BUILDINGS' ENERGY FLEXIBILITY: STARTING FROM THE USER TO SUPPORT THE SMART GRID

Wim Zeiler; Kennedy Aduda

Faculty of the Built Environment, TU Eindhoven, Eindhoven, Netherlands

ABSTRACT

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 process control strategies for improving the energy interaction within the building, its environment and the energy infrastructure by effectively incorporating the occupants' behaviour. An integral approach based on the Open Building strategy is used which divides the whole system in different layers from user up to centralized power generation and as a results offers new possibilities for buildings' energy flexibility towards the Smart Grid.

Keywords: energy flexibility, user, Smart Grid

INTRODUCTION

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. The built environment is the most complex distributed technical system with its energy infrastructures for electricity, gas, heat- and cold on utility level as well as all the ducts, pipes and cables within the buildings. 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 alternative renewable energy sources. As the future cannot be predicted there is a need for flexibility of the energy infrastructure. The current electricity system already uses many sources of flexibility to run efficiently such as: demand-side response, energy storage, distributed generation, demand change, time-shifting demand, embedded generation, fuel substitution, and efficiency schemes. However, new sources of flexibility are likely to be required to deal with the changing operation of the system. 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]. This paper presents an integral approach to optimize the flexible interaction between buildings, renewable energy sources and their energy infrastructure, especially the Smart Grid.

THE GRID

Electricity is traditionally generated in large central plants and distributed throughout the country. However, the last decades have seen the beginning of some change in this trend. More and more decentralized electricity production is now achieved using wind turbines, geothermal heat pumps and photovoltaic systems. Smart adaptive control of energy consumption and generation inside (nano Grid) and around buildings (micro Grid) can provide major contributions to address the imminent energy problems within the total energy infrastructure (Electricity as well as the Gas distribution). The stochastic nature of renewable production has a negative impact on system balancing. Further changes of the whole distribution system are expected from a strictly top down to a more bottom-up system; this will be capped by ability of the user to supply electricity to the distribution grid on different levels. Coping with complex and unpredictable factors related to DRES and the Grid requires a more flexible approach in the design process 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]. To model flexibility in energy systems there are several approaches: using heuristics, sector-specific highly detailed models or combining models [5]. However, currently available models do not seem to be able of capturing flexibility issues properly. New holistic approaches are needed in energy system modelling [5]. Besides the flexibility in energy systems there is also the flexibility in the demand: the energy flexibility of a building. This energy flexibility of a building is not yet defined but a working definition of the IEA Annex 67 Energy Flexible Buildings is its ability to manage energy demand and generation according to local climatic conditions, occupant needs and energy grid requirements [2]. New integral approaches are needed to increase buildings' flexibility towards the Smart Grid.

METHOD

In facing uncertainty in design, common practice in systems engineering is to optimize a system that satisfies a given set of parameters. Such an optimized solution is rigid and will not perform well when uncertainty is high [1]. This calls for a new approach that design systems can be easily changed to adapt and adjust to changing conditions. Flexibility in design is needed to cope with the effects of uncertainty [1,6]. To optimize the energy infrastructure in the built environment, an integral approach based on general systems theory developed by von Bertalanffy [7] is proposed [8,9]. 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. 1:

- building level (possible energy supply from micro Grid, nano Grid and RES),
- 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), and
- human level (different comfort needs of individuals).

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 Building Energy Management Systems BEMS) as well as a bottom-up approach (demand driven by the human behaviour).

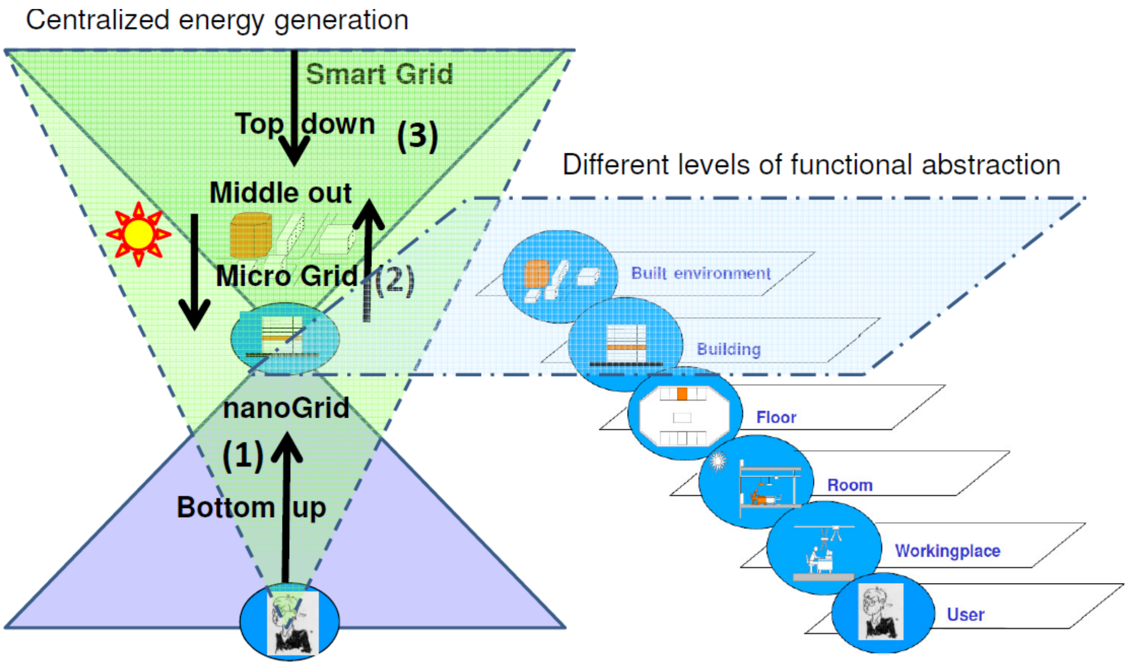

Figure 1. Representation of the approaches for optimizing building interaction with the Smart Grid, complementary to the traditional top-down approach.

The open building concept developed by Habraken [10] approached the built environment as a constantly changing product caused by human activity, with the central features of the environment resulting from decisions made at various levels which is also typically the case with the energy infrastructure of the built environment. During the design process participants and their decisions were structured at several levels of decision-making the infill-level; the support-level; and the tissue-level. On each level a balance has to be made between the performances of supply and demand for buildings during the life-cycle. The levels of city structure, urban tissue, support, space and infill were usually distinguished. Open Building lends formal structure to traditionally and inherent levels of environmental decision making [11,12]. The principal tool used by those working in an open building way is the organization of the process of designing and building on environmental levels. Open building entailed the idea that the need for change at a lower level such as the dwelling, emerged faster than at upper levels, such as the support. The "thinking in levels" approach of Open Building was introduced to improve the design and decision making process by structuring them at different levels of abstraction. Different decisions have to be taken at each level in the energy infrastructure of the built environment. One of those decisions is the application of sustainable energy systems and components. However, this is rather complex to integrate in the early stages of building design as many aspects still have to be taken into account. Applying the principles of Open Building design 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. There is a close similarity between the highly abstract approach of Integral Design with the hierarchical abstraction used within Open Building, see Fig. 2.

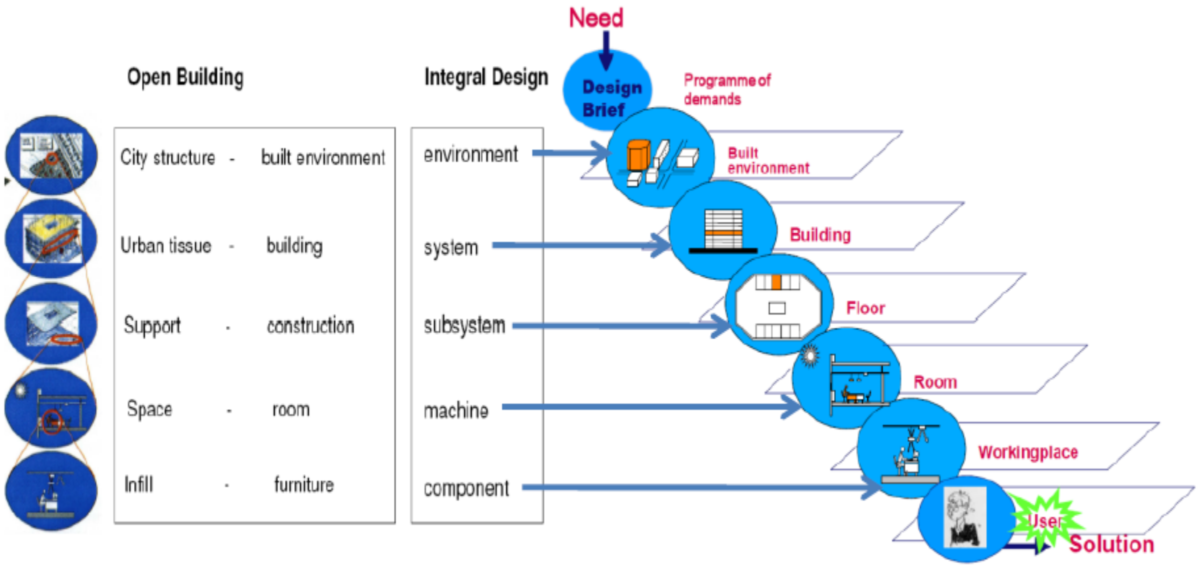

Figure 2. Comparison hierarchical abstraction Open Building and Integral Design approach.

RESULTS

There is a different focus on the processes that occur in the 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). As mentioned by Bloem and Strachan [13] a top-down approach gives mainly the boundaries for energy consumption related to occupancy behaviour. The bottom-up approach is able to estimate the individual energy consumption and then aggregate it to predict the total building energy demand, which is highly desirable despite the uncertainties in end-user's behaviours in time and space.

Based on each of these approaches the results and insights are used to specify specific functionalities for the level below and the level above. In this way flexibility enables the developers to gain from upside opportunities and minimize downside risks [1,6]. Taking cue from the required dynamism and flexible operations, we adapt the framework of Kofler et al. [14] as ideal for realization of the pervasive control envisioned by Kolokotsa et al.[151] with a central role for Building Automation (BEMS) and Multi Agent System (MAS), see Fig. 3.
In general two kinds of flexibilities can be distinguished in energy infrastructures [1];
- architectural, enables with relative ease to modify configurations or layouts of the system to future uncertainty
- operational, which allows energy modification of operating strategies without major changes.

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 [16-19]. The energy demand characteristics of buildings available in Building Automation Systems represent crucial information for grid optimisation [20] 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 [17

DISCUSSION AND CONCLUSION

The responsiveness of SG to changing uncertainties & requirements can be realized through the intrinsic flexibility measures embedded in energy infrastructures design processes. A methodological design framework based on a unified theoretical system engineering concept related to Open Building gives the designers the opportunity to systematically integrate architectural and operational flexibility early on in the conceptual design phase of energy infrastructures of the built environment. This hierarchical design framework aims at providing support for integrating flexibility at the early stage of the conceptual designs of infrastructure systems. The manner of description of a system influences the identification of the possible changes that may take place and the interpretation of their demands for flexibility. In this paper the focus was on operational flexibility for which the integration of the end-user through a bottom-up approach is essential for BEMS.

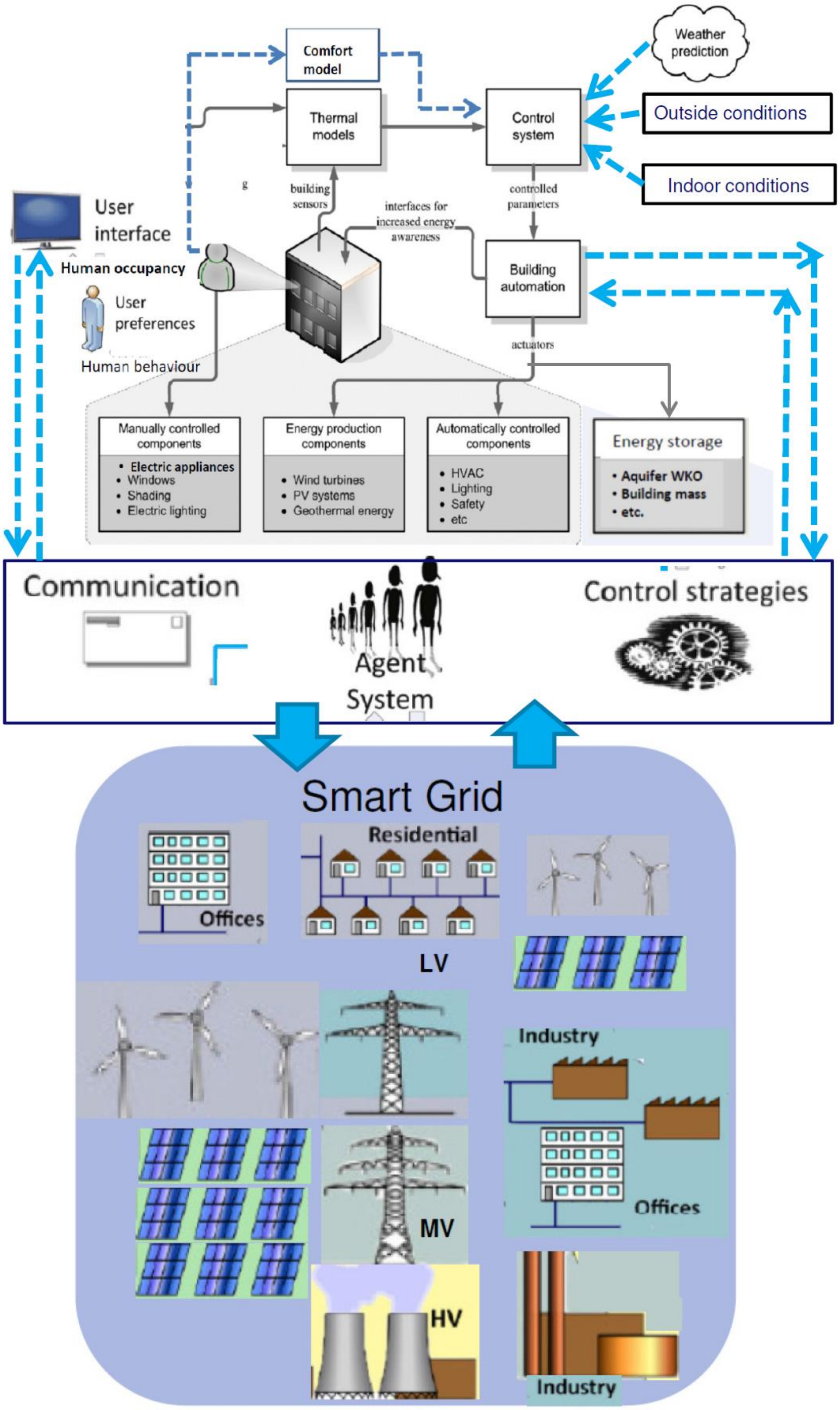

Figure 3. SG and User Interaction, based on Kolokotsa et al. [15] and Kofler et al[14]

REFERENCES

1.Melese Y.G., Heijnen P.W., Stikkelman R.M., 2014, Designing Networked Energy Infrastructure with Architectural Flexibility, Procedia Computer Science 28: 179-186.

2. IEA 2015, International Energy Agency, Energy in Buildings and Communities programme, EBC Annual Report 2014

3. Frerk M., 2015, Open letter: facilitating efficient use of flexibility sources in the GB electricity system, OFGEM, The Office of Gas and Electricity Markets, 28 January 2015

4. Papaefthymiou G., Grave K., Dragoon K., 2014, Flexibility options in electricity systems, Project number: POWDE14426, Ecofys 2014 by order of: European Copper Institute

5. Hidalgo Gonzalez I., Pablo Ruiz Castello P., Sgobbi A., Nijs W., Quolin S., Zucker A., Thiel C., 2015, Addressing flexibility in energy system models, European Commission Joint Research Centre, Institute for Energy and Transport, Report EUR 27183 EN

6. Neufville R.de, Scholtes S., 2011, Flexibility in Engineering Design, MIT Press, Cambridge, MA, USA

7. Blanchard B.S., Fabrycky W.J., 2005, Systems Engineering and Analysis, fourth Edition

8. Savanović P., 2009, Integral design method in the context of sustainable building design, PhD thesis, Technische Universiteit Eindhoven.

9. Zeiler W., Savanović P., 2009, General Systems Theory based Integral Design Method, Proceedings ICED'09, Stanford, USA.

10. Habraken N.J., 1961, De dragers en de mensen, Haarlem (Dutch)

11. Kendall S., Open Building Concepts, CIB W104,www.open-building.org/ob/concepts.html

12. Kendall S., Teicher, J., 2000, Residential Open Building, E & FN SPON, London

13. Bloem J.J.,Strachan P., 2012, Evaluating and Modelling Near-Zero Energy Buildings; Are we ready for 2018?, Expert Meeting 30-31 January 2012 Glasgow, JRC Technical report

14. Kofler M.J., Reinisch C., Kastner W., 2012, A semantic representation of energy-related information in future smart homes, Energy and Buildings 47:169-79.

15. Kolokotsa D, Rovas D, Kosmatopoulos E, Kalaitzakis K., 2011, A roadmap towards intelligent net zero- and positive-energy buildings. Solar Energy 85: 3067–3084

16. Lo C., Ansari N., 2011, The Progressive Smart Grid System from Both Power and Communications Aspects, Communications Surveys & Tutorials, IEEE PP(99): 1-23.

17. Dave S., Sooriyabandara M., Yearworth M., 2011, A Systems Approach to the Smart Grid, The First International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies.

18. Lopes A. J., Lezama R., Pineda R., 2011, Model Based Systems Engineering for Smart Grids as Systems of Systems, Procedia Computer Science 6: 441-450.

19. Acevedo S., Molinas M., 2012, Identifying Unstable Region of Operation in a Micro-grid System, Energy Procedia 20: 237-246.

20. Wang S., 2013, Intelligent Building Electricity Demand Management and Interactions with Smart Grid, Proceedings Clima 2013, Prague