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Load shifting using the heating and cooling system of an office building: Quantitative potential evaluation for different flexibility and storage options

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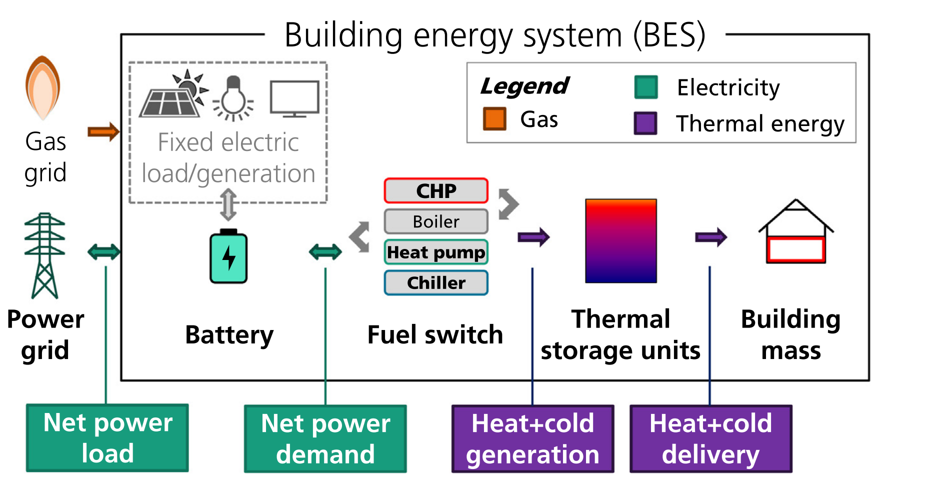
HIGHLIGHTS

- The energy flexibility of the HVAC system of a generic office building is analyzed.
- Energy flexibility is unlocked by a novel hybrid, rule-based control concept.
- Four flexibility and storage options are compared regarding effectiveness and efficiency.
- Which option is best suited depends on the available heat and cold generators.
- More variable electricity prices are needed to stimulate load shifting.

GRAPHICAL ABSTRACT



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ABSTRACT

This numerical study evaluates and compares four different flexibility and storage options in building energy systems (batteries, fuel switch, water tanks, and thermal building mass) in terms of potential improvements in load scheduling and energy efficiency. Using a generic modern office building with concrete core conditioning as an example, two different supply concepts (one based on a heat pump, one based on a CHP unit) are considered. A novel hybrid control concept is applied which is designed to be compatible with state-of-the-art controllers implemented in the field. The results show that batteries are the most technically attractive options in terms of grid support, efficiency and ease of implementation. Fuel switch is comparably straightforward to implement, but provides significant benefits only for the considered CHP system. Water tanks with a capacity of about two full operation hours offer nearly the same flexibility as much larger tanks, but negatively influence the efficiency of heat pump systems. The thermal building mass can be used effectively and efficiently for thermal storage, particularly in the heating season, but this is technically challenging to realize. It is shown that current electricity prices do not offer sufficient variations to stimulate grid-supportive operation.

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1. Introduction

1.1. Motivation

As part of the *Energy Transition* announced in 2011, the Federal Government of Germany aims to cover at least 80% of the national electricity generation by renewable energy sources by the year 2030 [1,2]. This policy is in line with the latest international agreements to reduce greenhouse gas emissions, such as the Paris agreement of 2016, which was signed by 195 countries [3]. In the case of Germany, most of the renewable power will be provided by wind and solar plants, which generate electricity intermittently depending on the current weather and are not dispatchable like conventional power plants.

A large amount of intermittent renewable energy in the energy system is a major challenge, since supply and demand must match at any time. A high level of flexibility, both on the demand side and by dispatchable generators, can greatly facilitate and promote a reliable and efficient electricity supply based on intermittent renewable energy sources. Possible flexibility measures include grid ancillary services (at time ranges from milliseconds to days or even months), energy storage, supply-side flexibility, advanced energy conversion processes (e.g., hydrogen, power-to-liquid), strengthening of the grid infrastructure, and demand side management [4]. According to the United States Department of Energy [5] as cited by Behrangrad [6], "Demand Side Management (DSM) can be defined as modifications in the demand side energy consumption pattern to foster better efficiency and operations in electrical energy systems." This increased efficiency can be achieved in various different ways.

- Maximization of local load and generation matching: as an example, it can be preferable to use electricity from local PV generation on-site than to feed it into the grid, since the latter causes electrical transmission losses.
- Reduction of grid stress can increase the reliability of grid operation and reduce or delay the need for investments into the grid infrastructure.
- Minimized cost of generation: Cost savings may be achieved by consuming electricity during times when the marginal cost of power generation on a system level is minimal.
- Short-term flexibility: The ability to increase or decrease the load at short notice in the case of unforeseen events (e.g. load prediction errors, power plant or transmission grid congestion) provides benefits by increasing the stability of the electricity supply and preventing power outages.

This paper evaluates the potential of office buildings to act as flexible loads and generators aiming at minimizing the cost of generation. In this sense, the term "grid" does not refer to the physical utilization of the distribution grid, but is used in a wider sense to represent the upstream energy system and markets. The focus of the evaluation is on the electricity load and generation caused by heating and cooling systems, i.e. heat pumps, chillers, and CHP units. Heating and cooling systems in buildings are worth investigating because the cumulative load shifting potential in the heating and cooling sector is quite large considering the high energy consumption [7] and thermal storage potential [8] of the building stock.

The impact of a building on the power grid and electric energy system is determined by the trajectory of the net power load. Within the heating and cooling system of a building, different flexibility and storage options can be used to alter the load trajectory (see Fig. 1).

- Batteries can create a time shift between the net power load and the net power demand of the building.
- Fuel switch involves a change in the sequencing of different heat and cold generators in order to alter the relation between power demand and generation of heating and cooling power, based on a grid signal. Technically, it relies on a variation of the end energy form which is used to provide thermal energy to the building. This may effectively cause an energy storage process at a higher energy system level, e.g. in the gas grid.
- Water tanks can introduce a time shift between heat generation and heat delivery.
- The thermal building mass can be used for thermal storage by modifying the heat delivery trajectory.

It is generally not well understood how much load shifting potential each of these flexibility and storage options provides, how this potential relates to the type and sizing of the flexibility and storage options as well as the available thermal generators, during what times of the day and year the desired flexibility is available, and how the performance of the heating and cooling system is affected by load shifting. Answers to these questions are essential to defining the possible role of energy flexible buildings in an integrated sustainable energy system and to understanding how buildings can contribute to the conservation of energy resources and optimization of energy processes at a system level. Furthermore, it is important to better understand the suitability of specific technologies in building energy systems to provide flexibility, as an information base for a variety of stakeholders, from researchers to policy makers. Finally, as of this writing, there are still open questions as to how the existing flexibility can be utilized

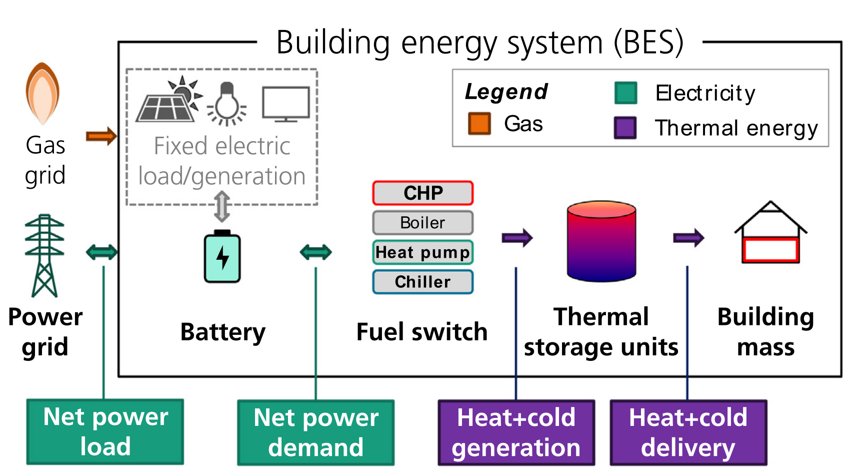

Fig. 1. Illustration of different flexibility and storage options within a building.