Building Energy Management Systems and Their Role in the Energy Transition

Results from Research Projects and Applications in Germany

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Abstract - **The building sector is responsible for a major share of the final energy consumption in the European Union. Most attempts to improve this situation to date have focused on construction or retrofitting measures. In contrast, this article centers on the role of building energy management systems and its ability to improve energy efficiency as well as to increase the consumption rate of renewable energies in the building sector.**

The authors present findings from two research projects in Germany that have analyzed applications of the technology for reducing heating demand and electricity consumption in residential buildings and households. Particular attention was paid to life-cycle-wide and rebound effects of the technology to ensure that the applications achieve net savings.

The results also illustrate that building energy management systems can facilitate the implementation of the next phase of the energy transition, which will require flexibility from the building sector to adapt energy consumption to more volatile production patterns from renewable energies. Open architectures, standards, and interfaces play a crucial role in this process.

Index Terms
Building energy management, energy transition, flexible energy consumption, demand-side management

I. THE ENERGY TRANSITION IN THE BUILDING SECTOR

The building sector is of considerable importance for the transition and decarbonization of the energy system. Almost 80% of total final energy consumption in the EU is used for heating and hot water in residential and non-residential buildings [1]. Moreover, approximately half of the stock of residential buildings in European countries was built before thermal regulations or building codes were introduced in the 1970s [2], resulting in poor insulation and high thermal losses.

The EU has therefore agreed on two policy goals for 2030. First, energy efficiency should be improved (in all sectors) by 27% and greenhouse gas (GHG) emissions reduced by at least 40%. Second, the share of renewable energies is to be increased to 27% of the energy supply [3]. These policy goals present two challenges to the building sector: an increase in efficiency and the integration of fluctuating renewable energy sources into a system with a steady demand.

Although efficiency measures (e.g., high-quality building insulation, solar architecture) and decarbonization strategies (e.g., using more renewable energies), are widely applied in the construction of new buildings,[1] retrofitting the existing residential building stock is extremely challenging. High costs and inadequate financing schemes [4] and [5], long life cycles of materials and appliances, as well as social constraints (increasing rents and housing prices) and cultural constraints (preserving historic buildings and urban centers) delay the implementation of efficiency measures and the roll-out of renewables in the building sector.

Another approach to increasing efficiency is through smart building technology, in other words, distributed, intelligent, and networked hardware and software systems that can reduce and shift energy consumption in buildings and households (see Section II). Smart building technology is becoming more important for the following reasons:

- Networked information and communication technology (ICT) in the energy sector: autonomous and ubiquitous sensors, smart measuring technologies (smart meters and smart meter gateways), and open platforms and interfaces are sweeping the building sector, becoming integral components of existing technologies and products (heating, cooling, appliances, etc.) [6]. Energy networks and infrastructure (transmission and distribution networks) are also being equipped with smart technologies, gradually allowing communication across different levels of the energy system (see II.B).

- Demand for energy management in buildings: in addition to the objectives for energy efficiency, the increasing share of fluctuating energy production from renewable sources is creating a need for more demand-side flexibility in the energy system and the building sector [1]. Smart building technologies provide solutions for managing energy consumption in buildings and households, for coupling heating and electricity consumption, and for adapting energy consumption patterns to fluctuating energy production.

- User and behavior orientation: finally, users are an important factor in the transition towards an efficient

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[1] These principles and strategies are integral parts of building codes and directives for energy performance (see, e.g., the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED)).

and flexible energy system. Besides rapidly developing technology and improved usability, behavior is crucial for mobilizing efficiency and flexibility potentials in the building sector. Smart building technology and applications can facilitate and incentivize a change in consumption patterns (e.g., through visualization and efficient feedback mechanisms) [8] and [9].

Against this background, the objectives of the present paper are: (1) to summarize and demonstrate that state-of-the-art smart building technology can contribute to significant (net) energy savings, and (2) to describe how the technology can be applied to use inherent flexibility[2] and demand management potential in the building sector for the energy transition.

The findings presented in this paper were gained from two research projects and selected pilot installations of smart building technology in Germany. Although the German objectives and strategies for a transition of the energy system result from national policies and a specific building stock, the findings can be transferred to other countries.

II. ROLE OF SMART BUILDING TECHNOLOGY FOR THE ENERGY TRANSITION

A. Definition of Smart Building Technology and Building Energy Management Systems

Smart building technology is based on building automation systems (BAS). A BAS is used to monitor and control mechanical devices, lighting, heating, ventilation, and air conditioning (HVAC) systems, etc. in buildings [10]. BAS can generally be used in residential as well as commercial and public buildings, and also in industrial sites, where microcontroller-based automation emerged back in the 1970s [11]. The following definition focuses solely on residential buildings and their role in the energy transition, which is different to industrial applications.

Building energy management systems (BEMS) are a subcategory of BAS that are specifically used for energy management in buildings and households. BEMS consist of distributed sensors (temperature, humidity, motion, etc.) and actuators (pumps, radiator valves, vents, etc.) in rooms, apartments, and buildings that are hierarchically linked to control units (apartment manager and building manager, see Fig. 1). Their main function is to control and monitor heating demand in buildings [6] and to adapt the central heat generating unit (gas boiler, district heating station, combined heat and power (CHP) plant, etc.) according to the demand of the building and its residents. The difference between BEMS and simple thermostat-based heating control derives from the architecture (hierarchical optimization vs selective optimization) and the number and accuracy of the measured variables and values used for optimization [12]. While thermostat-based heating control often relies on one or a small number of measuring points, BEMS take many measured values from individual rooms, user preferences, building characteristics, and the weather forecast into account.

B. Evolution Toward Open Standards and Platforms

Smart building technology is undergoing a radical change. In the past, BAS and BEMS were known for their proprietary approaches and communication protocols that often led to technological and financial dependencies [14]. Furthermore, applications were often user-unfriendly, forcing customers to adapt to autonomous control systems and leaving very little room for interaction. This situation has changed significantly over the past decade. Many (although not all) systems are based on interoperable hierarchical architectures and (semi-)open standards and protocols (e.g., Connected Living,[3] OpenTherm, Open Metering System).[4] The energy sector itself is a strong driver for open architectures and interfaces with the objective of creating integrated and networked smart energy systems and markets, integrating energy generation, distribution, and consumption (see e.g., USEF,[5] VHPready,[6] and EEBUS.[7])

Finally, BEMS user interfaces and feedback mechanisms have improved significantly, benefiting from the general development of smart devices such as smartphones and tablets [13]. Another advantage of BEMS open architectures for users is that these allow the integration of additional services from other smart building domains such as facility and service companies (e.g., assisted living or security services).
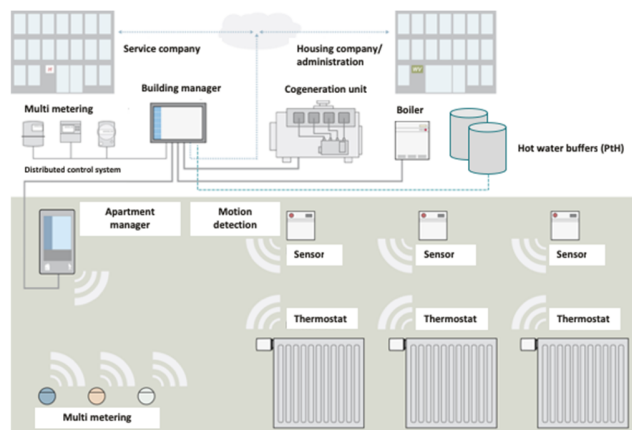

Fig. 1 BEMS with sensors, actors, and control units and an open platform for services (source/©: © Riedel Automatisierungstechnik GmbH)

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[2] This preliminary definition of flexibility for the energy system was developed as part of the research project WindNODE (see Section VI).

[3] Connected Living is an innovation center and association that aims at creating a network and platform for a cross-sector and cross-producer smart home platform (https://connected-living.org/en, retrieved December 2018).

[4] A number of open standards have been established. OpenTherm is a standard communications protocol used in central heating systems (www.opentherm.eu, retrieved December 2018), and the Open Metering System is a standard for manufacturers and utilities for communication between different utility meters (www.oms-group.org, retrieved December 2018).

[5] USEF is a foundation created by organizations active in the smart energy industry. Its goal is to develop a framework and market model for an integrated smart energy system (www.usef.energy, retrieved December 2018).

[6] VHPready is an open industry standard for the control and integration of decentralized power and heat generation plants, consumers, and energy storage systems into virtual power plants and smart grid applications (www.vhpready.de/en/home/, retrieved December 2018).

[7] EEBUS is an initiative that seeks to introduce a global language for devices in the energy sector to communicate with one another (www.eebus.org/en/vision/language-for-energy/, retrieved December 2018).

C. Building Energy Management Systems: Interoperable Platforms for Flexibility

The evolution of BEMS toward open and interoperable systems and platforms has unlocked new areas of application. While in the past systems often focused on the optimization of energy efficiency in single apartments and the behavior of individual residents [15], [16], and [17], new interoperable (best available) technology takes into account the optimization of whole buildings and neighborhoods[8] as well as the supply system with increasing shares of renewable energies, a more decentralized energy production (e.g., integration of solar panels, heat pumps, or CHP) and consumption (e.g., storage in batteries, electric mobility) (see Fig. 2) [21].
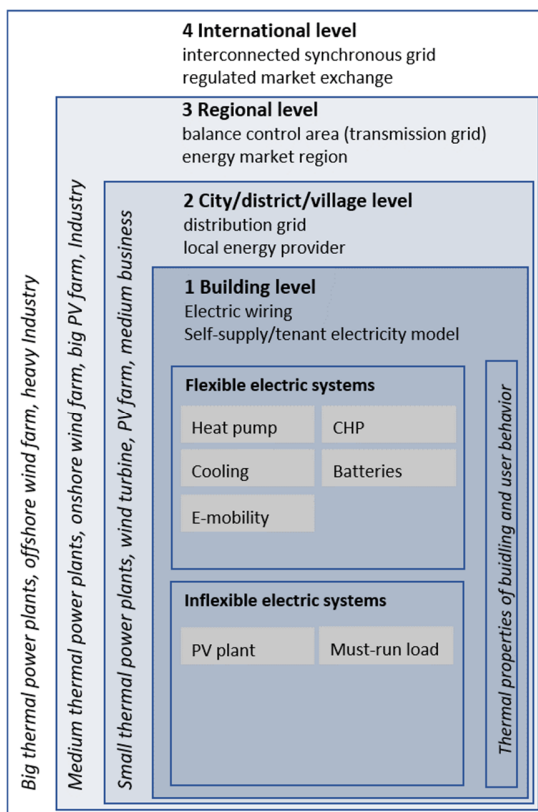

Fig. 2 The role of energy management in buildings against the background of a changing energy system (source: according to [7])

BEMS can be used to optimize complex systems and facilitate and allocate flexibility.[9] Flexibility is becoming more important with the increasing share of fluctuating renewable energies (solar, wind, etc.) in the grid. Alternative strategies for dealing with a fluctuating energy supply are demand response management, storage technologies, and dynamic pricing schemes [18] and [19].

BEMS provide interfaces to receive signals for external incentives for flexibility (see Fig. 3). The signals might be either control, price, or other incentives that ensure that an economic optimum is achieved at the local level. The system is able to react flexibly to external events such as surpluses from wind energy or bottlenecks in the electricity grid. Signals can either be used to stimulate adaptive behavior or for autonomous optimization with BEMS. Signals can be emitted by market participants (e.g., aggregators[10]) that collect smaller flexibilities and trade these either via virtual power plants[11] (VPP) or directly on energy markets. New flexibility markets and models of the above-mentioned aggregators are described for example in "The Framework explained" by Universal Smart Energy Framework (USEF) [19].

III. RESULTS FROM THE DEVELOPMENT AND APPLICATION OF BEMS IN A GERMAN NEIGHBORHOOD

The results presented in the following section were derived from two joint research projects funded by the German Federal Ministry for Economic Affairs and Energy (see Section VI).

The objective of the projects was to integrate an existing BEMS into an open smart building platform and to further develop its optimization functions. The improved technology was implemented in two different neighborhoods in Germany and the effects of the energy management were monitored over a period of several years.

A. Integration of BEMS into an Open Smart Building Platform

In a first step, an existing BEMS for the optimization of the energy consumption (heat and electricity) in households and buildings was integrated into an open smart home platform.[12] This allows the system to communicate and interact with standardized bus systems and interfaces from the home automation sector (IP-Bus, EnOcean, wireless M-Bus, etc.). A Smart Home Internet Protocol (SHIP) connects proprietary with open standards (see Fig. 3).

During integration and further development, particular attention was paid to the usability of the BEMS. A newly designed graphical user interface and feedback mechanisms for single room temperature control were implemented.

Integration of BEMS into interoperable platforms is a prerequisite for the fast-developing demand for flexibility and energy management in a future smart grid (see Section IV). The main driver for this is the increasing share of fluctuating renewable energies (solar and wind) in the grid [18].

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[8] A neighborhood is defined in this paper as an aggregation of several (multistory) residential buildings.

[9] Flexibility is understood as the capability of elements in the energy system to actively react with adapted performance to an external signal that reflects the variability in electricity production and consumption. (This preliminary definition of flexibility for the energy system was developed in the research project WindNODE, see Section VI).

[10]An aggregator is a generic market role combining electrical appliances to make their energy and flexibility more valuable on the market.

[11] A virtual power plant is an approach to connecting decentralized energy systems to capitalize them in a combined form and it appears on the market like a traditional power plant.

[12] The existing BEMS of the German company Riedel Automatisierungstechnik GmbH was integrated into the open smart home platform concept of the German Connected Living Association (see www.connected-living.org/en).
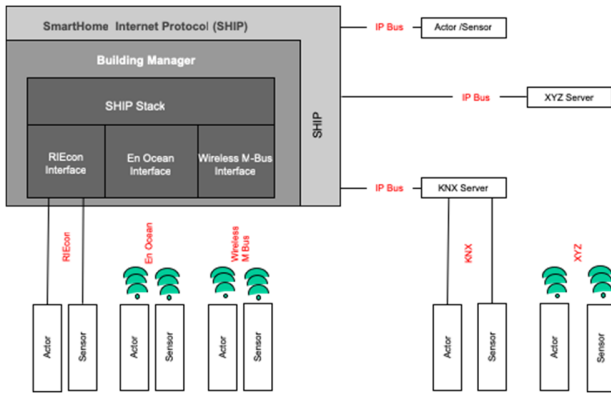
Fig. 3 Open architecture of BEMS (source/©: Riedel Automatisierungstechnik GmbH)

B. Reduction of Energy Demand in Residential Buildings

In a second step, the BEMS was installed in a neighborhood consisting of six multistory residential buildings with 224 apartments in Berlin, Germany. These buildings, owned by a cooperative, were built in the 1950s/1960s and partially refurbished in the 1990s (with new windows and moderate insultation on walls and attic). The buildings are supplied with locally produced heat and electricity from a CHP plant (34 kW$_{el}$/ 78 kW$_{th}$), operated by a contractor, and additional boilers. Subsequently, the energy consumption of the individual tenants and apartments for heating and warm water in the complex was monitored from 2015 to 2018.

The introduction of the BEMS in the neighborhood led to an average reduction of heat demand of 24% (80.8 kWh/m^{2}a to 61.4 kWh/m^{2}a). Residents' operating costs were cut by 17% [21].

Although the heating energy savings depend on the characteristics of the building (size, building material and physical properties, structure of residents, behavior, etc.), similar savings (approximately 20%) have been documented in comparable projects and types of buildings in Germany [21], [22], and [23]. The results also show that efficiency gains are higher in multistory buildings with multiple apartments and distinct heating demands than in individual or semidetached houses with simple heating patterns [22].

In the same neighborhood, the BEMS was used (in combination with smart meters) to visualize electricity consumption of the residents in the apartments. Although transparency of electricity consumption can lead to individual savings (e.g., through exchange of appliances with high energy consumption and behavior change of residents) [8], there are currently no incentives for residents in Germany (e.g., dynamic prices) that would encourage an adapted consumption to a fluctuating energy supply.

C. Mobilizing Thermal Storage Capacity of Buildings

In a third step, the objective was to prove that BEMS can be used to mobilize flexibility in the building sector. This can be done either by shifting energy consumption in households and buildings to times with lower grid loads or by actively feeding energy (electricity from CHP plant) into the grid.

In the above-mentioned case of the neighborhood in Berlin, it was done by using the thermal building mass. Simulations of the buildings have demonstrated that up to 16% of the yearly heating demand in the multistory buildings can be shifted by the temporary adaption of average room temperatures by ±1 °C in apartments [21]. This thermal storage capacity of the building's mass can be made accessible through BEMS, as the system allows precise predictions of heating demand.

Combined with technologies such as CHP, heat pumps or electric heating, this thermal flexibility can be made available to adapt the dynamic electricity consumption/production profiles of these systems [24]. Furthermore, the technology enables the efficient allocation and coordination of small price-incentivized flexibilities.

The simulation was verified in the buildings with short trials of adapted operation modes of the CHP plant. This result is of interest for various reasons. First, it indicates that the inherent building mass can be used to reduce and shift energy consumption in households and buildings. Second, it provides inexpensive flexibility that can be used and increased with manageable additional measures (see Section IV).

D. BEMS and User Acceptance

The introduction of BEMS in the selected residential buildings was accompanied by an intense and continuous discussion with the residents of the apartments. The residents learned to operate the BEMS and to adapt the standard operating scheme of the single room temperature control to their individual needs. To avoid a rejection and malfunction of the system, the following steps were taken:

- High priority during the development of the BEMS was given to a user-friendly design and the user interface of the control system (apartment manager) with simple feedback mechanisms.
- The cooperative (owner of the buildings) asked the residents ahead of implementation to endorse introducing the efficiency measures and achieved an approval rating of over 75%.
- The residents were trained to use the systems. Their concerns regarding comfort and costs were respected and they learned how to change the settings if so desired.

Two years after implementation, a survey with all residents was conducted. Acceptance of the system was unchanged and reduced operating costs, energy efficiency, and comfort were discussed with representatives of the residents.[13]

E. Assessment of Environmental Effects of BEMS

Finally, assessment of the life-cycle-wide energy and resource consumption of BEMS is of interest in order to judge whether the technology can contribute to net savings. Research by the authors has proven that:

- Potential net emissions savings through the application of BEMS strongly depend on the heat energy saved

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[13] The results of the survey have not been published. The data are the property of the building cooperative.

(functional unit: 1 kWh saved), and can vary from approximately 0.4 kg CO_2 equivalent (for natural gas heating avoided) to over 1 kg CO_2 equivalent (for electric heating avoided in regions with GHG-intensive electricity generation). At present, BEMS typically avoid at least 40 times as many GHG emissions as they produce over their entire life cycle if they are used in regions with moderate to cold climates [12].

- A comparison of building insulation and BEMS in Germany showed that CO_2 abatement costs for building insulation (approximately. €100/tCO_2) are at least three times higher than the costs for BEMS (approx. 30 €/tCO_2) [25]. It follows from this that BEMS can be efficiently used to quickly reduce energy consumption in the building sector, even when cost restrictions for refurbishments or strict conservation codes for buildings apply.

Finally, as with other technologies, BEMS can have rebound effects [26]. Direct or primary rebound effects deriving from BEMS can be eliminated with a high degree of certainty due to the high efficiency achieved by the technology. Indirect or macroeconomic effects are more difficult to assess. At this point, it can only be assumed that these effects are not dominant because of rising operating costs (heating and electricity) for residents in the German housing and rental market.

IV. FUTURE APPLICATIONS OF BEMS FOR THE ENERGY TRANSITION

The results presented in the preceding section indicate that BEMS can successfully be used to manage complex buildings and neighborhoods with multiple power generating units (e.g., boilers, CHP plants). In these applications, BEMS serve as a platform for complex controlling and optimization processes. They minimize costs (e.g., residents' operating costs) and environmental effects (e.g., GHG emissions) and translate this into specific objective functions of the BEMS, using priority circuits for CHP plants (to prevent wear and tear)) [6]. Hence, BEMS can also be used to facilitate and allocate flexibility or grid-reactive behavior of buildings by using inherent storage. Thus, buildings can provide affordable alternatives in comparison with other storage solutions (batteries, power-to-x, etc.) [18].

A key insight from research projects to date is that, although technically possible, the mobilization of flexibilities from the building sector is highly dependent on (financial) incentives. These incentives could be, for instance, dynamic pricing schemes that take into account availability of renewable energies, storage options, and grid capacity. Dynamic pricing would be a strong driver for the allocation of (relatively speaking, compared to other sectors such as industry) smaller flexibilities from residential buildings. Such smaller flexibilities could then be allocated to dimension in the GW range with significance for the energy system. Further research by the authors therefore focuses on two questions:

- How can smaller flexibilities from buildings be complemented with other approaches or technologies to form bundles that are technologically and commercially useful?
- What are use cases, value chains, and business models that allow the aggregation of smaller flexibilities from buildings and how can they be realized?

The following sections will describe how these questions are being pursued in ongoing research of the authors, using the technology and neighborhood described in Section III above.

A. Increasing the Flexibility Potentials from Buildings

With residential buildings, there are several options to increase flexibility potentials. Although BEMS were primarily developed to control and optimize heating systems and electricity consumption in buildings, thanks to their open architecture and interfaces, they can also integrate (existing and additional) sources for flexibility, such as cooling, air conditioning, heat pumps, electric mobility, etc.

One option that can easily be realized in residential buildings is power-to-heat (PtH) elements in existing warm water buffer systems. These can be retrofitted in existing hot water storage tanks and local district heating networks and they provide inexpensive solutions for flexibility by converting excessive renewable energies (e.g., PV or wind) into heat[14]. PtH elements are therefore simple solutions for coupling the electricity sector to the heat sector.

The neighborhood in Berlin, Germany described in Section III.B was equipped with such PtH elements (6 x kW = 48 kW) in existing warm water buffer tanks. The PtH elements were integrated in the BEMS (see Fig. 1) and are now, together with the CHP plant (36 kW), part of the flexibility potentials of the buildings. The flexibility can be used to:

- consume electricity from the grid by turning off the CHP plant and charging the warm water storage tanks (negative balancing power in times of high grid loads) or by
- feeding electricity into the grid from CHP plant and slightly overriding the present temperatures in the complex by max 1°C and using the buildings as inherent thermal storage (see Section III.C) (positive balancing power in times of low grid loads).

Control via the BEMS ensures that costs are minimized and changes made due to flexibility options will be in line with the temperatures preset by the residents with minor alterations.

B. Analyzing Value Chains for Energy Flexibility of Residential Buildings

For the commercialization of flexibility of the building sector, it is important to understand the flexibility needs in the energy market and to identify approaches or instruments that can serve these market needs. Although demand for flexibility is subject to national (in this case, German) regulations, some general rules apply. First, flexibility is needed to balance upcoming supply and demand on the market (day-ahead and

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[14] The installation of PtH elements in warm water storage/buffer tanks is inexpensive and can be performed by plumbers in a few working hours.

intraday). Second, there is a need for flexibility to stabilize the transmission grid (frequency control) and to avoid network bottlenecks (congestion management). Third, electricity suppliers (the balance responsible party) have to supply their electricity to customers continuously and precisely as required. They need to be flexible for short-term adaptation to unforeseeable fluctuations in electricity generation and consumption [27]. Finally, flexibility can be used to achieve a high self-sufficiency rate. For prosumers, this means that their own production is able to meet their needs most of the time, so that they rarely have to buy energy from suppliers.

These needs have a strong impact on the technological options for flexible energy supply of buildings. At present, market demand for flexibility is almost exclusively met by bigger power plants (multiple MW each). Market access for smaller (individual) plants, for example, from the building sector, is therefore difficult to realize.

For this reason, instruments that might help operators of smaller plants or units to achieve flexible energy supply are being examined. Digital platforms and virtual power plants are one approach for overcoming the existing barriers for smaller flexibility providers. They can efficiently pool flexibilities by streamlining processes and minimizing costs that arise, for instance, through registration and trading.

Marketing via VPP can also allow producers to offer flexibility to more than one market at the same time ("multi-use"). Based on precise predictions, it is possible to sell electricity (e.g., from CHP) on the market 24 hours a day and simultaneously hold back negative balancing power for frequency control. Therefore, CHP units are usually operated at full power. If, for example, high loads occur in the grid (e.g., due to surplus feed-in from wind generators), the output power of a CHP unit can be reduced at short notice to support grid balancing.

C. Identifying Use Cases and Market Incentives for Digitally Enabled Flexibility Services Provided by the Building Sector

To explore options for flexible or grid-reactive behavior of buildings and to align them with market demand, research on the current electricity system/market was conducted together with relevant stakeholders. Potential models were drafted from a local consortium consisting of a BEMS supplier, a CHP operator, a housing company, and two research organizations. These drafts were presented and discussed at a stakeholder workshop in Berlin in 2017.[15]

On the basis of these workshops, potential models for flexibility services of local neighborhoods were developed. Two models that fit the current framework of the electricity system best are presented below:

1) Grid Services for a DSO/TSO Flexibility Platform

The first model aims at offering flexibility to the electricity grid. It combines the functions of a TSO[16]/DSO[17] operational online platform (acquiring flexibility from plant operators) and a coordination platform (optimization between TSO and DSO, in this case, a project specific platform, see Fig. 3) according to USEF [28].
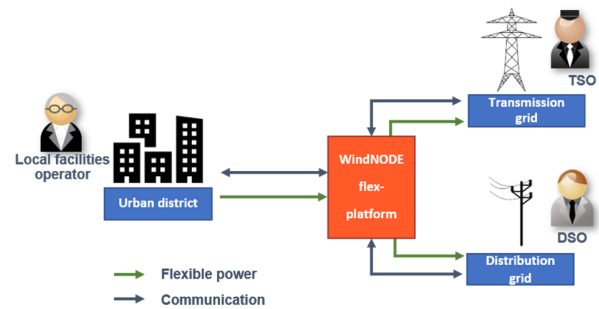

Fig. 4. Flexibility of buildings through TSO flexibility platform (source: own)

Offers for flexibility can be submitted both a day ahead and intraday for individual quarters of an hour (96 values per day). The call for flexibility can be both day-ahead and intraday.

Flexible systems can be registered and offers submitted either manually via a browser interface[18] or automatically via transfer of an xml file. An automated process fundamentally reduces the specific registration/transaction costs per kilowatt. This is of importance for small flexible devices/systems wishing to compete with larger ones in the future.

2) Market Flexibility via Virtual Power Plant

The second model aims at integrating flexibility into the market through a virtual power plant (VPP). VPP operators usually control various plants for the generation and consumption of electricity in order to be able to react flexibly to demand on the energy market and to generate optimum results across their entire portfolio.
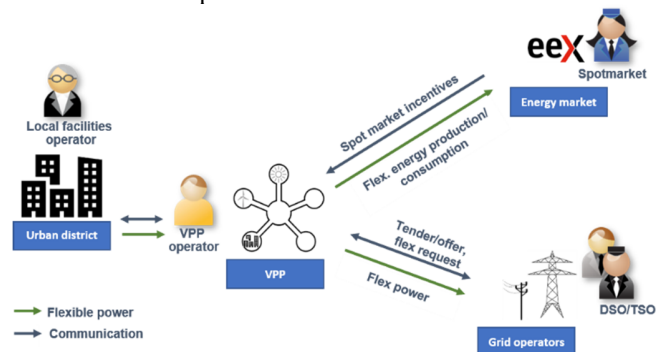

Fig. 5. Flexibility of buildings through VPP (source: own)

This case allows VPP operators to react to predictable fluctuations of electricity production in advance by optimizing

schedules. In an ideal market, only facilities that produce the smallest specific emissions at the lowest cost, just enough to cover the load (see Fig. 4), will operate.

A control box (gateway) is installed in one or more buildings to connect the neighborhood to the VPP operator. The box interacts with the BEMS which determines the local flexibility options and optimizes their operation.

D. Testing of Use Cases

The two cases developed for the building sector (DSO/TSO flexibility as well as market flexibility for VPP) will be implemented and verified with tests in the neighborhood in Berlin, Germany (see Section III.C). Time-limited trials (24-48 hours each) under changing conditions (different seasons) are planned. A major challenge is the requirement to not interfere with the need for continuous supply of heat and electricity for the residents.

The trials will encompass the processing of external signals for flexibility (e.g., signal from platform or VPP operator) via interfaces of the open BEMS architecture (including interfaces between the BEMS and the plant/units for flexibility), as well as the ability of the buildings to react to the signals.

It is expected that the flexibility potential will depend on various factors such as building physics (building construction, materials, etc.), utilization of the building, and types of heating and hot water systems.

It is also expected that, due to the current market and pricing scheme (fixed prices for electricity, no incentive for flexibility, etc.), options for commercialization of the flexibility will be limited (see Section B), but that with dynamic prices in the future (due to higher shares of renewable energies) new business models will develop.

V. CONCLUSIONS

Results from the research, development, and trials with BEMS allow the following conclusions.

A. BEMS and their Contribution to Energy Efficiency in the Building Sector

The building sector plays an important role in the transition of the energy system and BEMS can help to make the building sector accessible for this development. The technology can improve energy efficiency in buildings and households by significantly reducing heating demand. If state-of-the art knowledge and technology is applied, 20% of heat energy can be saved in partially refurbished residential buildings in moderate to cold climates. This can be done in an economically reasonable way, without interfering with the autonomy and comfort of the residents, and with net energy savings over the life cycle.

B. BEMS Foster the Integration of Renewable Energies into the Grid

In addition, BEMS can act as a key technology to balance fluctuating electricity production from renewable sources with the need for a steady energy supply in households and buildings. The technology (together with smart meters) can be used to increase transparency on energy consumption. When combined with dynamic pricing, decentralized production (e.g., CHP or PV) and power-to-heat technologies, BEMS can serve as an optimization platform for coupling the electricity and the heat sector.

Although the individual flexibility from buildings and neighborhoods appears small (below 100 kW), the total for this sector in Germany amounts to gigawatts [29]. Thus, the building sector with its inherent flexibility potential can be made accessible for a renewable energy supply.

C. The Role of ICT Open Architectures, Standards, and Interfaces

ICT and autonomous algorithms that optimize energy management on different levels of the system (building, neighborhood, local (distribution) grid, and transmission grid) are prerequisites for the efficient organization of a future energy system. Not only does the technology make it possible to balance energy production and storage, but it also allows the integration of decentralized flexibilities of buildings and private households (including appliances such as refrigerators, air conditioners, etc.), which can serve as additional reserves for demand-side flexibility.

Although open standards and interfaces in the home automation and energy sector are currently developing, we are still a long way from having open, interoperable, and (inter-) nationally accepted architectures that cover different sectors of the energy transition (energy production and distribution, industrial production, buildings and mobility).

D. Economic Incentives for the Energy Transition

Finally, it can be concluded that financial incentives play an important role in the energy transition. Initial assessments indicate that under today's regulatory and pricing scheme (in Germany), only small revenues can be obtained from these decentralized flexibilities in the building sector. However, it is also assumed that automated handling of flexibilities from the building sector with BEMS, platforms, and marketplaces will significantly lower the costs of aggregation.

Thus, it is likely that handling and trading of smaller flexibilities will become more efficient. Together with incentives for flexibility (e.g., dynamic pricing schemes for grid-reactive behavior, a flexible grid fee or tax) the development of viable business models will be possible in the near future.

VI. ACKNOWLEDGMENTS

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