Building Energy Management Systems using an Innovative "Smart City Platform"

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ABSTRACT

Smart Energy Cities (SEC), as a core pillar of the Smart Cities, constitute an emerging urban development strategy and are expected to play a key role in the implementation of Europe 2020 and the achievement of 2030 climate and energy objectives. Making SEC a reality requires the adoption of multidisciplinary and integrated approaches and management of various data sets, as well as relevant intelligent systems in a transparent and accessible manner. In this context, the aim of this paper is to present an innovative "Smart City Platform", based on building energy management system and smart decision support systems. The proposed platform sits on the top of existing energy management systems, integrating five data sources from various domains (weather, building monitoring, occupants' feedback, energy prices and energy production), in order to propose short-term action plans for building / energy managers to optimise energy use and thereby reducing energy costs and carbon emissions.

INTRODUCTION

It is a common practice of the European Union (EU) to formulate and adopt measures towards sustainable growth in Europe, with focus on energy and climate issues. Energy is an essential component of life in cities, since it supports the whole spectrum of their economic activities, and secures a certain level of quality of life to residents. Cities are responsible for more than 70% of the humanity's overall ecological footprint (Ecological Footprint Network, 2008; Mega, 2010). Due to urbanisation at least 75% of the human population lives in countries that are ecological debtors, consuming more bio capacity than they have within their borders, constitutes a proof of the cities' severe environmental impact. Therefore, cities that reduce their ecological imprint to a minimum can play a fundamental role regarding their countries' sustainability efforts.

Cities are turning to advanced technologies to become Smart. In the process of building the future Smart Cities, Information and Communication Technology (ICT) infrastructure is considered to be a key enabler (Glick et. al., 2012; Van Landegem, 2012) providing city authorities with innovative methodologies and tools for monitoring and managing the energy use more efficiently to achieve financial, environmental and social sustainability. Smart Energy Cities (SEC), as a core pillar of the Smart Cities, constitute an emerging urban development strategy and are expected to play a key role in the implementation of Europe 2020 and the achievement of 2030 climate and energy objectives. This solution can consist of several components and a holistic approach is required in this respect. Optimizing the energy use in cities is a current research trend. Although numerous initiatives exist, promoting the use of Decision Support Systems (DSS) in local communities' energy policy and planning, there is still enough space for improvement. Making SEC a reality requires the adoption of multidisciplinary and integrated approaches and management of various data sets, as well as relevant intelligent systems in a transparent and accessible manner.

In this context, the aim of this paper is to present an innovative "Smart City Platform", based on Building Energy Management System (BEMS) and Smart Decision Support Systems (DSS). The proposed platform sits on the top of existing energy management systems, integrating five data sources from various domains (weather, building monitoring, occupants' feedback, energy prices and energy production), in order to propose short-term action plans for building / energy managers to optimise energy use and thereby reducing energy costs and carbon emissions.

Apart from the introduction, the paper is structured along five sections. Section 2 provides the relevant policy context that is identified concerning the EU, while Section 3 enumerates initiatives relevant to the ideas of optimizing the energy use in cities and describes the key data parameters that are proposed to be integrated within an innovative approach of a decision support framework for optimizing short-term energy action plans in cities and enumerates relevant methodologies, techniques, tools and best practices. Section 4 presents overall strategy and upscaling of the proposed platform, while Section 5 elaborates the expected range of each action plan's impact on different aspects of energy optimization. Finally, the last section is summarizing the key issues that have arisen in this paper.

POLICY CONTEXT

The EU tries to promote a shared European vision of sustainable urban development. European cities should be characterized by social progress and developed environmental consciousness, as well as economic growth based on a holistic integrated approach in which all aspects of sustainability are taken into account (European Commission, 2011a). A number of European initiatives have been launched related to these ideas, as presented in the following paragraphs. Cities, as consumers, demonstrate their willingness to implement sound local sustainable energy policies, especially through their participation in the *Covenant of Mayors (CoM)* initiative. The CoM is a European initiative addressed to local and regional authorities, focused on the promotion of energy efficiency and renewable energy sources on their territories.

The *Energy-efficient Buildings Public Private Partnership in research (EeB PPP)* (European Commission, 2010a), represents the first step set by the industry to create more efficient districts and cities while improving the quality of life of European citizens. In addition, the *Directive 2010/31/EU* (EPBD recast) has indicated that the public sector has an important role in the field of energy performance of buildings, as new buildings occupied and owned by public authorities should be nearly zero-energy buildings, after 31 December 2018. A new *European Innovation Partnership (EIP) on Smart Cities and Communities (SCC)* (European Commission, 2012) was launched in July 2012 to promote the deployment of smart city solutions in Europe, focusing on the intersections of ICT, energy and transport. Cities themselves have also taken a pro-active role and launched the Green Digital Charter in 2009. The idea is that the cities signing up to the Charter commit to reduce the carbon footprint of their ICT and roll-out ICT solutions which lead to more energy efficiency in areas such as buildings, transport and energy. The *Smart Cities Stakeholder Platform* aims to support EU to achieve the target of 80% reduction of GHG emissions by 2050 by promoting the development and market deployment of energy efficiency and low-carbon technology applications addressed to the urban environment. The *European Energy Research Alliance (EERA) Joint Programme on Smart Cities* was launched in September 2010. The main scope of the programme is to promote the development of tools and methods to enable a more sophisticated design, planning and operation of the energy system of a city in the near future. Finally, two of the main pillars of Europe 2020 strategy are the Digital Agenda for Europe and the resource efficient Europe:

- *Digital Agenda for Europe - DAE* (European Commission, 2010b): The Digital Agenda for Europe provides a policy framework aiming at delivering economic and social benefits from a digital single market based on internet and interoperable applications (Petrović et. al., 2014).
- *Resource-efficient Europe* (European Commission. 2011b): This initiative under the Europe 2020 strategy supports the shift towards a resource-efficient, low-carbon economy to achieve sustainable growth.

It becomes clear that EU places the issue of optimizing the energy-use in cities in the "heart" of its agenda. It is also treated as a necessary part of the research on Smart Cities. To this direction, the most suitable and available pilots for the first implementation of research are the municipal buildings.

RELEVANT INITIATIVES

Several initiatives have been identified in the international research scene, relevant to the ideas of optimizing the energy use in cities. In terms of semantic data modeling –a modeling technique that enables information stored in different formats and different places to be used to create a multi-level energy model of an area -, the SEMANCO initiative (Semantic Tools for Carbon Reduction in Urban Planning) is worth mentioning. The technological approach of the project is based on the integration of energy related open data, structured according to standards, semantically modelled and interoperable with a set of tools for visualizing, simulating and analysing the multiple relationships between the factors determining CO2 production. The tools and methods in SEMANCO enable structuring energy related data, held in distributed sources and diverse formats, using data mining techniques (SEMANCO Project Methodology Report, 2012).

The CitInES initiative (Design of a decision support tool for sustainable, reliable and cost-effective energy strategies in cities and industrial complexes) aims to design innovative energy system modelling and optimization algorithms to allow end-users to optimize their energy strategy using data sources on local energy generation, storage, transport, distribution and demand, including demand-side management and functionalities enabled by smart grid technologies. CitInES integrates information about local renewable energies, smart grid integration and demand-side management, as well as fuel price uncertainties (Page et. al., 2013).

The ICT 4 E2B FORUM (European stakeholders forum crossing value and innovation chains to explore needs, challenges and opportunities in further research and integration of ICT systems for Energy Efficiency in Buildings) aims to the creation of a strategic research roadmap for ICT supported energy efficiency in construction, by bringing together all relevant stakeholders involved in ICT systems and solutions for energy efficiency in buildings, at identifying and reviewing the needs in terms of research and systems integration as well as at accelerating implementation and take-up (Mastrodonato et. al., 2011). The roadmap produced (ICT 4 E2B, Final Research Report, 2012) consists of the Vision, the Strategic Research Agenda and it also provides suggestions and implementation activities.

In the framework of IREEN (ICT Roadmap for Energy Efficient Neighbourhoods) initiative the ways that ICT for energy efficiency and performance can be extended beyond individual homes and buildings to the wider context of neighbourhoods and communities are examined (IREEN Roadmap for European-scale innovation and take-up, 2013).

NiCE (Networking intelligent Cities for Energy Efficiency) promotes the implementation of commitments to the Green Digital Charter while in the framework of FINSENY (Future Internet for Smart Energy) initiative Future Internet technologies are exploited for the development of Smart Energy infrastructures, enabling new functionality while reducing costs (Fluhr & Williams, 2011). ENPROVE (Energy consumption prediction with building usage measurements for software-based decision support) provides an innovative service to model the energy consumption of structures supported by sensor-based data. The service makes use of novel ICT solutions to predict the performance of alternative energy-savings building scenarios in order to support relevant stakeholders in the procedure of identifying optimal investments for maximizing energy efficiency of an existing building (ENPROVE Final Report, 2013).

The INTENSE initiative (From Estonia till Croatia: Intelligent Energy Saving Measures for Municipal housing in Central and Eastern European countries) provides a holistic approach for planning of energy optimized housing. The project comprises an analysis of legal preconditions, experience exchange on best practice examples, pilot planning activities at partner municipalities, and public awareness raising. i-SCOPE (Interoperable Smart City services through an Open Platform for urban Ecosystems) delivers an open platform on top of which it develops, within different domains, a series of "smart city" services, based on interoperable 3D Urban Information Models (UIMs) (Patti et. al., 2013). In the framework of RESSOL-MEDBUILD (RESearch Elevation on Integration of SOLar Technologies into MEDiterranean BUILDings) simulation models are developed for the optimization of building energy management and energy performance (RESSOL-MEDBUILD Periodic Report Summary, 2013). The ENRIMA initiative (Energy Efficiency and Risk Management in Public Buildings) specifies the development of a DSS engine for integrated management of energy-efficient sites, promoting adaptation of the DSS on buildings and/or spaces of public use (Cano et. al., 2013). TRACE (Tool for Rapid Assessment of City Energy) is a DSS tool designed and implemented by WorldBank within the Energy Sector Management Assistance Program (ESMAP) to assist municipal authorities in identifying and prioritizing Energy Efficiency actions. The methodology incorporated within the TRACE project initially evaluates the city performance focusing on energy consuming municipal sectors (passenger transport, municipal buildings, water and wastewater, public lighting, power and heat, and solid waste), and then it prioritizes energy efficiency improvement actions and interventions for the most energy intense sectors (ESMAP WorldBank, 2010).

Table 1 summarizes the main scope of each of the relevant identified initiatives. The indication X in the Table means that an Initiative applies to the indicated scope. Most of the Initiatives presented deal with more technical issues, such as Smart Grids and ICT, while the least covered scopes are those of DSS and Information Exchange, meaning weakness in participatory approaches and in combination of criteria to support actions.

Table 1. Initiatives and Objectives.

Initiatives	DSS	ICT	Stakeholder Participation	Smart Grids	Information Exchange	Policy Support	Data Categories	Source
SEMANCO		x		x		x	Energy Profile	http://www.semanco-project.eu
CitInES	x			x		x	Energy Profile Energy Production	Page et. al., 2013
ICT 4 E2B FORUM		x	x	x	x	x	Energy Profile Energy Production Energy Prices	ICT 4 E2B, Final Research Report, 2012
IREEN		x	x	x	x	x	Energy Profile	IREEN Roadmap for European-scale innovation and take-up, 2013
NiCE		x	x	x	x		Energy Profile	http://www.greendigitalcharter.eu/niceproject
FINSENY		x		x		x	Energy Profile Energy Prices	Fluhr & Williams, 2011; http://www.fi-ppp-finseny.eu/
ENPROVE		x	x	x			Energy Profile	ENPROVE Final Report, 2013
INTENSE			x	x	x	x	Energy Profile Weather	http://www.intense-energy.eu
i-SCOPE		x		x			Energy Profile Energy Production	Patti et. al., 2013
RESSOL-MEDBUILD		x		x			Energy Profile Energy Production Data Weather	Periodic Report Summary; 2013 http://www.ressol-medbuild.eu/
ENRIMA	x	x	x	x	x	x	Energy Profile Energy Production Energy Prices	Cano et. al., 2013 forthcoming; http://www.enrima-project.eu/
TRACE	x	x		x		x	Energy Profile	ESMAP WorldBank, 2010

Based on the initiatives presented in Table 1 optimizing the energy use in cities is a current research trend, with several existing initiatives promoting the use of DSSs in local communities' energy planning. Although many research initiatives have been proposed so far, there is a gap in integrating data from multiple domains (e.g. weather forecasts, occupants' feedback, energy prices, energy profiles), with the use of semantic technologies, to assist city authorities to produce short-term energy plans in a transparent and comprehensive way. Modeling and simulation are valuable tools to understand how cities work and how the various different elements interact among them (Doyle, 2009), such as renewable energy systems and innovative generation technologies for local energy production, as well as smart electricity grids and smart district heating/cooling grids. Models and datasets, however, typically cover one particular field only and it is difficult to span across its boundaries.

Except from the usually considered data sources that are focusing on energy, there are also other types of data, which may affect the energy demand and energy production at the city level, such as weather conditions and data on events that can affect energy use and patterns. To this end, a considerable variety of data sources need to be used to fully reflect the most important aspects that affect the energy use in a city on the one side, as well as to take into consideration the most important parameters in the decision making process.

SMART CITY PLATFORM

SEC, as a core pillar of the Smart Cities, constitute an emerging urban development strategy and are expected to play a key role in the implementation of Europe 2020. Among the primary targets of SEC is also the achievement of the 2030 climate and energy objectives, towards carbon neutral cities and neighborhoods. In the process of building the future Cities, ICT infrastructure are the key enabler. The "Smart City Platform" constitutes a subset of SEC, offering a package of consulting tools for energy managers and energy consultancies, in order to make cities more energy efficient and sustainable. The purpose is to optimize the energy use in main city's buildings (municipal and educational buildings, buildings for entertainment and sports facilities, hospitals, hotels, etc.), taking into consideration their interaction with energy systems, such as renewable energy production, smart district heating and cooling grids through CHP (Combined Heat and Power) and other energy sources.

The proposed platform is on the top of existing energy management systems, integrating five multidisciplinary data sources (weather conditions, buildings' energy profiles, feedback provided by occupants, energy prices and energy production), in order to propose short-term action plans for energy managers with the goal of reducing energy consumption and cost. Through the successful combination of advanced ICT tools (SCEAF Tool, Tracker, DSS) and smart technologies (smart meters, etc.), "Smart City Platform" provides an integrated solution for energy managers and energy consultancies, addressing the following questions:

- **How optimus is your city / building in terms of energy optimization?**
  SCEAF (Smart City Energy Assessment Framework) Tool (http://sceaf.optimus-smartcity.eu) provides energy managers with a framework for assessing the performance of the city / building, in terms of energy optimization, CO_2 emissions reduction and energy cost minimization. It includes two versions, namely the "Whole City Level SCEAF" and the customized "Municipal Building Level SCEAF". Using appropriate indicators, the progress of the city/building in that direction can be revealed by analyzing and evaluating three pillars: "Political Field of Action", "Energy and Environmental Profile" and "Related Infrastructures and ICT". It is more than important to initially have a detailed assessment of the status of the city in relation to them, prior to the application of the DSS (ex-ante), so as to find out what needs to be optimized, as well as after its application (ex-post).
- **What is the potential of the city / building for optimization?**
  Tracker (http://tracker.optimus-smartcity.eu) constitutes a web tool for the energy managers, in order to assess the potential of the city / building for optimization and identify specific buildings where the DSS can be applied. Providing information on energy consumption overall figures and selecting action plans that are more suitable for application in the buildings, Tracker offers the opportunity to create different scenarios of the DSS application. These scenarios can be compared in terms of the expected impacts, through the calculation of the DSS indicators:

reduction of energy consumption; reduction of CO_2 emissions; energy cost reduction; increase of RES production. In this way, the energy manager can take the decision to plug in single buildings and/or buildings connected to energy production and other energy systems.

- **What domains / action plans can DSS support in your case?**
  Based on real-time data monitored (weather conditions, buildings' energy profiles, feedback provided by occupants, energy prices and energy production) and predicted data produced by the prediction models, DSS (http://optimus-smartcity.eu/optimus-dss) introduces a list of practical Action Plans. A total of seven Action Plans, are available from the DSS, ready to accommodate energy managers willing to plug - in their buildings. The Action Plans refer to the energy optimization in buildings, examining them not as isolated entities. Taking into consideration their interaction with energy systems, they can foster efficient management of energy flows at a broader level, integrating energy demand, generation and data/energy infrastructures. DSS is characterized by a combination of advanced technologies that enables integration of multiple domains. The action plans are categorized, according to their applicability, to buildings and/or block of buildings, with some of them allowing more comfort, functionality, and flexibility through integration of energy generation and storage systems ("Sustainable Districts & Built Environment" Domain). Moreover, some of the action plans enable the interconnection of energy infrastructures and new technologies ("Integrated Infrastructures & Processes across Energy and ICT" Domain).

POTENTIAL IMPACT

Table 3 provides the expected range of each action plan's impact on different aspects of energy optimization. The full potential is estimated from each action plan, both empirically and through literature. The numbers presented in the table below have been duly assessed and considered reliable for the purposes of the analysis.

Table 3: Potential Impact of the Action Plans

	Action Plan	Use	MIN	MAX	Reference
Reduction of Energy Consumption					
AP1	Scheduling and management of the occupancy	Cooling	5%	9%	"The results showed that room reassignment could further enhance the energy use reduction by up to 4,4% for heating and 9% for cooling" (Yang and Becerik-Gerber, 2014)
		Heating	2%	4%	"~8-11% energy savings" (UNC, 2016)
AP2	Scheduling the set-point temperature	Cooling	5%	9%	"For each degree rise in supply-air temperature set point, there is about 5% to 6% reduction in total HVAC energy consumption, depending on climate", (Fernandez et al., 2012) "A reduction of 1 K in internal temperature will reduce the energy consumption by 6%" (Sala et al., 1999).
		Heating	5%	9%	"Energy savings using an adaptive comfort model was estimated as 10 ÷ 18% of the overall cooling load" (Attia and Carlucci, 2015).
AP3	Scheduling the ON/OFF of the heating system	Heating	5%	10%	"The replacement of existing fixed start time control with optimum start/stop control can generate 10% energy savings for heating systems operating single shifts (Curbontrust, 2016).
AP4	Management of the air side economizer	Cooling	10%	20%	"As much as 20% savings in electrical energy for cooling were possible with demand-controlled ventilation" (Brandemuehl and Braun, 1999).

		Heating	5%	10%	“Comfort is largely enhanced without mechanical cooling and reaches usual criteria while impact on energy demand is limited to 10% of heating demand (Moeseke et al., 2007).
Increase of RES Production					
AP5	Scheduling the photovoltaic (PV) maintenance		3%	8%	Empirically (based on the available data from the pilot cities)
Reduction of Energy Cost					
AP6	Scheduling the sale/consumption of the electricity produced through the PV system		5%	10%	“The cost savings achieved by charging according to the price-optimal strategy was about 10-15%” (Steen et al., 2016).
AP7	Scheduling the operation of heating and electricity systems towards energy cost optimization		5%	10%	“research shows that 20%–30% of building energy consumption can be saved through optimized operation and management without changing the structure and hardware configuration of the building energy supply system.” (Guan, 2010). “Energy costs with and without battery” (reductions between 7 an 10%) (Guan, 2010)

CONCLUSIONS

Through this paper the need for integrated, transparent and comprehensive energy management decision support systems was highlighted. Based on the investigation conducted, an integrated approach using different sources of data was proposed and different techniques and methods needed to be employed are discussed in this respect. The “Smart City Platform” integrates decision support tools to assess SEC and improve the energy performance of their buildings.

Although particular emphasis is given on the municipal building sector, the overall approach can be applied to different types of buildings, such as buildings for entertainment and sports facilities, hospitals, hotels, etc. The proposed platform has, by design, the necessary degree of generalization, so as to be easily adapted to additional buildings of the participating cities, as well as additional cities outside the consortium with different characteristics, energy infrastructures, needs, priorities and types of energy demand. Moreover, the developed approach gives the opportunity for the development of new action plans that will integrate additional energy systems and domains (priority areas) of the SEC, such as “Sustainable Urban Mobility” (e.g. optimal charging scheduling of the electrical vehicles, etc.).

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