BEMS in the Era of Internet of Energy: A Review

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Abstract. A Building Energy Management System (BEMS) is a fundamental computer-based system aiming at optimizing management of building assets towards energy savings without compromising occupants' comfort, while developing a potential to apply demand response strategies. Building energy management systems nowadays have evolved and comprise of heterogeneous components and complex architectures. Building management systems monitor indoor building conditions while controlling building assets like lights, security systems, and heating and air ventilation's systems. Furthermore, to facilitate the specification of the building's attributes for building energy management systems the use of semantic technologies is needed within building energy tools. This paper undertakes a comprehensive review of Building Energy systems in the context of Internet of Energy.

Keywords: Building Management Systems · Building Energy Management Systems · Building Automation · IoT · IoE · SIM

1 Introduction

Presently, one of the the most important topics is sustainable development and the preservation of energy levels. The global energy demand is estimated to increase by almost 2/3 until the year 2035 [31]. Moreover, the increased energy demand leads to increased emissions and green house effect, which makes the problem of energy usage even more challenging. Therefore, the concept of energy management and smart grids has been exploited to manage energy demand and energy savings while preserving comfort for the residents.

Particularly, Building Management Systems (BMS) intend to increase energy awareness, control RES distribution, and storage aiming to mitigate the total world energy demand. Nowadays, the BMS have focused more on energy BMS (Building Energy Management Systems (BEMS) and their main purpose is to distribute the energy efficiently. Hence, the Internet of Energy (IoE) [21] has been developed for these systems as an extension of the Internet of Things (IoT)

to manage Energy in Buildings [30]. This is different from IoE representing the Internet of Everything, and shall be used carefully. In this paper, the IoE will be used with the meaning of Internet of Energy.

IoE is a fusion of smart grid and IoT, combining the basic features of smart grid and IoT, providing a more powerful and tailored-to-energy technology [24]. IoT facilitates the exchange of big data and information retrieved by sensors and smart objects while producing useful services. The IoT is an Internet-based architecture widely used in various sectors like safety systems, military applications, energy monitoring, smart grid management and many others.

The BEMS intend to follow a pattern that will create the Zero Energy Buildings (ZEB) or the modern net zero Energy Buildings (nZEB) [15] (Figure 1). Based on the European Energy Performance of Buildings Directive Recast 2010 legislation all types of buildings that are going to be built after 31st December 2020 must meet this standard [4]. The nZEB comprises of many parameters like the energy consumed, the renewable supply facilities, the connection to the Distribution System Operators (DSO) and the energy requirements of the building [29]. In view of this, BEMS use building information and data for real-time energy optimization, carbon reduction and also the production of more cost benefit models. Many of the techniques of the IoE-based BEMS are in an early development stage and their performance is under research.

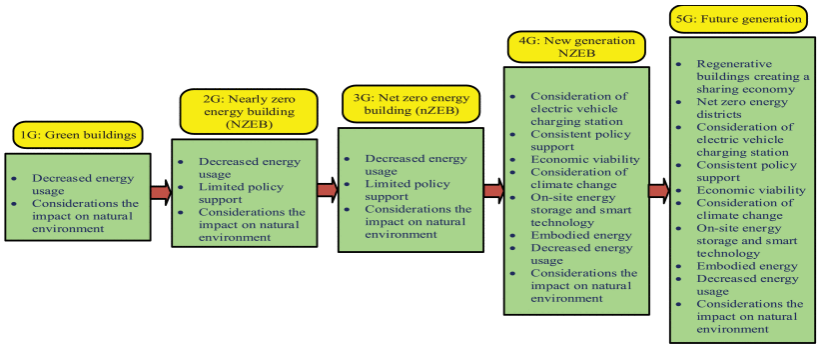


Fig. 1. ZEB history [15]

This paper aims to highlight the different applications of the IoE-based BEMS and Semantics for smart energy management. This review is organized as follows: in Section 2 the BEMS are presented. Moreover, in Section 3 the semantics for integrating smart control and data management are presented, Finally, conclusions are drawn in the final Section 4.

2 Building Energy Management Systems (BEMSs)

A BEMS is a highly developed multi-objective technique aiming to monitor and control the energy balance of a building [29]. Subsequently, the objective of a BEMS is to gain access and maintain the proper energy profile for each building without the need to be fed in detailed parameters for all electric equipment and building's structural information. In addition, a BEMS is supposed to reduce the amount of energy consumed without compromising the residents comfort levels (thermal and visual) through an optimization process that integrates a passive heating and cooling system.

2.1 Energy consumption monitoring and management

To manage the energy consumed in a building there must be a system installed that monitors the power consumption of the facilities. The load monitoring system is one of the main aspects of the energy management of BEMS. There are two approaches used to monitor the energy load, the Intrusive Load Monitoring (ILM) and the Non-Intrusive Load Monitoring (NILM). Another widely disseminated approach for energy consumption monitoring is by exploiting measuring devices.

Intrusive Load Monitoring (ILM) The term intrusive, refers to a metering device installed in the habitation, usually close or inside to the appliance that needs to be monitored. This device is commonly a low-end metering device [37]. ILM is used in many applications like local energy consumption understanding, global energy consumption understanding, appliance monitoring, evaluation of NILM environments, simulation of NILM environments, human activity recognition and appliance localization. The ILM framework comprises of three basic layers. In the first layer, a sensor technology is used to detect the load of an appliance. In the second layer (middleware), there is the software needed to interpret the load of the device. The final layer represents the operational status of the device and is used to monitor and control the device.

Non-Intrusive Load Monitoring (NILM) The NILM approach does not require an installation to each device for the load monitoring. The NILM approach is based on a single device installation at the central electric panel [23]. NILM commonly exploits the disaggregation process to estimate the individual device's consumption [23]. Disaggregation receives an aggregated signal and decomposes it into its individual devices' consumption. Energy disaggregation is a thorny task as each building has many and different appliances, operating at a different power level (nominal power). The load wave forms are decomposed based on the load signatures of each appliance.

Measuring devices Measuring devices are all devices used in measuring the energy load of the selected building. There are many types of load monitoring devices like current sensors, voltage sensors, smart meters, smart plugs, fluke meters, energy detectives, and power quality transducers [22]. Moreover, smart plugs can measure and monitor the distinct device load. There are many commercially used smart plugs [22]. The most common device used for load measurement is a smart meter. A smart meter is a device that is used to collect data from the end-users' home appliances and monitors the energy consumption [22]. The handling of an Advanced Metering Infrastructure (AMI) service can support real-time data regarding electricity power [22]. Energy monitoring is essential as energy savings is the fundamental goal of an IoE-based BEMS. The energy management refers to balancing the buildings energy by using multi-attribute decision making methods like the ones proposed in [20].

2.2 IoE-based management applications

Hernández et al. [25] introduced a novel version of an IoE enabled system which is separated into layers and modules comprising of functional components. This layered structure facilitates the interoperability and common operation of the BEMS. Specifically, the model includes three layers: the sensing, delivery and management layer, the data processing and modeling layer, and the smart building services buildings layer as depicetd in Figure 2.

Sensing, delivery and management layer. This layer is responsible for the sensing, delivery, and management enriched with the important functions of data collection and translation. Initially, all the sensors and actuators retrieving real-time data are installed in the building's specific location. The raw input data is retrieved by an IoT based framework including the sensors, the actuators and databases. Afterwards, this raw data is preprocessed, encoded, and translated in a standard data type that is compatible with all various sub-systems while simplifying the data processing of the next stages.

Data processing and modeling layer. This layer processes and models data based on the key functions. Data processing is used to create the knowledge base for the final stage. This knowledge is user-oriented and customized based on the specific situations and services provision of this stage. Specific forms of provisions are generated like the control actions of household devices, energy consumption monitoring, energy savings etc. Finally, this layer includes the third-party operation modes and encodes the rules and output sources to the specified information platform.

Smart building services buildings layer In this layer, the output services like thermal comfort, energy efficiency, security, management, and visual comfort are provided and analyzed. The results reflect the processing of all data which was retrieved in the previous layers. Moreover, this layer includes all applications that may be provided to the end-user, such as graphics, notifications, functions, alarms, and sections of the graphical user interface.

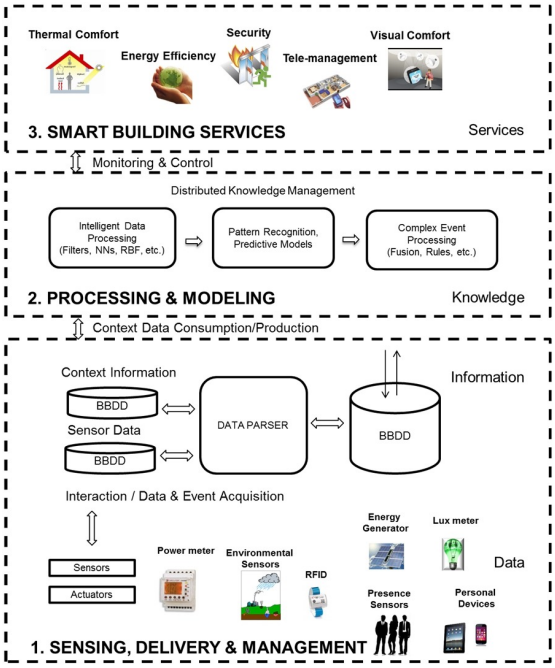


Fig. 2. Conceptual architecture for smart buildings [25]

2.3 Integration of several systems to one overall system

Existing BEMS are comprised by sub-systems where each sub-system monitors and controls its own system separately from the other systems. Specifically, each sub-system is a unique system that could be autonomous. The same procedure is followed by the sensors. Under those circumstances, the same sensors cannot operate and be used in parallel by the sub-systems as there is no inter communication and connection.

To reduce the cost and increase the BEMS efficiency, new technologies are suggested by using a single IP backbone (Figure 3) for the communication with all the sub-systems needed for the integration of BEMS [33]. As a consequence, all systems may exchange data and information and interact with each other deployed as a unified system. A standard proposed architecture of a BEMS includes of a centralized system which interacts with all the sub-systems and retrieves and sends real-time data while exploiting open communication protocols for buildings.

Using the various protocols, a BEMS is capable to communicate with all sub-systems. The most common supported communication protocols (wired and wireless) of a centralized BEMS are:

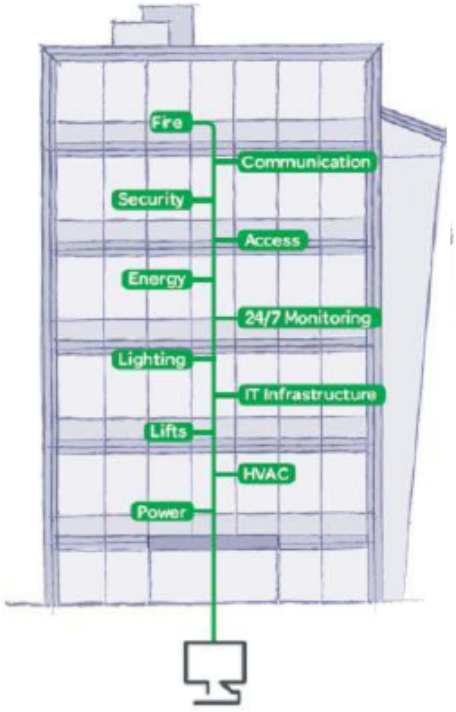


Fig. 3. Single IP backbone [33]

- Modbus is a method mainly used for transmitting over serial lines between devices. The simplest setup is a single serial cable connecting the serial ports on two devices, a Master and a Slave [8].
- BacNet is a standard, open protocol specifically for the building automation industry. BacNet offers an open architecture and the ability to control and monitor any building automation process [1].
- LonWorks is a networking solution for Building Automation. The novelty of LonWorks is that it can use twisted pair, Ethernet or even a power line as its communication channel [6].
- Zigbee standard operates on the IEEE 802.15.4 physical radio specification and operates in unlicensed bands including 2.4 GHz, 900 MHz and 868 MHz [12].
- Z-wave is a wireless, radio frequency (RF) based communications technology designed particularly for control, monitoring and status reading of household applications [11].
- Mbus is a communication standard. It is determined for applications of the data collection from consumption meters of various types [7].

- KNX is a uniform, manufacturer-independent communication protocol for intelligently networking state-of-the-art home and building system technologies [5].
- "Digital Addressable Lighting Interface" (DALI) is a communication protocol for building lighting applications and is used for communication between lighting control devices, such as electronic ballasts, brightness sensors, or motion detectors [2].
- Structure of Management Information (SMI) defines the rules for describing management information. The SMI is defined using ASN.1 [10].
- EnOcean protocol is defined by the new ISO/IEC 14543-3-10 standard, is the first energy harvesting wireless protocol [3].

3 Semantics for smart control and data management.

In order to satisfy the specific requirements of BEMS and enable communication between disparate and heterogeneous technologies of both IoE and IoT devices, technological mappings must be introduced to cover all levels of IoT interoperability [35]. The mapping is usually used between the management level and the automation level. This type of technique is used at the gateways to integrate isolated Building Automation Systems (BAS). This type of integration facilitates syntactic and semantic interoperability. Ontologies have been already exploited for semantic modeling and reasoning [16]. Nowadays, many semantic frameworks are utilizing ontologies for semantically describing heterogeneous systems related to building automation and energy management for a complete IoT/IoE-based BEMS.

3.1 Conceptual BEMS architecture

The modern BEMS are based on the efficiency and effectiveness of high-quality data and information. The key objective of this data and information transportation is to retain the interoperability of different Building Automation technologies and sub-systems that compose the overall system while providing compatibility to the data and information transportation in a perpetual basis. Furthermore, interoperability must be provided on top of the protocol stacks at the information level [39]. Exclusively, integration of resources, context information, raw data, systems functionality must be enriched with semantics to ensure a dynamic control of the BAS. Considering this, the most suitable technology is to to use ontological models for representing the related knowledge, as well as to use reasoning mechanisms to infer new one [39].

The traditional BMS propose a hierarchical integration [41] where the BAS is directly linked to the top-level BMS. On the contrary, new BEMS using ontologies propose a system where a semantic layer exists between the BAS and the BMS [40] (Fig. 4). This intermediate layer is the central layer of the overall architecture. This central layer leads to high-level abstraction between the connected technologies and data while concentrating a point for information and

knowledge sharing and exchange. As a result, the inferred knowledge based on ontologies and links over various technologies and their generated data may be deployed [40].

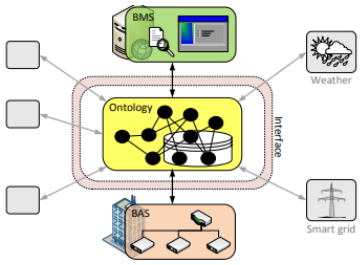


Fig. 4. Conceptual BEMS architecture

A prevailing consistent interface may be used to gain access to the semantic layer. The semantic layer is facilitating the interconnection and communication with the knowledge base. A technology connector aware to the ontology must be exploited [38] to map the formentioned interface. Based on the protocols that the BAS uses, the automation level can be also directly linked to the semantic layer. All the control actions are implemented in the semantic layer and the BMS and BAS do not communicate directly, but they are informed about the changes in the semantic layer. Specifically, all actions like turn off the lights, reduce indoor temperature are made through the BAS control layer, and the ontology retains this historical information.

Several components and sub-systems may be connected to the central semantic layer, like a smart grid, APIs, agents etc. As a result, the communication between different components and sub-systems is handled by the semantic layer interface. To sum up, this setup aims to promote interoperability and integrate semantically enriched and interlinked data while providing access to the knowledge base from various technologies and systems.

3.2 Ontologies

The purpose of the ontology is to interlink the building's information, the building's automation components, and the control actions, at a semantically-enriched level of abstraction. Several ontology engineering (OE) methodologies have been proposed and used so far for the engineering of domain ontologies. A recent and detailed review on the use of modern collaborative OE methodologies and their impact to developed ontologies is presented in Kotis et al, 2020 [28]. Furthermore, there are already developed ontologies for both the BA and the building components. Some of the most well-known and widely-used are described in the following paragraphs.

- DogOnt [17] was initially presented in 2008 and was used to address interoperability mainly for home automation devices. During the years, DogOnt was extended and now includes almost all devices and technologies that comprise an indoor IoT network. DogOnt is implemented through five hierarchical trees [17]: Building Thing, which models available thing, Building Environment, which models where things are located. State, which models the stable configurations of controllable things. Functionality, which models what controllable things can do. Domotic Network Component, which models the features peculiar to each domotic plant (or network)
- BASont [27]. The BASont undertakes different use cases over the life cycle of a building automation system for design, operation, and refurbishment [27]. The BASont is divided into several parts. The central element of the ontology describes the device instances. Around this, there are other ontologies like the location of instances in the building structure, the instances' device types and their semantics, the used abstract and detailed design templates, the topology of the BAS as well as the network addresses of the devices.
- The ThinkHome ontology [36] formalizes all relevant concepts needed to realize energy analysis in residential buildings and was addressed in 2010. The ThinkHome system consists of two main parts, a comprehensive knowledgebase (KB) and a multi-agent system (MAS).
- Smart Appliances REFerence (SAREF) ontology [19]. This ontology facilitates the communication of existing standards and protocols mainly for smart appliances using the ETSI TS 103 267 [13]. SAREF is widely used in energy realted aplications but is easily adopted for many different sectors like transportation, health, smart grid, and others.

The above is not an in-depth list of BEMS and energy-related ontologies as there are other ontologies that due to space limitations, were not presented here.

3.3 Building energy performance simulation tools

Moreover, there exist many building energy performance simulation tools. The main objective of energy simulation tools is to simulate the buildings energy performance and the comfort levels of the building while predicting the energy demand. such simulation tools are EnergyPlus [18] and DOE-2 [42], which use custom schema definitions like IDD [26] and BDL[26]. A Simulation Domain Model (SimModel)[32] was proposed for a new interoperable XML-based data model for building simulation domain. Its ontology moves away from tool-specific, non-standard nomenclature by implementing an industry-validated terminology aligned with the Industry Foundation Classes (IFC) [32] (Figure 5.

SimModel was introduced [9] as an internal data model by the Simergy software developed at LBNL [9], the successor of the Mojito platform presented by [14]. Data flow was possible to all existing tools like DOE-2, EnergyPlus and all tools that used gbXML export. Data from any of these environments can be mapped to and from the SimModel data model using the Simergy software

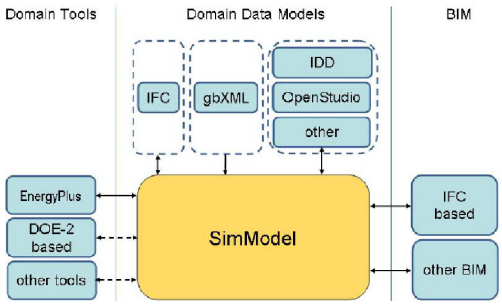


Fig. 5. Conceptual SIM architecture [32]

[9]. The underlying SimModel is an object-oriented data model which defines all object/attribute/relationship sets used for Building Energy Performance (BEP) simulation [34]. The primary aim of the SimModel is to exploit the existing infrastructure and data input of EnergyPlus, while facilitating mapping towards and from other data models and establishement of additional definitions [14]. SimModel is represented using the XML markup language. The SimModel can be converted easily into an OWL ontology.

4 Conclusions

In the course of the past decades, BEMS have become quite popular mainly due to the information technology development in the field of automation in buildings and is mostly deployed in the commercial sector. As a consequence, exploiting the appropriate technologies, it is feasible to ensure both comfort conditions and energy savings for the residents. Furthermore, unlike to the conventional electrical installations, these systems are characterized by the application of structured cabling and wireless systems, through which the maintenance of the installation becomes a simple process. Furthermore, the diversity of various technologies and protocols used for BEMS demand the exploitation of existing protocols and energy ontologies. To sum up, BEMS's data models enriched with semantic information can manage all the data that is retrieved, created, and saved in the overall system.

Acknowledgements

This work is partially supported by the PLUG-N-HARVEST project funded by the EU H2020 under Grant Agreement No. 768735.

References

1. Bacnet, url: `http://www.bacnet.org/Bibliography/EC-9-97/EC-9-97.html` , accessed: 2021-02-03

2. Digital addressable lighting interface, url: https://www.infineon.com/dgdl/tp4-9.pdf?fileId=5546d462533600a401535748acdd3fe7 , accessed: 2021-02-03
3. Enocean, url: https://www.enocean.com/en/technology/ , accessed: 2021-02-03
4. Europeean union law, url: https://eur-lex.europa.eu/homepage.html?locale=en , accessed: 2021-02-03
5. Knx, url: ://www.csanyigroup.com/knx-architecture , accessed: 2021-02-03
6. Lonworks, url: https://www.ecmweb.com/content/article/20892561/the-basics-of-lonworks , accessed: 2021-02-03
7. M-bus, url: http://www.metro-fr.com/en/ , accessed: 2021-02-03
8. Modbus, url: https://radiflow.com/blog/hack-the-modbus/ , accessed: 2021-02-03
9. Simergy homepage, url: https://simergy-beta.lbl.gov/ , accessed: 2021-02-03
10. Structure of management information, url: http://osr507doc.sco.com/%E2%80%A6n/NetAdminG/snmpC.smi.html , accessed: 2021-02-03
11. Z-wave, url: https://z-wavealliance.org/ , accessed: 2021-02-03
12. Zigbee, url: https://zigbeealliance.org/ , accessed: 2021-02-03
13. Appliances, S.: Smartm2m; smart appliances; reference ontology and onem2m mapping (2017)
14. Bazjanac, V.: Acquisition of building geometry in the simulation of energy performance (2001)
15. Berardi, U.: Zeb and nzeb (definitions, design methodologies, good practices, and case studies). Handbook of Energy Efficiency in Buildings: A Life Cycle Approach **88** (2018)
16. Bonatti, P.A., Decker, S., Polleres, A., Presutti, V.: Knowledge graphs: New directions for knowledge representation on the semantic web (dagstuhl seminar 18371). In: Dagstuhl Reports. vol. 8. Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik (2019)
17. Bonino, D., Corno, F.: Dogont-ontology modeling for intelligent domotic environments. In: International Semantic Web Conference. pp. 790–803. Springer (2008)
18. Crawley, D.B., Lawrie, L.K., Winkelmann, F.C., Buhl, W.F., Huang, Y.J., Pedersen, C.O., Strand, R.K., Liesen, R.J., Fisher, D.E., Witte, M.J., et al.: Energyplus: creating a new-generation building energy simulation program. Energy and buildings **33**(4), 319–331 (2001)
19. Degha, H.E., Laallam, F.Z., Said, B.: Intelligent context-awareness system for energy efficiency in smart building based on ontology. Sustainable computing: informatics and systems **21**, 212–233 (2019)
20. Dimara, A., Timplalexis, C., Krinidis, S., Arvanitis, K., Tzovaras, D.: Energy consumption in public buildings-a survey in greece. In: 2020 5th International Conference on Smart and Sustainable Technologies (SpliTech). pp. 1–6. IEEE (2020)
21. Doost, H.: Internet of energy: A solutionfor improving the efficiency of reversible energy. In: 2018 IEEE Global Engineering Education Conference (EDUCON). pp. 1890–1895. IEEE (2018)
22. Giaconi, G., Gündüz, D., Poor, H.V.: Smart meter privacy with renewable energy and an energy storage device. IEEE Transactions on Information Forensics and Security **13**(1), 129–142 (2017)
23. Gopinath, R., Kumar, M., Joshua, C.P.C., Srinivas, K.: Energy management using non-intrusive load monitoring techniques-state-of-the-art and future research directions. Sustainable Cities and Society p. 102411 (2020)
24. Hannan, M.A., Faisal, M., Ker, P.J., Mun, L.H., Parvin, K., Mahlia, T.M.I., Blaabjerg, F.: A review of internet of energy based building energy management systems: Issues and recommendations. Ieee Access **6**, 38997–39014 (2018)

25. Hernández-Ramos, J.L., Moreno, M.V., Bernabé, J.B., Carrillo, D.G., Skarmeta, A.F.: Safir: Secure access framework for iot-enabled services on smart buildings. Journal of Computer and System Sciences **81**(8), 1452–1463 (2015)
26. Horrocks, I., Patel-Schneider, P.F., Van Harmelen, F.: From shiq and rdf to owl: The making of a web ontology language. Journal of web semantics **1**(1), 7–26 (2003)
27. Kofler, M.J., Reinisch, C., Kastner, W.: A semantic representation of energy-related information in future smart homes. Energy and Buildings **47**, 169–179 (2012)
28. Kotis, K.I., Vouros, G.A., Spiliotopoulos, D.: Ontology engineering methodologies for the evolution of living and reused ontologies: status, trends, findings and recommendations. The Knowledge Engineering Review **35** (2020)
29. Marszal, A.J., Heiselberg, P., Bourrelle, J.S., Musall, E., Voss, K., Sartori, I., Napolitano, A.: Zero energy building–a review of definitions and calculation methodologies. Energy and buildings **43**(4), 971–979 (2011)
30. Moghaddam, M.H.Y., Leon-Garcia, A.: A fog-based internet of energy architecture for transactive energy management systems. IEEE Internet of Things Journal **5**(2), 1055–1069 (2018)
31. Newell, R.G., Qian, Y., Raimi, D.: Global energy outlook 2015. Tech. rep., National Bureau of Economic Research (2016)
32. O'Donnell, J.: Simmodel: A domain data model for whole building energy simulation (2012)
33. Papantoniou, S., Mangili, S., Mangialenti, I.: Using intelligent building energy management system for the integration of several systems to one overall monitoring and management system. Energy Procedia **111**, 639–647 (2017)
34. Pauwels, P., Corry, E., O'Donnell, J.: Representing simmodel in the web ontology language. In: Computing in Civil and Building Engineering (2014), pp. 2271–2278 (2014)
35. Pliatsios, A., Goumopoulos, C., Kotis, K.: A review on iot frameworks supporting multi-level interoperability–the semantic social network of things framework. Int. J. Adv. Internet Technol **13**, 46–64 (2020)
36. Ploennigs, J., Hensel, B., Dibowski, H., Kabitzsch, K.: Basont-a modular, adaptive building automation system ontology. In: IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society. pp. 4827–4833. IEEE (2012)
37. Ridi, A., Gisler, C., Hennebert, J.: A survey on intrusive load monitoring for appliance recognition. In: 2014 22nd international conference on pattern recognition. pp. 3702–3707. IEEE (2014)
38. Roldan-Molina, G.R., Mendez, J.R., Yevseyeva, I., Basto-Fernandes, V.: Ontology fixing by using software engineering technology. Applied Sciences **10**(18), 6328 (2020)
39. Schachinger, D., Kastner, W.: Semantics for smart control of building automation. In: 2016 IEEE 25th International Symposium on Industrial Electronics (ISIE). pp. 1073–1078. IEEE (2016)
40. Schachinger, D., Kastner, W.: Semantics for smart control of building automation. In: 2016 IEEE 25th International Symposium on Industrial Electronics (ISIE). pp. 1073–1078. IEEE (2016)
41. Schustek, P., Hyafil, A., Moreno-Bote, R.: Human confidence judgments reflect reliability-based hierarchical integration of contextual information. Nature communications **10**(1), 1–15 (2019)
42. Sousa, J.: Energy simulation software for buildings: review and comparison. In: International Workshop on Information Technology for Energy Applicatons-IT4Energy, Lisabon (2012)