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The role of smart grids in the building sector

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ABSTRACT

The smart grids are modern electric power grid infrastructure for enhanced efficiency and reliability through automated control, high-power converters, modern communications infrastructure, sensing and metering technologies, and modern energy management techniques based on the optimization of demand, energy and network availability. The role of buildings in this framework is very crucial. This paper addresses critical issues on smart grid technologies and the integration of buildings in this new power grid framework. The main objective of this paper is to provide a contemporary look at the current state of the art in the potential of buildings and communities to be integrated in smart grids as well as to discuss the still-open research issues in this field. The challenges for the building sector are discussed and future research prospects are analysed.

Contents

1. Introduction

Smart grid is a dynamically interactive real-time infrastructure concept that encompasses the many visions of the stakeholders of diverse energy systems. [1]. Smart grids are electrical power grids that are more efficient and more resilient and therefore, "smarter" than the existing conventional power grids. The smartness is focused not only on the elimination of black-outs, but also on making the grid greener, more efficient, adaptable to customers' needs, and therefore, less costly [1,2]. Smart grids incorporate the innovative IT technology that allows for two-way communication between the utility and its customers/users. As a result the sensing along the transmission lines and the sensing from the customer's side is what makes the grid "smart".

Like the Internet, the Smart Grid consists of controls, computers, automation, new technologies, smart buildings and equipment working together, but in this case these technologies will work with the electrical grid to respond digitally to the quickly changing energy demands of the users. Therefore smart grids create an exceptional opportunity for the support of the development of smart zero energy buildings and communities and offer the step towards the Internet of Things for the Energy and Building Industry [3,4].

Smart Grids open the door to new applications with far-reaching inter-disciplinary impacts: providing the capacity to safely integrate more renewable energy sources (RES), smart buildings and distributed generators into the network; delivering power more efficiently and reliably through demand response and comprehensive control and monitoring capabilities; using automatic grid reconfiguration to prevent or restore outages (self-healing capabilities); enabling consumers to have greater control over their electricity consumption and to actively participate in the electricity market.

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Smart Grids can create a revolution in the building sector. The accumulated experience of the last decades has shown that the hierarchical, centrally controlled grid of the 20th Century is ill-suited to the needs of the 21st Century. The smart grid can be considered as a modern electric power grid infrastructure for enhanced efficiency and reliability through automated control, high-power converters, modern communications infrastructure, sensing and metering technologies, and modern energy management techniques based on the optimization of demand, energy and network availability. The role of buildings in this framework is very crucial. This paper addresses critical issues on smart grid technologies and the integration of buildings in this new power grid framework [5]. The main objective of this paper is to provide a contemporary look at the current state of the art in the potential of buildings and communities to be integrated in smart grids as well as to discuss the still-open research issues in this field. Since the vast majority of smart grids' potential customers are buildings (residential, commercial, retail and industrial) and communities, the paper addresses the challenges posed by smart grids on building and community level.

2. Smart and zero energy buildings

The energy consumption for buildings accounts for 40% of the energy used worldwide. It has become a widely-accepted fact that measures and changes in the building modus operandi can yield substantial energy savings minimizing the buildings' carbon footprint [6,7]. Moreover, buildings in the near future should be able to produce the amount of energy they consume, i.e., become zero or nearly zero energy buildings (ZEBs) [8,9]. This is a mandatory requirement based on the fact that by 31 December 2020, all new buildings shall be nearly zero-energy consumption buildings. New buildings occupied and owned by public authorities shall comply with the same criteria by 31 December 2018 [8,10].

ZEBs are buildings that work in synergy with the grid, avoiding putting additional stress on the power infrastructure [11]. Achieving a ZEB includes apart from minimizing the required energy through efficient measures and covering the minimized energy needs by adopting renewable sources, a series of optimised and well balanced operations between consumption and production coupled with successful grid integration [12].

Information and Computer enabled Technologies (ICT) and smart grids implementation are the keys to achieve the aforementioned zero energy goals [13]. ICT for energy management in buildings has evolved considerably the last decades leading to a better understanding and penetration of the term "smart buildings" [14]. Advances in the design, operation optimization and control of energy-influencing building elements (e.g., HVAC, solar, fuel cells, CHP, shading, natural ventilation, etc.) unleashed the potential for realization of significant energy savings and efficiencies in the operation of both new and existing dwellings worldwide. Smart buildings ready to be interconnected with smart grids should comply with the following requirements:

(a) Incorporation of smart metering.
(b) Demand response capabilities.
(c) Distributed architecture.
(d) Interoperability.

2.1. Smart metering

Smart metering is a prerequisite and starting point for effective implementation of smart grids and zero energy buildings' perspective. In Finland, the usage of smart metering encouraged consumers to increase energy efficiency by 7%. In order for electricity providers to deliver intelligent services for customers, bidirectional metering interfaces should be used to obtain customers' energy demand information [15]. Moreover through the advances of smart metering, sensors based approaches can be exploited to provide energy load forecasting [16]. Data collected from smart meters, building management systems and weather stations can be used by advanced artificial intelligent techniques and machine learning algorithms to infer the complex relationships between the energy consumption and various variables such as temperature, solar radiation, time of day and occupancy [16–21]. Due to the fast development and application of low cost options for energy metering in recent years, energy load prediction is becoming increasingly relevant and cost effective[16,22].

Smart metering with sensor based approaches was exploited in the framework of Green@Hospital project (www.greenhospital-project.eu/). In this project, the outdoor temperatures and hospitals' energy demand were predicted for 4, 8, 12 and 24 h ahead [23]. This prediction is then used for optimal control of the hospitals' air handling units leading to almost 20% reduction of the energy use. Other researchers exploit neural networks' capabilities for 24 h-ahead building-level electricity load forecasting using data collected from various operational commercial and industrial building sites [19]. Data mining based approaches to developing ensemble models for predicting next-day energy consumption and peak power demand, with the aim of improving the prediction accuracy are also developed. This approach was adopted to analyse the large energy consumption data of the tallest building in Hong Kong [22] with very satisfactory results. These ensemble models can be valuable tools for developing strategies of fault detection and diagnosis, operation optimization and interactions between buildings and smart grid. Moreover, data processing and interpretation extracted by the smart metering can provide useful information for the buildings' energy behaviour. Advanced techniques such as cluster analysis are used by various researchers [14,24] leading to the determination of optimum clustering procedures as well as building benchmarking.

2.2. Demand response (DR)

DR [25,26] offers the capability to apply changes in the electricity usage by the consumers from their normal consumption patterns in response to changes in the electricity pricing over time [27]. This leads to lower energy demand during peak hours or during periods that electricity grid's reliability is put at risk. Therefore demand response is a reduction in demand designed to reduce peak load or avoid system emergencies. Hence, demand response can be a more cost-effective alternative than adding generation capabilities to meet the peak and or occasional demand spikes. The underlying objective of DR is to actively engage customers in modifying their consumption in response to pricing signals. Demand response is expected to increase energy market efficiency and security of supply, which will ultimately benefit customers by way of options for managing their electricity costs and lead to reduced environmental impact.

The already available DR programs are generally categorized into incentive- and price-based programs. Incentive-based programs provide economic incentives for customers to reduce demand at times of capacity shortage or exceptionally high electricity prices, whereas price-based demand response programs involve dynamic tariff rates that promote general changes in patterns of electricity use. Time-of-use tariffs, which are one of the major price-based demand response programs in use involve different unit prices within different blocks of time, and reflect the average cost of utilities during these periods [26].

There are some efforts in country level to show the benefits of DR in electricity supply. The policy discussions in UK on the economic case for DR are analysed by Bradley et al. [27]. A cost/benefit analysis is performed in a quantitative manner showing that the benefits on country level are clearly very significant, i.e., 2.8% reduction in overall electricity use and a 1.3% shift in peak demand. Moreover the economic viability of the DR mainly depends on ensuring participation by the end users, i.e., the building sector. Increase of participation can be ensured by lowering the participant costs and sharing of benefits. Finally it is revealed that the actual costs of the infrastructure are also affected by customer engagement and trust. An empirical study for Sweden is performed by Bartusch et al. [26], in order to estimate the end users' response to a demand-based time-of-use electricity distribution tariff among Swedish single-family residential houses. The study showed that in a long term the residential households still respond to the price signals of the tariff by cutting demand in peak hours and shifting electricity consumption from peak to off-peak hours.

Energy efficient smart buildings are possible by integrating smart meter, smart sockets, domestic renewable energy generation and energy storage systems for integrated energy management, and this integrated system supports demand side load management, distributed generation and distributed storage provisions of future smart grids [28,29]. Consequently, the effective integration of buildings in smart grids requires the appropriate levels of digital technology and **interoperability** [30]. The successful implementation of DR as mentioned in the previous paragraphs requires near-real-time power management [31] and advanced building automation and communication protocols. More information on the various communication protocols that can support the ZEB perspective can be found in [8]. Recent studies interconnect ASHRAE BACNET protocol with the wireless ZigBee protocol to provide DR in the buildings' energy management side. The Addendum announced by ASHRAE specifies that the wireless communication for BACnet will be based on ZigBee protocol [32]. The interconnection of Bacnet with ZigBee allows the management of electrical resources and devices' load, targeting to optimise and reduce the electricity cost and reduce peak power consumption. The real time characteristics and functionalities of the BACnet–ZigBee interconnection are examined, showing the potential and critical role of recent developments in the implementation of smart grids' infrastructure in buildings. Other researchers provide interconnection of the BACnet and EnOcean protocols to measure energy metering of various appliances in buildings and control the load using wireless communications [25]. Additionally, the DR using the specific connectivity is shown using experimental facilities that can respond to real-time changes in the electricity price.

2.3. Distributed systems

Distributed systems play a crucial part in effecting smart buildings' demand response as they provide the necessary technical infrastructure [33]. Moreover distributed systems support the effective exploitation of energy storage. Since smart grids may integrate renewable energy sources, energy storage is often seen as necessary for the electric utility systems with large amounts of solar or wind power generation to compensate for the inability to schedule these facilities to match power demand.

Load shifting through effective thermal energy storage or electricity storage is a major part of smart grids and already exploited by various studies for generation–consumption matching and zero energy targeting [32,33]. Therefore as the major power consumers at demand side, buildings can actually perform as distributed thermal storages to help relieve power imbalance of a grid. This requires accurate prediction of possible power demand variations of buildings and energy information from the grid side for interaction and optimization [36] based on measurements acquired from smart metering.

Finally smart grids can play a significant role in the building sector due to the fact that they create a physical proximity between consumers and energy production that may help increase end users' awareness towards a more rational use of energy for buildings. Studies show that the users awareness combined with smart grids can decrease the energy costs by 15% [37].

3. Smart and zero energy communities

Moving from the building to the community level, the requests of the future communities are very demanding. They should be places of advanced social progress and environmental regeneration, as well as places of attraction and engines of economic growth based on a holistic integrated approach in which all aspects of sustainability are taken into account.

As mentioned in the Leipzig Charter (http://ec.europa.eu/regional_policy/archive/themes/urban/leipzig_charter.pdf), sustainable communities and cities should:

- Create the suitable environment for urban populations that can attract industry, businesses, tourism and workforces.
- Modernize the infrastructure networks. This approach is about achieving a high-quality and affordable urban transport system that includes a network linking the city to the region, as well as providing and improving supply networks such as energy, waste-water treatment and water supply.
- Ensure the efficient use of natural resources, economic efficiency and the energy efficiency in new and existing buildings.

The National Renewable Energy Laboratory defined the zero energy community as "*one that has greatly reduced energy needs through efficiency gain such that the balance of energy for vehicles, thermal, and electrical energy within the community is met by renewable energy*" [12] and "*community scenarios could link transportation, home and the electric grid as well as enable large quantities of renewable power onto the grid*".

Therefore, a smart zero energy community (http://www.smartcommunities.org) is a region where its citizens and local authorities are exploiting the information technology to "*transform life and work in significant and fundamental rather than incremental ways*" to meet the aforementioned strategies and objectives. As mentioned in the Smart Communities website: "*The goal of such an effort is more than the mere deployment of technology. Rather it is about preparing one's community to meet the challenges of a global, knowledge economy*".

Smart Grids can be the basis of smart zero energy communities offering:

(1) Reliability and security as the prominence of information technology.
(2) Optimal operation thus contributing to a generation–consumption matching [8] through the full exploitation of Low Zero Carbon (LZC) emissions' technologies [12,36].
(3) Adaptation to the rapidly evolving ICT technologies, as well as exploitation of the internet capabilities and smart devices and applications [4].
(4) The necessary balance between the energy demand and energy production on community, neighbourhood and district level contributing to the smart and sustainable urban environment.

Effective management of the intermittency of Renewable Energy Sources power generation as well as of operational and capacity reserve in conjunction with the buildings' energy demand profiles. In order to understand more clearly the role of smart grids in zero energy communities, some examples are presented in

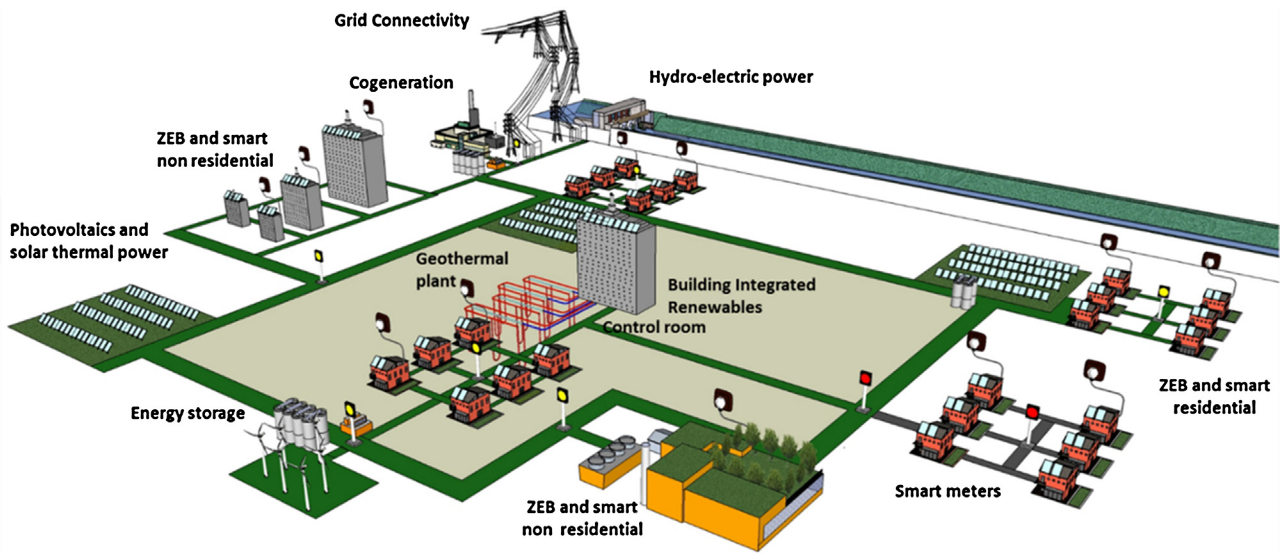

Fig. 1. The smart grid's components.

the next paragraphs. More details on the Smart Grids penetration worldwide can be found in [39].

The role of net energy metering and the time of use rate in the electricity demand of a zero energy apartment community are investigated [40]. The apartments' community is placed in West Village in Davis, California. Smart scheduling is applied in order to achieve peak load shaving by using the various household appliances during off-peak hours. The peak demand is reduced by 18%, the part-peak demand by 32% and the off-peak demand is increased by 12%. Since the apartments are using photovoltaics for electricity, the community occupants can benefit significantly if the surplus generation by the photovoltaics is maximized and sold to the grid during peak hours (Fig. 1) .

Moreover a low energy community configuration for the Island of Hawaii is proposed in [41]. The overall work included energy production using photovoltaics, storage systems using batteries and compressed air systems, demand response of buildings, passive cooling techniques for energy efficiency as well as microclimate and landscape assessment.

An advanced energy management and optimization model for the operation of the Leaf Microcrid Community is proposed by Kolokotsa et al. [42]. The aim of the model is to minimize the energy cost of the microgrid by performing a generation–consumption matching using genetic algorithms. The optimization procedure is supported by energy load forecasting and energy production prediction (by the photovoltaics and hydroelectric plant) using artificial neural networks. While the optimization horizon is 24 h ahead, the optimization and management procedure leads to almost 6% reduction of the energy costs for the microgrid and significant cost savings for the community without extra energy investment.

Similar works include apart from genetic algorithms [43,44] the use of fuzzy logic and Particle Swarm Optimization (PSO) method [45] as well as non-linear constrain multiobjective optimization method[46].

Another potential application of smart grids in community level is the operation of small and medium enterprises (SMEs) which have multiple operational characteristics ranging from office buildings, retail, industrial, etc. and different energy patterns and needs [47]. Though the potential for carbon reduction of SMEs is unclear due to the diversity of the end uses, smart grids can be a viable tool for SMEs decarbonization since additional data can be available through detailed smart metering. Therefore the electricity loads of the SMEs can ne discretized and the proportions that are available for load shifting or shaving can be more easily identified.

These can be space heating, cooling and hot water in the commercial sector and heating or cooling in industry.

Last but not least, the social aspects of smart grids in community level should be clearly examined. The fast promotion of smart grids' capabilities and potential applications will be much easily digested by the local communities if social inclusion is taken into account. The role of social experts in this aspect is of great importance [48].

4. Conclusions and future prospects

Smart Grids can be considered very promising for the energy and building environment industry due to the fact that create a physical proximity between consumers and micro energy sources that help increase consumer awareness towards a more rational use of energy.

Moreover smart grids can offer new opportunities for the reduction of gas emissions by creating technical conditions that increase the connection of devices and renewable energy resources at the low voltage level.

In addition, smart grids in the building sector offer a great opportunity for improving the power quality and reliability of energy sources due to the fact that it offers decentralization of supply, better supply and demand matching, reduction of transmission losses and minimization of downtimes. Thus energy investments can be shifted from the expansion of transmission and large scale generation systems to the energy efficiency in the building sector, i.e., improving building fabric, increasing green infrastructure in the community, improving indoor and outdoor environment interaction by landscape solutions.

In addition, widespread application of modular micro generation sources on community level may contribute to the reduction of the energy price in the power market. Further, price reduction may be achieved by optimizing micro-generation operation and performing building load forecasting which is possible due to the available data from the metering process. As a result the smart grids can be viewed as aggregators of buildings, consumers and communities that will be empowered with better prices and valuable opportunities.

In order to reach the aforementioned goals, several challenges and drawbacks should be overcome. Technical challenges are mainly related to the lack of experience, knowledge and competence to operate successfully the micro generation energy sources as well as to interact with the building occupants. These aspects require extensive research efforts with an interdisciplinary perspective that will examine smart grids' real time management, protection and control. Simultaneously, the role of the end users and building occupants should be enhanced and successfully incorporated. Internet of things can play a significant role in this direction as it can support awareness raising of end users and provide user friendly applications for demand response and load management capabilities. In order to achieve this, specific telecommunication in infrastructures as well as open communication protocols should be provided to help managing, operating and controlling buildings within smart grids.

Another significant challenge is related to the increased initial installation cost which constitutes a great disadvantage. Specific policies and incentives should be provided by the governmental bodies to encourage investment in order to reach national carbon reduction goals.

Finally, significant effort should be put in the development of standards concerning the operational characteristics, the power quality, real time optimization and overall management.

References

[1] M.E. El-hawary, The smart grid—state-of-the-art and future trends, Electric Power Compon. Syst. 42 (2014) 239–250, http://dx.doi.org/10.1080/15325008.2013.868558.

[2] C.F. Covrig, A. Mengolini, Smart grid projects in Europe: lessons learned and current developments 2012 update, 2013.

[3] L. Chen, Z.C. Huang, P. Wu, C. Liu, Transmission line condition monitoring based on Internet of things in smart grid, Appl. Mech. Mater. 336–338 (2013) 2488–2493, http://dx.doi.org/10.4028/www.scientific.net/AMM.336-338.2488.

[4] Y. Zhen, X. Li, Y. Zhang, L. Zeng, Q. Ou, X. Yin, Transmission tower protection system based on Internet of things in smart grid, Proceedings of the 7th International Conference on Computer Science & Education (ICCSE), IEEE, 2012, pp. 863–867, doi: 10.1109/ICCSE.2012.6295205.

[5] V.C. Güngör, D. Sahin, T. Kocak, S. Ergüt, C. Buccella, C. Cecati, et al., Smart grid technologies: communication technologies and standards, IEEE Trans. Ind. Inform. 7 (2011) 529–539, http://dx.doi.org/10.1109/TII.2011.2166794.

[6] S. Deng, R.Z. Wang, Y.J. Dai, How to evaluate performance of net zero energy building—a literature research, Energy 71 (2014) 1–16, http://dx.doi.org/10.1016/j.energy.2014.05.007.

[7] M. Santamouris, D. Kolokotsa, Passive cooling dissipation techniques for buildings and other structures: the state of the art, Energy Build. 57 (2013) 74–94, ⟨http://dx.doi.org/10.1016/j.enbuild.2012.11.002⟩.

[8] D. Kolokotsa, D. Rovas, E. Kosmatopoulos, K. Kalaitzakis, A roadmap towards intelligent net zero- and positive-energy buildings, Solar Energy 85 (2011) 3067–3084.

[9] E. Pyloudi, S. Papantoniou, D. Kolokotsa, Retrofitting an office building towards a net zero energy building, Adv. Build. Energy Res. (2014) 1–14, http://dx.doi.org/10.1080/17512549.2014.917985.

[10] M. Kapsalaki, V. Leal, Recent progress on net zero energy buildings, Adv. Build. Energy Res. 5 (2011) 129–162.

[11] D.H.W. Li, L. Yang, J.C. Lam, Zero energy buildings and sustainable development implications: a review, Energy 54 (2013) 1–10, http://dx.doi.org/10.1016/j.energy.2013.01.070 (**The specific paper provides a deep review on the available technologies and case studies for the development and implementation of zero energy buildings. Moreover a summary of recently developed ZEB is provided).

[12] N. Carlisle, O. Van Geet, Definition of a "Zero Net Energy" Community, NREL, Colorado, USA, 2009.

[13] G. Privat, How information and communication technologies will shape SmartGrids, In: Smart Grids, 2013, pp. 263–280, doi: 10.1002/9781118562581 (chapter 9).

[14] T.G. Nikolaou, D.S. Kolokotsa, G.S. Stavrakakis, I.D. Skias, On the application of clustering techniques for office buildings' energy and thermal comfort classification, IEEE Trans. Smart Grid 3 (2012) 2196–2210.

[15] M. Bae, H. Kim, E. Kim, A.Y. Chung, H. Kim, J.H. Roh, Toward electricity retail competition: survey and case study on technical infrastructure for advanced electricity market system, Appl. Energy 133 (2014) 252–273, http://dx.doi.org/10.1016/j.apenergy.2014.07.044.

[16] R.K. Jain, K.M. Smith, P.J. Culligan, J.E. Taylor, Forecasting energy consumption of multi-family residential buildings using support vector regression: Investigating the impact of temporal and spatial monitoring granularity on performance accuracy, Appl. Energy 123 (2014) 168–178, http://dx.doi.org/10.1016/j.apenergy.2014.02.057.

[17] H. Zhao, F. Magoulès, A review on the prediction of building energy consumption, Renew. Sustain. Energy Rev. 16 (2012) 3586–3592, http://dx.doi.org/10.1016/j.rser.2012.02.049.

[18] K. Gobakis, D. Kolokotsa, A. Synnefa, M. Saliari, K. Giannopoulou, M. Santamouris, Development of a model for urban heat island prediction using neural network techniques, Sustain. Cities Soc. 1 (2011) 104–115.

[19] J.G. Jetcheva, M. Majidpour, W.-P. Chen, Neural network model ensembles for building-level electricity load forecasts, Energy Build. 84 (2014) 214–223, http://dx.doi.org/10.1016/j.enbuild.2014.08.004.

[20] A. Mellit, A.M. Pavan, A 24-h forecast of solar irradiance using artificial neural network: application for performance prediction of a grid-connected PV plant at Trieste, Italy, Solar Energy 84 (2010) 807–821.

[21] S. Papantoniou, D. Kolokotsa, K. Kalaitzakis, D.N. Cesarini, E. Cubi, C. Cristalli, Adaptive lighting controllers using smart sensors, Int. J. Sustain. Energy (2014) 1–17, http://dx.doi.org/10.1080/14786451.2014.923887.

[22] C. Fan, F. Xiao, S. Wang, Development of prediction models for next-day building energy consumption and peak power demand using data mining techniques, Appl. Energy 127 (2014) 1–10, http://dx.doi.org/10.1016/j.apenergy.2014.04.016.

[23] S. Papantoniou, D. Kolokotsa, K. Kalaitzakis, Building optimization and control algorithms implemented in existing BEMS using a web based energy management and control system, Energy Build. (2014), http://dx.doi.org/10.1016/j.enbuild.2014.10.083.

[24] I.P. Panapakidis, T.A. Papadopoulos, G.C. Christoforidis, G.K. Papagiannis, Pattern recognition algorithms for electricity load curve analysis of buildings, Energy Build. 73 (2014) 137–145, http://dx.doi.org/10.1016/j.enbuild.2014.01.002.

[25] Y.-C. Li, S.H. Hong, BACnet–EnOcean Smart Grid Gateway and its application to demand response in buildings, Energy Build. 78 (2014) 183–191, http://dx.doi.org/10.1016/j.enbuild.2014.04.022.

[26] C. Bartusch, K. Alvehag, Further exploring the potential of residential demand response programs in electricity distribution, Appl. Energy 125 (2014) 39–59, http://dx.doi.org/10.1016/j.apenergy.2014.03.054.

[27] P. Bradley, M. Leach, J. Torriti, A review of the costs and benefits of demand response for electricity in the UK, Energy Policy 52 (2013) 312–327, http://dx.doi.org/10.1016/j.enpol.2012.09.039.

[28] C. Keles, A. Karabiber, M. Akcin, A. Kaygusuz, B.B. Alagoz, O. Gul, A smart building power management concept: smart socket applications with DC distribution, Int. J. Electr. Power Energy Syst. 64 (2015) 679–688, http://dx.doi.org/10.1016/j.ijepes.2014.07.075.

[29] G. Kayo, A. Hasan, K. Siren, Energy sharing and matching in different combinations of buildings, CHP capacities and operation strategy, Energy Build. 82 (2014) 685–695, http://dx.doi.org/10.1016/j.enbuild.2014.07.077.

[30] J.A. Oliveira-Lima, V. Delgado-Gomes, J.F. Martins, C. Lima, Standard-based service-oriented infrastructure to integrate intelligent buildings in distributed generation and smart grids, Energy Build. 76 (2014) 450–458, http://dx.doi.org/10.1016/j.enbuild.2014.03.013.

[31] S.H. Hong, S.H. Kim, G.M. Kim, H.L. Kim, Experimental evaluation of BZ-GW (BACnet-ZigBee smart grid gateway) for demand response in buildings, Energy 65 (2014) 62–70, http://dx.doi.org/10.1016/j.energy.2013.12.008.

[32] ANSI/SHRAE standard 135-2010: a data communication protocol for building automation and control network, 2012.

[33] G. Chalkiadakis, V. Robu, R. Kota, A. Rogers, N. Jennings, Cooperatives of distributed energy resources for efficient virtual power plants, Proceedings of the 10th International Conference on Autonomous Agents and Multiagent Systems, Taipei, Taiwan, 2011.

[36] X. Xue, S. Wang, Y. Sun, F. Xiao, An interactive building power demand management strategy for facilitating smart grid optimization, Appl. Energy 116 (2014) 297–310, http://dx.doi.org/10.1016/j.apenergy.2013.11.064.

[37] X.H. Li, S.H. Hong, User-expected price-based demand response algorithm for a home-to-grid system, Energy 64 (2014) 437–449, http://dx.doi.org/10.1016/j.energy.2013.11.049.

[39] G. Bartels, Global Smart Grid Federation Report, 2012 (The specific report underlines the recent trends and penetration of smart grids in various parts of the world. It indicates the methodology for large scale deployment of smart grids in cities).

[40] K. Gaiser, P. Stroeve, The impact of scheduling appliances and rate structure on bill savings for net-zero energy communities: application to West Village, Appl. Energy 113 (2014) 1586–1595, http://dx.doi.org/10.1016/j.apenergy.2013.08.075.

[41] K.M. Zhang, R.J. Thomas, M. Bohm, M. Miller, An integrated design approach for sustainable community development, Proceedings of the 42nd Hawaii International Conference on System Sciences, IEEE, 2009, pp. 1–10, doi: 10.1109/HICSS.2009.67.

[42] E. Provata, D. Kolokotsa, S. Papantoniou, M. Pietrini, A. Giovannelli, G. Romiti, Development of optimization algorithms for the Leaf Community microgrid, Renew. Energy 74 (2015) 782–795, http://dx.doi.org/10.1016/j.renene.2014.08.080 (*The specific paper focuses on the aplication of artificial intelligence in management practices for smart grids. The LEAF microgrid community's resources are used for the implementation of advanced energy management and optimisation techniques).

[43] F.A. Mohamed, H.N. Koivo, Online management genetic algorithms of microgrid for residential application, Energy Convers. Manag. (2012) 562–568, http://dx.doi.org/10.1016/j.enconman.2012.06.010.

[44] H.Z. Liang, H.B. Gooi, Unit commitment in microgrids by improved genetic algorithm, IPEC, 2010 Conference Proceedings, 2010, pp. 842–847, doi: 10.1109/IPECON.2010.5697083.
[45] G. Kyriakarakos, A.I. Dounis, K.G. Arvanitis, G. Papadakis, A fuzzy logic energy management system for polygeneration microgrids, Renew. Energy 41 (2012) 315–327, http://dx.doi.org/10.1016/j.renene. 2011 11.019.
[46] F.A. Mohamed, H.N. Koivo, Online management of microgrid with battery storage using multiobjective optimization, Proceedings of the International Conference on Power Engineering, Energy and Electrical Drives, 2007, doi: 10.1109/POWERENG.2007.4380118.
[47] J. Rawlings, P. Coker, J. Doak, B. Burfoot, Do smart grids offer a new incentive for SME carbon reduction? Sustain. Cities Soc. 10 (2014) 245–250, http://dx.doi.org/10.1016/j.scs.2013.04.003.
[48] M. Wolsink, The research agenda on social acceptance of distributed generation in smart grids: renewable as common pool resources, Renew. Sustain. Energy Rev. 16 (2012) 822–835, http://dx.doi.org/10.1016/j.rser.2011.09.006.