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Buildings' Energy flexibility: towards neighborhood level for Smart grid support

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Abstract

Applying Decentralized Renewable Energy in the built environment is a good approach to reduce the CO₂ emissions. However this is not without restrictions towards the stability of the energy grid. Using the flexibility within energy generation, distribution infrastructure, renewable energy sources and the built environment is the ultimate sustainable strategy within the Built Environment. However, at the moment this flexibility on building level is still to be defined. The new IEA Annex 67 is just starting work to define this specific flexibility. Our research is aimed at developing, implementing and evaluating new integral process control strategies for improving the energy interaction within the building, its environment and the energy infrastructure by effectively incorporating the occupants' needs for health (ventilation) and comfort heating/cooling). A bottom-up approach, starting from the user up to the Smart Grid, offers new possibilities for buildings' energy flexibility. To make use of the dynamic possibilities offered by flexibility of new intelligent process control concepts are necessary. Multi Agent Systems in combination with Community/Neighborhood and Building Energy Management Systems could offer the required additional functionalities.

Keywords - energy flexibility; user; Smart Grid

1. Introduction

The electrical energy infrastructures form the back bone of modern society as energy is needed for nearly all necessary services [1]. The built environment is currently a major consumer of fossil energy with nearly 40% [2] but it also has huge potential to contribute to the supply and management of renewable energy. As concerns grow about the environmental cost and limited supply of fossil energy resources, so does the importance to society of carefully managing the energy resources available and of developing and implementing renewable energy sources such as wind turbines, geothermal heat pumps and photovoltaic systems. Traditionally top down organized energy supply in electricity and gas networks have to cope with decentralized renewable energy production. Energy consumption could be

predicted quite well on macro level, and large power plants pre-schedule their power generation based on this.

Coping with complex and unpredictable factors related to Decentralized Renewable Energy Source (DRES) and the grid requires a more flexible approach to process control that is increasingly bottom up rather than top down. As a result the influence of the building's design and its users' interactions becomes more important. Buildings, building services systems and energy infrastructure must be designed for more flexibility. It is widely recognized that increasing flexibility is key for the reliable operation of future power systems with very high penetration levels of DRES [4]. In general two kinds of flexibilities can be distinguished in energy infrastructures [1]:

- architectural, enables to modify configurations of the system to future uncertainty,
- operational, which allows energy modification of operating strategies without major changes.

Performance results for operation of thermal comfort systems in demand side flexibility modes (that is cooling air temperature set point reset mode and fixed cooling schedule mode) indicate that improvements are needed for both models in efforts towards unitary performance metrics that capture both demand side (buildings) and power network side (grid). Specifically, availability window concept energy delivery during power flexibility periods, ramp rates and ramp duration come out as important just like power flexibility potential. Clearly the energy demand characteristics of buildings, available from Building Energy Management Systems (BEMS), are very valuable information on flexibility for grid optimization. Smart control of energy consumption and generation inside (nanoGrid) and around buildings (microGrid) can provide major flexibility contributions to address the imminent energy problems within the total energy infrastructure, the Smart Grid (SG).

However, at the moment this building flexibility on building level is still to be defined. The new IEA Annex 67 has just started their work to define this specific building energy flexibility [2, 28]: its ability to manage energy demand and generation according to local climatic conditions, occupant needs and energy grid requirements. To cope with the total complexity a functional layered approach is proposed, see Fig. 1. The preliminary main project objectives of Annex 67 [28]: Development of common technology, a definition of energy flexibility in buildings and a classification method and investigation of user comfort, motivation and acceptance associated with the introduction of energy flexibility in buildings

There is a need to take a more holistic approach to system flexibility, which looks at the potential interactions between new and traditional sources of flexibility and how these sources are used by different parties [3]. New

integral approaches are needed to increase the buildings' flexibility towards the Smart Grid.

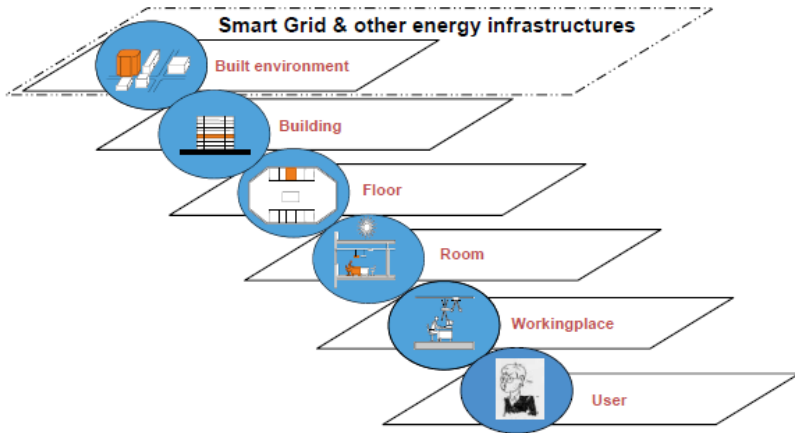


Fig. 1 IEA Annex 67 Energy Flexible Buildings proposed functional layered approach

2. Methodology

To optimize the energy infrastructure in the built environment, an integral approach based on general systems theory developed by von Bertalanffy [5] is proposed [6,7]. This system engineering like method uses functional decomposition and different levels of abstraction to cope with the complexity of the energy infrastructure of the built environment, see Fig. 2:

- built environment (possible energy supply from Smart Grid, big Renewable Energy Systems (RES))
- building level (possible energy supply from microGrid, nanoGrid, small RES, storage and other buildings),
- floor level (distribution of occupancy and the necessary energy flows)
- room level (energy need depends on outside environmental conditions and internal heat load),
- workplace level (workplace conditions and energy needs from appliances),
- user level (different comfort needs of individuals).

Applying the principles of system engineering to the optimization of the energy infrastructure of a building makes it possible to integrate in a flexible way the energy flows connected to heating, cooling, ventilation, lighting, and power demand, within a building and between buildings and the built environment. This leads to flexibility of energy exchange between different energy requirements and sustainable energy supply on the different levels of abstraction in the built environment. Traditionally the energy approach towards the built environment is top-down (centralized energy

generation/distribution through the Smart Grid). We want to use instead a middle-out (control on building level by the BEMS as well as a bottom-up approach (demand driven by the human needs for energy/comfort), see Fig. 2. Energy infrastructure’s functionalities boil down to energy management making use of the flexibilities of all grid-connected systems which will lead to a better balanced and controlled network at all levels [8-11]. The energy demand characteristics of buildings available in BEMS represent crucial information for grid optimization [12] to activate participation of buildings in the grid. For an optimal SG from a system of systems point of view, the BEMS has to be coupled with the management platform of the grid [9], this can be done by combining different BEMS to Neighborhood Energy Management Systems (NEMS), which supervise the individual BEMS, see Fig. 2.

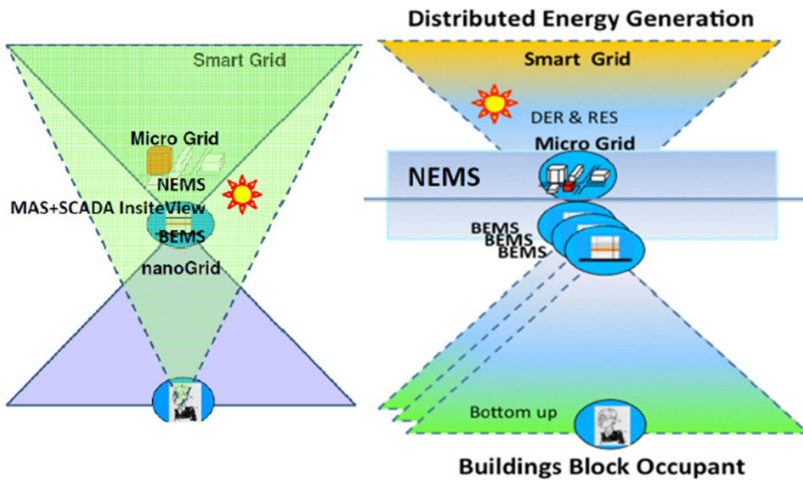


Fig. 2 Change from top-down towards bottom-up approach and coupling individual buildings to the grid by combining BEMS to NEMS

3. Multi-agents system (MAS)

The concept of intelligent agent technology is at an intriguing stage in its development as commercial strength agent applications are increasingly being developed in domains as diverse as manufacturing, defense systems as well as in the operation and management of the smart grid [13,14]. In artificial intelligence, agents are physical or virtual entities that intelligently interact in an environment by both perceiving and affecting it. Consequently, an agent can be described as a computational system with a high degree of autonomy performing actions based on the information received from the environment. Within a MAS, agents interact to achieve cooperative (e.g.

distributed problem solving) or competitive (e.g. coalition formation, auction) group behavior. Agents achieve this by sharing a minimum amount of information between modules and asynchronous operation implemented via message exchanges. The agent paradigm promotes the use of independent, loosely coupled software entities that encapsulate some specific functionality and interaction with each other to solve tasks [15].

The proposed framework is based on the MAS paradigm due to its easier manageability, distributed and robust properties. As depicted in table 1, distinct levels of hierarchy that include the user, room, zone, building, neighborhood aggregators, low voltage aggregators, medium voltage aggregators, Distribution Service Operator (DSO) and Transmission Service Operator (TSO) are notable.

As the primary goal is to ensure occupants' comfort is not compromised in the process of attaining the maximum possible peak-load reduction for use in DR, information on building occupancy as depicted in figure 2 is obtained using embedded chair sensors [16]. The availability and use of fine-grained building occupancy information in addition to contributing towards improving the energy performance of buildings through demand driven control, can also contribute towards improvement of building responsiveness to DR.

Table 1 Hierarchical Levels in Distributed Approach

Actor/Hierarchy Level	Role
User	Registers comprehensive user preference, associated comfort and energy profile.
Room	Aggregate comfort and energy profile inside the room.
Zone	Aggregate comfort and energy profile for all spaces associated with a zone.
Building	Aggregate energy use and available power flexibility for the whole building dynamically.
Neighborhood Aggregators	Dynamically aggregates available power flexibility for buildings in a neighborhood.
Low Voltage Aggregators	Dynamically aggregates available power flexibility for a number of neighborhoods at low voltage level of the network.
Medium Voltage Aggregators	Dynamically aggregates available power flexibility of connections at medium voltage level of the network.
DSO	Ensure network reliability and integrity of the power distribution network.
TSO	1. Operates & manage market 2. Ensures network reliability & integrity power transmission network.

Leveraging on the distributed but cooperative properties of MAS, the agent architecture of the Multi Agent platform as depicted in figure 3, is composed of the following agents: User, Room, Zone, Building, Services and Admin. The Multi Agent platform is an execution environment for agents. It supplies the agents with various functionalities such as agent intercommunication, autonomy and mobility [22]. The agents are designed

using an open source web-based and fully decentralized agent design platform called EVE [23], which promotes Data Mining (DM) process and Fault Detection (FD). The concept is presented in Fig. 3.

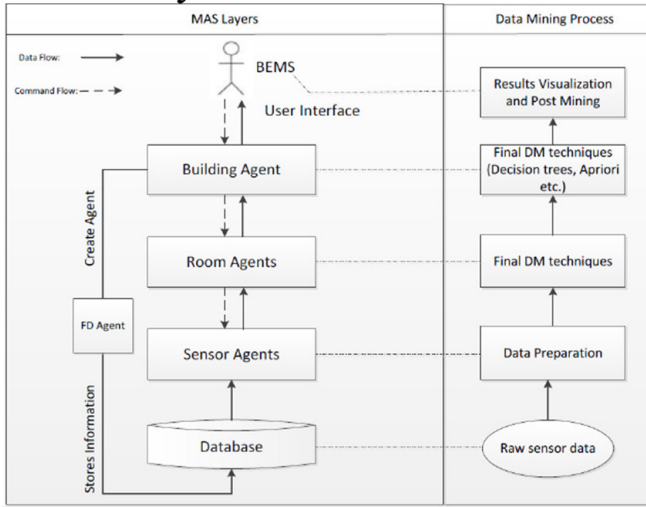


Fig. 3 Concept of the multi agent design platform for implementation

The Multi Agent platform consists of the following agents:

User Agent: represents each room occupant. It communicates with its environment via the installed sensors to ensure information on building occupancy and individual user preferences are readily available.

Room-agent: is critical for striking a balance between user comfort and energy efficiency, as this is where both goals have contradictory requirements [17]. In addition, the orientation, occupancy use pattern, appliance and equipment type as well as room function are contributory factors that determine the amount of flexibility available for participation in a Demand Response (DR) event. A utility function and the Available Service Table (AST) are introduced at the room level and used in describing the appropriate trade-off in situations where there are conflicting goals (e.g. comfort versus energy consumption). [18]. AST is a concept derived from networking protocols [19] and information push strategy [20].

Zone-agent: is an aggregator as identified earlier in table 1. It computes the sum of services available for its zone using the information provided by the room agents in the zone.

Building agent: is the contact point between the grid and the building. The building agent receives a Demand Respond request from the grid and responds appropriately to such request. In most typical MAS coordinated DR events [21], the building agent is often responsible for making decisions on both comfort and a building's participation in a DR event. However,

within this framework, the building agent is mainly tasked with negotiating a building's participation using available information in the AST.

Services agent: introduces more task distribution in the agent structure. As it is with daily human interaction where specialized tasks are often assigned to specialists, the services agent offers specialized services to the agents within the system. Such as a data mining function which could be utilized by any of the agents in the system.

Admin agent: monitors all agents (active, passive, dead or alive) operating in the system. MAS design paradigm provides a flexible framework in which agents can be included and removed at any time without causing disruption in the systems operation. It is however necessary to have up-to-date information about the state of agents operating in the system and their response to the requestor response of the Grid-side agent, see Fig. 4.

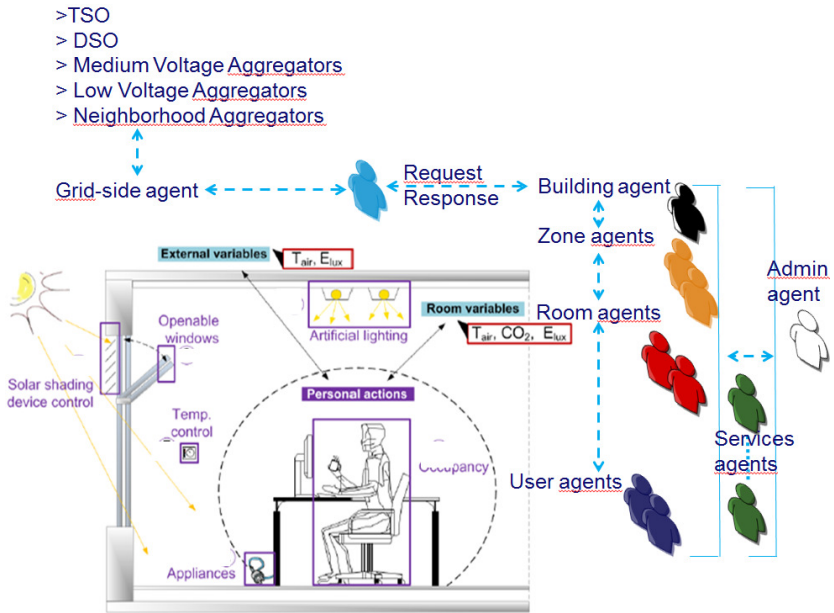


Fig. 4. Multi Agent System Structure and the functional layers

4. Resulting concept

There is a different focus on the processes that occur in a building, which also depends on the strategy that is leading: bottom-up (user orientated), middle out (building services systems orientated) and top-down (Smart Grid). A top-down approach gives mainly the boundaries for energy consumption [24]. The bottom-up approach is able to estimate the individual

energy consumption and then aggregate it to predict the total building energy demand, based on end-user's behaviors in time and space. This enables to gain from upside flexibility opportunities and minimize downside risks [1, 25]. The framework of Kofler et al. [15] and Kolokotsa et al. [26] was adapted with a central role for BEMS/NEMS and MAS, see Fig. 5.

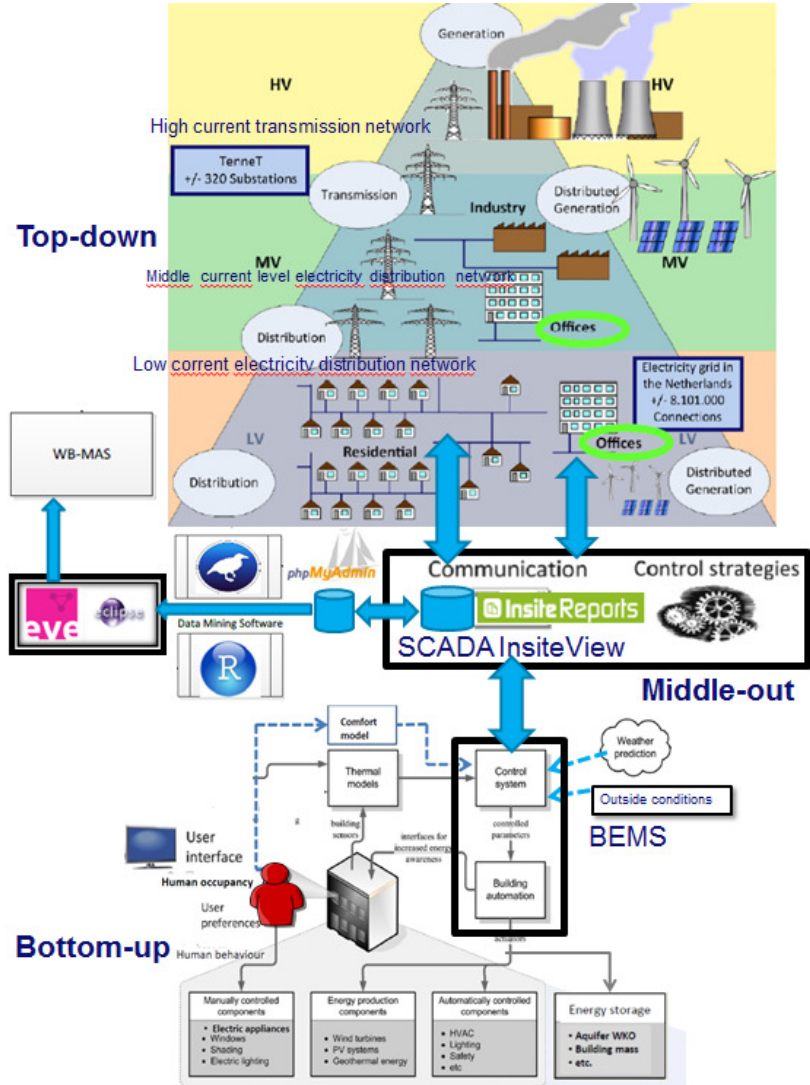


Fig. 5 SG and User Interaction, based on Kolokotsa et al. [26] and Kofler et al [15]

5. Discussion and conclusion

Breakthroughs need to be realized in the field of flexibility necessary for demand and distribution process control of heat, cold and electricity. The responsiveness of Smart Grid to changing uncertainties & requirements can be partly realized through the intrinsic flexibility measures embedded in energy infrastructures of buildings. With the advent of distributed and dispersed loads in the grid, a top-down approach is no longer feasible and has to be replaced by a more distributed approach. In the EU-FP7 DREAM project [27], a more heterarchical approach to coordination and control is investigated. Agent based techniques are used to coordinate demand and supply for increasing the embedding capacity of dispersed, badly predictable, renewable energy based power systems, see Fig.6.

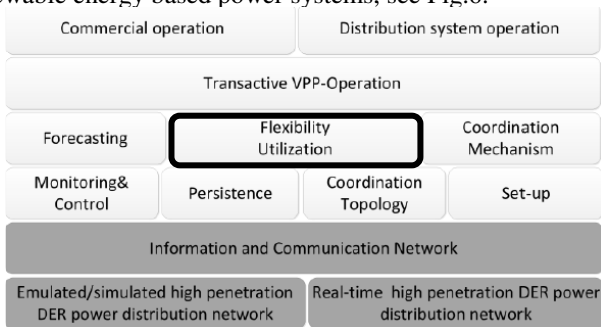


Fig. 6 Heterarchical approach of the EU-FP7 DREAM project [27]

Compared to this approach, our system engineering approach also gives the opportunity to systematically integrate operational flexibility as a virtual power plant within the energy infrastructures of the built environment. The derived hierarchical framework aims at providing support for integrating flexibility of the infrastructure systems to build MAS structures based on it. Next step is to define Neighborhood Energy Management systems as a virtual coupling with the BEMSs and the SCADA systems of the Grid operators.

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