DEVELOPMENT OF AN INNOVATIVE ENERGY MANAGEMENT SYSTEM FOR UNIVERSITY CAMPUSES

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ABSTRACT

Universities' campuses can be viewed as small communities considering their size, users and mixed complex activities. The energy and environmental impact caused by universities due to activities and operations in teaching and research could be considerably reduced by an effective choice of organizational and managerial measures. In addition, there is considerable room for improvement and research potential in energy management, when leaving from the single building aspect and moving towards a "district" approach, where a set of different buildings and outdoor spaces are considered. The aim of this paper is to present an integrated and holistic indoor - outdoor Web-based Energy Management System for Campuses, which is developed, tested and validated through the accurate modeling of two Campus buildings and their outdoor spaces, as well as the corresponding expert systems and control algorithms. Thus, the load demand in real-time can be predicted, giving the capability of providing optimal or nearly-optimal demand balance, while maintaining the users' safety, health and comfort. The overall concept is estimated to contribute at least a 25% reduction of the primary energy consumption, due to reduction of energy waste. The proposed system will create the basis for a future Smart Grid community.
The system will be developed under the Project CAMP_IT, financed by General Secretariat for Research and Technology.

KEYWORDS

Please provide a maximum of five keywords which reflect the content of the paper Energy efficiency, energy consumption, Building Management System, zero- energy buildings, control algorithms, smart grid

1 INTRODUCTION

Considering the size of Universities' campuses it can be said can be viewed as small cities due to their size, users and mixed complex activities. The energy and environmental impact caused by universities via activities and operations in teaching and research, as well as provision of support services could be considerably reduced by an effective choice of organizational and managerial measures (Alshuwaikhat et al, 2008). Since the University campuses natural land is replaced with artificial surfaces and buildings with undesirable thermal effects, the overheating by human energy release and absorption of solar radiation on dark surfaces and buildings is possible. Hence, campuses create an urban-kind climate which cannot be neglected. To design and operate a sustainable campus, it is necessary to factor the indoor-outdoor environment and information holistically and strategically into the planning and operational process.

Nowadays, the improvement of the outdoor environment has gained a substantial attention. Open urban spaces can contribute to the quality of life within cities, or contrarily, enhance isolation and social exclusion. The major factor that determines the quality of the open urban spaces is the climate conditions that occur in the micro scale environment. The strategies to improve urban environment include the use of smart materials, the increase of vegetation, ventilation, shading and evaporation. On the other hand, ICT for energy management has evolved considerably the last decades. 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 building sites worldwide. Last but not least nowadays it is vital that Europe's electricity networks are able to integrate all low carbon generation technologies as well as to encourage the demand side to play an active part in the supply chain. In this part, ICT technology plays a vital role. Currently the issue of Energy Management for large sites, such University Campuses is addressed by the Energy Information Systems (EIS) which have evolved out of the electric utility industry in order to manage time-series electric consumption data. However, other energy management technologies have also expanded their functionalities, and have partly come to merge with EIS technology. Since EIS products are relatively new technologies, they are changing quickly as the market unfolds (Motegi et al, 2003).

2 OBJECTIVES – EXPECTED RESULTS

Based on the above analysis, there is a considerable room for improvement and research potential in energy management, when leaving from the single building aspect and moving towards a "district" approach where different buildings and outdoor spaces are considered. Towards this "district approach" the use of University Campuses, as a field of application, is considerably advantageous compared to a community or city district as the overall area belongs to a single owner. Therefore the aim of the CAMP-IT is to develop, test and validate an integrated and holistic indoor - outdoor Web based Energy management System for Campuses. This major objective is pursued within CAMP-IT via a number of multifaceted actions and S&T Objectives: (a) Advance the state of the art in modeling of buildings and outdoor spaces by creating a modeling procedure and a holistic methodology. In addition a simplification process will be developed to provide "district models" "as accurate as possible". (b) Advance the state of the art in expert systems and control algorithms for energy load prediction and shaping in small communities by developing an efficient, robust and rapidly-adapting real-time expert system capable of providing optimal – or nearly-optimal – demand balance, while maintaining users' safety and health and, most importantly, complying with end-users comfort-related commands and requests. (c) Advance the state-of-the-art in user-interaction, sensoring and interfacing by either employing wireless technologies or using the existing IP infrastructure and connectivity of Campuses to ensure interoperability, expandability, flexibility and easiness of installation. (d) Integrate the above-mentioned systems and designs in order to come up with a fully-functional system capable of providing efficient, robust, safe and user-acceptable conditions on Campus level. (e) Application and validation of the developed system in TUC Campus during their ordinary operation. The Campus buildings selected (Annex 1) cover a wide range of different building designs and operations, self-generating components, automatically and manually-controlled energy-influencing elements and environmental conditions. (f) Evaluation of the impact of the CAMP-IT system with emphasis on its effect in significantly contributing towards the easy and cost/energy-efficient deployment and operation of an Advanced Campus Web Based Energy Management, as well as the user-friendliness and user-acceptance of the CAMP-IT concept. In CAMP-IT we have chosen to move rapidly towards commercially viable prototyping and proof-of-concept systems by deploying and testing the system in real time conditions.

Therefore the specific system by exploiting the existing Internet connectivity and infrastructure of the University Campuses, as well as existing knowledge and experience of the involved teams will cover the aforementioned specific objectives for two TUC Campus buildings and the space of public use around them (see Annex 1). The overall concept is depicted in

Figure 1 and is estimated to contribute to at least 25% reduction of the primary energy consumption due to reduction of energy waste. Moreover the CAMP-IT system will create the basis for a future smart grid community.

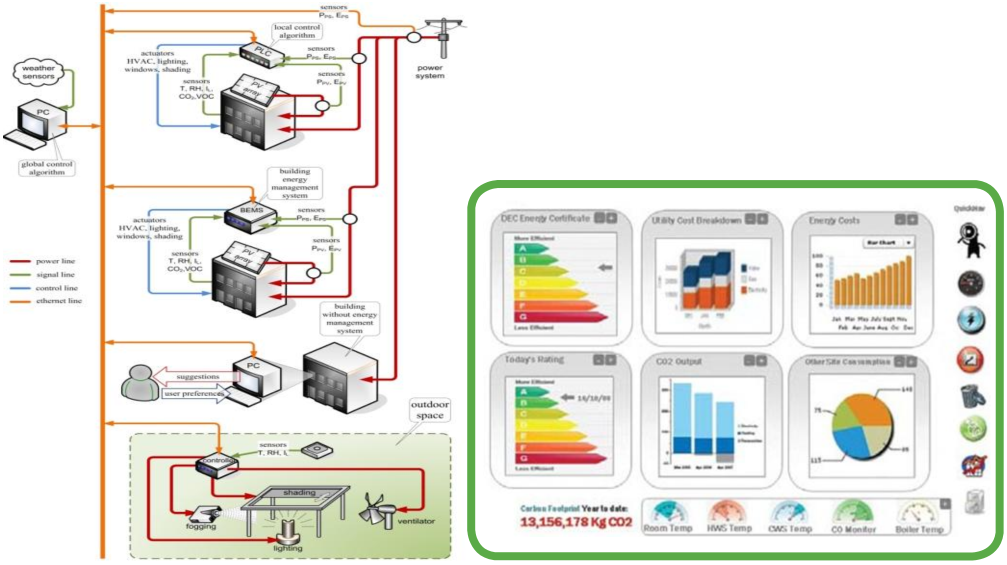

Figure 1. The Concept and a view of the CAMP-IT custom application using industrial automation products and services

<u>Progress beyond the state-of-the-art:</u> The building services management systems and control are now approximately thirty years old. Their increasing use during the last decades has led to the collection of significant experience and the market is approaching maturity. Simulation and application of artificial intelligence control techniques (such as fuzzy logic and artificial neural networks), has indicated that they have the potential to make significant energy savings in buildings, especially when the renewable energy sources are controlled in an integrated fashion with the rest of the building system. The development and demonstration of CAMP-IT system involves groundbreaking innovations and progress beyond the state-of-the-art in various fields. This includes the indoor-outdoor modeling and integration, real-time expert system and system connectivity. In the following paragraphs the key S&T questions of the proposal are shortly addressed and the state-of-the-art is discussed.

Apart from progress in the different fields presented below, the system integration plays a key role for reaching and validating the set goals.

<u>Indoor – outdoor modeling and interaction:</u> In the last two decades, a considerable amount of research studies show that the air movement in and around buildings may be predicted using Computational Fluid Dynamics (CFD) models (for example, in the year 2007 the 70% of publications dealing with airflow in buildings include CFD models) (Chen et al, 2009;

Chen et al, 2010). The implementation of comfort and environmental indices into a CFD model leads to local information about the living conditions in buildings. Currently, numerous

studies dealing with the evaluation of indoor thermal comfort and environmental conditions using CFD models exist (Zhou & Haghighat, 2009a&b; Stavrakakis et al., 2011). It should be mentioned, however, that researches which utilize appropriately modified thermal and environmental indices (e.g. for non air-conditioned spaces) are few and they focus mainly on outdoor or semi-outdoor spaces (Bouyer et al., 2007). On the other hand, various researches focus in the improvement of outdoor comfort conditions by applying several techniques based on bioclimatic architecture criteria and on passive cooling and energy conservation principles (Gaitani et al, 2007). It is noticeable that until now, there exists no integrated and holistic approach for buildings' operation optimization by taking advantage of the indoor-outdoor full-scale simulations. The proposed system targets to fulfill requirements beyond the state-of-the-art and to expand the existing knowledge in the built environment' modeling by: (a) creating a modeling methodology for the functioning of the building throughout its all life cycle (design, operation, etc.); (b) using a single methodology and tools to model the overall process. Finally a Meta program developed by Lawrence Berkley National Laboratory, where EnergyPlus (CFD is integrated), Radiance, Modelica and Matlab are interconnected, will be used for the CAMP-IT; (c) providing a simplification methodology for modeling Campus areas.

Development of a decision support tool and optimization method for web based energy management system: The main challenge in the design of control systems for energy performance of buildings is to find the balance between implementation costs, operation costs, energy consumption, indoor climate quality, users' satisfaction and contribution to sustainable building. Intelligently designed buildings are those that involve environmentally responsive design, taking into account the surroundings and building usage and involving the selection of appropriate building services and control systems to further enhance building operation with a view to the reduction of energy consumption and environmental impact over its lifetime. This procedure requires advanced control techniques to establish a balance among user comfort requirements, energy consumption, passive solar design concepts, solar heating and cooling technologies, as well as photovoltaics. A significant attention is drawn by the model based predictive systems as the intelligent combination of all available energy-generation, together with automatically- and manually-controlled building elements, cannot be achieved if simple heuristic or data-driven strategies are employed. Therefore decision support systems that compute their control and optimization decisions based on efficient and accurate built environment models are required in order to obtain efficient and nearly-optimal operation on a community level. Based on the analysis presented in the previous subsection, a prerequisite for the deployment of an efficient web based energy management system for Campuses is the development of an expert system which: (a) Manages in an energy efficient way the Campus buildings and spaces of public use. (b) Monitors the energy load and perform load balancing and load shaping per building and per Campus and as a whole. (c) Interacts with each building's BEMS and each user through e-mails and web forms. (d) Optimizes of the overall strategy based on historical data. (e) Focuses on the Campus as a district and creates a holistic methodology for buildings and outdoor spaces of public use.

Integration into campus existing infrastructure- Interconnection of buildings and outdoor spaces: Sensors, actuators and interfaces are essential components for the successful implementation and real-time operation of a web based energy management system. The evolution of the specific components was quite rapid during the last decades leading to the intelligent buildings' concept derived from artificial intelligence and information technology. While ICT infrastructure networks are seen as an important part in emerging building and community energy management systems through i.e. Metropolitan Area Networks, the integration of sensor networks with future energy management systems is still an open problem. The aim of the present project is to advance the existing knowledge in ICT for energy management infrastructure by establishing an IP-based sensor network system, where nodes communicate their information using Web services, allowing direct integration in modern IT systems. To guarantee the system scalability and respect consolidated and diffused standards, the logical/architectural level of the whole Campus Energy Management System will be linked to an infrastructure based on Internet Protocol (IP). The IP choice will lead to wired networks realization in combination with Wi-Fi networks. Another advantage of the Ethernet protocol must be searched in the possibility to realize networks even in already existing buildings. The system will be exposed towards the external part of the network by means of Web Services, enabling the XML information exchange through communications on Internet channels (according to the SOAP standard). The same architectural approach will be guaranteed both, in the transport with the IP standard and in the application with the data flows exchange in XML. The Campus Energy Management System and Hub will be designed to integrate different communication protocols for recovering the field data. The model logics will follow a plug-in approach for the insertion of modules dedicated to the analysis of specific sub-systems.

3 TECHNICAL DESCRIPTION, S&T METHODOLOGY, OVERALL STRATEGYAND ASSOCIATED WORK PLAN

Campus sustainability has become an issue of global concern as a result of the realization of the impacts which the activities and operations of universities have on the environment. On July 2000, the U.S. Environmental Protection Agency (EPA) issued an Enforcement Alert which explained that the agency was now holding colleges and universities to the "same standards as industry" in order to "create a safe haven for human health and the environment" (Savely et al, 2007). The energy management on Campus level is not a straightforward issue. It includes the management of multi buildings with different operational characteristics and schedules such as labs, auditoriums, classrooms, small shops, coffee areas, together with the outdoor environment (outdoor lighting, shading, etc.). The general framework of analysis, CAMP-IT will develop a web based energy management for measuring and mitigating the possible dimensions of energy and environmental impact that the University Campuses can generate. The overall methodology is based on 5 phases:

Phase 1: Development of the necessary models for indoor-outdoor environment interaction and load prediction - The objective is to create and deliver indoor-outdoor interactions models to assist the development of the expert system as well as the overall Campus Energy Management system validation

Phase 2: Development of the expert system and control algorithms for campus energy management-The objective is to develop the suitable control strategy to be incorporated in the Web based Campus Management System. The control strategy will monitor and control the building systems and outdoor environment. In addition, the system will analyze the performance during operation and will therefore be able to detect buildings or parts of buildings with performance problems

Phase 3: Development and Specifications for the necessary infrastructure and communication technologies for Campus networking- The objective is to prepare the installation procedure and the integration of the Web based Campus Energy Management into the TUC Campus

Phase 4: Installation of the necessary components at the Campus case study and demonstration-Objective is to test the developed Web based campus energy management system by implementing it to the TUC Campus

Phase 5: Validation of the methodology- The objective is the evaluation of the CAMP-IT system and its impact on the energy performance terms of technical, operational, and economic aspects. The evaluation will be based on: (a) quantitative performance indices, like primary energy savings and demand reductions from external sources, and (b) qualitative features, like user's response to the systems, as well as indoor and outdoor comfort and satisfaction

4 CONCLUSION

The ICT for energy efficiency has been identified as a key major player in the fight against climate change being the fastest, cheapest and cleanest way to address energy resources issues. Today there are two major challenges in ICT for the built environment as far as enabling the vision of intelligent community. First is how the different elements can cooperate together in an integrated manner, and second, how the buildings can be connected in real-time to a web based ICT enterprise or Community systems. In the CAMP-IT project a web based ICT energy management in district–campus level will be developed to support the interconnection of multi buildings and spaces of public use. CAMP-IT is not just about the installation of another advanced energy management system in buildings, it is about utilizing harmoniously, and most effectively all buildings in a district level, taking into account buildings' interaction and outdoor spaces in a holistic approach and adapting the decisions in real-time based on a predictive and integrative manner. Furthermore CAMP-IT is not just about improved energy-efficiency in a fragmented way. The holistic but realistic view taken by the proposed system along with the potential of harmoniously regulating multiple buildings with outdoor spaces makes it an ICT-based "enabler of energy efficiency and comfort" and along with a reasonable installation of renewable sources will help realize significant energy savings and carbon emissions reduction reaching or even surpassing a target of 25% reduction. Another critical issue is the support of smart grids' effective deployment which is vital for Europe's electricity networks liberalization. Those networks should be able to integrate all low carbon generation technologies as well as to encourage the demand side to play an active part in the supply chain in a district and community level. Therefore a number of further R&D activities need to be initiated now, in order to deliver applications and solutions for the long term perspective of 2050 and beyond. To move towards an increasing low-carbon economy, European electricity networks will need to evolve to provide support for possible future energy vectors, for effective introduction of carbon credits, taxes and trading, for generating buildings integrated with energy distribution and finally for massive combination of renewable generation in the built environment. The CAMP-IT project contributes towards this perspective by providing the necessary knowledge and state of the art uptake to move towards smart grids integration in a large scale by starting the demand-supply integration in communities with only one owner as University Campuses where the various decisions are easier to be undertaken. Overall through integrated approaches, understanding and tools, the CAMP-IT project will reinforce the European industrial and technological position in ICT-enabled technologies for multi buildings and outdoor spaces and, more importantly, lead to reduced energy intensity of the economy.

5 ACKNOWLEDGEMENTS

The research project is implemented within the framework of the Action «Supporting Postdoctoral Researchers» of the Operational Program "Education and Lifelong Learning" (Action's Beneficiary: General Secretariat for Research and Technology), and is co-financed by the European Social Fund (ESF) and the Greek State.

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Annex 1: Description of the buildings

Technical University of Crete

Building K1 AND K2 – Environmental engineering department buildings

Buildings data

- Location (ZIP code, climate zone)
    - Technical University of Crete Campus, Chania, Crete, 73100
    - Climate of South Europe – mild Winter, hot Summer
- Year of construction
    - 2002
- Three main types of building utilization, f.i. office, laboratory, lecture hall, storage
    - Office, Laboratory, computer room
- Reference area, f.i. net floor area and conditioned net floor area, fraction of different building utilizations
    - Floor area: 2450 m^2
- Number of storeys, rough sketch of building shape and floor plan
    - Two storeys, Figures show the view and the layout of the building
- Building envelope (i.e. type of façade, fraction of total window area, …)
    - The construction is a combination of concrete and metal. Specifically, the ground floor is made of concrete while the second floor has metal framework and cement plates as external walls. The building is insulated and double glazed.
- Technical installations (i.e. type of ventilation, air conditioning, fraction of conditioned net floor area, …)
    - The building serviced by FCU systems with thermostats available in each room.
- Building energy management systems (BEMS)
    - 2 different BEMS are used in the building The first is used for controlling cooling and heating while the second for lights, fire systems and elevators
- Current state of repair and year of latest major renovation of building envelope and main technical installations respectively
    - Building is fairly maintained but has not been upgraded considerably in terms of energy performance during the recent years

Energy Data

- Estimated consumption of electricity for 2009
    - Electricity 136 kWh/m^2
- Utilizations of electricity included in the measured values (i.e. lighting, ventilation, air conditioning, cooking, IT, elevators …)
    - Not available
- Measured consumption of fuels for 2009
    - The building is heated using electricity for the FCU systems.
- Utilizations of thermal energy included in the measured values (i.e. heating, hot water, absorption chillers …)
    - Heating
- Energy generation in the building (cogeneration, solar thermal, PV, …), measured production of the last 3 years

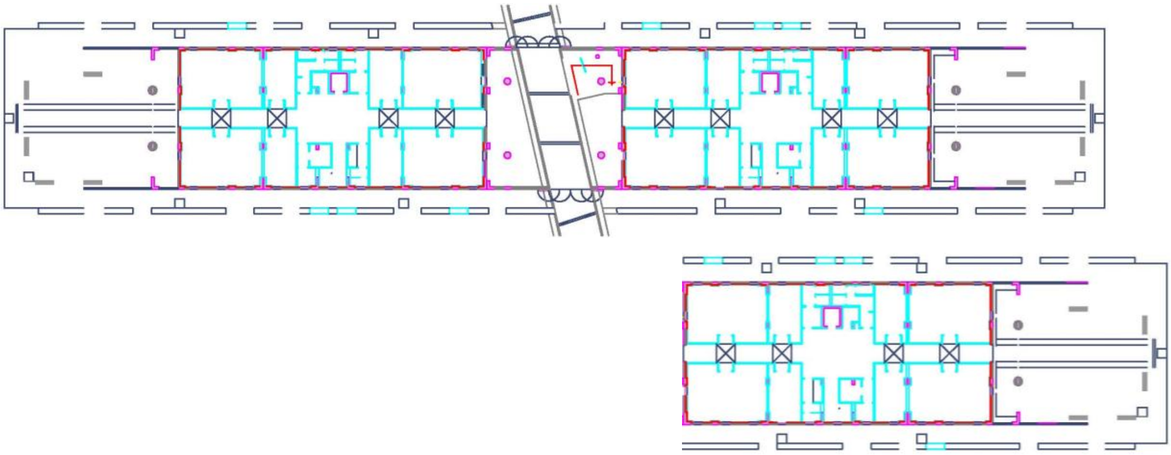

Figure 1: Floor plans of environmental engineering department buildings

Figure 2: Back view of environmental engineering department main building

Figure 3: Internal views of the buildings

Figure 4: Outdoor space of environmental engineering building