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Building operation and energy performance: Monitoring, analysis and optimisation toolkit

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ABSTRACT

Buildings consume 40% of global primary energy and contribute to in excess of 30% CO_2 emissions. The potential to save energy by systematic building management is known to be significant and estimates range from 5% to 30%. Many research projects have developed IT tools and methodologies to address the complex problem of building energy performance management with various approaches. This research reviews some of these new approaches and proposes a novel integrated toolkit designed to assist energy managers at different stages of their activity relating to systematic energy management in buildings. The focus of this paper is particularly centred on the applicability of the integrated toolkit in the building industry and the potential of the integrated toolkit to achieve energy savings on an industrial scale.

1. Introduction

Facing climate change and the decrease in natural resources, the European Union has demonstrated its commitment to addressing this problem through its "2020 by 2020" initiative. "2020 by 2020" intends to reduce its overall emissions to at least 20% below 1990 levels by 2020 as well as to increase the share of renewables in energy use to 20% by 2020 [1]. The buildings sector plays a major role in this respect. Buildings consume 40% of global primary energy and contribute to in excess of 30% CO_2 emissions. This places building energy consumption above that of both industry and transportation [2]. With the consolidation of the demand for thermal comfort in developed countries, HVAC systems account for almost 50% of the energy consumed in buildings and account for 10–20% of total energy consumption. Energy consumption in Europe is growing at an average annual rate of 1.5% because of economic growth, expansion of the building sector and the spread of building services, especially heating, ventilation and air conditioning systems (HVAC). Simultaneously, the potential to save energy by appropriate building operation management is great [3].

Continuous Commissioning (CC[SM]) is an approach that was first established in USA that has achieved significant results in terms of energy savings in buildings [4]. Also other European research projects have demonstrated that the potential to save energy by appropriate building operation management, i.e. by taking measures involving very low or no investment costs, ranges from 5% to 30% [5].

However, while researchers have demonstrated success by bringing in experts who use their knowledge, experience and resources to 'fix' building systems [6] few tools are available to the on-site engineer or building energy manager to conduct such improvements utilising a Building Life Cycle (BLC) perspective [7,8]. In relation to this, the goal of Annex 47 [9] is to develop commissioning techniques, tools and methodologies that will help the transition of the industry from the intuitive approach that is currently employed in the operation of buildings to a more systematic approach that focuses on achieving significant energy savings.

Different research projects have been focusing on this goal with different approaches in developing IT tools and methodologies to address the complex problem of building energy performance management during operation. The common final goal of these projects is to support the energy manager at different stages of the BLC in reducing building energy consumption without compromising environmental performances.

Thus, this paper reviews these new approaches and proposes a novel integrated toolkit designed to assist energy managers at different stages of their activity throughout the BLC. This toolkit is built upon a:

1. Structured performance definition using Building Information Model (BIM) methods and technology.
2. Performance monitoring and analysis including transforming the measured data into useful information for Fault Detection and Diagnosis (FDD) activities.
3. Evaluation of different building operation strategies based on calibrated whole building energy simulation models.

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Two industrial toolsets which were analysed within the Building EQ project [10] are available and fulfill some of the requirements covered by the toolkit described in this paper. Despite their advance features neither of these tools (the Grandlund Tool TaloInfo and the Ennovatis Tool EnEV+) allows for a full BIM interoperability which supports a structured BIM performance definition and visualisation throughout the BLC. The other novel feature of the proposed toolkit is the dynamic use of building energy simulation which can support multiple tests of new and different operation strategies that can vary during the BLC (e.g. different building use).

Several publications show that the research community is moving towards the direction discussed in this paper especially in relation to the use of building energy simulation in the optimisation of building operation strategies. Tzivanidis et al. [11] show the effects of thermostat operation mode and cooling power in terms of the time and on the total cooling energy consumption leading to energy savings up to 10%. Lehmann et al. [12] document that a strong impact on energy efficiency can also be observed for the control strategy in thermally activated building systems (TABS). Thus, by intermittent operation of the system using pulse width modulation control (PWM), the electricity demand for the water circulation pumps can be reduced by more than 50% compared to continuous operation. Ryan et al. [13] describe building combined heat and power (BCHP) is a promising efficiency improvement and carbon mitigation strategy, but careful selection of technology and operation mode is required to achieve a reasonable system performance according to energy consumption characteristics of buildings and technical features of equipments. Luo et al. [14] results indicate that the COP (coefficient of performance) and cooling power of the solar-powered adsorption chiller could be improved greatly by optimising the key operation parameters, such as solar hot water temperature, heating/cooling time, mass recovery time, and chilled water temperature.

This paper builds upon these results and integrate them in a toolkit available to the onsite energy manager such as MultiOpt, a multicriteria tool, for the optimisation of building renovation operations which can be used to compare different combinations of options and constraints, thus constituting a basis for operational decision-making [15]. The proposed toolkit additionally integrates the advancements in simulation with fault detection activities and BIM based performance definition in a BLC approach.

In the following sections these approaches and their relative methodologies will be presented and a final section will discuss advantages and issues of the proposed toolkit that captures the energy manager requirements and addresses them in three stages.

2. BIM based performance definition

A Building Information Model (BIM) consists of two major components: a three dimensional graphical reproduction of the building geometry and a related database in which all data, properties, and relations are stored [16].

The value of a BIM created during design and construction phase is well documented and can result in an estimated 30% reduction in total construction costs [17]. Throughout the typical Building Life Cycle there are series of discontinuities in the transmission of building data that occur. Transitions from design to construction to operation result in loss of data, added cost to reconstitute the data, and overall reduction in data integrity. The impact, growing at each handover, culminates with the handover to the facility operator and therefore to the energy manager. In financial terms it was reported that in the US the annual cost (in 2002) associated with inadequate interoperability among computer-aided design, engineering, and software systems was $15.8B. Owners and operators shoulder almost two thirds of that cost, which is incurred during ongoing facility operation and maintenance (O&M) [18].

With the implementation of the asset building energy rating certification process, driven by the EPBD [19], this cost is likely to increase in the EU market due to the difficulty of gathering stock data for existing and new buildings for which an energy certificate is now mandatory. The loss of information relative to the HVAC and BMS/BAS systems also affects the effectiveness of the energy manager in understanding the operation of the system and, more importantly, in using available measurements to monitor systems efficiencies and energy end uses. This results in reducing the already low monitoring capabilities of BMS/BAS systems that are currently mainly designed only for control and automation rather than monitoring [20].

BuildWise and ITOBO are respectively an Enterprise Ireland and Science Foundation Ireland funded research projects aimed at developing a technology platform capable of supporting holistic environmental and energy management in buildings by leveraging cutting edge technologies and in particular formal performance frameworks [21,22]. The methodology proposed in this paper was developed in the BuildWise and ITOBO using BIM technology to define and store performance related information that are associated to specific building geometry objects (e.g. building, floor, zone, wall...) or to specific HVAC system objects (e.g. pipe, air duct, pump, AHU...) and their relevant metrics. The required underpinning sensors/meters are also instantiated and defined in the BIM [23]. All these information are stored through the use of a tool named "Performance Framework Tool (PFT)" that has been implemented within the project in accordance with the requirements defined by O'Donnell [7]. The performances are structured in performance objects, objectives, metrics, aspects and scenarios (Fig. 1). A performance objective can be thought of as a qualitative objective that may be assigned to a particular performance object (building object). The easiest example of performance objective is "monitor" a parameter, but more complex performance objectives include qualifiers such as "maintain". In this case a benchmark value has to be defined accordingly. For example, a building manager may wish to maintain the temperature within a particular zone, within a building. This objective can be quantified by associating it with a performance metric, while the zone itself may be considered a performance object.

A building may have hundreds of performance objectives, so it makes sense to categorise them under particular performance aspects. In this way, similar performance objectives can be viewed together, in order to provide a clearer picture for the building manager. The five defined performance aspects are: *building function, thermal loads, energy consumption, system performance and legislation*. A scenario is a collection of associated performance objectives, concerned with a particular aspect of the building operation.

Concerning the current technical implementation, the PFT tool takes an Industry Foundation Class (IFC) file as its input, defines and appends scenario definitions, and exports the file in IFC format again. The output of this process is a formal description of the building, measurement framework available, the associated algorithms and measured data required to monitor the prescribed performance. The measured data can be stored in a standard data base or in a data warehouse that is IFC compatible. The data warehousing technology is a more powerful way to structure the data that allows the user to elaborate, pre-process and display data in different formats. The integration of the PFT tool with an IFC compatible data warehouse is currently ongoing in the research projects that include BuildWise [21] and ITOBO [22].