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Key factors methodology—A novel support to the decision making process of the building energy manager in defining optimal operation strategies

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ABSTRACT

This paper presents the key factors methodology that supports energy managers in determining the optimal building operation strategy in relation to both energy consumption and thermal comfort. The methodology is supported by the utilization of calibrated building energy simulation models that match measured data gathered by an extensive measurement framework. Building management systems, do not allow energy managers to test the impact of changes in control settings of energy systems on energy consumption and thermal comfort. The proposed methodology and prototype tool chain enables energy managers to virtually develop and test the impact of proposed changes to the control settings in the building energy systems prior to their implementation in the physical building. The paper outlines the proposed methodology defining the underpinning concepts and illustrating the performance metrics required to capture the effect of different building operation strategies. A case study is discussed to demonstrate the application of the methodology.

1. Introduction

Prescriptive based approaches to the design, construction and operation of buildings have substantially failed to deliver operationally energy efficient buildings [1]. Performance based assessment is now being promoted and several performance rating methodologies have been developed worldwide [2].

Focusing on building operation, energy efficiency measures can be effective in addressing the problem of high building energy consumption. In particular, considering the existing building stock, there is large scope for energy savings. In relation to that, Continuous Commissioning (CC^{SM}) is an approach that was first established in USA that has achieved an average reduction of over 20% of the total energy cost in more than eighty American buildings [3]. Continuous commissioning denotes an ongoing process for the quality assurance of building performance. It is a process designed to develop targets in terms of energy efficiency and to verify and document their achievement. CC is seen as a prerequisite for the long-term energy efficient operation of buildings [4].

According to Liu et al. [5] the starting point of this process is typically an energy audit during which CC measures are identified. This is then followed by a second phase during which the CC measures are refined and implemented following six steps: (1) develop the CC plan and form the project team, (2) develop performance baselines, (3) conduct system measurements and refine proposed CC measures, (4) implement CC measures, (5) document comfort improvements and energy savings, and (6) keep the commissioning continuous [6].

However, while researchers have demonstrated success by bringing in CC experts who use their knowledge, experience and resources to 'fix' building systems [7] few tools are available to the on-site engineer or energy manager to conduct such improvements [8,9]. In relation to this, the goal of Annex 47 [10] is to develop commissioning techniques, tools and methodologies that will help 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. Thus this paper proposes a new performance based methodology, named key factors methodology that intends to support the energy manager in easily determining the most effective operation strategy in terms of comfort provided and building energy consumption.

To achieve the expected results it is essential to define performance metrics to assess energy and environmental building performances and also a rigorous way to formally represent a specific building operation strategy that can be tested and compared against others. The core technology adopted in this methodology is a calibrated whole building energy simulation (BES) model capable of capturing environmental and energy performances according

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to the predefined metrics. The BES model calibration is achieved according to a structured methodology [11].

The following sections describe the calibrated BES models concept and then present the details of the key factors methodology focusing in particular on three aspects: the underpinning concepts, the implementation level and the performance metrics definition. Also a case study with detailed results and discussion is presented.

2. Calibrated BES models

Dynamic building energy simulation (BES) models are a mean of reducing greenhouse gas emissions and can provide substantial improvements in fuel consumption [12]. However, BES models are primarily used at the design stage of the Building Life Cycle (BLC) [13] and not during building operation. This is because when assuming values and schedules for most of the input parameters the results are meaningful only for a comparison analysis between different design choices and are not accurate enough to predict the energy consumption during operation. Assuming that an adequate measurement framework is in place and a calibration methodology is defined, calibrated BES models can be used to investigate and optimize energy performance during the operation stage of the BLC. This demands an extensive physical measurement framework capable of gathering data to be used as building specific input for BES models. This need has driven both industry and academia to develop more robust and reliable cost effective measurement technologies to obtain values not only at the building level but also at more detailed level such as system components and thermal zones [14]. The resulting instrumented measurement framework gives the opportunity to measure different parameters from real buildings and use these measured values in place of those normally assumed with a significant margin of error during the design phase [15]. For example, with a set of electricity meters, it is possible to measure the real lighting and plug loads and their effective schedules for each zone, likewise for system components such as a fan or a pump. With CO_2 level or Passive Infra-Red (PIR) sensors it is be possible to identify proper occupancy patterns within a given zone, etc. These measurements are also beneficial for fault detection activities [16]. Therefore, a proper measurement framework can obtain building specific information for many of the parameters that are needed to input into the model and mitigates the number of assumptions that need to be made. Consequently BES models can be calibrated in order to provide outputs that match measured energy consumption [11].

There are at least *three downstream advantages* arising from the use of calibrated energy simulation models during the operation stage of the BLC.

1. *Continuity and consistent predictions* – The first important advantage is that, thanks to the available data streams and energy simulation models, it will be possible to *explicitly tie the design intent to the energy performance of the real building*. With a model-based assessment it will be possible to measure the same metrics during both design and operation and compare predicted to measured performance. This will in turn improve the design quality of new buildings as they will be more performance oriented [8].
2. *Support energy managers* – A calibrated energy simulation model represents *a live, ideal building specific energy benchmark for a given building during its operation*. This will be a significant advantage for energy managers in monitoring the energy consumption of their buildings.
3. *Enhancement of the operation strategy* – The third advantage will be to facilitate the testing of different operation strategies in the model virtual environment *analyzing the influence of each change in operation strategy on both the energy consumption and the occupant comfort*. In this manner, a more accurate selection of the most efficient operation strategy for a given level of comfort is possible. This process is formally described by the key factors methodology presented in this paper.

3. Key factors methodology

3.1. Underpinning concepts

The objective of the key factors (K_f) methodology is to support energy managers in determining the optimal building operation strategy in relation to both energy consumption and occupants comfort. The key factors (K_f) are those parameters of the operation strategy that influence the environmental and energy performance of the building. Examples include temperature set-point, lighting levels set-point, etc. The determination of the optimal building operation is done following a systematic procedure. It consists of defining a process that allows evaluation of energy performance and thermal comfort resulting from changes to values and schedules that relate to the building's key factors. The effects of these changes are investigated in the virtual environment of the calibrated building energy simulation model and conveyed to the user in a structured and effective way.

The final goal is to reduce building energy consumption in a cost effective way. For this reason, this methodology focuses on the optimization of the operation strategy, which requires only changes in the control parameters; this is much more convenient than other improvements or Energy Conservation Measures (ECM) such as improvements to building envelope or system and plant retrofits.

Other researchers have done similar work regarding optimization of building operation and control. Burhenne and Jacob [17] focus on the optimization of the pump schedule of the heating circuit. In this case, the set-point temperature in the conditioned space is given as a boundary condition with the aim of optimizing system component operation. In our case, the set-point temperature will be investigated as a variable instead of being a boundary condition. The idea is to carry out a model-based choice of the operation strategy of the building in relation to predefined metrics. This means, for example, that the set-point temperature in the conditioned space will be occupancy and comfort driven instead of a default values and schedules as common practice.

Nowadays building performance control is done normally on a monthly basis by evaluating energy consumption, which is based on utility bills, and by monitoring the occupant comfort, which is based on received complaints. Within this timescale, any effect of a single change in building operation is evaluated over a period of 1 month (and in some cases 1 year) comparing the result of the energy consumption with the previous years and taking into account the influence of a different external climate. This is usually done with weather normalization (typically using the degree-days method). Calibrated building energy simulation models offer a virtual environment in which to test potentially thousands of different modifications to operation strategies and quickly evaluate their effects on the monthly/yearly energy consumption and occupant comfort.

The key factors (K_f) methodology proposes to focus on the relationship between energy consumption, thermal comfort and the operation strategy defined by the key factors set (K_f SET). The set contains a specific schedules and values combination of the selected key factors.

The key factors are dependent on the available actuators in the considered building and on its HVAC system components. The larger the number of actuators, the more control the user has over