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Surveying the Capabilities of Building Intelligent Systems

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Abstract

This paper surveys state of art technologies used for building energy monitoring and management. Rapid growth of automated meter reading (AMR) technology combined with integrated circuit technology is in the focus of discussion. Combination of smart metering and building management systems (BMS) improves building energy efficiency up to 50%. BMS improve energy through real time monitoring and efficient control techniques, on the other hand AMR provide and store information about energy consumption. Data stored in databases can be used for energy prediction using different techniques like statistical and artificial intelligence approaches. We take in consideration case studies highlighting improvements of energy use when BMS systems installed and the advantages of predicting next hour's energy consumption.

Keywords: Energy efficiency, smart metering, building management systems, energy prediction, artificial intelligence.

Introduction

Last decades building energy consumption is increased significantly, especially in developing countries as can be seen from Figure.1. Developed countries Europe and North America strategy in energy efficiency shows decreasing in consumption, dissimilarly in developing countries the need for more energy has put consumption in increasing trends. In Albania, energy efficiency issues are currently incorporated in a number of strategies and action plans such as the Strategic Energy Action Plan for Power Sector (2015), Action Plan for Implementing the PowerSector Policy Statement (April 2005), the National Strategy of Energy (July 2003), Action Plan for Implementing the National Strategy of Energy (September 2003), Energy Efficiency Law (April 2015), etc. These documents outline the policy measures as well as practical actions to be undertaken in a time span lasting up to 2015. According to National Strategy of Energy, energy savings are expected to be around 22.5% of the total energy consumption [1].

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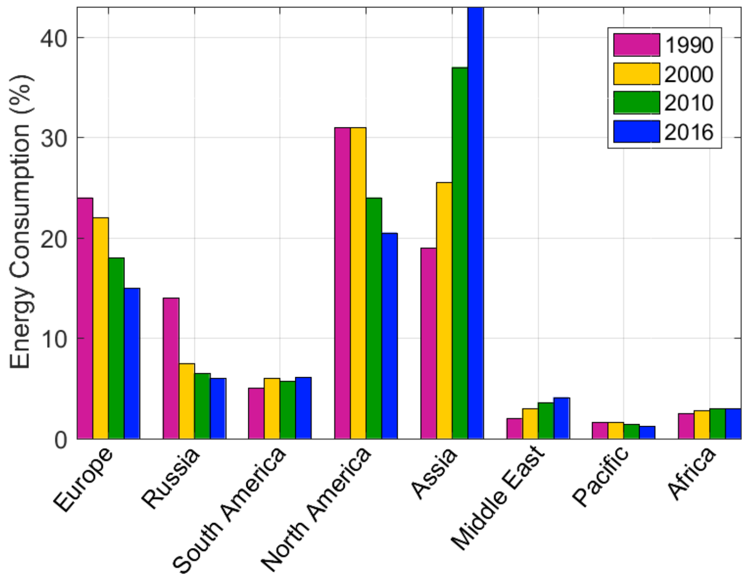

Fig.1: Global electricity trend consumption in last decades [2].

Approximately 40% of total energy and 75% of total electricity consumption in USA goes for commercial and residential buildings [2], as well in Albania about 77% of total electricity [3] goes for building sector as shown in Figure.2.

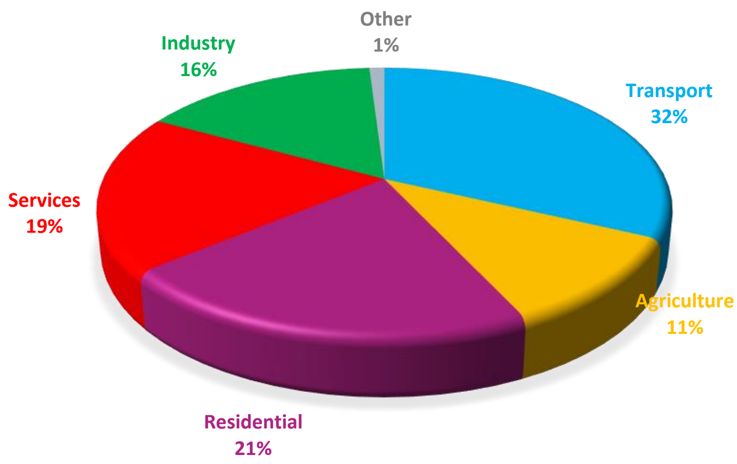

Fig.2: Total energy consumption in 2005 by sector in Albania [4].

Improving building energy efficiency is a growing concern worldwide. Two major approaches are crucially involved in energy efficiency improvement [5]. First, energy use in commercial and residential buildings can be reduced since early design phase, when architects and designers apply wall thermal insulation techniques, and other techniques in a so called "passive building" environment. Second, a more broadly approach through intelligent control and maintenance is applied. Intelligent techniques mainly include three sub processes: smart metering and monitoring, control strategies and building management systems. Smart metering and monitoring involves integrated circuit technology and sensors for monitoring, metering and storing energy consumption information. Control strategies involve expert knowledge like building engineers and operators. Those strategies can be improved through forecasted energy parameters, so building operators are equipped with prior information gained from predictive approaches. Last, building management systems monitor and control each sublevel component installed inside a building also environmental parameters.

This paper starts with describing intelligent building environment in section II, and then by continuing in section III with advantages of installing smart meter technologies. Section IV describes building management systems. Then, in section V and IV implementation of building management system and capabilities of online measured information is presented. Conclusion is presented in section VII.

Intelligent Buildings

There is no precise concept of intelligent building. In literature there exists various of them, according to [6] the concept has been defined by many organizations as the Intelligent Building Institute Foundation (I.B.I.) in 1989, Associazione Italiana per lí Automazione degli Edifici (AIACE) in 1995, the European Intelligent Buildings Group (EIBG) in 1998, and The Smart Homes, one of the first definitions presented by Intelligent Building Institute IBS an extracted definition from [7, 8, 9].

"An intelligent building is one which provides a productive and cost effective environment through the optimization of its four basic elements – systems, structure, services, management – and the inter-relationship between them.

Intelligent buildings help building owners, property managers, and occupants realize their goals in the areas of cost, comfort, convenience, safety, long-term flexibility, and marketability. There is no intelligence threshold past, which a building "passes" or "fails". Optimal building intelligence is the matching of solutions to occupant needs. The only characteristic that all intelligent buildings have in common is a structured design to accommodate change in a convenient, cost-effective manner."

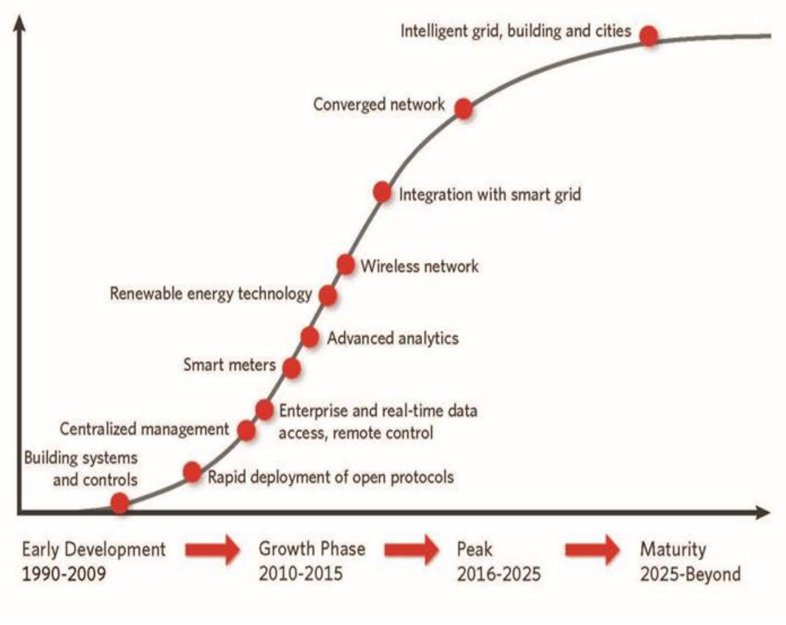

Fig.3: Intelligent Building Solutions Market Life Cycle Analysis [10].

Intelligent building focuses on improving energy control strategies to reduce consumption focusing on occupant comfort (indoor comfort, thermal comfort, air quality and visual comfort). According to CABA [10] process of incorporating intelligence in buildings starts in 1990's with system controls, continuing with smart meter technology and ending to a large scale design like smart cities as shown in Figure 3.

An intelligent building system engages a lot of subsystem level components and devices. Mostly the system involves sensors and actuators communicating with each other to central control system by means of latest communication protocols.

Himanen in his dissertation "*The Intelligence of Intelligent Buildings"* [6] concludes with the following concepts an intelligent building includes:

i. IBs provide the stakeholders with an effective and productive environment for higher performance.
ii. Associates in this field can be: local and global community, real estate developers and providers, building managers, designers, building purchasers, building owners, speculators, occupants or tenants and other end-users.
iii. Occupant needs are dominant in the terms of performance of the building.
iv. The performance is evaluated with regard to environmental friendliness, flexibility and space utilization, life cycle costing, comfort, convenience, safety and security, working efficiency, construction process, long-term flexibility, marketability, information intensity, interaction, service-orientation, and other human comfort indicating factors.

Monitoring and metering energy consumption in building is fundamental for better understanding and improving control strategies. Rapid growth of integrated circuit technology ICT has make an abrupt change in automated reading technology installation. As shown in Figure.4 the rapid growth of installed devices for different sectors is very visible.

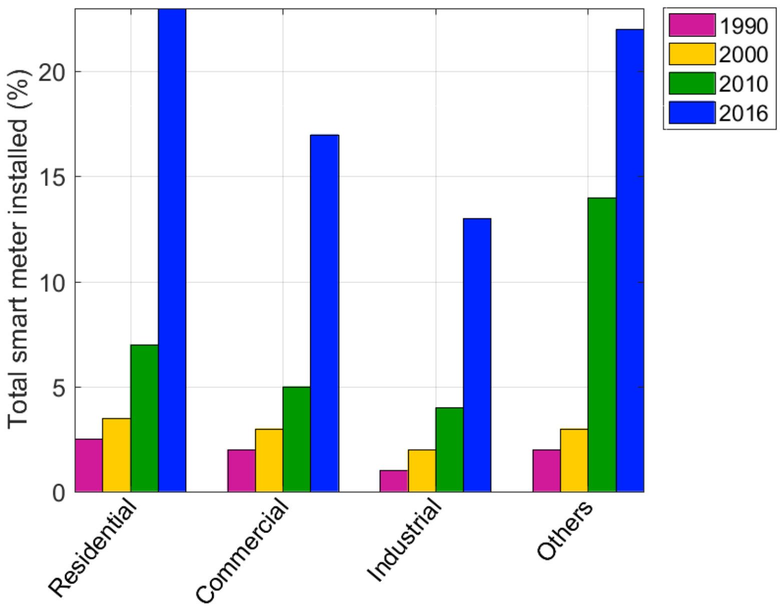

Fig.4: Intelligent smart meters installed by sector [2].

Smart meter device measures energy consumption in intervals, which can vary from minutes to hours. The most used devices are those, which measure in 15 minutes, 30 minutes and 1-hour intervals, there exist devices with higher resolution like seconds to milliseconds intervals. Those devices usually are used mainly for scientific purposes, like gathering data for load disaggregation [11].

Most used devices in buildings are those measuring in 15-30 minutes intervals. An analysis of energy savings by half-hourly energy data observations for 81 municipal buildings used for different purposes is presented by Ferreira and Fleming [12].

Measuring systems provide on time information about energy consumption to end users and to building operators, the information is also stored in databases for later use like statistical analysis and energy consumption prediction. Development of sensors especially wireless communicating ones, except of building energy and sublevel building components measurements provides also environmental factors. According to measured factors by smart meter systems in Table.1, there is a summary of database typologies related to measured factors. Typology of the future will be type C, due to the indication of data driven approaches to as much as possible information included.

TABLE I: Database typologies of smart metering technologies [13]

Database typology	Categories of influencing factors			
	I	II	III	+
A Level 1 (basic)	IF1. (Outdoor) Climate IF2. Building envelope IF3. Building equipment			IF7. Social, legal and economical aspects
B Level 2 (intermediate)	IF1. (Outdoor) Climate IF2. Building envelope IF3. Building equipment	IF4. Operation & Maintenance IF5. Indoor Env. Conditions		IF7. Social, legal and economical aspects
C Level 3 (detailed)	IF1. (Outdoor) Climate IF2. Building envelope IF3. Building equipment	IF4. Operation & Maintenance IF5. Indoor Env. Conditions	IF6. Occupant behavior	IF7. Social, legal and economical aspects

Rapid growth of smart metering devices installation also requires application of directives and standards. In Europe there exists two directives: [Directive 2004/22/EC] on measuring instruments and [Directive 2006/32/EC] on energy end-use efficiency and energy services. Smart metering systems should have the basic functionalities according to European Standards' Organizations (ESO) CEN, CENELEC and ETSI (M/441) [14]:

1. Remote reading of metrological register(s) and provision to designated market organisation(s)
2. Two-way communication between the metering system and designated market organisation(s)
3. Meter supporting advanced tariffing and payment systems Meter allowing remote disablement and enablement of supply

4. Communicating with (and where appropriate directly controlling) individual devices within the home/building

5. Meter providing information via portal/gateway to an in-home/building display or auxiliary equipment

Available online information regarding energy consumption helps occupants to reduce energy consumption, according to Ueno and Nakano [15] provided information about energy consumption for eight residential buildings reduced energy consumption with 9%. In literature, different online data collection systems have been proposed and used. Most used network topologies are Bus, Star, Mesh, Ring and Tree. Han [16] proposed a sensor metering system storing metered values in a database created using MySQL and the control interface was built in LabVIEW.

Jang designed an operating system by optimizing node sensors energy consumption in sleep mode. Oksa [17] presented other opportunities about energy monitoring and metering systems. A low cost, low power and wireless communication technology like ZigBee introduced by Sung in [18].

Building Energy Management Systems

The historical roots of EMS are in the automatic control of HVAC systems, which have been subject to automation since the early 20th century. The domain of indoor climate control still is the main focus of this discipline due to its key role in making buildings a comfortable environment. Modern EMS have extended the operator's reach from having to handle each piece of equipment locally over a whole building or complex, allowing the detection of abnormal conditions without being on-site. Besides environmental parameters, such conditions include technical alarms indicating the need for repair and maintenance. Trend logs provide valuable information for improving control strategies [19].

BACnet, LonWorks and EIB/KNX are open systems claiming the ability to cover EMS applications in their entirety. They all have achieved considerable significance in the worldwide market. One of significant features of open systems is their ability to keep the system design open for future integration requirements. Since building installations are long-lived, system evolution is an important issue [19].

In comparison with classic electrical installations, an energy control system offers noticeable advantages. All the different engineering systems within the building are integrated via a bus connection to a single communicating system. This enables the optimal, energy efficient interaction of these systems, which is almost impossible with conventional technology. EMS is able to do this thanks to:

1. Energy-saving individual space control for heating, ventilation and air-conditioning
2. Optimum lighting tailored to the requirements at hand
3. Intelligent shutter control for making use of daylight and the sun's energy
4. Optimization of energy consumption via acquisition and evaluation of operational data from the building
5. Transparent visualizations for supporting facility management

In commercial and residential buildings with a lifespan that generally covers several decades, it is only a matter of time until rooms change use. Therefore, it is good if the building functions can be adapted to the needs of the user simply and at low cost during this time. With an open and interoperable EMS, these requirements are implemented quickly and easily by reprogramming or expansion. EMS are extremely high quality, future-proof installations. The bus system enables considerable simplification of *building monitoring and maintenance.*

Central acquisition of the relevant values, immediate error messages or possible corrections via remote maintenance – these are all measures which guarantee the reliable operation of the building [20].

Above a short description of building management systems mainly for control was presented, in addition to that also those systems provide information and monitor different variables. Energy information systems (EIS) differ from smart metering devices because they are incorporated with electrical installations and help for building internal control. Main functions and system features were described by Granderson [21] and summarized by authors in [13]:

1. *Data collection, transmission, storage, and security* - energy inputs, storage capacity, minimum trend interval, upload frequency, supported protocols and interoperability, archived and exported data formats, and security measures
2. *Display and visualization* - different potting intervals, trend display overlays, three-dimensional plotting, demand response status and reduction
3. *Energy analysis* – average values, peaks or lows, efficiencies, carbon tracking, multi-site, historical, and standard-based benchmarking
4. *Advanced analysis* - prediction, fault detection and diagnostics, data analyzation and statistics, on-site generation, load shape analysis
5. *Financial analysis* - tariff-based energy costing, meter or bill verification, estimation of savings from capital or operational changes, bill processing or payment, and end use allocation
6. *Demand response* - Signal notification, event response recording, manual vs. automated response, blackout, test dates, response analysis, and quantification
7. Remote control and management - automated and remote management
8. *General information* - browse support, purchase and subscription costs, number of users, traditional and newly targeted markets

Implementation of Building Management System: Case Study

A business centre with offices, VIP apartments, restaurants and bars, high class shopping centre and parking area is constructed in Tirana with a total surface of near 34000m2 analyzed also in [22, 23, 5]. The building is designed to satisfy the European Commission's directive for the energy performance of buildings 2002/91/EC [24] and requirements of European Standard EN 15232 [25].

To realize, monitor, manage and control the energy efficiency strategies of the building an energy management system (EMS) is incorporated in the building. The EMS is part of the Intelligent Building Management System (IBMS) of the building, which provides the integration of all engineering systems through an open, interoperable and portable system.

The scope of EMS was to realize through a software application significant savings in energy consumption by optimizing control schemes of HVAC system, lighting, and other consumers of the building. The intelligence of the system, offers different control energy saving strategies based also in user requirements. EMS application was constructed to do remote data acquisition from electronic energy meters of all engineering systems of the building at every half hourly interval and automatically highlights variances from set patterns or unexpected outputs. It monitors on line all consumption parameters and assists management in diagnosing consumption patterns that might be indicative of excessive energy consumption allowing potential savings to be accurately quantified. These savings would probably be undetected if it was not for the continuous monitoring system, and they even could pass unnoticed in a short walk around survey to the building, or at least would not be fully explored. Most of these savings were not physically visible, as the building manager and/or occupants did not notice them. These were only detected because of the analysis of high-resolution data, which pinpointed unusual patterns that were then proved to be caused [1].

EMS application offers to managers access to all data in a control room within the building (over a secure Intranet) or by remote access by a standard Web Browser over Internet. It is constructed also to provide monitoring, control, alarm and operational services based on operator decisions. It also tests the relationship between energy use and weather and/or occupancy and can plot charts at various resolutions. It can also provide by request regression analysis and generate alarms when consumption falls outside predetermined levels.

The selected hardware architecture of the system consisted of an Ethernet backbone that runs from the -3 to +21st floor and 21 KNX independent floor networks. This Ethernet LAN permits the exchange of data between the floor's KNX networks to the control room through IP/KNX gateways. In the control room is installed an EMS building supervision software (application) that run on a server structured computer.

Smart Metering and BMS Information used for Energy Prediction

Except the fact that AMR and BMs systems can provide online information about energy consumption, the stored information can be used for other purposes. One of those are data driven approaches used for predicting short term energy consumption. Their existence depends on previously gathered information about energy consumption and its influencing factors. Data driven approaches based on machine learning (ML) require enough data to get reliable results. ML tools train classifiers or repressor's based on pair (X, y), where X is a vector of input features and in case of energy prediction features can be air temperature and humidity, solar radiation, occupancy, building operation, working and non-working day and also other relevant features that affect building energy consumption behaviour.

An evaluation of best prediction method to use in smart grid context presented in [26]. They use a neural network model selecting best predictor. However, the core of predictionmethods are machine-learning algorithms, for the sake of their high accuracy and efficiency of the methods.

Most popular machine learning methods used in building energy prediction are artificial neural networks [27, 28, 29, 30, 31, 32, 33], the other class of methods are support vector regression [34, 35, 36, 37, 38, 39], other we can mention are regression trees [40, 41, 42]. Brief review papers about data driven approaches used to predict energy consumption can be found in [43] and also [44].

Discussion and Conclusions

Since building energy efficiency is essential factor in reducing air pollution and use of resources, here we presented a survey with respect to the impact that automated smart metering and building energy management systems have on improving energy efficiency.

A brief description combined with statistics about smart metering technology and future directions of this technology covered the first part. The impact in energy efficiency improvements that application of these technologies takes an important place in our survey.

Continuing with intelligent building environment, building system installation and features the paper provides useful information about advantages of installing those systems. In addition, the paper provides information about BMS features and presents a case study of a system installed in a multifunction building in Albania.

The capabilities of using metered and stored data, as data-driven approaches analyze the potential of widely using these technologies in developing countries.

References

[1] O. Zavalani, "Innovative approach to identify energy and water savings in municipality facilities in Albania," Proceedings of selected Applied Automatic Systems AAS-2009 papers, pp. 73-78, 2009.

[2] IEA, "World energy outlook 2016. International Energy Agency; September 2016".

[3] O. Zavalani and Y. Luga, "Energy and Water Saving Possibilities in Public Facilities in Albania," in Fourth UKSim European Symposium on Computer Modeling and Simulation (EMS), Pisa, Italy, 2010.

[4] E. Charter, "Regular Review of Energy Efficiency Policies,Albania, Part I," Tirana, 2007.

[5] O. Zavalani, "Reducing energy in buildings by using energy management systems andalternative energy-saving systems," in 8th InternationalConference on the European Energy Market (EEM-11), Zagreb, 2011.

[6] M. Himanen, The Intelligence of Intelligent Buildings, The Feasibility of the Intelligent Building Concept in Office Buildings, Espoo, Finland: Helsinki University of Technology , 2003.

[7] Anonymus, "The Intelligent Building Definition, First Edition," I.B.I. Intelligent, 1988.

[8] Anonymus, "Nordx CDT Network Cabling Solutions," The Intelligent Building Solutions, 2001.

[9] L. Brown, "Intelligent Building, Key Factors," University of Reading, 2001.

[10] CABA, "CABA's North American Intelligent Buildings Roadmap 2011," CABA, 2011.

[11] A. Zoha, A. Gluhak, M. A. Imran and S. Rajasegarar, "Non-Intrusive Load Monitoring Approaches for Disaggregated Energy Sensing: A Survey," sensors, vol. 12, pp. 16838-16866, 2012.

[12] V. Ferreira and P. Fleming, "The use of sub-hourly primary meter data to identify electricity savings in municipal buildings," Energy Efficiency, vol. 7, p. 879–889, 2014.

[13] G. Cao and J. Pietiläinen, "Total energy use in buildings analysis and evaluation methods, Final Report Annex 53," International Energy Agency, November 14, 2013.

[14] CEN-CENELEC-ETSI, "Introduction and Guide to the work undertaken under the M/441 mandate," A report by the CEN-CENELEC-ETSI Smart Meters Coordination Group , 2012.

[15] T. Ueno and Y. Nakano, "Effectiveness of Displaying Energy Consumption Data in Residential Buildings: To Know Is to Change," ACEEE Summer Study on Energy

Efficiency in Buildings, pp. 7-264–7-277, 2006.

[16] Q. Han and S. Mehrotra, "Application-aware integration of data collection and power management in wireless sensor networks," Journal of Parallel and Distributed Computing, vol. 67, no. 9, pp. 992-1006, 2007.

[17] P. Oksa and M. Soini, "Kilavi platform for wireless building automation," Energy and Buildings, vol. 40, no. 9, pp. 1721-1730, 2008.

[18] W. T. Sung and Y. C. Hsu, "Designing an industrial real-time measurement and monitoring system based on embedded system and ZigBee," Expert Systems with Applications, vol. 38, no. 4, pp. 4522-4529, 2011.

[19] W. Kastner, G. Neugschwandtner, S. Soucek and H. M. Newman, "Communication systems for building automation and control," Proceedings of the IEEE, vol. 93, no. 6, pp. 1178-1203, 2005.

[20] ABB, "Smart Home and Intelligent Building Control, Energy Efficiency in Buildings," ABB, 2009.

[21] J. Granderson, M. Piette , G. Ghatikar and P. Price, "Building Energy Information Systems: State of the Technology and User Case Studies," Lawrence Berkeley National, LBNL-2899E, 2009.

[22] O. Zavalani, A. Shabani, A. Spahiu and L. Dhamo, "Innovation, Technology Transfer and Automation Systems in Albania," HCTL Open International Journal of Technology Innovations and Research, vol. 14, pp. 1-9, 2015.

[23] O. Zavalani, M. Braneshi and Y. Luga, "Technology Transfer and Building Automation Systems in Albania," in Workshop on Supplemental Ways for Improving International Stability, Pristina, 2010.

[24] "2002/91/EC Energy Performance of Buildings Directive EPBD".

[25] "Energy performance of buildings – Impact of Building Automation, Controls and Building Management," European Standard 15232 EN.

[26] M. Frincu, C. Chelmis, M. U. Noor and V. Prasanna, "Accurate and efficient selection of the best consumption prediction method in smart grids," in IEEE International Conference on Big Data (Big Data), Washington, 2014.

[27] A. Azadeh, S. Ghaderi and S. Sohrabkhani, "Annual electricity consumption forecasting by neural network in high energy consuming industrial sectors," Energy Conversion and Management, vol. 49, no. (8), pp. 2272 -- 2278, 2008.

[28] S. Kalogirou, "Artificial neural networks in energy applications in buildings," International Journal of Low-Carbon Technologies, vol. 1, no. 3, pp. 201-216, 2006.

[29] A. Ben-Nakhi and M. Mahmoud, "Cooling load prediction for buildings using general regression neural networks," Energy Conversion and Management, vol. 45, no. 13-14, pp. 2127 -2141, 2004.

[30] P. González and J. Zamarreño, "Prediction of hourly energy consumption in buildings based on a feedback artificial neural network," Energy and Buildings, vol. 37, no. (6), pp. 595 -- 601, 2005.

[31] R. Yokoyama, T. Wakui and T. Satake, "Prediction of energy demands using neural network with model identification by global optimization," Energy Conversion and Management, vol. 50, no. 2, p. 319–327, 2009.

[32] S. Kalogirou and M. Bojic, "Artificial neural networks for the prediction of the energy consumption of a passive solar building," Energy, vol. 25, no. (5), pp. 479 -- 491.

[33] R. Yokoyama, T. Wakui and R. Satake, “Prediction of energy demands using neural network with model identification by global optimisation,” Energy Conversion and Management, vol. 50, no. 2, pp. 319-327, 2009.

[34] H. X. Zhao and F. Magoulès, “Parallel support vector machines applied to the prediction of multiple buildings energy consumption,” Journal of Algorithms and Computational Technology, vol. 4, no. 2, pp. 231-249, 2010.

[35] B. Dong, C. Cao and S. E. Lee, “Applying support vector machines to predict building energy consumption in tropical region,” Energy and Buildings, vol. 37, no. 5, pp. 545-553, 2005.

[36] Y. Fu, Z. Li, H. Zhang and P. Xu, “Using support vector machine to predict next day electricity load of public buildings with sub-metering devices,” Procedia Engineering, vol. 121, pp. 1016-1022, 2015.

[37] F. Lai, F. Magoules and F. Lherminier, “Vapnik's learning theory applied to energy consumption forecasts in residential buildings,” International Journal of Computer Mathematics, vol. 85, pp. 1563-1588, 2008.

[38] Q. LI, Q. Meng, J. Cai, H. Yoshin and A. Mochida, “Applying support vector machine to predict hourly cooling load in the building,” Applied Energy, vol. 86, no. 10, pp. 2249-2256, 2009.

[39] Q. Li, Q. Meng, J. Cai, H. Yoshino and A. Mochida, “Predicting hourly cooling load in the building: A comparison of support vector machine and different artificial neural networks,” Energy Conversion and Management, vol. 5, no. 1, pp. 90-96, 2009.

[40] Z. Yu, F. Haghighat, B. C. Fung and H. Yoshino, “A decision tree method for building energy demand modeling,” Energy and Buildings, vol. 42, no. 10, pp. 1637-1646, 2010.

[41] G. Tso and K. Yau, “Predicting electricity energy consumption: A comparison of regression analysis, decision tree and neural networks,” Energy, vol. 32, no. 9, pp. 1761-1768, 2007.

[42] J. Yang and J. Stenzel, “Short-term load forecasting with increment regression tree,” Electric Power Systems Research, vol. 76, pp. 880-888, 2006.

[43] A. Shabani and O. Zavalani, “Predicting Building Energy Consumption using Engineering and Data Driven Approaches: A Review,” European Journal of Engineering Research and Science, vol. 2, no. 5, pp. 44-49, 2017.

[44] H.-x. Zhao and F. Magoulès, “A review on the prediction of building energy consumption,” Renewable and Sustainable Energy Reviews, vol. 16, pp. 3586-3592, 2012.