Introduction

Our future requires a sustainable energy system. It needs to be holistic and cover all kinds of energy related sectors, including electricity, heating and mobility. It is inevitable, that the interdependence between different energy networks becomes stronger with the availability and penetration of renewable energies, storage systems, low carbon technologies, including Combined Heat and Power (CHP), heat pumps, Power-to-X systems and electric vehicles. The tight integration of sectors is mathematically described by multi-vector energy systems, as described by Liu and Mancarella [1], Geidl et. al [2], Orehouning et. al [3] and others. They introduce models to describe the energy system as an input to output relation. They use those models to optimize the operation and planning in districts.

Current buildings with energy supply equipment, be it photovoltaics, solar thermic heat production, CHPs, heat pumps and also cooling are planned to deliver the required energy even under harsh weather conditions. Consequently, the installed capacity often is larger than required during the most time of the year. Because of that, the equipment operates either in a non-optimal energy efficiency range, or turns on and off too often leading to high maintenance costs. When we consider only the operation, two possible solutions exist to improve the situation. First, single buildings can be optimized as much as possible using an intelligent building energy management systems (BEMS), as shown by [4]. The second option is the interconnection of the neighbourhood, as suggested by [1, 3]. This introduces the possibility to exchange energy between the entities and use the potential of the connected buildings much better. This work compares the two operational possibilities.

Model

Our model describes a decentralized multi-energy system at district level. Instead of modeling the district as a sum of demands and power generation, each building is modeled with its own demand and devices, which can only directly provide energy for this particular building. In order to still enable exchange of power between buildings, the power flow is represented as a part of the power input vector. The heat flow between buildings becomes visible and distinguishable, which allows for an individual loss calculation. We extend the general power flow model:

$$\boldsymbol{L} = \boldsymbol{C}\boldsymbol{P}, \tag{1}$$

$$\boldsymbol{P}_{LB} \leq \boldsymbol{P} \leq \boldsymbol{P}_{UB}, \tag{2}$$

$$\boldsymbol{G}\boldsymbol{P} \leq \boldsymbol{h}. \tag{3}$$

by additional entries to the power vector $\boldsymbol{P}$ and the coupling matrix $\boldsymbol{C}$:

$$\boldsymbol{L} = \underbrace{\begin{bmatrix} \boldsymbol{C} & \boldsymbol{C_{HDN}} \end{bmatrix}}_{\tilde{\boldsymbol{C}}} \underbrace{\begin{bmatrix} \boldsymbol{P} \\ \boldsymbol{X_{HDN}} \end{bmatrix}}_{\tilde{\boldsymbol{P}}}$$

$\boldsymbol{X_{HDN}}$ and $\boldsymbol{C_{HDN}}$ describe the heat distribution system with losses that are described by the line efficiencies. The model is designed not only for single optimization, but rather as an input for a model predictive controller (MPC) that runs on an aggregation platform[5].

Main Results

We model five buildings using typical demand profiles and equip each building with a set of common components that have certain benefits to see some variation. The scenario is explained in more detail by [5]. We calculate the expected operational costs of each building individually and compare it to a holistic district optimization using MPC with perfect predictions assumed. For the simulation we use a co-simulation framework[1].

The simulation results show the impact of different prediction horizons on the cost savings of the buildings operated with individual MPCs. In the exemplary scenario a single building can improve its costs with optimization depending on its equipment from 0% (without storage) up to 10% (with batteries). The savings are less on cloudy days and only slightly better on sunny days. The introduction of other external factors, for instance dynamic pricing, further improves the optimization of the individual buildings.

In contrast to single buildings the interconnected district reaches savings of around 20% in our scenario even with an MPC horizon of 1 timestep, independent of fixed or dynamic pricing. The major reason is that inefficient components, like oil and gas boilers, are substituted by more efficient ones. Surprisingly, the savings are not improved with longer MPC horizons. The main reason for this is that in the interconnected case of the investigated scenario no storages are used and no foresighted

[1] URL: https://github.com/SES-fortiss/SmartGridCoSimulation

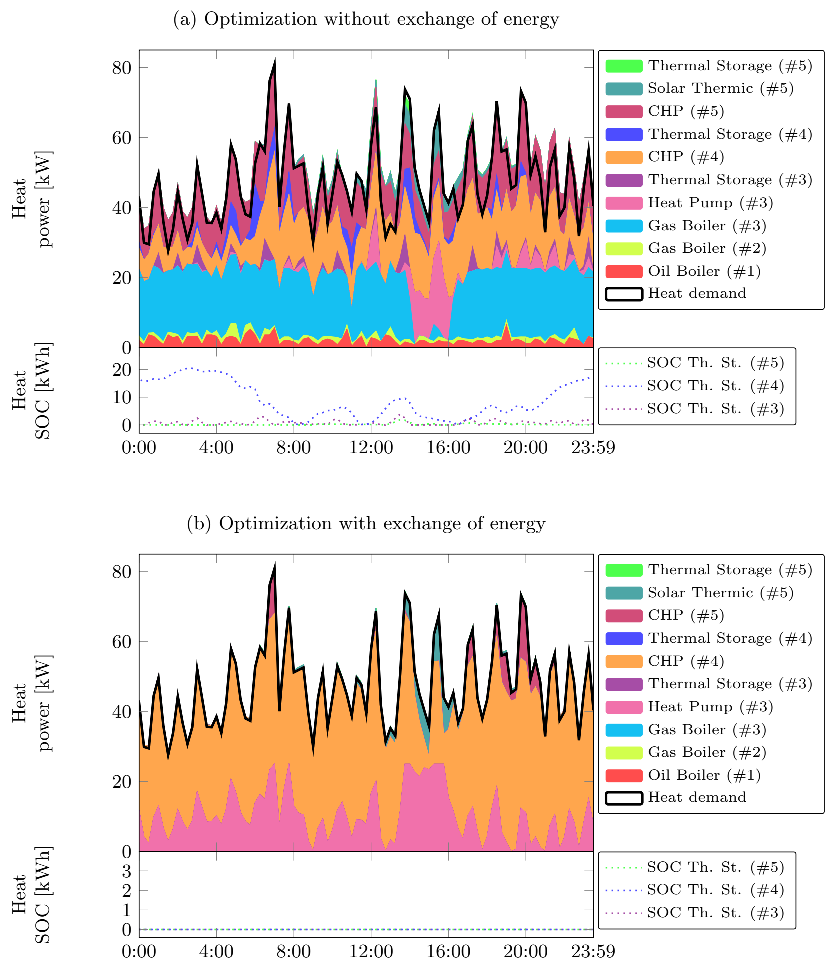

Figure 1 Comparison of the reference scenario (a) without exchange of energy and our system (b) with exchange of energy, 1h prediction horizon, fixed electricity price.

loading or unloading takes place. Therefore, longer MPC horizons do not affect the optimization. Storages are not used because of two aspects: The PVs, CHPs and heat pumps establish a very self-sustaining system, that is able to cover the demand in every timestep. Additionally, the parametrization of the scenario makes energy exchange more efficient then storing it. Therefore in every timestep the demand is covered by instantaneous generation and distribution. The appearance of such phenomena is an indicator for the plausibility of the underlying model.

The combination of CHPs and heat pumps also reveals one large limitation of our system: CHPs and heat pumps typically provide heat at totally different temperature levels (e.g. 80°C vs. 40°C). Therefore, they are hardly combinable in a common district heating network. Low temperature heat networks or multi-pipe networks with different temperature levels could be an approach therefore. Our model can be easily extended to these options, however this opens many technical questions with respect to the hydraulic implementation.

On top, there are also economical questions rising: in the interconnected case efficient components consume more fuel than before, while inefficient components do not consume fuel at all. Hence, the cost savings shift the overall financial obligations and requires new business model for compensation. Here further research has to be done.

Conclusion

We introduced a district energy system with sector coupling and exchange of energy with the goal to exploit the full potential within the district and decrease operational costs. By means of a comparison to single buildings, we explored the different behavior of the systems. Our system achieved a considerable cost reduction by using the district's devices in a more efficient way. Our model builds on the energy hub approach proposed by Geidl et al. [6, 2], but extends it to a neighborhood level. Orehounig et al. (2015) [3] take a similar approach, but their focus is on the design and sizing of a decentralized district energy system, less on the operation. Losses for energy distribution are also considered, but on a network level. Our model can identify the paths and amount of heat flow between the buildings with its heat distribution network. The system is modeled in a simplified manner, but detailed heat networks can easily be included in the model and used for a more sophisticated calculation of transport losses. It is also not limited to the presented example. The modular approach allows to adapt our scenario to other network topologies and a different set of devices.

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Availability of data and materials
The data, models and the co-simulation environment used for this work are available as open source under the URL: https://github.com/SES-fortiss/SmartGridCoSimulation

Author's contributions
All authors contributed to this work. Author #1 implemented the presented work in the co-simulation environment, carried out the comparison study with the network losses and wrote the major part of this paper. Author #2 implemented the co-simulation environment including the initial version of the presented work (without network losses). Author #3 developed the initial version of the model, helped in transferring this concept into the co-simulation. Author #4 has proof read the work, carefully analyzed and interpreted our simulation results, made several suggestions for the improvement of the scenario. Author #5 has substantially contributed to the overall project.

Competing interests
The authors declare that they have no competing interests.

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