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An integrated system for buildings' energy-efficient automation: Application in the tertiary sector

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HIGHLIGHTS

- We developed an interactive software for building automation systems.
- Monitoring of energy consumption in real time.
- Optimization of energy consumption implementing appropriate control scenarios.
- Pilot appraisal on remote control of active systems in the tertiary sector building.
- Significant decrease in energy and operating cost of A/C system.

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ABSTRACT

Although integrated building automation systems have become increasingly popular, an integrated system which includes remote control technology to enable real-time monitoring of the energy consumption by energy end-users, as well as optimization functions is required. To respond to this common interest, the main aim of the paper is to present an integrated system for buildings' energy-efficient automation. The proposed system is based on a prototype software tool for the simulation and optimization of energy consumption in the building sector, enhancing the interactivity of building automation systems. The system can incorporate energy-efficient automation functions for heating, cooling and/or lighting based on recent guidance and decisions of the National Law, energy efficiency requirements of EN 15232 and ISO 50001 Energy Management Standard among others. The presented system was applied to a supermarket building in Greece and focused on the remote control of active systems.

1. Introduction

The current financial and economic crisis as well as the wider environmental pressures, including climate change and security of energy supply put energy back at the "heart" of the European Union's (EU) action. In this context, ambitious targets have been set for 2020 ("20–20–20" energy policy package) aiming to foster European economy to more sustainable energy paths [1]. This policy is a first resolute step towards achievement of the low-carbon economy ultimate goal, whilst making at the same time the consumed energy more secure, competitive and sustainable.

Nowadays, buildings are responsible for about 40% of the EU's total final energy consumption and greenhouses gas (GHG) emissions, putting them among the largest end-use sectors globally [2]. However, taking into consideration their untapped potential for cost-effective energy savings (estimated at 1509 Mtoe by 2050) the penetration of energy efficiency technologies in the building sector could play an active role among the EU's efforts in development of a viable strategic framework towards a low-carbon economy [3].

In October 2006, the European Commission (EC) adopted an Action Plan for Energy Efficiency (2007–2012) following the Green Paper for Energy Efficiency aiming at 20% reduction on energy consumption by 2020 [4]. A comprehensive framework of directives supports this initiative, key of which are the Directive 2006/32/EC on energy end-use efficiency and energy services and the Directive 2002/91/EC on energy performance of buildings [5,6]. Furthermore, the Directive 2003/66/EC on labelling of refrigerators [7], the Directive 2002/40/EC on labelling of electric ovens [8], the Directive 2002/31/EC on labelling of air-conditioners [9], the Directive 2000/55/EC on energy efficiency requirements for ballasts for fluorescent lighting [10], as well as the Regulation 2422/2001/EC on Energy Star labelling for office equipment [11] foster an integrated European legislative framework for the promotion of energy efficiency and green buildings. Furthermore, the recent Directive

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2010/31/EU promotes the improvement of buildings' energy performance within the whole EU, with the ultimate goal of ensure all new buildings are net zero energy consumers by 2020, ''Nearly zero-energy building'' [12].

As a result of the Directive of Energy Performance of Building (EPBD) a number of EN standards have been developed to harmonize the energy calculation methods concerning buildings. In this context, a new European standard EN 15232 ''Energy Performance of Buildings – Impact of Building Automation, Control and building Management'' was compiled to support the EPBD [13]. The standard describes methods for evaluating the influence of building automation and technical building management on the energy consumption of buildings. Four efficiency classes A to D have been introduced to this purpose. Furthermore, the ISO 50001 ''Energy Management Standard'' enables organizations to establish the systems and processes necessary to improve energy performance [14]. More especially, the ISO 50001 aims to establish a framework for industrial plants, commercial, institutional and governmental facilities to increase energy efficiency, reduce costs and improve energy performance.

The successful fulfillment of the abovementioned can be supported by developing actively advance new technology applications and especially technologies for energy efficiency and renewable or zero carbon buildings [15], as well as by market-based tools (mainly taxes, subsidies and the CO_2 emissions trading scheme) and by community financial instruments [16]. In this context, Sgouridis and Kennedy (2010) presented an integrated system for total energy management and accounting on a city-wide scale [17]. A scientific reference system has been also set up to enhance availability, quality and completeness of data on new energy technologies, energy end-use efficiency, as well as measures to support the related energy research and technology development [18].

In recent years, great efforts have been focused on green building constructions revealing the ongoing interest of the scientific community on this topic [19]. A number of methodologies and tools have been developed regarding the energy performance and energy efficiency measures in the building sector [20–22]. In particular, the impact of energy efficiency measures on the economic value of buildings has been studied by Popescu et al. [23]. Moreover, the impact of climate change on building energy use has been thoroughly examined by Wan et al. [24].

A number of studies exist, which mainly focus on the simulation [25,26] and optimization [27] of energy consumption in the building sector. In this context, integrated building automation systems are applied to control heating, ventilation, and air-conditioning (HVAC) systems, lighting, pumps and lifts [28–32]. To the best of our knowledge, techniques for HVAC control, such as pole-placement, optimal regulator and adaptive control have been presented [33,34]. A number of studies have been also implemented regarding state of the art control systems in buildings [35–38], as well as HVAC simulation in building energy management [38,39,35,40].

In the past, less ''intelligent'' systems were used for energy and environmental management, mainly for optional monitoring of energy consumption with insufficient control functions and high dependence on the human factor [41,42]. The majority of recent developments have followed the advances made in computer technology, telecommunications and information technology [43–47]. In addition, the building electrical facilities are nowadays in a stage of transition. Indeed, the building's facilities are becoming more and more complex, and the needs for interaction among them increases [48].

Although building automation systems have developed and have become increasingly popular, the necessity for intelligent tools and methods to provide remote control and real time monitoring of energy consumption, remains [49,50]. The current empirical and simulation models, such as SBCI 2010 [51], EnergyPlus 2009 [52], eQuest 2009 [53], provide very little flexibility, especially when accounting for occupants, ignoring the impact of their behavior on building energy use [54]. To the best of our knowledge, a system which also includes remote control technology to enable energy end-users to monitor the energy consumption and control the operation of buildings' appliances, as well as optimization functions for the reduction of the energy consumption is required. Such an integrated system is not present in the international scientific literature.

This is particular true for Greece, which beyond the current economic crisis, faces numerous challenges associated with the high and volatile energy prices [55]. Indeed, the existing Greek building stock needs appropriate interventions to improve the poor quality of construction practiced until the 1990s [56]. Greece has recently incorporated the Directive 2002/91/EC on the energy performance of buildings, as well as the related procedures and modalities, so as to be fully harmonized with European directives and commitments [57].

To respond to this common interest, this paper aims to present an integrated system for the simulation and optimization of energy consumption in the building sector, providing a supportive tool for the energy end-users of industrial, domestic, tertiary and public buildings. The proposed system is based on a prototype software tool for the simulation and optimization of energy consumption in the building sector, enhancing the interactivity of building automation systems. The pilot appraisal is focused on the remote control of air conditioning (A/C) system during the summer peak hours, maintaining the desirable comfort.

Apart from the introduction the paper is structured along four sections. The second section is devoted to the presentation of the interactive software for building energy and environmental management in terms of its philosophy and the procedure followed. The third section is devoted to the system's pilot appraisal and results. Finally, in the last section the main points drawn up from this paper are summarized.

2. The proposed interactive software

2.1. Background

Building automations are a fundamental part of the energy management systems. However, the traditional automation system may have limited level of intelligence, based on their purely ''mechanical logic''. In the traditional automation systems, each sensor and actuator needs its own wiring, which makes the initial installation cost high. Expansion is also a problem, and even ongoing maintenance costs are high.

In this context, the hierarchy in industrial automation systems is presented in Fig. 1. Data exchange takes place both between and within the different levels. To this end, numerous systems and communication protocols have been developed at international level, mainly Dupline, European Installation Bus (EIB), BatiBus, European Home Systems Protocol (EHS), X-10 international standard for communication among electronic devices, Consumer Electronics Bus (CEBus), Home bus System (HBS) as well as C-Bus communications protocol for home and Building automation, among others [58–61]. The higher level in the pyramid needs to handle multiple systems within the different levels using lower number of components and higher amount of data. In particular:

- *Component level*: Sensors, switches, relays, as well as valves, motors and other units comprise the lower level of the industrial automation pyramid.
- *Device level*: Counters and timers store, display and control the sequence of an event or process.