



International Journal of **Design Sciences & Technology**

Volume 22 Number 2

Zeiler W Aduda K and Thomassen T (2016) Integral BEMS controlled LVPP in the smart grid: An approach to a complex distributed system of the built environment for sustainability, *International Journal of Design Sciences and Technology*, 22:2 81-108

Editor-in-Chief:
Edwin Dado
Khalidoun Zreik

Editors:
Reza Beheshti
Daniel Estevez
Mithra Zahedi

Guest Editors:
Regine Vroom
Imre Horváth

ISSN 1630 - 7267

europia

ISSN 1630 - 7267

© europa Productions, 2016

15, avenue de Ségur,

75007 Paris, France.

Tel (Fr) 01 45 51 26 07 - (Int.) +33 1 45 51 26 07

Fax (Fr) 01 45 51 26 32- (Int.) +33 1 45 51 26 32

E-mail: ijdst@europa.org

<http://www.europa.org/ijdst>

International Journal of
Design Sciences and Technology

Volume 22 Number 2

ISSN 1630 - 7267



- Editor-in-Chief:** **Reza Beheshti**, Design Research Foundation, Netherlands
Khaldoun Zreik, University of Paris 8, France
- Editors:** **Daniel Estevez**, Toulouse University, France
Edwin Dado, NLDA, Netherlands
Mithra Zahedi, University of Montreal, Canada
- Editorial Board:** **ACHTEN**, Henri (Czech Technical University, Prague, Czech Republic)
AMOR, Robert (University of Auckland, New Zealand)
AOUAD, Ghassan (Gulf University for Science and Technology, Kuwait)
BAX, Thijs (Eindhoven University of Technology, Netherlands)
BECUE, Vincent (Université de Mons, Belgium)
BEHESHTI, Reza (Design Research Foundation, Netherlands)
BONNARDEL, Nathalie (Université d'Aix Marseille, France)
BOUDON, Philippe (EAPLV, France)
BRANGIER, Eric (Université de Lorraine, France)
CARRARA, Gianfranco (Università di Roma La Sapienza, Italy)
DADO, Edwin (NLDA, Netherlands)
EDER, W. Ernst (Royal Military College, Canada)
ESTEVEZ, Daniel (Toulouse University, France)
FARINHA, Fátima (University of Algarve, Portugal)
FINDELI, Alain (Université de Nîmes, France)
GERO, John (George Mason University and University of North Carolina at Charlotte, USA)
GUENA, François (ARIAM-LAREA, ENSA de Paris la Villette, France)
HASSAN, Tarek (Loughborough University Of Technology, UK)
HENSEL, Michael (Oslo School of Architecture and Design, Norway)
HORVATH, Imre (Delft University of Technology, Netherlands)
KATRANUSCHKOV, Peter (Dresden University of Technology, Germany)
KAZI, Sami (VTT, Finland)
KHOSROSHAHI, Farzad (University of Leeds, UK)
KUILEN, Jan-Willem van de (Munich University of Technology, Germany)
LAUDATI, Patrizia (Université de Valenciennes et du Hainaut Cambrésis, France)
LECLERCQ, Pierre (University of Liège, Belgium)
LEEUWEN, Jos van (Haagse Hogeschool, The Netherlands)
MONTARAS, Lopez de Ramon (ILIIA, Spain)
NEWTON, Sid (University of New South Wales, Australia)
PAOLI, Giovanni de (Université de Montréal, Canada)
REBOLJ, Daniel (University of Maribor, Slovenia)
ROBERTSON, Alec (4D Design Futures Philosopher, UK)
RUITENBEEK, Martinus van de (Delft University of Technology, Netherlands)
SARIYILDIZ, Sevil (Delft University of Technology, Netherlands)
SCHERER, Raimar (Dresden University of Technology, Germany)
SCHMITT, Gerhard (ETH Zurich, Switzerland)
SCIAMMA, Dominique (Strate Collège, France)
SMITH, Ian (EPFL, Switzerland)
TROUSSE, Brigitte (INRIA – Sophia Antipolis, France)
TURK, Žiga (University of Ljubljana, Slovenia)
ZAHEDI, Mithra (University of Montreal, Canada)
ZARLI, Alan (CSTB, France)
ZREIK, Khaldoun (University of Paris 8, France)

Integral BEMS controlled LVPP in the smart grid: An approach to a complex distributed system of the built environment for sustainability

Wim Zeiler¹ Kennedy Aduda² and Tom Thomassen³

¹ Eindhoven University of Technology, Faculty of Architecture, Eindhoven, The Netherlands. Email: w.zeiler@tue.nl

² Eindhoven University of Technology, Faculty of Architecture, Eindhoven, The Netherlands. Email: k.o.aduda@tue.nl

³ Royal BAM Group, BAM Building and Technology, The Netherlands. Email: bouwentechniek@bam.nl

The Built Environment is the most complex distributed system with its energy networks. It has a huge impact on ecology and economy as it is responsible for nearly 40% of the total energy use and the related emissions. There is growing interest in the proliferation of smart grid technologies to enable the growth of renewable energy installations both on a distributed basis as well as at the utility scale. Renewable energy, like wind and solar power, are depending on the weather conditions. This causes fluctuations in supply which can lead to instability of the electricity grids. Therefore there is a need of flexibility on the demand side. Office buildings, which consume relatively more energy than residential buildings, are a potential source of energy flexibility which can be offered to the Smart Grid as a local virtual power plant (LVPP) to reduce uncertainty and optimize interaction with the Smart Grid. An integral framework for interactive process control is presented based on the combination of state-of-the-art process control Building Energy Management System (BEMS) and future support by multi-agent systems. The proposed LVPP-BEMS concept is tested and validated in an office building.

Keywords: smart-grid, Nano-grid, micro-grid, building energy management system, multi-agents

1 Introduction

The built environment could be seen as the most complex distributed system with its on utility level energy infrastructures for electricity, gas, heat- and cold, combined within the buildings with all the ducts, pipes and cables. The ecological impact of the built environment is big as in the U.S. and Europe the built environment accounts for nearly 40% of the total energy use [25, 31] and related emissions. As concerns grow about the environmental effects (global warming and weather extremes), so does the importance to society of developing and carefully implementing alternative energy sources. The built environment is critical for the ecological and economic sustainability of society. As a result the subject of energy has become increasingly contentious with current energy prices and the strict emissions targets for the future [20]. An overview of CO₂ emissions distribution from fossil fuels by end use sector given by the Pew Centre on Global Climate Change shows that the commercial buildings contribute 17% compared to 21% for the residential buildings (Figure 1) [29].

Offices have a relatively high energy consumption: offices use in total around 1420 MJ/m² compared to around 880 MJ/m² for households in the Netherlands (Figure 2a) [21]. In the Netherlands the office buildings use in total around 225 PJ/year, compared to around 370 PJ/year for households (Figure 2b) [98]. So overall the energy use of offices is around 60% of the total energy use of the households, so quite substantial. The energy consumption of office buildings are increasing slightly, see Figure 1.b, despite the 2020 targets set by the EU, which call for a 20% reduction in energy use by the year 2020 [28, 98]. Therefore methods are necessary to reduce the energy consumption of office buildings not only for the new built offices but especially for the existing buildings. Besides deep renovation of buildings there are also very

cost effective measures to reduce the energy consumption by optimizing the functioning of the Lighting, Heating, Ventilation and Air conditioning (LHVAC) system. The control have become more and more advanced and the process control systems evolved from Building Management Systems (BMS) towards Building Energy management Systems (BEMS). These BEMS offer different possibilities to monitor and optimize the LHVAC systems and thus reduce the energy consumption. The latest trend are model based control BEMS. Due to the highly non-linear and varied nature in local environments, statistical methods based on historical data and regression analysis are used to predict energy consumption. Making a precise energy model to predict the real building's energy use is difficult because of the assumptions and evaluations that have to be made during the modelling process [45]. Polynomial approximations with their non-linear mapping capability can partially address requirements of the bottom-up context. Recently, Computational Intelligence (CI) has been extensively investigated in many domains and is becoming a proven means for forecasting renewable energy production and energy consumption.

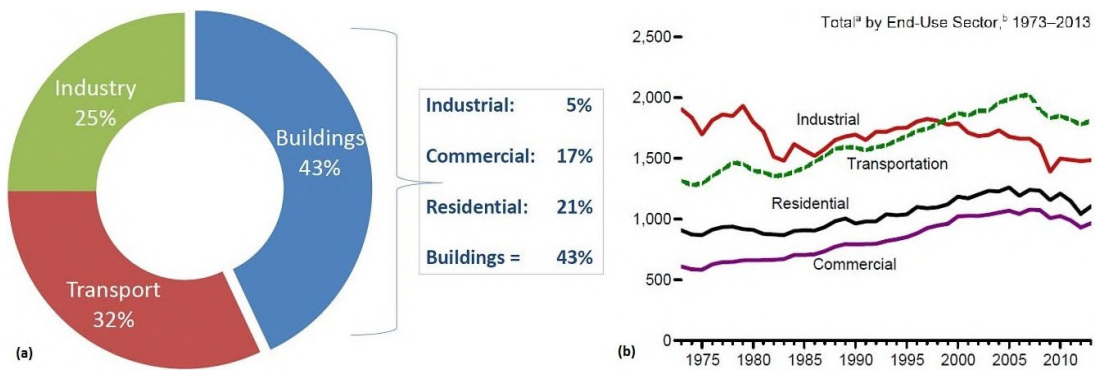


Figure 1 (a) CO2 emissions distribution from fossil fuels by end use sector, excluding emissions from biomass energy consumption. (b) Carbon Dioxide Emissions From Energy Consumption by Sector (Million Metric Tons of Carbon Dioxide). Emissions from energy consumption in the electric power sector are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales [29].

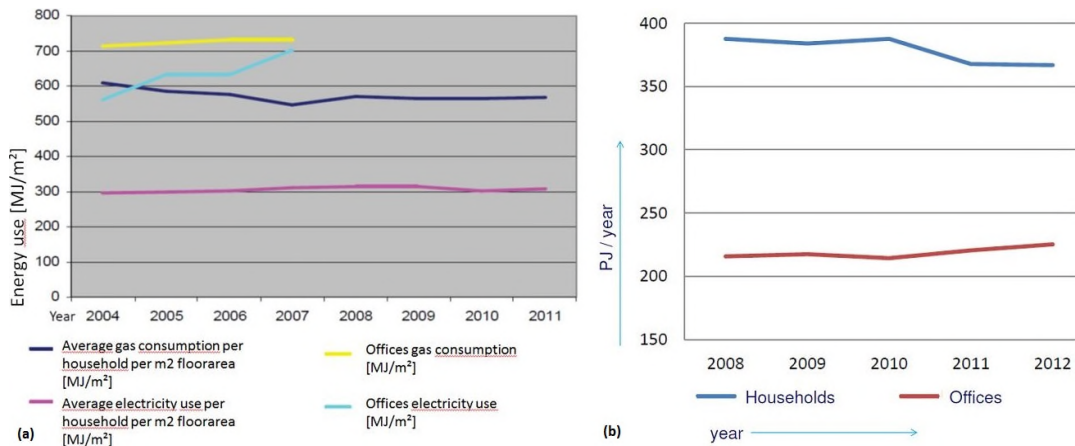


Figure 2 (a) The average energy use per m² for offices and for households between 2004-2010 [21]. (b) The total energy use for offices and for households [98]

Due to the complexity of the problem a large number of approaches have been proposed [126]: Engineering methods; Statistical methods; Neural networks; Support vector machine and Grey models [112]. Artificial Neural Network (ANN) is a popular CI technique, which is able to map any non-linear function. A properly trained ANN-based short-term forecasting tool is able to achieve very accurate approximations of the mapping of stochastic data. Learning techniques of CI can enrich local information that is highly uncertain due to end-user's behaviours and stochastic due to increasing on-site RES and DER units [3, 114]. Use of each model to predict the building's energy use has its advantages and disadvantages, therefore it is difficult to say which to apply it depends on the specific circumstances [126].

Electricity is traditionally generated in large central plants and distributed throughout the country. However, the last decades has 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. Further changes of the whole distribution system is slowly expected from a strictly top down one 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 (Figure 3).

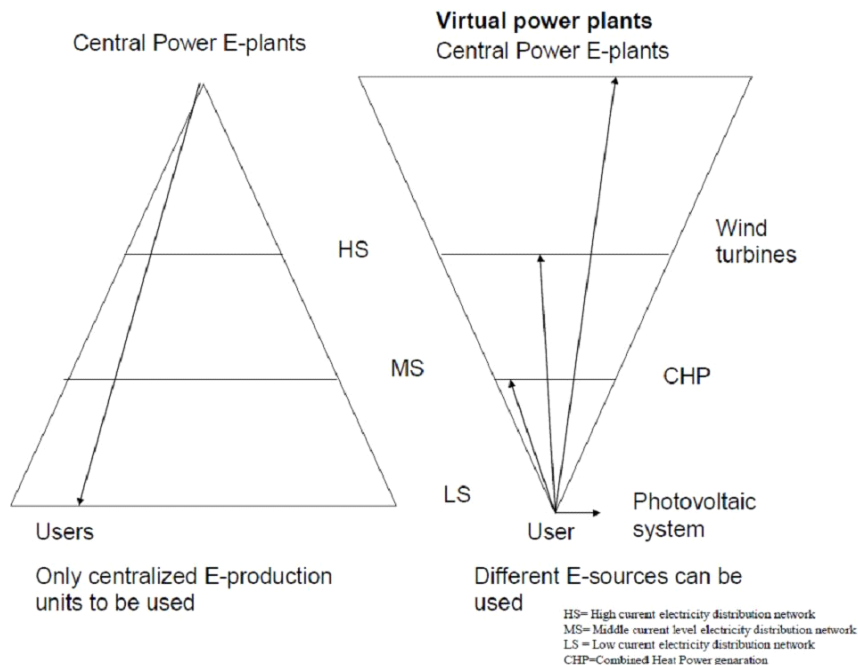


Figure 3 Change from a top-down electricity supply grid to a system with bottom-up supply possibilities

The built environment is currently a major consumer of fossil energy, but it also has huge potential to contribute to the supply and management of renewable energy. Large-scale integration of Renewable Energy Sources (RES), being widely dispersed and of a highly stochastic nature, challenges the current power system in balancing power supply and demand at all times. The stochastic nature of renewable production and its negative impact on system balancing is depicted in Figure 4 [108].

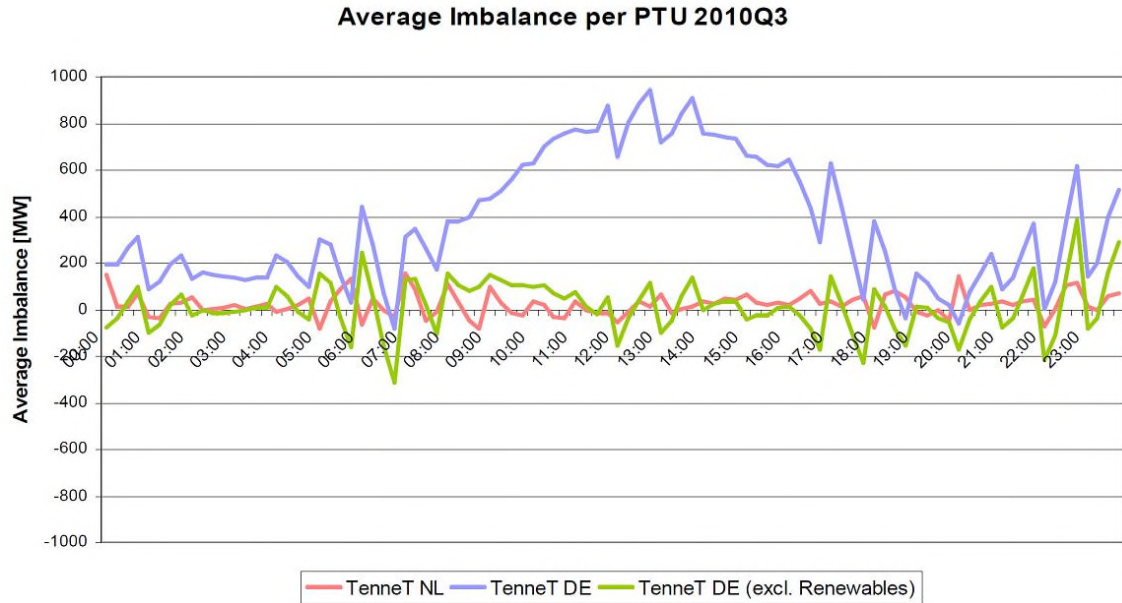


Figure 4 Impact of renewable production on the average imbalance [108]

Fluctuations of demand as well as in the supply of RES might result in instability of the supply system in specific situations of electricity production, as the electrical grid has essentially no storage [76]. Current grid management is facilitated by increasing or decreasing power generation based on behaviour of the power demand. With the expected increase of renewable generated energy in the total generated energy mix, which has stochastic behaviour, the management of the grid will possibly change in future. The local generated energy may be used to correct the mismatch between demand and supply resulting in the desired increase of buffer capacity [99]. Mostly in the situation of heat, this is less of a problem compared to the electrical energy generated. In most cases the surplus in electrical generated energy is fed back to the grid. This development introduces a new challenge for the grid, namely, possible changing energy flow direction at lower grid levels due to the feed in of renewable generated electrical energy [103].

Slotweg [103] predict increase of active loads, which can participate in the energy management and possibly react on grid requests or economic stimulations. For example: micro Combined Heat and Power (μ CHP), Electrical-Vehicles, Heat Pumps, and others, compared to the passive loads connected to the grid can be a solution for futures grid management. Active loads can request or in some cases even deliver energy to the grid and schedule their demand or even change their characteristics online. In order to stimulate their use an active load has to result in an economic compensation. A classic example of economic stimulation is the double tariff structure (off peak versus peak), evoking households to shift their energy use to economic stimulated period which is the most convenient period for the grid.

The mix of connected active and passive loads will keep changing in future just like the mix of electricity generators. The Smart Grid (SG) is suggested to be the solution to all of these possible challenges managing electrical energy production, distribution, buffering, and consumption matching supply and demand making

use of the available system flexibilities [103]. A Smart Grid is a representation of an ensemble of solutions to the challenges faced by energy supply and demand. Grids management, control, voltage management, power quality, and the need to modify the system security will change due to all mentioned developments. New policies and contracting with flexible tariff structures are possibilities which are being investigated [107]. One of the approaches to achieve 'smartness' is improving the demand-side management of energy.

The SG incorporates current physical electrical grid infrastructure integrated with Information and Communications Technology (ICT) in grid components, and a communication network to enable energy management [115]. The real 'Smartness' of the SG can be described as the integration of multiple functionalities to guarantee properties such as reliability, availability, stability, controllability, and security, whilst also realising overall system optimisation. Functionalities boil down to energy management making use of the flexibilities of all grid connected which will lead to a better balanced and controlled network at all levels [1, 23, 74, 75].

Research by Slootweg [103] and Hommelberg [46] indicate that the participation of the end users in grid management makes it necessary to look detailed at the possible flexibility of the energy source and energy use [67]. This makes designing of and the controlling of necessary energy infrastructures more complex. It requires a more flexible approach in the design process of energy infrastructures that is increasingly bottom up rather than top down, see Figure 3, as the building's energy demands becomes more important.

To reduce the energy demand of the built environment new design strategies are employed to strive towards net Zero Energy or nearly Zero Energy buildings. However, analysis of the nearly 400 projects uploaded to the CarbonBuzz database [57] demonstrates that, on average, most buildings consume 1.5 and 2.5 times more energy than that of the declared design stage calculations. In the case of offices this anomaly largely arises from increased electrical energy use [57]. The number of occupants, the type of activities and their general behaviour in buildings have a significant effect on energy consumption [86]. Various authors and researcher have through simulations [69, 85] and field experiments [2, 26] demonstrated the energy saving potentials of tracking and localizing occupants in thermal zones within commercial office buildings. Li et al [69] demonstrated that energy can be improved if Building Services systems, LHVAC, are operated by BEMS using actual building occupancy information. However building occupancy is stochastic and difficult to simply determine solely based on building function and type. There are high tendencies for a buildings usage to change with time and as a result occupants might over time display varying patterns of presence [78].

Buildings, building services systems and energy infrastructure must be designed so that uses of the building other than those intended by occupants should not result in great variations of the energy consumption or indoor environmental conditions. Also fluctuations in the supply of renewable energy should be dampened by a flexibility of the energy demand. To achieve all this the international state-of-the-art of building design should include the following specific aspects:

- 1 Optimizing energy management of a building by using decentralized energy storage possibilities within an intelligent building. These energy storage possibilities will be based on energetic behaviour of the building and the individual behaviour of occupants, and will be controlled by a multi-agents system
- 2 Using decentralized energy storage and energy supply control of the energy infrastructure within a building (Nano-Grid) and the energy infrastructure around the building (micro-Grid)

3 Enabling extended management on Nano-Grid level and micro Grid level

4 Developing functional process software modules to be tested on an open source multi-agent platform of the Process Control system concept as functional modules for Building Energy Management System for optimal use of energy storage

This paper presents an integral approach to optimize the interaction between buildings and their energy infrastructure. Especially is the focus on the consequences for the Smart Grid. It gives a theoretical framework and uses a test-case building to give more depth insight by testing and validation of the proposed approach. New integral approaches are needed to not only reduce the energy demand of existing buildings in the built environment but also increase the flexibility of energy producing buildings towards the Smart Grid.

2 Methodology

2.1 System approach: Integral approach and Open Building concept

With the increasing complexity of technical systems a unified principle for the study of complex systems became necessary. General systems theory [14] conceived by Ludwig von Bertalanffy in the 1940s provided a systematic framework for describing general relationships in the natural and the human-made world. Bertalanffy [11] saw it as a theoretical and methodological program, aimed at seeking principles common to systems in general that may allow scientists and researchers to think more clearly about the goals of any possible system and about the methods for reaching them. General systems theory is useful for conceptualizing phenomena which did not lend themselves to explanation by mechanistic reductionism of classic science. One approach to a supportive orderly framework is the structuring of a hierarchy of levels of complexity for basic elements in the various fields of inquiry. A hierarchy of levels can lead to a systematic approach to systems that has broad application and was formulated by Boulding [16].

To optimize the energy infrastructure in the built environment, an integral approach based on the general systems theory developed by von Bertalanffy is proposed [100, 121]. This method uses hierarchical functional decomposition and division into different levels of abstraction to cope with the complexity of the energy infrastructure of the built environment and its different functions:

- built environment (energy distribution networks on utility level)
- building level (possible energy supply from micro-Grid, Nano-Grid and RES)
- floor level (energy distribution throughout the whole building)
- room level (energy need depends on outside environmental conditions and external heat load, focus on the energy exchange at the facade)
- workplace level (workplace conditions, internal heat load and energy needs from appliances)
- user level (different thermal comfort and indoor air quality needs of individuals [7, 47, 51])

The decomposition of built environment is done based on functionality needed for each level. This is carried out hierarchically so that the energy infrastructure structure of the built environment is partitioned into sets of interrelated functions of manageable sized subsystems. For example the Smart Grid on the built environment level, the micro-Grid on building level and the Nano-Grid on floor or room level. The integral design approach with its functional hierarchical decomposition to cope with complexity and necessary flexibility is similar to the open building concept developed by Habraken [40]. Which 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. This is also typically the case with the energy

infrastructure of the built environment 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 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. During the life cycle of the built environment stakeholders make decisions which consequently (re)structure several levels of the energy infrastructure: the support-level (Smart Grid/city structure); the infill-level (Nano-Grid /neighbourhood); and the tissue-level (Nano-Grid/ building). On each level a balance has to be made between the performances of supply and demand of energy for buildings. Open Building lends formal structure to traditionally and inherent levels of environmental decision making (Figure 5) [55]. The principle tool used by those working in an open building way is the organization of the process of designing and building on environmental or functional levels.

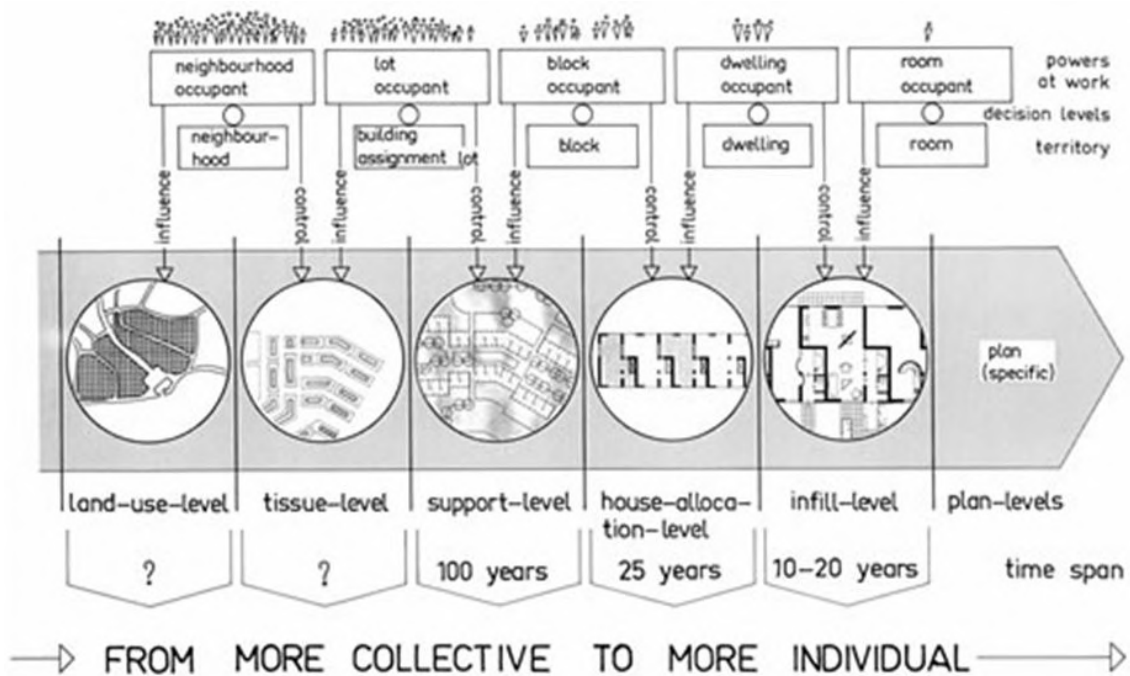


Figure 5 Decision-Making Levels in Open Building Diagram by Age van Randen [54]

The Living Building Concept (LBC) by de Ridder [95] proposes the change from demand-driven supply to supply-driven demand. The term ‘living’ refers to the life cycle approach which is incorporated in this concept and is often referred to as ‘Darwinism’: the structure of buildings is the same every project, but by changing one element per iteration, the effect of a certain development can be evaluated and the building will evolve over time.

The consequence of LBC is that the role of the designer is reduced to an integrator whose task is to fit the

offered solution systems of the producers to the asked functions by making new and surprising combinations / optimizations [95, 96]. LEGOlization is the strategy to implement the LBC [94]. Based on the client situation specific buildings are created with the use of standardized and industrially manufactured elements. These are the “LEGO”-blocks. High potential for the development of these blocks is seen in ICT-integration BIM (Building Information Model) approach. The strategy of LEGOlization resulted in a tool meant for the optimal technical assembly of buildings anticipating on cyclic processes of change during the live time of a building [94].

Another approach is the ‘smart building’ approach by Lichtenberg [72, 73], basic ideas based on the translation of ‘slimbouwen’ which in Dutch means both ‘smart’ and ‘slim’ building. The ‘smart building’ approach is based on construction processes that dictate separation of building services (energy infrastructure) from the building structure. The essence of this approach is to take care that building services can be mounted and removed from the building without interfering with other construction disciplines. This way the sequential construction process with a limited number of sub-activities can be reached, instead of a traditional parallel construction process characterized by a high rate of interdependent activities. It is interesting to note a difference between design and construction processes. Where during design efforts are focused on changing the sequential nature of design activities in current practice, at ‘smart building’ one encounters just the opposite in case of construction. Although the ‘smart building’ approach mainly concerns building construction, the type of design solution is largely predetermined: industrial, flexible and reusable (slim) modulated structures where building services are separated from building structure.

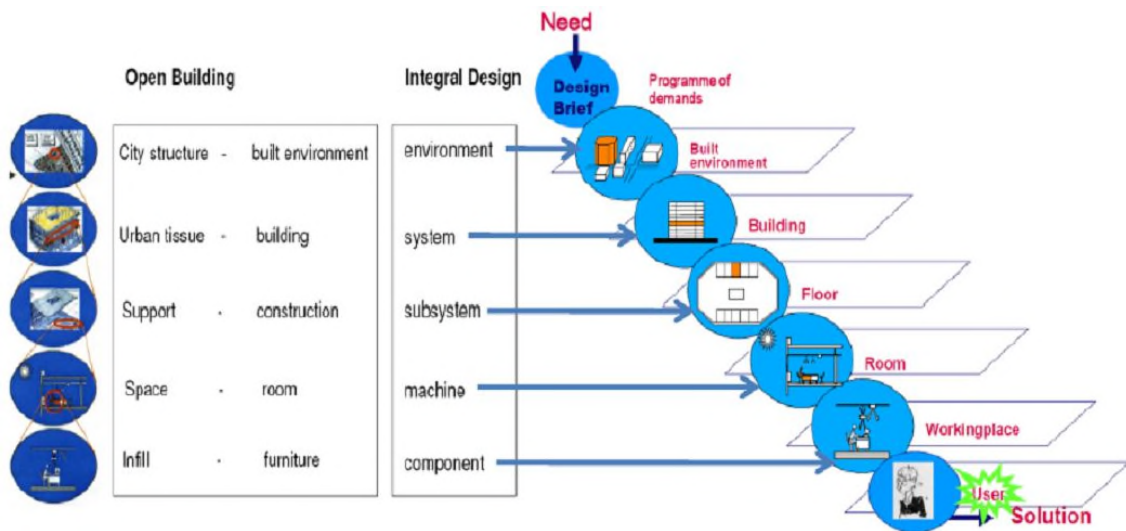


Figure 6 Comparison hierarchical abstraction Open Building and Integral Design approach

In the ‘Living Building Concept’, as well as the ‘smart building’ approach the demands and resulting functions are leading as well as a structures abstract approach to the building design process and a separation of building and building services (energy infrastructure). All this is very closed related to the basic ideas of Open Building design which is even more abstract. 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 external 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 (Figure 6).

2.2 Building Energy Management Systems

The process control infrastructure within office buildings is handled by Building Energy Management Systems (BEMS) derived from Building Management Systems (BMS) also known as Building Automation Systems (BAS). These systems control the HVAC systems to facilitate building operation and evolved over time with the addition of more and more systems, functionalities, and requirements. BMS with energy use reduction during life time as an extra goal, turned into Building Energy Management Systems (BEMS) [18, 42]. The main goal of the BEMS is to fulfil the occupant comfort requirements while reducing energy consumption during building operations [117]. However, the real behaviour of the occupants are not included in the process control. Traditional Building Energy Management Systems (BEMS) lack real time input of dynamic factors including occupancy, occupant preference, occupant actions, uses of appliances among others. Even with all of this new information, current BEMS still lack intelligent reasoning to optimize process control based on such dynamic and distributed input [59]. These limitations were observed [50,118]: non consideration of individual end-user's consumption behaviour and difficulty in integration of user behaviour into advanced autonomous and decentralized control technologies. Macek et al [77] present their energy management system ENERsip and discuss the role of metadata during design and practical application. The aim of the designed application is to support decision making in the area of local neighbourhood energy networks through near real-time optimization of generation and consumption matching in buildings and neighbourhoods. An integral approach is applied to look for synergetic effects within the building as well as outside of the building, by researching energy needs upwards from the (thermal) comfort based energy need to the total energy generation and distribution of an office building. Economic innovations (business models, arrangements and transactions) are needed to motivate the owner and users of office buildings to bring forth the flexibility offered in principle by BEMS. This flexibility is presently hindered by the fact that most manufacturers of BEMS systems tend not to embrace open source gateways and instead lean toward unique platforms which seem almost to be designed not to be fully comparable with generic software packages and tool sets. However, the fast development within the ICT domain makes that new players like Microsoft will open up this domain and new software platform will offer the in principle available flexibility.

As mentioned by Bloem and Strachan [15] a top-down approach could give the boundaries for energy consumption related to occupancy behaviour, this makes it important to include the top down approach in the combinative solution. Identifying the specific building energy consumption from available measured data could support the optimization of energy balancing. In the longer term, bottom-up research should give more insight in important aspects related to occupancy behaviour in a wider urban related energy consumption context (including transport, living-work relationships) [15]. There is a different focus on the processes within different timescales that occur in the building, which also depends on the strategy that is

leading: bottom-up (user orientated/ Nano-Grid), middle out (building orientated/ micro-Grid) and top-down (city orientated/ Smart Grid).

Important for energy efficient operation of energy storage facilities, like aquifer systems, is long term optimization on different scales of hours, days, months and years. The use for of example free cooling can help in energy efficient operation, over a period of hours: during the night cool outside air can be used to cool down the thermal mass of a building, which results during daytime in a reduced cooling load. So clearly, there are different time scales in the built environment where the energy storage processes takes place as shown in Figure 7 [89] Processes which fall in a particular time frame needs to be optimized over a specific time domain.

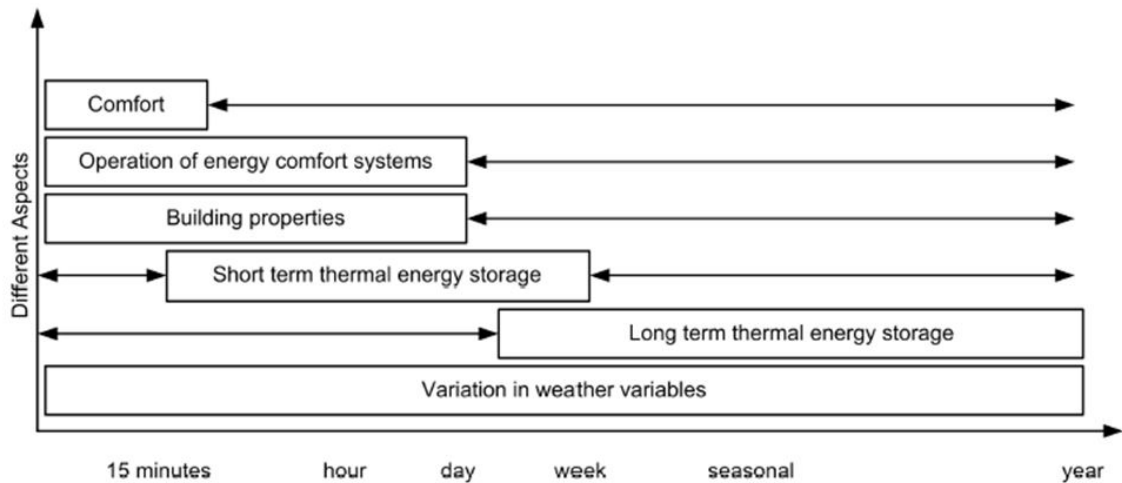


Figure 7 Timescales for optimizing different aspects in the built environment [89].

The potential of energy usage flexibility in the built environment can be realized by forecasting energy demand, taking into account boundaries of material constraints, weather conditions, appliances, occupants and their behaviour as well as internal gains. Forecasting methods developed for building energy demand are generally top-down approaches which estimate the long-term total energy consumption through macroeconomic indicators, energy price and general climate. A bottom-up approach that is able to estimate the individual energy consumption and then aggregate it to predict the total building energy demand is highly desirable. However, such bottom-up approaches have difficulty in sufficiently addressing impact factor. This could be attributed to challenges as a result of end-user's behaviours in the different dimensions of time, space, and geography.

2.3 Smart Grids

In Europe there are a large number of on-going research projects on smart electricity distribution network solutions and ICT systems for energy efficiency. An overview of the lessons learned and current developments can be found in the GeSI reports [34, 35] and Giordano et al [36, 37]. The main focus in the majority of these projects is on the combination of physical and virtual energy storage capacity in and

around buildings in an attempt to stabilize the Smart Grid. However, these projects still largely take an electrical engineering or mathematical perspective and use very simple models for the building services installations, or are limited to electricity generators like (μ)CHP units with some basic loads like cold storage, heat pumps or boilers as in the CRISP project or Power Matcher project in Hoogkerk [63].

The energy demand characteristics of buildings available in Building Automation Systems represent crucial information for grid optimisation [115]. The shift towards smart electrical grid cannot ignore connected buildings. This implies active participation of buildings in the grid. Energy management in the Micro-Grid depends highly on the energy management inside the buildings, called Nano-Grid, belonging to the Micro-Grid. The Nano-Grids can be seen as the network and consuming systems in the building managed by the BEMS.

2.4 Smart Grid and BEMS

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 [23]. The control of loads in the building, may also be a resource to the grid using the flexibilities in service of the grid [17]. However, these flexibilities remain largely undefined with respect to interactions with the power grid. Also, the development of the SG is still at an early stage and some parameters are yet to be fully defined with respect to interactions with SG.

With the development of a communication platform between the BEMS and Grid Energy Management System (GEMS) both systems get more interconnected and thus more dependent on each other. The present choices made in energy management have the capacity to, affect future choices [17].

For the built environment now is the chance to prepare for the coming SG. New strategies of energy management, building management, and comfort management have to be developed to anticipate on the coming possible changes on Demand Response (DR) and demand side management by load control. The function-oriented strategy of an Integral design allows the complexity levels of various Smart Energy Systems to be separately discussed and, subsequently, (sub) solutions for energy storage to be generated. This allows flexible integration of energy flows connected to heating, cooling, ventilation, lighting and power demand, within a building, between buildings as well as in the wider built environment. This leads to flexibility of energy exchange between different energy demands and (sustainable) energy supply on different levels in the built environment.

3 Description of the proposed solution

Instability of the electrical grid due to the supply issues as well as due to the unreliable predictability of specific types of RES, might lead to black-outs with enormous social and economic effects. Groups of buildings in the form of a Local Virtual Power Plant (LVPP) could reduce uncertainty within energy management and process control in a distributed but coordinated manner and on a critical scale, thereby addressing supply and demand balancing concerns. Flexibility in the system help user to adjust the demand profile as it is required from the electricity market [33]. Flexibility in the energy use by the buildings is provided under demand side management and demand response concepts. In a LVPP, demand side management (DSM) plays a key role in dealing with balancing problem. Therefore, it is necessary to

implement BEMSs that perform under real time dynamics to adjust energy use; thereby, integrate building into balancing market in LVPP. Several stochastic models were introduced to better predict energy demand and generation, however, so far it is not possible to completely avoid imbalances as a result of uncertainties in the system [53, 104, 113]. Charging and discharging capabilities of recently added devices can assist to deal with fluctuations from energy generation from renewable sources [124]. The extent of flexibility vary depending on the number and characteristics of elements (shiftable loads, on-site generation etc.) in the system.

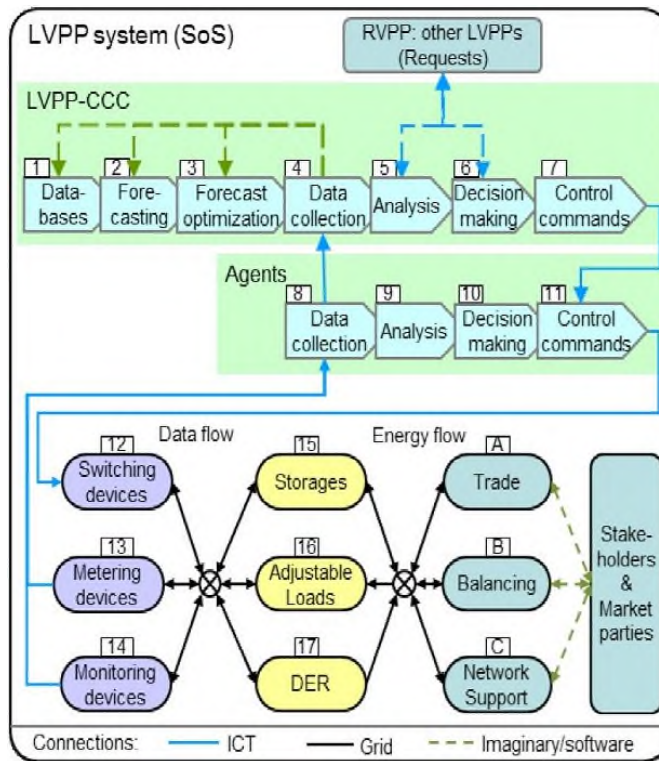


Figure 8 Modular LVPP system [30]

The LVPP owner (also called aggregator) can employ storage devices or may decrease the consumption at specific period of time by postponing or turning down the operation of devices with respect to comfort limits [32]. The aggregator can achieve more stable and reliable power supply by adding flexibility at high level of power by simultaneously employing non-dispatchable as well as dispatchable sources and storage devices. The owner of RES can get higher economic value for his energy generation by joining LVPP [106]. It is significant for aggregators to predict both demand and generation side in LVPP to develop reliable market bidding strategy [43] between predicted and actual energy result in profit losses [88, 106]. As a result, the integration of large scale renewable resources has led to switch the organization of power supply from top-down to down-top manner in order to gain full economic benefit of distributed energy resources. As part of this effort, there has been an opportunity to optimize the energy flow in residential

and commercial buildings by treating each building as an active participant under building energy management systems (BEMSs), thus can be offered to VPP [62, 87] the power of prediction incentivizing production at the right time and place.

Since traditional BEMS lack intelligent reasoning to optimize process control [58], multi-agent system technology will be used in addition in order to cope with all of the dynamic influences, internal as well as external, on building's in LVPPs. They can participate in the energy balancing market by employing the available RES units, storage devices and controllable loads (heating, cooling, ventilation, lighting and power demand) on different time scales [89]. These modular and scalable LVPPs can be clustered into Regional or even Large Scale Virtual Power Plants (RVPP or LSVPP) (Figure 8 [30] and Figure 9 [31]).

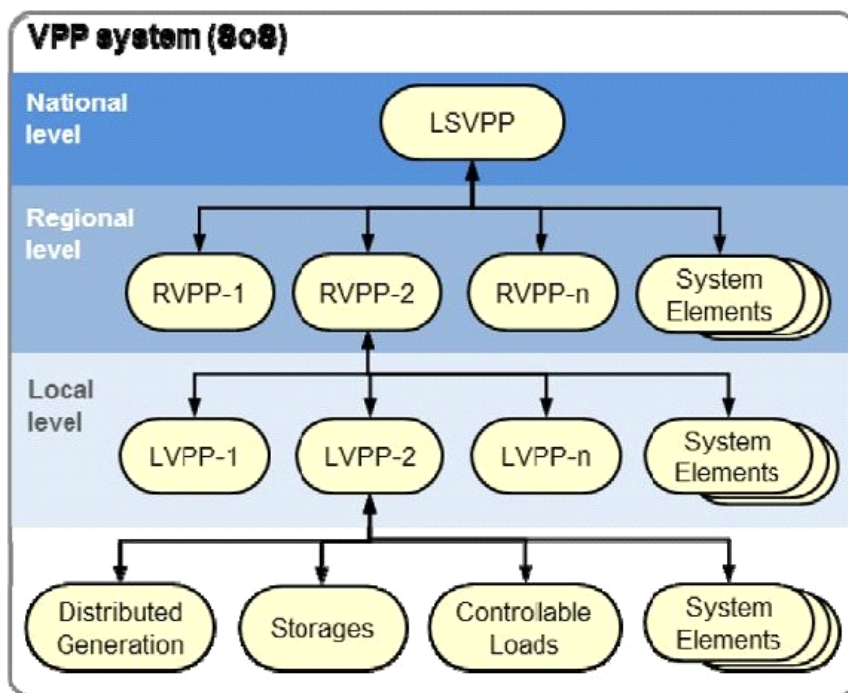


Figure 9 Scalable design of LVPP system [31]

The insights gained from the modelling of the energy demands on the different levels of a building and its surroundings lead to a concept for the monitoring and management of the energy flows in the Nano-Grid in a more detailed and accurate way. The viability of these solutions was investigated and demonstrated in a real office situations. First, simple representations of the process were made to look into the interrelations between the different levels within a building system, with a specific focus on the Smart Grid and Nano-Grid:

- building level (energy supply from the Smart Grid, needed flexibility in demand by the Smart Grid)
- room level (energy exchange depending on the outside environmental conditions and internal heat load)
- workplace level (workplace conditions and energy need from appliances)
- user level (defining the different comfort needs of individuals and the resulting energy demands)

For the information exchange between building and Smart Grid a middle-out approach was chosen using a BEMS: from the interface towards the SG and towards the BEMS. This focuses on the communication and interaction between the SG and the BEMS. However, also deals with the actual comfort and energy demands of the user and optimization of the energy flows. In the process the user has the leading role by setting the desired inside climate conditions. The energy demand of buildings is related to the physics of the building, the environmental climate, and significantly to the specific control scenario for indoor environment and building operations. According to Martani et al [80] there have been no attempts to develop a general model predicting the probability of switching on or off the range of HVAC equipment, together with occupants' desired set point temperature, and how these choices depend on the range of key environmental stimuli. An aggregated model was developed by Zhang et al [125] developed for a population of air conditioning loads. The model effectively includes statistical information of the load population and systematically deals with load heterogeneity. Based on this model, a novel aggregated control strategy was designed for the load population under realistic conditions, however only simulations were done and no measurements for verification. In addition, user's preferences are considered as a vital factor in deriving the appropriate control strategy [117].

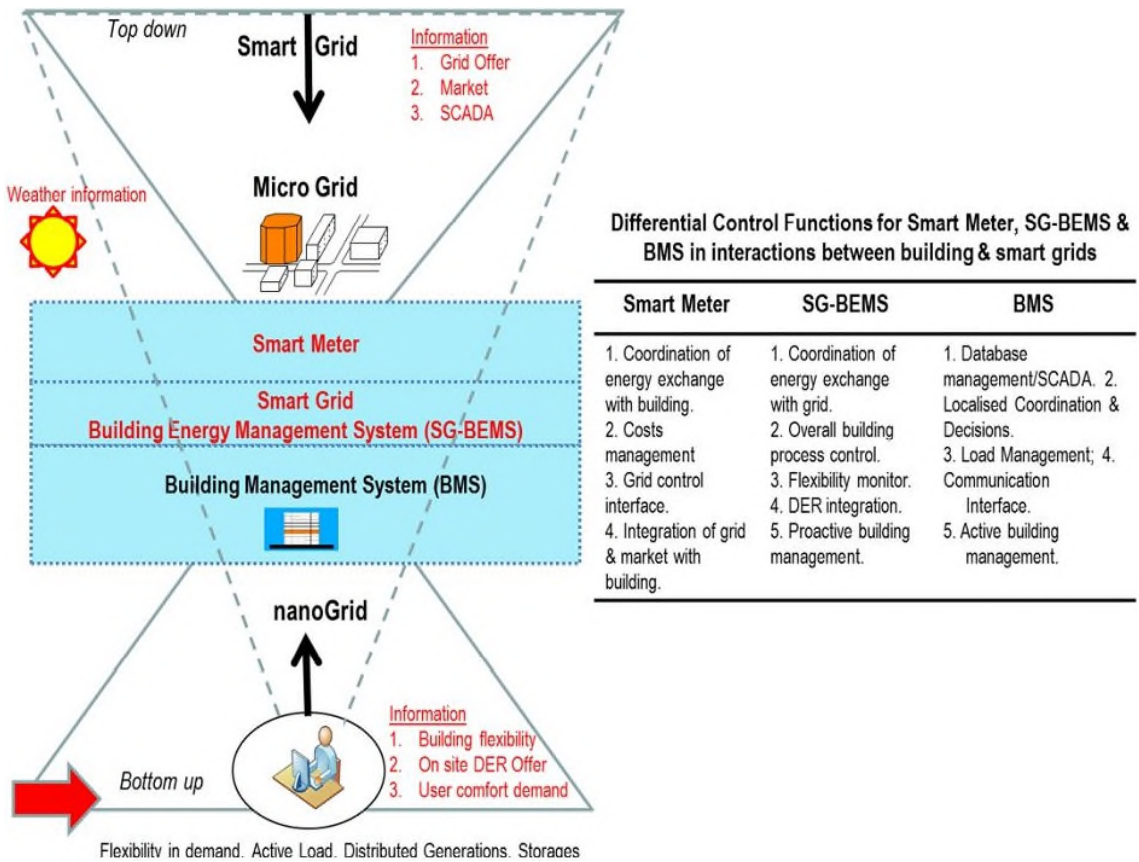


Figure 10 Control functions Smart Meter, SG-BEMS and BMS

The building systems control strategy relies on code defined occupant comfort ranges [59] and operate according to fixed schedules and a constant occupancy. This is inefficient in their energy usage for maintaining occupant comfort as they do not in-cooperate the effects of real occupant behaviour. Once a good model is obtained, many well established control methods can be directly applied to regulate the aggregated power response. Examples include according to Zhang [125] open-loop control [102], Model Predictive Control [60], Lyapunov based control [10], or simple inverse control [81] that computes the control action so that the predicted output matches the given reference signal. However, all the aforementioned approaches have several limitations that need to be addressed for realistic demand response applications [125]. Li et al [69] identifies a number of control strategies based on accurate building occupancy:

- lowering and reducing temperature in unoccupied areas during winter and summer periods respectively leads to overall building energy reductions [123]
- Maintaining lower ventilation rates in unoccupied areas; leading to less ventilation losses and building energy needed;
- supplying airflow based on occupancy; demand based dynamic airflows could achieve 15% to 56% reduction of ventilation energy [105, 118]
- responding to dynamic heat loads on a timely manner; if a change of the occupancy is detected in real time, associated changes of internal heat loads can be calculated, HVAC systems can respond to these changes immediately, before the temperature varies to an extent that is detectable by thermostats

The energy demand characteristics of buildings available in Building Automation Systems represent crucial information for grid optimization [115] 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 [23]. Compared to the traditional approach of Smart Meters and BMS, the SG-BEMS has clearly different control functions for the interactions between building & Smart Grid (Figure 10).

A proof of concept experiment at an office building in the Netherlands was performed. In this experiment, the building's HVAC-installations was flexibly operated to determine possible energy advantages of BEMS strategies, especially flexibility of energy demand on user/room and building level, in smart grid scenarios. The results of this experiment are used here to illustrate the possibilities in the built environment for LVPP.

3.1 The Case Study

The case study was conducted on an office building with a floor area of approximately 1500 m² with over 40 occupancy population. The operation schedule between: 7:00 h and 18:00 h for 5 working days of the week. The building was fitted with air handling unit (of 15.000 m³/hour ventilation capacity), heat recovery wheel (no recirculation of air), central cooling system functionally divided into three cooling zones, a gas fired boiler for hydrophonic heating arranged into 2 zones and an electrical steam humidifier (Figure 11).

In the experiment, room conditions were monitored for offices on the first floor as operational settings were adjusted. The HVAC control unit, controls the building systems by sending the control signals, supplies the electrical power to the fans and pumps, and facilitates the communication signals to the BEMS and all connected components. In order to evaluate the characteristics of the energy use of the installed systems measurements were done. All energy use profiles together form the total energy use profile as presented in Figure 12.

Continuous main base load of the office building was about 4 kWh/h; this is represented by 'A' in Figure 11. The maximum power use measured by the main connections I + II during the project was 36 kWh/h,

this is represented by 'B' in Figure 12. The main energy use profile during the day looks quite stable (see profile C) while some profiles of appliances can be clearly seen in the total profile. Profile D represents the early start scenarios for the Chiller. The Energy use profiles of the Chiller are also clearly visible (E) in Figure 12.

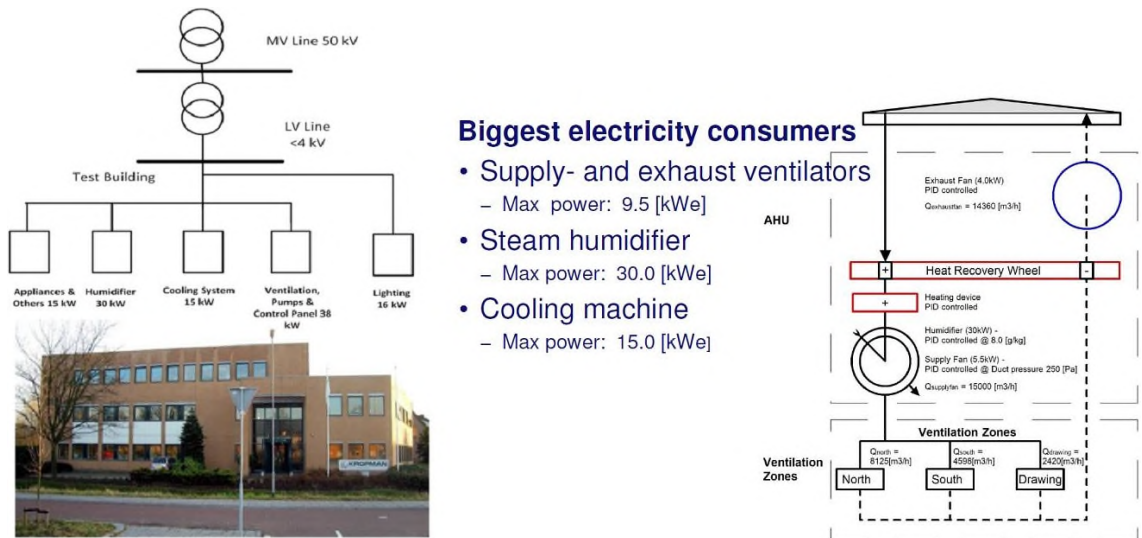


Figure 11 The electrical connections from Mid Voltage grid to building and its major electricity consumers

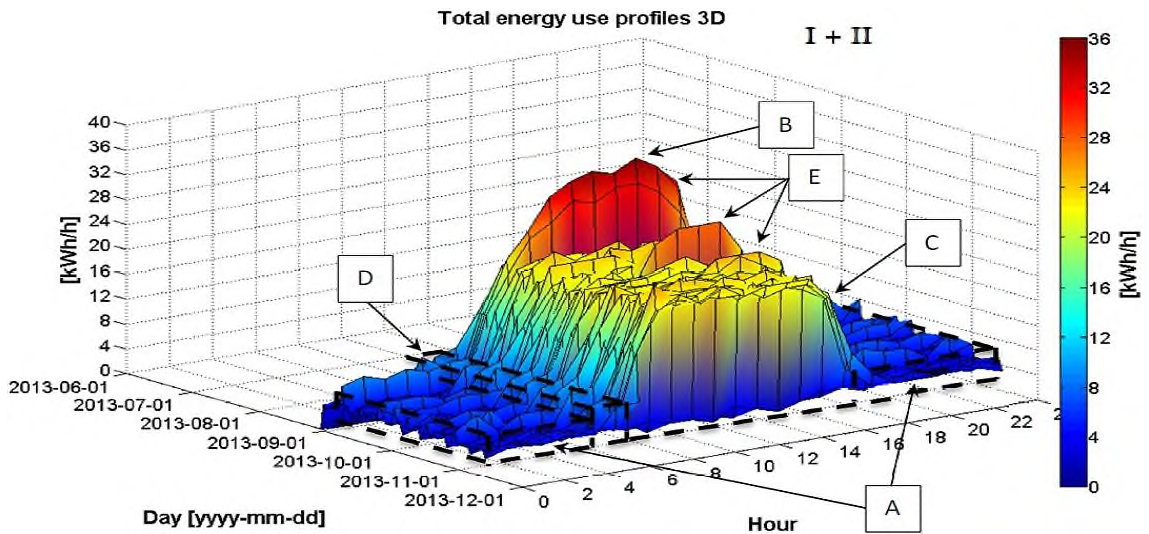


Figure 12 Total energy use profiles stacked by date [109]

3.2 Electrical steam humidifier

During wintertime the biggest controllable electrical energy user is the Air Handling Unit with its steam humidifier of maximum 30 kW. The actual power usage is usually lower than the maximum rated power as it can be decreased by changing the set point in the connected BEMS, dependent on the out- and indoor conditions the power consumption reduces from usually 6 – 20 kW. This could be applied as service for a future Smart-Grid, as an active load. In an experiment, short time interval energy savings from the steam humidifier were determined during winter time, as well as the resulting comfort conditions.



Figure 13 Air Handling Unit and steam pipe

The humidifier power reduction experiment took place at Friday, 20th of December 2013. Roof temperature and relative humidity measurements are shown in Figure 13. RH starts in the morning at 100% and begins declining from 10:45 h. The lowest measured RH is 76.8 % at 15:15 h. The outdoor temperature at start experiment is 5.2 °C and increases to 8.8 °C (Figure 14).

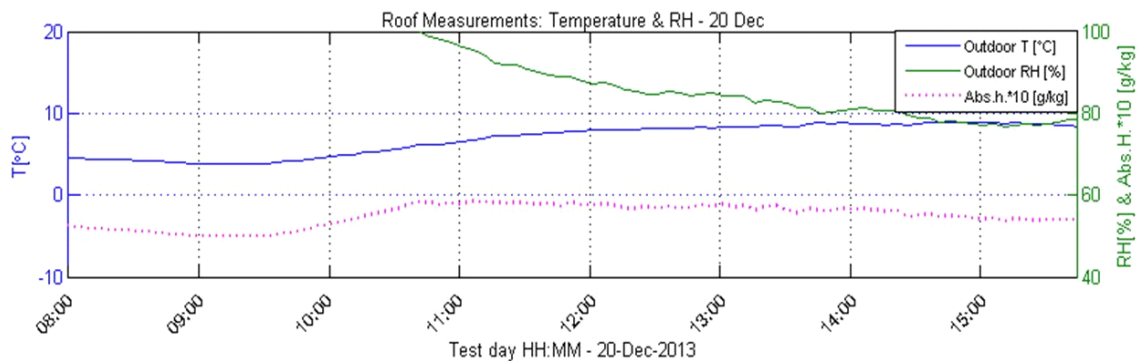


Figure 14 Roof measurements 20 December, black dashed are interval times I, II and III

From the meteorological data at the roof the absolute humidity content (mixing ratio) can be derived. The absolute humidity content in the outside air is increasing till 10:45 h and then slightly decreasing till the end of the experiment day (lowest dashed line). The humidifier normally starts at 7 in the morning and the peak power consumption when starting is 27 kW. The indoor absolute humidity at the AHU (steam humidifier) is during normal operations set at 8.0 gr moisture/kg air. The following experiment schedule was set-up to see the possibilities for reducing the applied power (Table 1).

Table 1 Steam humidifier reduction experiment

Interval time	Duration	Exact moments	Humidifier
Interval time I	15 minutes	9.57 – 10.14	reduction 25 % set point
Return to normal set point	60 minutes	10.14 – 11.14	
Interval time II	30 minutes	11.14 – 11.45	reduction 25 % set point
Return to normal set point	60 minutes	11.45 – 12.45	
Interval time III	60 minutes	12.45 – 13.45	reduction 25 % set point
Total experiment period	3 hours and 45 minutes		

There is at least one hour 'normal set point' between these intervals

The results in room B are represented in Figure 15 and show that an extra amount of vapour is needed to fulfil the demand since the absolute humidity ranges from 5.0 gr moisture/kg air at 9:15 h and peaks at 5.8 gr moisture/kg air at 10:45 h (lowest dashed line). During interval time I, II and III (Table 1) the absolute humidity set point is decreased to 6.0 gr/kg, a reduction of 25 %.

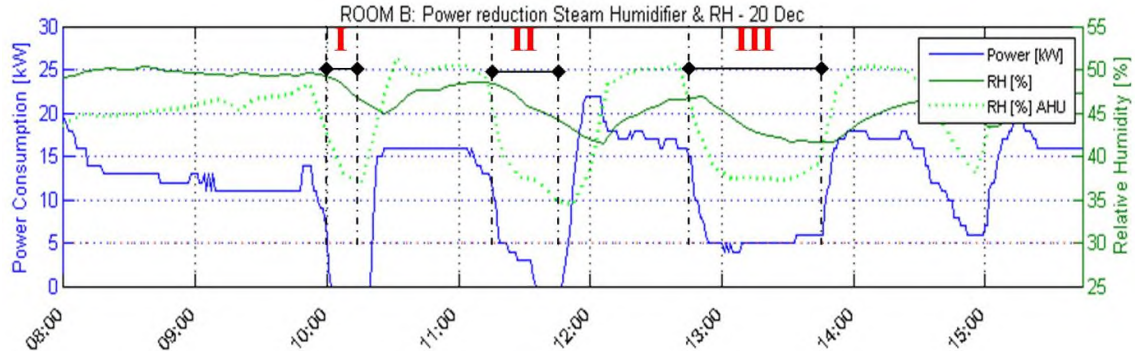


Figure 15 Room B: relative humidity and power measurements (blue line smoothed with 15 min. median filter)

Table 2 Humidifier power reduction at interval times

Interval time	Power reduction humidifier	Lowest supplied RH 6.0 gr/kg	Lowest indoor RH
Interval time I	- 14 kW	37 %	45 %
Interval time II	- 9 kW after 5 minutes - 14 kW after 25 minutes	37.5 – 34.3 %	45.5 %
Interval time III	- 12 kW	37.5 %	41.6 %

The relative humidity (RH) stayed in all 3 intervals within comfort boundary conditions (RH min is 30 %). To prevent power peaks after interval times it's important to set the humidifier not below the minimum supply capacity. From the humidifier power reduction experiment it is concluded that energy can be saved within set comfort boundary conditions.

4 Agents of the past and future

Buildings are complex systems involving several forms of interactions with systems, sub-systems, components and users [24]. Commissioning is important to achieve a good functioning building ASHRAE standard 202-2013[6] and CIBSE commissioning code M 2003[19] describes how to plan, conduct, and document this vital part of a successful project. Informative appendices provide sample documentation, including checklists, systems manual, reports, training plan, and more. However, in addressing the limitations of traditional BMS to provide the possible flexibility towards the Smart Grid, a number of strategies based on artificial intelligence techniques were developed and implemented in BEMS systems of both existing and new buildings [22, 38, 41, 84]. Resulting in improvements in occupant's comfort and buildings energy consumption over traditional controls used in BEMS systems [5, 27, 70]. However, due to the complexity often involved in implementing these systems in buildings, the building industry has been slow to adopt these advanced control strategies [22]. On the other hand however, there is a growing interest in design of BEMS systems based on the multi-agent (MAS) paradigm [27, 58]. This is mainly due to their decentralized, reasoning, autonomous and much easier re-configurative capabilities of MAS. The modular, decentralised, changeable and problem solving capabilities of MAS provides a much more flexible coordination of building systems, sub-systems, and improved user interactions in buildings [58, 111]. They have been used in a number of applications requiring distributed intelligent control and decision making as well as applications with high level of behavioural uncertainty [4, 61, 116].

Usually, multi-agent systems used in buildings for improving comfort and energy efficiency are designed using a layered hierarchy architecture based on either a market-based coordination mechanism [9, 122]. MAS coordination mechanism based on market-oriented algorithms provide a framework for distributed decision making and control based on the microeconomics theory [120]. Market-based mechanisms distribute planning required for task allocation mainly through an auction process and communication between agents in the system is limited to bids and price signals. Non-market based agent coordination mechanism on the other hand, depend on multi-objective functions developed from learning, bio-inspired, genetic and evolutionary algorithms as described in [39, 66, 68]. the performance advantages of designing multi-agent systems using market-based coordination has been quantified [116], its use in building for energy and comfort management may lead to user dissatisfaction. This is mainly because it requires users to make a decision between cost and comfort [68].

In improving occupants comfort and energy efficiency of buildings, agent systems based on non-market coordination mechanisms have been used in the design of a room thermostats [110] and to coordinate demand-driven control of systems based on individual preference and behaviour of occupants [58, 61, 79,83]. In addition, agent systems based on both market and non-market based coordination mechanism have been used in estimating impact of various initiatives, such as integration of storage facilities, renewables-Smart-Grid/micro-Gird/Nano-Grid), demand side management (DSM), changes to the building itself, changes in occupant behaviour as well as communications campaigns to encourage energy conservation in buildings [8, 71, 93, 97]. Through the review of key studies on MAS application in buildings for comfort and energy management some key requirements for designing a MAS were identified and are summarized in table 3. In order of relevance, the main requirements for the design of a multi-agent based on behaviour and computational intelligence are: the agent design platform, agent communication

and information infrastructure, agent architecture and structure and the agent, agent coordination mechanism.

Table 3 Summary of key reviewed papers

Authors	Klein et al [58]	Yang R & Wang L [120]	Yu D-Y et al [121]
Agent design platform	Opensteer - OpenGL	Matlab	Python
Agent communication and information infrastructure	NS Wireless sensor Network	NS Wireless sensor Network	XML-RPC Wireless sensor Network
Agent architecture and structure	Layered hierarchical Room agents Meeting room agent Device agents Personal agents	Layered hierarchical Local agents Central agents Personal agents	product agent Resource agent Order agents Staff agents
Agent coordination strategy	Non-market based	Non-market based	Non-market based
Method	Simulations	Simulations	Actual experiment

2012 → duration year → 2013

As shown from the literature, the agent structure plays a key role in determining the information flow between agents in the various designs discussed. To address the needs of building users and to further improve the balance between energy and comfort, an agent structure is proposed comprising the following agents: building agent, zone agent, room agent, personal web agent and services agent (Figure 16).

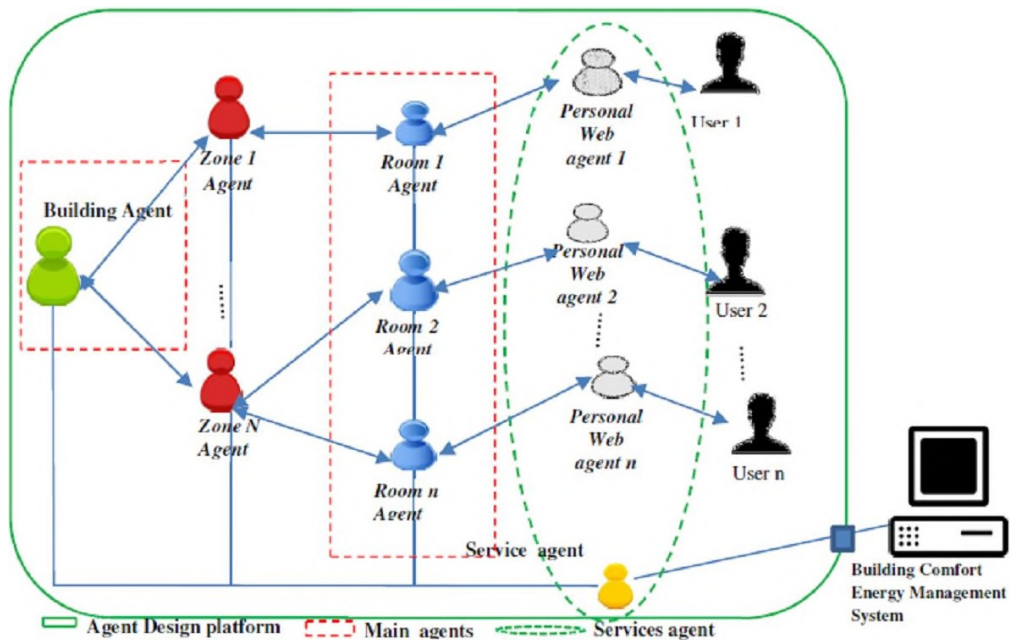


Figure 16 Proposed agent architecture

The building agent and the room agent are represented as main agents while the other agents are represented as services agents. The functions of each of the agents are explained below:

- Building agent: supervises and coordinates all the actions of all agents in the system using a dynamic rule base that is constantly updated. It ensures the building policies particularly regarding energy resources are enforced. It represents the building in the energy market using forecasted weather information and forecasted energy required for operating the building as provided by the zone agent
- Zone agent: relays to and enforces the building policy provided by the building agent on the room agents. It also constantly updates the building agent on changes in the energy profiles of the zone being monitored.
- Room agents: a key player in the agent structure and also necessitating its assignment as a main agent. The room agent keeps track of occupants position and location in a room using information provided by the user agent. The room agent has to decide on the optimal means to provide user comfort considering the available actuator possibilities in the space and in line with the laid down building energy
- Services agent: provides the rooms, zones and building agents with sensor data and also sends control signals to the relevant actuators
- Personal web agents: the building users main interface and connection to the building controls.

The choice for a multi-agent system (MAS) is motivated by the need to ensure flexibility and robustness. Firstly, individual agents can be assigned to be in charge of distinct subsystems (for example, based on location or objective). This simplifies the expansion of the monitoring and control system over time, as the introduction of new functionalities leaves the configuration of the existing system intact, and simply requires the addition of a new agent.

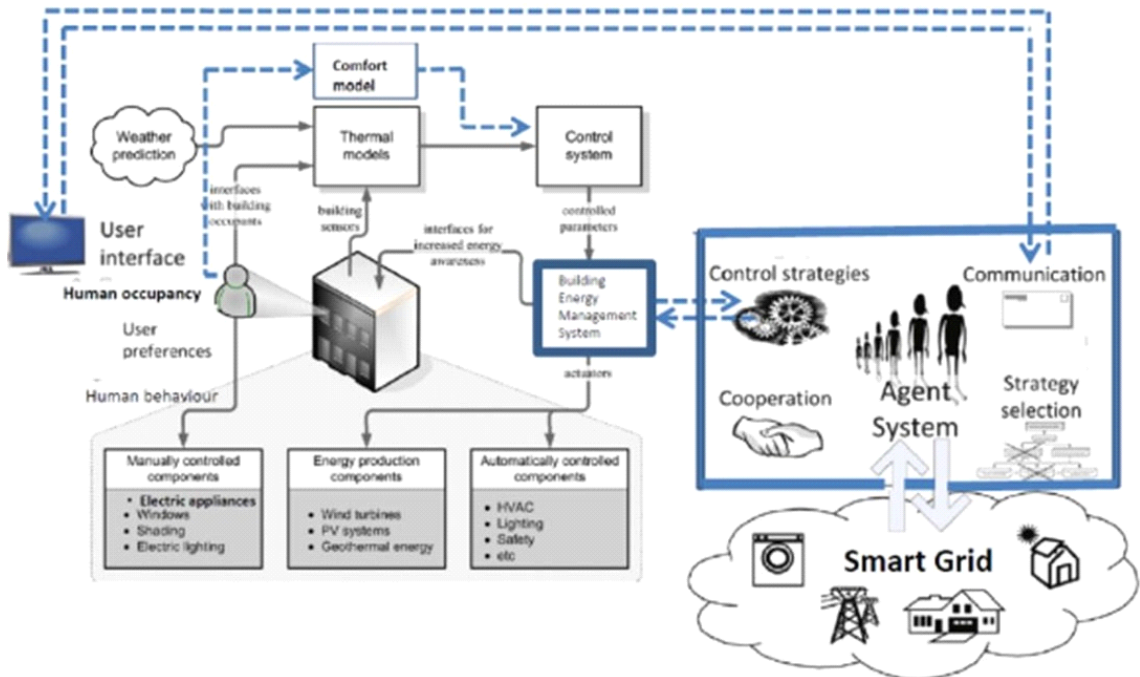


Figure 17 Mean functional orientation of the research (based on Kolokotsa et al [65] and Kofler et al [61])

The ICT architecture (or multi-agent algorithms for distributed optimization) could be based on different concepts, for example the PowerMatcher concept [44] or as smart-meter platforms as part of the Inovgrid [82] and FENIX project [56]. Starting from concepts such as PowerMatcher [64, 90] or HeatMatcher [91,

92], more refined models are used to include all functional levels of buildings and building services to make optimal use of all energy storage possibilities for energy balancing. Within the project there are different focusses on the processes that occur in each system, which depends on the strategy that is leading: bottom-up (user orientated), middle out (building services systems orientated) and top-down (Smart Grid). Based on each of these approaches the results and insights will be used to specify specific functionalities for the agents of the multi-agent platform that will be used (Figure 17) a semantic representation which is based on Kolokotsa et al [65] and Kofler et al [61].

Secondly, in view of the complexity and heterogeneity of the input data, it is advantageous to apply a wide range of modelling and learning strategies (for example, regression and time series models, as well as rule- or case-based models). Such widely different approaches are most naturally encoded by different agents, each of which communicates its results to a set of supervising agents which then, based on the estimated reliability of the individual decisions, fuse the information to reach a final decision. It is to be expected that over time it will become clear that particular strategies are more successful than others. Again, this can most easily be accommodated in a multi-agent platform setting where agents implementing unsuccessful approaches will be removed or downgraded from the pool, whereas agents with excellent performance will be boosted and diversified. An multi-agent platform will integrate a number of flexible components including thermal storage. Such devices are crucial to contribute in mitigating uncertainty within the built environment and Smart Energy System (SES) at large. Depending on their location, functions, and physical constraints, such devices can offer a certain degree of flexibility.

The multi-agent platform which acts as an aggregator will be a core element in the realization of the LVPP concept both in the built environment and in buildings. Due to the nature of the built environment, i.e. including different levels, zones, layers, with different physical components, the overall control system of BEMS is quite complex with quite different time reposes for different functions and services. Therefore, we introduced in this research a double control layer for the agent-aggregator platform that makes the LVPP responses with the direct control signal in a short time interval and with the price-based control signal in a longer time interval. The former depends on occupancy detection to meet a certain comfort level of end users, whereas the later aims to optimize the energy usage while taking into account flexibility of the built environment.

5 Discussion

The Best Project Manager for a Carbon and Energy Fund project 2013', Brian Golding, energy manager at York Teaching Hospital NHS Foundation Trust stated [48]: "Energy management is simple - you buy the energy at the best price, make sure you're using it well and find ways to use it better". However, like most things often there is more to it. Golding emphasized that the right experience and expertise is needed as well as an significant upgrade to the site-wide BMS. Which enables it to control the environmental temperatures better, it improves the resilience of the controls so that there are not as many faults, it enables to monitor and increases the useable information. It changes us from being reactive to proactive.

Energy management is the planning and implementation of all necessary measures to adequately and safely provide an organization with the ability to ensure [12]:

- The most efficient use of energy
- To reduce negative environmental impacts arising from energy consumption
- Reduce the cost of energy supply
- Capture and allocate charges of energy usage

Energy management is management [13] and follows the four phase procedure: expectation, clarification, finding and decision. Energy management is a long term commitment [12]. Significant barriers are: lack of knowledge, information and of adequate mechanisms and processes for capturing and recording energy use. This is where BEMS come in and can support the energy management as well as provide additional flexibility and value towards the Smart Grid.

For engineers it is interesting to look in a more abstract way to the design of the process control of the energy infrastructure of the built environment for a more function oriented perspective. This opens up the mind and enable to see new possibilities to create added value from within the building towards the Smart Grid. By performing detailed measurements in operational offices new possibilities for energy demand reduction can be detected based on experimenting with HVAC system. By doing so they get a much better understanding about the critical performance indicators to optimize its performance and the possible added value towards LVPP

The Integral approach with its function-oriented strategy of System Engineering allows the complexity levels of various Smart Energy Systems (Smart Grid, gas distribution network, heat- and cold infrastructures) within the Built Environment to be separately discussed. This allows flexible integration of energy flows connected to heating, cooling, ventilation, lighting and power demand, within a building as well as with the Smart Grid. This leads to new strategies of energy management of LVPP to be developed to anticipate on the coming possible changes on Demand Response (DR) and demand side management possibilities by active load control. This to optimize interaction between LVPP existing of buildings and the Smart Grid.

6 Conclusions

Concerns regarding energy costs and energy security have led to a proliferation of smart grid technologies and renewable energy installations, both on a distributed basis and at the utility scale. Office buildings consume relatively more energy than residential buildings, which explains their importance in the current research. Office buildings are a potential source of energy flexibility, which can be offered to the grid as a (part of a) local virtual power plant (LVPP). The basis is by intelligent agent supported BEMS which enables reducing uncertainty in the energy demands, introducing flexibility and optimizing interaction with the Smart Grid. In this way Information and Communications Technology (ICT) is used on top of the electric grid.

A bottom up approach is suggested that achieves smartness by improving the flexibility of the demand-side at the user/room/building level in relation to the functional needs at those levels. The function-oriented strategy of an Integral design allows the complexity levels of various Smart Energy Systems to be separately discussed and, subsequently, (sub) solutions for energy storage to be generated. This allows integration of energy flows connected to heating, cooling, ventilation, lighting and power demand, within a building, between buildings as well as in the wider built environment. This leads to flexibility of energy exchange controlled by BEMS assisted by Intelligent Multi Agents controlling all energy demands and (sustainable)

energy supplies on different levels in the built environment with the following innovative aspects;

- Dynamic energy management with the use of energy storage possibilities on different functional levels within buildings (nano Grid) and outside buildings (micro Grid).
- Offices as Virtual Power Plants with active process control of their physical storage capacities, adjustable loads and RES to optimize their interaction with micro Grid and Smart Grid
- Multi-agent approach to allow the system to respond in an optimized way to all the changing conditions and situations
- New ways of dynamic energy management of small scale LVPPs supported by economic models for nano/micro-markets
- With the combination of traditional BEMS process control and multi-agents systems, new options for energy optimization on different levels in the built environment. The paper presents a general design framework for:
- Reduction of uncertainty within Smart Energy Systems by applying different types of energy flexibility and storage on different systems levels within the built environment, connecting energy demand and energy supply within offices (nano Grid) through LVPP with Smart Grid
- BEMS at clusters of office buildings in Smart Energy System's LVPP and interplay between Smart Grid and cold, heat or gas networks on the level of offices

In this paper, the key requirements were presented for implementing a multi-agent system to address the drawbacks of traditional BEMS systems for LVPP. The consideration of user information, building parameters, processes, weather, energy resources and their respective behaviours is undoubtedly necessary for improving energy efficiency and sustainability by application of RES. When exact energy behaviour of installed appliances and user behaviour are known, a MAS based on behaviour and computational intelligence acting on behalf of the user demand can more effectively control the interaction with a LVPP as part of the Smart Grid. The integral BEMS controlled LVPP in Smart Grid results in a more energy efficient, more sustainable and ecological friendly manner of operation. As such it is an demonstration of the possibilities of an integral approach for a complex distributed system like the energy infrastructure of the built environment starting bottom up instead of the traditional top-down approaches from for example ISO 5001 [52] or IS399 [101]. These recognized key independent energy management approaches of course can also be used so that consequently a mixed strategy could be used. The complex distributed energy systems of the built environment can be controlled by integral BEMS. These BEMS are designed using an integral design approach reducing the complexity by functional layers. These layer dynamically interact by Intelligent Multi Agents with the BEMS. The intelligent dynamic interaction, resulting from the approach here described, offers additional functional flexibility especially for the interaction between building and the Smart Grid. In this way RES can be optimally used and the energy flows optimized. Resulting in a built environment that maximizes its sustainability.

Acknowledgments

This project is financial supported by BAM Techniek (the largest Dutch constructing company), PIT (Foundation of promoting Building Services industry) and OTIB (Education- and Development Fund for the Building Services industry). The support of Kropman Building Services in realising this study is highly appreciated.

Bibliography

- [1] **Acevedo SS** and **Molinas M** (2012) Identifying Unstable Region of Operation in a Micro-grid System, *Energy Procedia* 20 237-246
- [2] **Agarwal Y** **Balaji B** **Gupta R** **Dutta S** **Wei M** and **Weng T** (2010) Duty-cycling buildings aggressively: The next frontier in HVAC control, *Proceedings IPSN'11*
- [3] **Ahmed B** **Ampatzis M** **Nguyen PH** **Lopes Ferreira HM** and **Kling WL** (2013) Mitigating imbalances from wind power by using an agent-based matching mechanism, *Proceedings of the 48th Universities Power Engineering Conference*
- [4] **Al-Agtash S** (2013) Electricity agents in smart grid markets, *Computers in Industry* 64:3 235–241
- [5] **Arguello-Serrano B** and **Velez-Reyes M** (1999) Nonlinear control of a heating, ventilating, and air conditioning system with thermal load estimation, *IEEE Transactions on Control Systems Technology* 7 56-63

- [6] **ASHRAE** (2013) Standard 202-2013 Commissioning Process for Buildings and Systems, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, USA
- [7] **ASHRAE** (2013) Standard 55-2013 Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, USA
- [8] **Azar E** and **Menassa C** (2011) An agent-based approach to model the effect of occupants' energy use characteristics in commercial buildings, Proceedings International Workshop on Computing in Civil Engineers, Miami, Florida, USA
- [9] **Badawy R Hirsch B** and **Albayrak S** (2010) Agent-based coordination techniques for matching supply and demand in energy networks 17 373–382
- [10] **Banash S** and **Fathy H** (2011) Modeling and control insights into demand-side energy management through set point control of thermostatic loads, Proceedings American Control Conference, San Francisco, California, USA
- [11] **Bertalanffy L von** (1976) General Systems Theory: Foundations, Development, Applications, George Brazillers, New York USA
- [12] **Brulhart SJ** and **Hubbich M** (2014) Proceedings European Facility Management Conference, Berlin, Germany
- [13] **Brulhart SJ** and **Hubbich M** (2014) Energiemanagement, Vdf Zürich
- [14] **Blanchard BS** and **Fabrycky WJ** (2005) Systems Engineering and Analysis, Fourth Edition
- [15] **Bloem JJ** and **Strachan P** (2012) Evaluating and modelling nearly-zero energy buildings; are we ready for 2018? Proceedings of IECEB Frankfurt, European Commission JRC Technical Reports
- [16] **Boulding K** (1956) General Systems Theory: The skeleton of science, Management Science
- [17] **Callaway DS** (2011) Achieving controllability of Electric Loads, Proceedings of the IEEE 90:1 184-199
- [18] **Choi C-S Han J Park W-K Jeong Y-K** and **Lee I-W** (2011) Proactive energy management system architecture interworking with Smart Grid, 2011 IEEE 15th International Symposium on Consumer Electronics (ISCE), Singapore
- [19] **CIBSE** (2003) Commissioning Code M: Commissioning Management, Chartered Institution of Building Services Engineers, London, UK
- [20] **CIBSE** (2012) Mind the performance gap: regulated vs unregulated, CIBSE conference, London, UK
- [21] **Cloquet R** (2012) Kwantitatief data onderzoek Energie–innovaties, Agentschap NL projectnummer BA7156-100-100
- [22] **Counsell J Zaher J Brindley J** and **Murphy G** (2013) Robust nonlinear HVAC systems control with evolutionary optimisation, Engineering Computations 30:8 1147-1169
- [23] **Dave S Sooriyabandara M** and **Yearworth M** (2011) A Systems Approach to the Smart Grid, The First International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies, Venice Italy
- [24] **Dibley M Li H Rezgui Y** and **Miles J** (2012) An ontology framework for intelligent sensor-based building monitoring, Automation in Construction, 28 1-14
- [25] **DOE** (2008) US department of Energy 2008, Energy Efficiency Trends in Residential and Commercial Buildings
- [26] **Dong B Andrews B Lam K Hoyneck M Zhang R Chiou Y** and **Benitez D** (2010) An information technology enabled sustainability test-bed (ITEST) for occupancy detection through an environmental sensing network', Energy and Buildings 42 1038-1046
- [27] **Dounis I** and **Caraiscos C** (2009) Advanced control systems engineering for energy and comfort management in a building environment—A review, Renewable and Sustainable Energy Reviews 13:6-7 1246-1261
- [28] **ECN** (2014) Besparing en werkgelegenheid in bestaande gebouwen in 2013 voor monitor energiebesparing Agentschap NL
- [29] **EIA** (2011) US EIA US, Energy Information Administration - Independent Statistics and Analysis [www.eia.doe.gov]
- [30] **El Bakari K** and **Kling WL** (2012) Fitting distributed generation in future power markets through virtual power plants, Proceedings 9th International Conference on the European Energy Market, Florence Italy
- [31] **El Bakari K E** and **Kling WL** (2010) Virtual power plants: An answer to increasing distributed generation, IEEE PES Innovative Smart Grid Technologies Conference, Gothenburg Sweden
- [32] **Faria P Soares T Vale Z** and **Morais H** (2014) Distributed generation and demand response dispatch for a virtual power player energy and reserve provision, Renewable Energy 66 686-695
- [33] **Gelazanskas L** and **Gamage KAA** (2014) Demand side management in smart grid: A review and proposals for future direction, Sustainable Cities and Society 11 22-30
- [34] **GeSI** (2008) SMART 2020 [www.gesi.org/LinkClick.aspx?fileticket=tbp5WRTHUoY%3D&tabid]
- [35] **GeSI** (2012) GeSI SMARTer 2020: The Role of ICT in Driving a Sustainable Future, Global e-Sustainability Initiative, Aisbl and The Boston Consulting Group
- [36] **Giodano V Gangale F Fulli G** and **Jiménez MS** (2011) Smart Grid projects in Europe: lessons learned and current developments, JRC reference report, Petten The Netherlands
- [37] **Giordano V Meletiou A Covrig CF Mengolini A Ardelean M Fulli G Jiménez MS** and **Filiou C** (2013) Smart Grid projects in Europe: Lessons learned and current developments, JRC Scientific and policy reports, Luxembourg
- [38] **Guo C Song Q** and **Cai W** (2007) A neural network assisted cascade control system for air handling unit, IEEE Transactions on Industrial Electronics 54 620-628
- [39] **Guo Y Li J** and **James G** (2005) Evolutionary optimization of distributed energy resources, Proceedings 18th Australian Joint Conference on Artificial Intelligence, Sydney Australia
- [40] **Habraken NJ** (1961) De dragers en de mensen, Haarlem

- [41] **Hagras H Callaghan V Colley M and Clarke G** (2003) A hierarchical fuzzy – genetic multi-agent architecture for intelligent buildings online learning, adaptation and control, *Information Science* 150:1-2 33-57
- [42] **Han J Jeong Y and Lee I** (2011) Efficient Building Energy Management System Based on Ontology, Inference Rules, and Simulation, *Proceedings International Conference on Intelligent Building and Management*, Singapore
- [43] **Handschin E Neise F Neumann H and Schultz R** (2006) Optimal operation of dispersed generation under uncertainty using mathematical programming, *International Journal of Electrical Power & Energy Systems* 28:9 618-626
- [44] **Hermans RM Jokic A Bosch PPJ van den Frunt J Kamphuis IG and Warmer CJ** (2010) Limitations in the design of ancillary service markets imposed by communication network delays. *Proceedings of the 7th IEEE International Conference on the European Energy Market*, Madrid Spain
- [45] **Higgins JA** (2012) Energy Modeling Basics, *ASHRAE Journal* 12 26-30
- [46] **Hommelberg MPF Maisonobe JC Frascella A Schmidt S Andersen PB Lombardi M Hadjimichael S Larensgoiti I Ringelstein J Wu J Stefanova M Schwarzlaender F Franchioni G and Chebbo M** (2010) Report on ICT requirements offers and needs for demand side integration, SEESGEN-ICT WP4, CIP ICT-PSP-2008-2 ICT project for Energy Efficiency
- [47] **Horsten F** (2013) *Arbo informatieblad AI-7: Kantoren, 6^e herziene druk*, Sbu Den Haag
- [48] **Hospital Bulletin** (2014) Carbon and Energy Fund acclaims York Hospital scheme
- [49] **Houwing M Papaefthymiou G Heijnen PW and Ilic M D** (2009) Balancing wind power with virtual power plants of micro-CHPS, *Proceedings PowerTech*, Bucharest Hungary
- [50] **Hurtado LA Nguyen PH Kling WL and Zeiler W** (2013) Building energy management systems-optimization of comfort and energy use. *Proceedings 48th international universities' power engineering conference (UPEC)*, Dublin Ireland
- [51] **ISO** (2005) ISO 7730:2005 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, *International Organization for Standardization*, Geneva Switzerland
- [52] **ISO** (2011) ISO 50001: Energy management systems - Requirements with guidance for use, *International Organization for Standardization*, Geneva Switzerland
- [53] **Jain RK Smith KM Culligan PJ and Taylor JE** (2014) Forecasting energy consumption of multi-family residential buildings using support vector regression: Investigating the impact of temporal and spatial monitoring granularity on performance accuracy, *Applied Energy* 123 168-178
- [54] **Kendall S** (2015) *Open Building Concepts*, CIB W104 [www.open-building.org/ob/concepts.html]
- [55] **Kendall S and Teicher J** (2000) *Residential Open Building*, E & FN SPON London
- [56] **Kieny C Berseneff B Hadjsaid N Besanger Y and Maire J** (2009) On the concept and the interest of Virtual Power plant: some results from the European project FENIX
- [57] **Kimpian Ma J** (2013) *Fantasy VS Reality*, CIBSE 22-24
- [58] **Klein L Kwak J Kavulya F Becerik-Gerber B Varakantham P and Tambe M** (2012) Coordinating occupant behaviour for building energy and comfort management using multi-agent systems, *Automation in Construction* 22 525-536
- [59] **Kwak J Varakantham P Maheswaran RT Tambe M Jazizadeh F Kavulya G Klein L Becerik-Gerber B Hayes T and Wood W** (2012) SAVES: a sustainable multi-agent application to conserve building energy considering occupants *Proceedings AAMAS*, Valencia Spain
- [60] **Koch S Mathieu J and Callaway D** (2011) Modelling and control of aggregated heterogeneous thermostatically controlled loads for ancillary services, *Proceedings 17th Power system Computation Conference*, Stockholm Sweden
- [61] **Kofler MJ Reinisch C and Kastner W** (2012) A semantic representation of energy-related information in future smart homes, *Energy and Buildings* 47 169-179
- [62] **Kok K Arnouskos S Nestle D Dimea A Weidlich A Warmer C Strauss P Buchholz B Drenkard S Hatziagyriou N and Lioliou V** (2009) Smart houses for a smart grid, *Proceedings 20th International Conference on Electricity Distribution*, Prague Czech
- [63] **Kok K** (2013) *The PowerMatcher: Smart Coordination for the Smart Electricity Grid*, PhD thesis, Vrije Universiteit Amsterdam, Netherlands
- [64] **Kok K Warmer C and Kamphuis R** (2005) PowerMatcher: multiagent control in the electricity infrastructure, *Proceedings Autonomous Agents and Multiagent Systems*, volume industry track, New York USA
- [65] **Kolokotsa D Rovas D Kosmatopoulos E and Kalaitzakis K** (2011) A roadmap towards intelligent net zero- and positive-energy buildings, *Solar Energy* 85 3067-3084
- [66] **Krieger B Billeter B and Keller L** (2000) Ant-like task allocation and recruitment in cooperative robots, *Nature* 406 992-995
- [67] **Lawrence TM Watson RT Boudreau MC Johnson K Mohammadpour J and Ding L** (2013) Smart Buildings Systems for Adaptation to the Coming Smart Grid, *Proceedings CLIMA*, Prague Czech
- [68] **Li J Poulton G and James G** (2007) Agent-based distributed energy management, In *Proceeding 20th Australian Joint Conference on Artificial intelligence*, Gold Coast Australia
- [69] **Li N Calis G and Becerik-Gerber B** (2012) Measuring and monitoring occupancy with an RFID-based system for demand-driven HVAC operations, *Automation in Construction* 24 89-99
- [70] **Liang J and Du R** (2005) Thermal comfort control based on neural network for HVAC application, *Proceedings IEEE conference on Control*, Toronto Canada

- [71] **Liao C Lin Y** and **Barooah P** (2012) Agent-based and graphical modelling of building occupancy. *Journal of Building Performance Simulation* 5:1 5-25
- [72] **Lichtenberg JJN** (2005) Slimbouwen, Aeneas, Boxel Netherlands
- [73] **Lichtenberg JJN** (2004) Slimbouwen, a rethinking of building : a strategy for product development. Proceedings 21st PLEA international conference Passive and low energy architecture, Eindhoven Netherlands
- [74] **Lo C** and **Ansari N** (2011) The Progressive Smart Grid System from Both Power and Communications Aspects, *Communications Surveys & Tutorials*, IEEE PP99 1-23
- [75] **Lopes AJ Lezama R** and **Pineda R** (2011) Model Based Systems Engineering for Smart Grids as Systems of Systems, *Proceedings Computer Science* 6 441-450
- [76] **MacCracken M** (2010) Energy Storage, Providing for a Low-Carbon Future, *ASHRAE Journal* 28-34
- [77] **Macek K Marik K** and **Stuka P** (2011) Ontology-driven design of an Energy Management System, 21th European Symposium on Computer Aided Process Engineering, ESCAPE, Chalkidiki Greece
- [78] **Mahdavi A** (2011) The human dimension of building performance simulation, *Proceedings IBPSA '11*
- [79] **Mamidi S Chang YH** and **Maheswaran R** (2012) Improving building energy efficiency with a network of sensing, learning and prediction agents, *Proceedings 11th Conference on Autonomous Agents and Multi-agent Systems*, Valencia Spain
- [80] **Martani C Lee D Robinson P Britter R** and **Ratti C** (2012) Enernet: studying the dynamic relationship between building occupancy and energy consumption, *Energy and Building* 47 584-9.
- [81] **Mathieu JL** and **Callaway DS** (2012) State estimation and control of heterogeneous thermostatically controlled loads for load following, *Proceedings IEEE 45th Hawaii International Conference on System Sciences*, Maui USA
- [82] **Melo N Prata R Concalves R** and **Mira F** (2009) Micro Generation in Portugal – EDP experience and future perspective, 20th International conference on Electricity Distribution, Prague Czech
- [83] **Mokhtar M Stables M Liu X** and **Howe J** (2013) Intelligent multi-agent system for building heat distribution control with combined gas boilers and ground source heat pump, *Energy and Buildings*, 62 615-626
- [84] **Oldewurtel F Parisio A Jones CN Gyalistras D Gwerder M Stauch V** and **Morari M** (2012) Use of model predictive control and weather forecasts for energy efficient building climate control, *Energy and Buildings* 45 15-27
- [85] **Oldewurtel F Sturzenegger D** and **Morari M** (2013) Importance of occupancy information for building climate control, *Applied Energy* 101 521-532
- [86] **Page J Robinson D Morel N** and **Scartezzini J** (2008) A generalized stochastic model for the simulation of occupant presence, *Energy and Buildings* 40 83-98
- [87] **Palizban O Kauhaniemi K** and **Guerrero JM** (2014) Microgrids in active network management - Part I: Hierarchical control, energy storage, virtual power plants, and market participation, *Renewable and Sustainable Energy Reviews* 1 1-13
- [88] **Pandzic H Morales JM Conejo AJ** and **Kuzle I** (2013) Offering model for a virtual power plant based on stochastic programming, *Applied Energy* 105 282-292
- [89] **Pennings LWHA** (2009) Multi Agent System to Optimize Comfort and Energy Flows in the Built Environment, MSc Thesis, Technische Universiteit Eindhoven
- [90] **PowerMatcher** (2015) [www.powermatcher.net]
- [91] **Pruissen OP van** and **Kamphuis R** (2010) Multi agent building study on the control of the energy balance of an aquifer, *Proceedings Improving Energy Efficiency in Commercial Buildings*, Frankfurt Germany
- [92] **Pruissen OP van Kamphuis IG Boxem G Zeiler W Wortel W** and **Velden JAJ van der** (2009) Design of an agent architecture based on the powermatcher approach, *Proceedings CISBAT*, Lausanne Switzerland
- [93] **Ramchurn SD Vytelingum P Rogers A** and **Jennings NR** (2011) Agent-based control for decentralized demand side management in the smart grid, *Proceedings 10th Conference on Autonomous Agents and Multi-agent Systems*, Taipei Taiwan
- [94] **Ridder HAJ de** (2011) LEGOlising? Mauritsgroen
- [95] **Ridder HAJ de** (2006) Het living building concept: een weekend perspectief voor de bouw PSIBouw, Gouda Netherlands
- [96] **Ridder HAJ de** (2007) Living building concept for market dynamics, innovation and sustainable buildings, *Proceedings of the second international conference world of construction project management*, TU Delft, Netherlands
- [97] **Robinson D** and **Haldi F** (2011) Modelling Occupants' Presence and Behaviour – Part I, *Journal of Building Performance Simulation* 4:4 301-302
- [98] **RVO** (2014) Monitor Energiebesparing Gebouwde Omgeving 2013
- [99] **Saputro N Akkaya K** and **Uludag S** (2012) A survey of routing protocols for smart grid communications, *Computer Networks* 56:11 2742-2771
- [100] **Savanović P** (2009) Integral design method in the context of sustainable building design, PhD thesis, TU Eindhoven, Netherlands
- [101] **SEAT** (2014) IS399: Energy Efficient Design Management, Sustainable Energy Authority of Ireland (SEAI), Dublin Ireland
- [102] **Sinitzyn NA Kundu S** and **Backhaus S** (2013) Safe protocols for generating power pulses with heterogeneous populations of thermostatically controlled loads, *Energy Conversion and Management*, 67 297-308
- [103] **Slootweg J Meijden DM van Knigge J** and **Veldman E** (2011) Demystifying smart grids - Different concepts and the connection with smart metering, *Proceedings 21st International Conference on Electricity Distribution Frankfurt Germany*
- [104] **Soman S Zareipour H Malik O** and **Mandal P** (2010) A review of wind power and wind speed forecasting methods with different time horizons, *Proceedings North American Power Symposium*

- [105] **Sun Z Shengwei W** and **Na Z** (2011) Model-based optimal control of outdoor air flow rate of an air-conditioning system with primary air-handling unit, *Indoor and Built Environment* 20 626-637
- [106] **Tascikaraogly A Erdinc O Uzunoglu M** and **Karakas A** (2014) An adaptive load dispatching and forecasting strategy for a virtual power plant including renewable energy conversion units, *Applied Energy* 119 445
- [107] **Taskforce Intelligente Netten** (2011) Op weg naar intelligente netten in Nederland, Einddocument van de Taskforce Intelligente Netten
- [108] **TenneT** (2011) Imbalance Management TenneT Analysis report, Version 1.0
- [109] **Thomassen TPW** (2014) Smart Grid Building energy management, MSc Thesis TU Eindhoven, Netherlands
- [110] **Van Breemen AJ** and **Vries TJ de** (2001) Design and implementation of a room thermostat using an agent-based approach, *Control Engineering Practice* 9:3 233-248
- [111] **Van Dyke Parunak H** (1999) Industrial and practical applications of DAI, Multi-agent systems. 377-421 MIT Press Cambridge
- [112] **Venayagamoorthy G Rohrig K** and **Erllich I** (2012) One Step Ahead: Short-Term Wind Power Forecasting and Intelligent Predictive Control Based on Data Analytics, *IEEE Power and Energy Magazine* 10:5 70-78
- [113] **Virote J** and **Neves-Silva R** (2012) Stochastic models for building energy prediction based on occupant behaviour assessment, *Energy and Buildings* 53 183-193
- [114] **Vonk BMJ Nguyen PH Grand MOW Slootweg JG** and **Kling WL** (2012) Improving Short-term load forecasting for a local energy storage system, *Proceedings 47th Universities Power Engineering Conference*, Uxbridge UK
- [115] **Wang S** (2013) Intelligent Building Electricity Demand Management and Interactions with Smart Grid, *Proceedings CLIMA*, Prague Czech
- [116] **Warmer J Hommelberg , Kok** and **Kamphuis I** (2008) Local DER driven grid support by coordinated operation of devices, *Proceedings IEEE Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century*, Pittsburgh USA
- [117] **Yang R and Wang L** (2011) Multi-objective optimization for decision-making of energy and comfort management in building automation and control, *Sustainable Cities and Society* 2:1 1-7
- [118] **Yang R** and **Wang L** (2013) Development of multi-agent system for building energy and comfort management based on occupant behaviours, *Energy and Buildings* 56 1-7
- [119] **Ygge F** (1998) Market-Oriented Programming and its Application to Power Load Management, PhD Thesis, Lund University, Sweden
- [120] **Yu D Ferranti E** and **Hadeli H** (2013) An intelligent building that listens to your needs. In: *Proceedings 28th ACM Symposium*, Coimbra Portugal
- [121] **Zeiler W** and **Savanović P** (2009) General Systems Theory based Integral Design Method, *Proceedings ICED'09*, Stanford USA
- [122] **Zeman A Prokopenko M Guoand Y** and **Li R** (2008) Adaptive Control of Distributed Energy Management: A Comparative Study. *Proceedings 2nd IEEE International Conference on Self-Adaptive and Self- Organizing Systems*, Venice Italy
- [123] **Zhang D Shah N** and **Papageorgiou LG** (2013) Efficient energy consumption and operation management in a smart building with microgrid, *Energy Conversion and Management* 74 209-222
- [124] **Zhang Q Tezuka T Ishihara KN** and **McLellan BC** (2012) Integration of PV power into future low-carbon smart electricity systems with EV and HP in Kansai Area. Japan, *Renewable Energy* 44 99-108
- [125] **Zhang W Lian J Chang C** and **Kalsi K** (2013) Aggregated Modelling and Control of Air Conditioning Loads for Demand Response, *Power Systems, IEEE Transactions on* 28:4 4655-4664
- [126] **Zhao H-X** and **Magoulès F** (2012) A review on the prediction of building energy consumption, *Renewable and Sustainable Energy Reviews* 16:6 3586-3592



International Journal of Design Sciences and Technology

Design Sciences, Advanced Technologies and Design Innovations

Towards a better, stronger and sustainable built environment

Aims and scope

Today's design strongly seeks ways to change itself into a more competitive and innovative discipline taking advantage of the emerging advanced technologies as well as evolution of design research disciplines with their profound effects on emerging design theories, methods and techniques. A number of reform programmes have been initiated by national governments, research institutes, universities and design practices. Although the objectives of different reform programmes show many more differences than commonalities, they all agree that the adoption of advanced information, communication and knowledge technologies is a key enabler for achieving the long-term objectives of these programmes and thus providing the basis for a better, stronger and sustainable future for all design disciplines. The term sustainability - in its environmental usage - refers to the conservation of the natural environment and resources for future generations. The application of sustainability refers to approaches such as Green Design, Sustainable Architecture etc. The concept of sustainability in design has evolved over many years. In the early years, the focus was mainly on how to deal with the issue of increasingly scarce resources and on how to reduce the design impact on the natural environment. It is now recognized that "sustainable" or "green" approaches should take into account the so-called triple bottom line of economic viability, social responsibility and environmental impact. In other words: the sustainable solutions need to be socially equitable, economically viable and environmentally sound.

IJDST promotes the advancement of information and communication technology and effective application of advanced technologies for all design disciplines related to the built environment including but not limited to architecture, building design, civil engineering, urban planning and industrial design. Based on these objectives the journal challenges design researchers and design professionals from all over the world to submit papers on how the application of advanced technologies (theories, methods, experiments and techniques) can address the long-term ambitions of the design disciplines in order to enhance its competitive qualities and to provide solutions for the increasing demand from society for more sustainable design products. In addition, IJDST challenges authors to submit research papers on the subject of green design. In this context "green design" is regarded as the application of sustainability in design by means of the advanced technologies (theories, methods, experiments and techniques), which focuses on the research, education and practice of design which is capable of using resources efficiently and effectively. The main objective of this approach is to develop new products and services for corporations and their clients in order to reduce their energy consumption.

The main goal of the *International Journal of Design Sciences and Technology* (IJDST) is to disseminate design knowledge. The design of new products drives to solve problems that their solutions are still partial and their tools and methods are rudimentary. Design is applied in extremely various fields and implies numerous agents during the entire process of elaboration and realisation. The International Journal of Design Sciences and Technology is a multidisciplinary forum dealing with all facets and fields of design. It endeavours to provide a framework with which to support debates on different social, economic, political, historical, pedagogical, philosophical, scientific and technological issues surrounding design and their implications for both professional and educational design environments. The focus is on both general as well as specific design issues, at the level of design ideas, experiments and applications. Besides examining the concepts and the questions raised by academic and professional communities, IJDST also addresses the concerns and approaches of different academic, industrial and professional design disciplines. IJDST seeks to follow the growth of the universe of design theories, methods and techniques in order to observe, to interpret and to contribute to design's dynamic and expanding sciences and technology. IJDST will examine

design in its broadest context. Papers are expected to clearly address design research, applications and methods. Conclusions need to be sufficiently supported by both evidence from existing research (reference to existing design research knowledge) as well as strong case-studies from any design discipline. A paper must contain at least one chapter on research questions, methodology of research and methods of analysis (the minimum length is 1500 words). The concluding chapter (the minimum length is 1000 words) will summarise the paper and its results. The concluding chapter also examines and discuss applications, advantage, shortcomings and implications of the investigation for both professional and educational design communities as well as for the people and the society. Also authors are also encouraged to include in this chapter a discussion of the possible future research that is required or is possible in order to enhance the research findings.

The papers considered for IJDST cover a wide range of research areas including but not limited to the following topics: Design research, design science, design thinking, design knowledge, design history, design taxonomy, design technology, design praxeology, design modelling, design metrology, design axiology, design philosophy, design epistemology, design pedagogy, design management, design policy, design politics, design sociology, design economics, design aesthetics, design semantics, design decision-making, design decisions, design evaluation, design sustainability, design logic, design ontology, design logistics, design syntaxis, design ethics, design objective, design responsibility, design environment, design awareness, design informatics, design organization, design communication, design intelligence, design evaluation, design education, design theories, design techniques, design methods, design operations, design processes, design products, design users, design participation, design innovation, design inspired by nature, design case studies, design experiments, etc.

The *International Journal of Design Sciences and Technology* is devoted to further exploration of all themes and issues that are directly or indirectly relevant to the exploration, introduction, discussion of design sciences and technology, cross referencing domains and any other themes emerging in the future.

Instructions for Authors and Review Process

Pre-review Stage (Editor Global Review): Papers can only be considered for review when they deal with a subject relevant to the content of the journal. In addition all papers submitted must follow the journal's paper structure and author instructions before they can be considered for review. These instructions also affect the content of the paper. The preferred size of a paper is about 10000 words (The minimum length of a paper is about 7000 words). The title must not be longer than seven words. Subtitles are not permitted. The maximum length of the abstract is 150 words. The paper must contain an introductory chapter with extensive literature review of similar research (the minimum length of the introduction chapter is about 1000 words). The paper devotes at least one chapter to detailed discussion of research questions, research analysis and research contributions (the minimum length of this chapter is about 1000 words). The conclusion will summarise the research and its results. In addition this chapter includes a detailed discussion of applications, advantage, shortcomings and implications of the investigation as well as future research for both design professionals and the design education (the minimum length of conclusions is about 1000 words). Submit a paper at this stage as PDF.

Review Stage (Peer Review): Only papers meeting all IJDST requirements can be considered for review. All papers are reviewed by at least two expert reviewers. The main author of a reviewed and accepted paper will be notified with instructions to resubmit the paper. All reviewed and accepted papers have to be resubmitted, implementing reviewers and editors comments and/or suggestions. Only accepted papers conforming to instructions should be considered for publication in the *International Journal of Design Sciences and Technology*. A paper should follow the IJDST paper structure. The review process will be repeated until all requirements are met.

The first page of the paper must contain the full title of the paper as well as the Name+Surname (no initials), affiliation, address, telephone, fax and email of the corresponding author to whom all correspondence to be directed. Also mention the Name+Surname (no initials), affiliation, postal address, telephone, fax and email of the co-authors (if any).

The second page contains the full title of the paper (maximum 7 words), the sub-title is not permitted, an abstract of about 50 to 150 words summarising the content of the paper and 3-5 keywords for the purpose of indexing (the use of references in the abstract is discouraged). The length of a paper is about 7000 words (10000 words is preferred). Short papers will not be accepted for publication and have to be resubmitted. The use of Footnotes is permitted (maximum length is about 50 words). Footnotes should be numbered consecutively. For instance: [[17 A 'footnote' reflects additional information, a reference or the URL of a website]].

The paper will be written in the UK English. It will be single-spaced with 30 mm margins on all sides (paper size A4). Use Times New Roman for the main body of text (size 10), figures (size 8) or tables (size 8). The use of Bold, Italics, ALL CAPS, SMALL CAPS, etc. is discouraged. All chapters should be numbered consecutively (more than two level sub-headings is discouraged). All Figures and Tables with their respective captions should be numbered consecutively. They should each, be placed on a separate page, at the end of the paper. Give an approximate insertion point for figures and tables, between double square brackets. For instance: [[insert Figure 5]]. You will be asked to resubmit tables, figures and images if necessary. The paper must be submitted in plain text. Do not layout your paper. Do not use any styles or any automatic layout system. Please do not use 'Track Changes'.

All tables should be clearly referred to in the main body of text as Table 1, Table 2, etc. All Figures should be clearly referred to in the main body of text as Figure 1, Figure 2, etc. Line drawings should be of good quality. Use light background if possible (white is preferred). Photographs and screen-shots should also be submitted separately as JPEG files (use high resolution for better results). Authors should prepare high quality figures and drawings. The use of colours in your illustrations is permitted although the hardcopy of the journal is not published in colour. Maximum width and height of a figure are respectively 150 mm and 190 mm. Maximum width and height of a table are respectively 115 mm and 170 mm. All Equations will be numbered consecutively and should be clearly mentioned in the main body of text.

All references will appear at appropriate places in the main body of text. References are collected at the end of the paper, arranged in alphabetical order (numbered consecutively) by the first author's surname, followed by initials. All authors should be mentioned. Dates will appear between brackets after the authors' name(s). This is followed by the title of the book, name of the publisher, place of publication and page numbers (if applicable). To refer to a journal paper, add the full title of the journal followed by Volume:Number and page(s). The number of references to the author's own previous publications will not exceed 5% of the total number of references. References that are not mentioned in the main body of text are not allowed. Examples of references to a book, a journal or a website are shown below:

- [1] **Beckett KL and Shaffer DW** (2004) Augmented by Reality: The Pedagogical Praxis of Urban Planning as a Pathway to Ecological Thinking, University of Wisconsin, Madison
- [2] **Blackman, DA** (2001) Does a Learning Organisation Facilitate Knowledge Acquisition and Transfer? Electronic Journal of Radical Organization Theory, 7:2 [www.mngt.waikato.ac.nz/Research/ejrot/Vol7_1/Vol7_1articles/blackman.asp]
- [3] **Buxton, W** (1997) Living in Augmented Reality: Ubiquitous Media and Reflective Environments. In: Finne K, Sellen A and Wilber S eds, Video Mediated Communication, Erlbaum, Hillsdale NJ, 363-384
- [4] **Dixon, NM** (2000) Common Knowledge: How companies thrive by sharing what they know, Harvard Business School Press, Boston, MA

- [5] **Djenidi H, Ramdane-Cherif A, Tadj C and Levy N** (2004). Generic Pipelined Multi-Agents Architecture for Multimedia Multimodal Software Environment, *Journal of Object Technology*, 3:8, 147-169
- [6] **Gorard, S and Selwynn, N** (1999) Switching on to the learning society? Questioning the role of technology in widening participation in lifelong learning, *Journal of Education Policy*, 14:5, 523-534
- [7] **World Bank** (2002) Social assessment as a method for social analysis, World Bank Group [www.worldbank.org/gender/resources/assessment/samethod.htm]

The definitive paper is submitted as plain text MS Word file for the PC (MS Word RTF format for the Apple). In addition, a formatted version of the paper (including images and tables at their approximate places) will be submitted in PDF format. All figures must be submitted separately in high resolution jpg format. Submit your paper as an email attachment to: submit2ijdst@gmail.com.

Author(s) of an accepted paper have to complete, sign and return a *Copyrights Transfer Form* to the publisher. This copyrights transfer assignment will ensure the widest possible dissemination of information. Papers published in the *International Journal of Design Sciences and Technology* cannot be published elsewhere, in any form (digital, paper-based or otherwise) without a prior written permission from the publisher.

The author(s) are responsible for obtaining permission to utilize any copyrighted material. For more details about this subject, please contact the publisher at an early stage.

A paper can be rejected at any stage if the requirements are not met. The decision of the Editor-in-Chief on all matters related to the *International Journal of Design Sciences and Technology* including the review process, publication of papers, etc. is final and cannot be disputed.

There is no deadline for the publication of an accepted paper that will be published online within one to four months after the final re-submission is accepted. The hardcopy book of the volume will be published when 8 papers are published online. The corresponding author of a paper published in the *International Journal of Design Sciences and Technology* will receive a digital copy of the author's paper free of charge. Hard copies of any individual paper (minimum 100 copies) and the hardcopy of the IJDST Volume (containing 8 papers published online) can be purchased from the publisher (ask for an invoice from the publisher ijdst@europia.org).



How to Order

IJDST-online

You can view and download a digital version of individual papers free of charge from the journal's website.

IJDST Hardcopies

Hardcopies of individual papers (minimum order 100 copies) and volumes (minimum order is one single copy of the book containing 2 issues) can be ordered directly from Europaia Productions. You need to send your **Request for an Invoice** (preferably by email, Fax or letter) indicating details of your order and the quantities. Please provide your full name and initials, postal address, email and telephone number. An invoice will be sent to you indicating the total amount of your order, the cost of packing/postage and method of payment.

Individual Subscription IJDST Hardcopies

Individuals can subscribe to receive a hardcopy of the book containing 2 issues for € 200.00 (incl. 5.5 % VAT, packing and postage). You need to send your **Request for a Subscription Invoice** (preferably by email, Fax or letter) indicating the IJDST Volume. Please provide your full name and initials, postal address, email and telephone number. An invoice will be sent to you indicating the method of payment.

Institutional Subscription IJDST Hardcopies

Libraries and organisations can subscribe to receive a hardcopy of the book containing 2 issues for € 200.00 (incl. 5.5 % VAT, packing and postage). You need to send your **Request for a Subscription Invoice** (preferably by email, Fax or letter) indicating the IJDST Volume. Please provide details of the library or organisation, name contact person, postal address, email, telephone number and Fax number. An invoice will be sent to you indicating the method of payment.

Other Publications

Other Europaia Productions publications can be ordered from the address below. You always need to send your **Request for an Invoice** (preferably by email, Fax or letter) indicating details of your order and the quantities. Please provide your full name and initials, postal address, email and telephone number. An invoice will be sent to you indicating the total amount of your order, the cost of packing/postage and method of payment.

Europaia Productions

15, avenue de Ségur, 75007 Paris, France

Telephone +33 1 4551 2607 / Fax +33 1 4551 2632

E-mail: ijdst@europia.fr

URL: <http://europia.org/ijdst/>

europa