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Multi dimensional energy monitoring, analysis and optimization system for energy efficient building operations

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ABSTRACT

Monitoring, analysis and optimization of buildings' energy consumption is of central importance for the renovation and energy-efficient operation of buildings since it allows the identification and correction of inefficient energy usage. However, the monitoring and control systems adoption for building management and control applications is hampered by the unavailability of appropriate tool environments. This paper addresses the need for integration concepts, holistic monitoring, analysis methodologies, multi dimensional decision support and scenario based control strategies through the seamless integration of ubiquitous sensing infrastructures, service oriented architectures, BIM tools and Data Warehouse technologies. The developed system is demonstrated and validated in the Environmental Research Institute (ERI) building located on the campus of National University of Ireland-University College Cork.

1. Introduction

The energy consumption of buildings during the whole life cycle is responsible for 40% of total European Union (EU) energy consumption and is the main contributor to greenhouse gas (GHG) emissions since buildings account for 36% of EU's total CO_2 emissions (EC, 2007, 2009a; EC, 2009b, 2010; Itard, Meijer, Vrins, & Hoiting, 2008). Future projections indicate that in 2030 buildings will be responsible for 35.6% of primary energy use in the world, and continue to maintain its importance (DoE, 2008; LBNL, 2006). Therefore reducing energy consumption during the whole lifecycle of the buildings is an effective action against climate change and will also contribute to decreasing the EU's energy import dependence (EC, 2012).

The European Council (EC) outlined clear objectives for the European Union's 20–20–20 strategy. These are: 20% reduction of the total energy consumption; 20% contribution of renewable energy sources to total energy production; 20% reduction of greenhouse gases below 1990 emissions before 2020 (EC, 2010).

In this context, the building sector must assume very ambitious objectives of 165 Mtoe (millions of tons of oil equivalent) in energy reduction and contribute with 50 Mtoe from Renewable energies in 2020. In order to understand the nature of the challenge, these figures are equivalent to the total joint energy consumption of Spain, Portugal, Greece and Ireland in 2004 (Eurostat, 2008).

The European Commission (EC) undertakes much effort to reduce the building energy consumption emphasizing on energy rating to inform and stimulate subsequent building renovation activities. About 85% of the European buildings are older than 20 years, 60% are older than 40 years, and 30% are pre-war buildings (Itard et al., 2008). Most of them are not equipped with advanced building management and control systems (Gökçe & Gökçe, 2011). It is estimated that about 50% of these buildings will be renovated in the next 20 years opening the potential to improve their energy performance. Apart from meaningful building insulation measures, the only means of achieving marked improvements in the buildings' energy efficiency is to make use of efficient building automation technologies (VDMA, 2008). According to European standard "*EN 15232 Energy Performance of Buildings-Impact of Building Automation*" building automation systems can, depending on building type and equipment standard, produce the following potential energy savings: restaurants 31%, hotels 25%, offices 39%, shopping centers 49%, hospitals 18%, schools/universities 34% and residential 27% (DIN EN, 2007). Furthermore, it is often faster and less costly to automate building systems than it is to insulate building shells (IEA, 2008). Thus, flexible and easy to handle Building Energy Management Systems (BEMS) are essential.

From the energy management perspective, one of the main weaknesses of the current BEMS is that these are operated according to predefined energy control strategies. Current operation algorithms are based on conventional control approaches, which are not able to learn from previous operations and to forecast

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the impact in the building behavior of the control orders. This results in a loss of overall energy efficiency of 10–15% at system level. Automation and self-adaptation are needed to adapt to the changing operation conditions of the buildings, including building/grid energy balancing. BEMS are needed which implement holistic approaches, going beyond current technology which manages every energy related systems (HVAC, lighting, local generation, etc.) as fully decoupled systems, resulting in a loss of efficiency of at most 5%. The BEMS will be able to support and give feedback to the building users on how the energy is being spent, providing advice for a more efficient energy use. New strategies for monitoring, protocols, service platforms, standards as well as ambient intelligence and context sensitive Graphical User Interfaces are needed, which are developed fully understanding/working with end users (stakeholders) (EC, 2010).

On the basis of on-going research in the area of energy efficiency and legislative drivers launched by the national and international organizations, the role of integration concepts, holistic monitoring and analysis methodologies and sophisticated control strategies through the seamless integration of people, ICT devices and computational resources is gaining significant importance for reducing the energy consumption and the operational costs (BuildingEQ, 2012; Hesmos, 2012; Marini, Ghatikar, & Diamond, 2011; Rowe et al., 2010). However, a holistic approach which integrates sensing devices, BIM tools, monitoring and optimization tools under a single a repository for energy optimized building operations is not supported by appropriate information and communication technologies (EC, 2010; Kabitzsch, Naake, Theiss, & Vasyutynskyy, 2006; Karavan, Neugebauer, & Kabitzsch, 2008; Schmidt, 2008).

Presently, many sophisticated building services systems are available for facilities management. However, their focus on energy performance rating of buildings is at best sporadic often consisting of an ad-hoc combination of off-the-shelf building management systems (Jagemar, Olsson, & Schmidt, 2007; Keller, O'Donnell, Keane, & Gökçe, 2008). These systems provide many problems to building owners with regard to interoperability. Available commercial BMS solutions do not support integration of the various BIM tools (e.g. CAD Tools, Energy Simulation) with the database systems for automated creation of the information management platform (Gökçe, Wang, & Gökçe, 2009; Keller et al., 2008). This adhoc combination presents many difficulties for building owners in relation to the management and upgrade of these systems, as the BMS can consist of a number of components utilizing various information exchange protocols that have to be integrated within the monitoring software packages. The optimization of these systems for energy management adds another layer of complexity to the design and management procedures of these systems (Nikolaus, 2008). It requires analyzing the system, developing new interfaces for extracting data from BIM tools, adjusting, and optimizing parameters.

Furthermore the engineering and deployment aspects of current systems require extensive manual work with much trial-and-error in programming devices, composing applications from devices, deploying devices in buildings with complex radio propagation characteristics, the development of data structures for data acquisition and analysing tasks (Gökçe & Gökçe, 2011). Integration of different software tools for these activities does not exist; available tools are stand-alone products, often tied to specific standards (Karavan et al., 2008). These existing tools neither support the exchange of information between different application stages nor do they consider the extension of an existing wired or wireless monitoring and control system during operation (Gökçe, 2010; Keller et al., 2008). This lack of appropriate tools currently outweighs the benefit of software interoperability. As this technology gap spans in all application domains, it will likely hamper further adoption of IT solutions in other sectors as it already does in the building sector.

In order to address these issues, in this research we focus on: (1) establishing a model-driven development approach that strongly automates the systems from component to application level, and (2) the creation of an integrated system concept for optimized building operations. A specific objective, addressed in the paper, is the development of a multi dimensional data aggregation system for flexible and automated creation of a range of applications and services for energy performance monitoring, analysis and intelligent control using modern Data Warehouse (DW) technologies.

2. Research objectives

The objective is to research and develop a methodology leading to a system which is appropriate to process and analyze building performance data for monitoring and intelligent control of building operations to reduce energy consumption. To reach this objective, new methods and tools are researched which increase system functionality covering the recent building energy regulations, wireless embedded devices, Building Information Modeling (BIM) tools, intelligent control algorithms, monitoring tools and integration of these to the information management backend system; the Data Warehouse (DW) core. This consists of the following key elements to research: (1) a new, model-based device development approach based on software product lines allows for accelerated development of dedicated, interoperable, resource optimized, and energy-efficient device applications according to the user and system requirements, (2) a novel modular modeling approach targets the existing energy system components optimization, and the handling of upgrades with minimum effort, (3) unique, multi dimensional information management platform offering e-services for energy monitoring and intelligent control using Data Warehouse technologies, data mining, and web-services, (4) an open, extensible data exchange method named as Extraction, Transformation and Loading (ETL) tool facilitates the interoperability of the involved tools, (5) a scenario based Intelligent Control module to optimize the building systems energy consumption for the different use cases and scenarios, (6) context sensitive and web based Graphical User Interfaces (GUIs) for multiple stakeholders.

3. Multi dimensional monitoring, analysis and optimization process

In this section, "The Building Performance Monitoring, Analysis and Optimization Process (Gökçe, 2010)" is introduced which creates the basis for the developed multi dimensional energy monitoring, analysis and optimization system architecture.

A basic monitoring system should aim to: (a) state current consumption, (b) compare current consumption with historical data and benchmarks, and (c) identify trends and patterns (CIBSE, 2004).

The proposed multi dimensional monitoring, analysis and optimization process establishes a standard for energy performance and CO_2 emissions through conversion factors for each energy consuming object, e.g. zone, individual, organization and building system.

In order to achieve energy savings, the standard performance of each energy consuming object in buildings needs to be improved. The level of object performance improvement is determined through comparison of the standard performance values with the benchmark performance values underlined by several regulations, e.g. CIBSE Guide F Benchmarks.

In this context, proposed multi dimensional monitoring, analysis and optimization process is depicted in Fig. 1.