Energy and Buildings 98 (2015) 82–91

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

The concept of an integrated performance monitoring system for promotion of energy awareness in buildings

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ARTICLE INFO

Article history:
Available online 8 October 2014

Keywords:
Performance monitoring
Performance indicators
Energy management
Energy awareness
Energy models
Prediction engine

ABSTRACT

In many modern buildings, different monitoring and control systems are used, but majority of them are not directly connected with the energy consumption optimisation. This paper presents a concept of an integrated performance monitoring system for promotion of energy awareness in buildings. The reference architecture of the envisioned system evolved from the traditional management structure, plan-do-check-act model. Traditional plan-do-check-act model has been upgraded with the integration of prediction engine, knowledge repository and modern scientific approaches for supporting energy awareness including early warning, optimisation and supervision. The proposed concept is constituted upon three modules: (1) data acquisition and processing, (2) knowledge repository, (3) performance monitoring system including prediction engine, consumption modelling, emissions calculation and decision support. The concept of three modules evolved from the idea to enrich existing solutions with the awareness about possible future abnormal situations and to enable preventive actions. Presented case study represents a repeatable application of the energy cost centres based modelling of energy consumption in educational and research buildings by using neuro-fuzzy modelling approach. Initial testing results are indicating the potential of electricity savings up to 15% enabled by visualisation and awareness about electricity consumption.

1. Introduction

According to International Energy Agency [1], in 2010 nearly 35% of the world's final energy consumption and 33% of CO_2 emissions (including fuel combustion related emissions and indirect emissions from electricity and heat) are attributable to buildings. Energy consumption and emissions reduction in the buildings sector are vital element in the long-term transition to low carbon society. Majority of contemporary energy efficiency related policies and instruments are mainly oriented to technical systems (building envelope, heating systems, electrical appliances), while behavioural changes are addressed only by the improved availability of information through awareness campaigns [2,3]. The soft organisational potentials for energy efficiency improvements are often neglected in policies both at the national and at the local level [4]. However, Gram-Hanssen [5] demonstrated that user behaviour is at least as important as building physics when it comes to energy consumption for heating, while electricity consumption for lighting and appliances is more dependent on user behaviour than on energy efficiency of appliances. Also, several other studies have clearly confirmed that user behaviour can be influenced and different models can be used for explaining why and how feedback on electricity consumption can reduce consumption [6,7]. The similar situation is with the energy consumption for heating where several research and empirical results have demonstrated the significant impact of the behaviour of building users on energy consumption [8,9]. Zhuang and Wu [10] have concluded that government regulations are generally not effective in changing end user behaviour related with the air conditioning and that electricity consumption was not considered by the end users in setting air conditioners.

During recent years energy and environmental management is becoming an essential aspect of daily operations in buildings sector and is supported by several international standards or schemes like ISO 14001 [11] or ISO 50001 [12]. One of the requirements of the ISO 50001 is linked with the need for monitoring relevant variables related to significant energy use and evaluation of actual and expected energy consumption [12]. Unfortunately, energy

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http://dx.doi.org/10.1016/j.enbuild.2014.09.065
0378-7788/

Nomenclature

ANFIS	adaptive neuro-fuzzy inference system
ANN	artificial neural network
A_{out}	activity output
ECC	energy cost centre
EnPC	energy performance coefficient
E_{act}	actual energy consumption
E_{bench}	benchmark energy consumption
E_{mes}	measured energy consumption
E_{pred}	predicted energy consumption
ERP	enterprise resource planning
H	hypothesis
HDD	heating degree day
CDD	cooling degree day
ISO	international organisation for standardisation
PDCA	plan-do-check-act
PI	performance indicator
RMSE	root mean squared error
SCADA	supervisory control and data acquisition

management in the building sector, in majority of cases, is still perceived as a simple collection of energy consumption data for heating, cooling and electricity on a monthly or annual basis. The main bottlenecks for an efficient energy management within building management systems are still the poor possibilities for graphical performance visualisation and the cumbersome handling and analysis of measured performance data [13]. Also, monitoring and targeting as core technique of the energy management system can facilitate desired organisational learning through providing feedback on real performance in the field of energy efficiency [14]. An excellent understanding of the energy consumption or energy awareness is the key prerequisite for proper and timely decisions to reduce energy use [15]. Vital parts of any building energy management system are measurements and data acquisition at all levels, from the different machines to systems, depending on the nature of the analysis to be performed. Figueiredo and Sá da Costa [16] have recently shown the benefits of an energy management platform for intelligent buildings using a SCADA system (Supervisory Control and Data Acquisition), which integrates different types of information coming from the several technologies present in modern buildings (control of ventilation, temperature and illumination). Interesting concept of an advanced energy management framework to promote energy awareness in industry can be found in [17] where special attention is given on standardisation of all measured energy data for future analysis and visualisation. According to Vikhorev et al. [17], visualisation of energy data represents vital element in the process of sustainable and continuous energy consumption reduction. Based on the empirical studies in Korea, Kang et al. [18] and Chung and Rhee [19] have recently confirmed that certain internal factors, especially 'awareness', 'willingness' and 'support from top management', have significant and positive relationships with energy savings activities in residential and educational buildings. Wang et al. [20] demonstrated that support from university leadership, safeguarding of long-term funding, development of appropriate capacities and overall integration of sustainable development into existing academic structures and administrative processes were critical factors for the success of greening university campus operations in the short and longer-term. Also, Kastner and Matthies [21] reported that energy efficiency intervention programs in higher education institutions should be complemented with elements that help people to overcome old habits.

Development of proper energy models is necessary to estimate or predict energy consumption in any building. Methodologies to estimate building energy consumption varies from pure regression to very complex models of particular components and systems [22–27]. Rapid development of information and communication technologies enabled acquisition and storage of huge amount of energy and non-energy related data in buildings. Unfortunately, in many cases, this data is used only for single purpose of process control and not for improvement of energy efficiency in building as a whole and number of opportunities for performance improvement are missed [28]. According to [29], it is essential to quantify the improvement potential for existing buildings, as well as, the corresponding reduction in energy consumption after switching to an optimised management of the buildings that can be achieved using the automatic control systems. Morvay and Gvozdenac [30] recently presented an interesting concept for modelling energy consumption in industrial application, which is based on setting up energy cost centres (ECC), the core elements of an entire energy model of the industrial factory. On the conceptual level, the approach based on ECC has a potential to be used in buildings since an ECC can be any department, section or machine that uses a significant amount of energy or creates significant environmental impacts.

The research work described in this paper was inspired by the recommendations proposed by Nguyen and Aiello [15] and Zhao and Magoules [26], where the future research should focus on developing efficient and effective performance monitoring system for promotion of energy awareness in buildings to enable building users to become aware of the energy performance in real-time, facilitating more effective business decisions based on accurate and timely information. The research question that arises in this context is: "How to sustainably empower building users, who operate various systems and work in buildings, to achieve enduring performance improvements?" This research question is based on four hypotheses:

- H1: Monitored energy consumption, enriched with information about its context, can be the basis for the identification of energy profiles and optimisation.
- H2: Only technical innovations cannot eliminate the risk of human errors associated with the operation of buildings.
- H3: Understanding past performance is a key element of the knowledge creation and retention processes and together with positive competitiveness among different building users can be important enabler for achieving enduring performance improvements.
- H4: Awareness about energy performance and impact on the environment means sustainably empowered building users, which are capable to make justifiable decisions about process reconfiguration and optimisation.

A comprehensive literature review clearly confirmed that there is a need to connect energy consumption with human factor in a systematic manner through a system of metering, monitoring and evaluation of business, energy and environmental performance. Also, it is vitally important to properly appreciate the internal and external contextual factors that influence energy and environmental performance. Related to the energy performance in buildings the notion of context refers to characteristics of the building's operation, installed devices and systems, energy prices, presence of building occupant and behaviour. The conventional performance monitoring methods and tools do not include prediction engines, which would allow early warnings in the case of potential future abnormal situation(s). This lack of awareness about possible future abnormal situation(s) limits the scope of today's performance monitoring systems and was the trigger for the development of an