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A Conceptual Framework for Occupant-Centered Building Management Decision Support System

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Abstract. Buildings' energy consumption makes the largest portion of the overall energy consumption. Commercial buildings are specific and their energy efficiency should not be viewed as a standalone issue. On the contrary, it needs to be viewed in function of the goals of the hosted businesses and organizations. The critical factor for achieving these goals are employees, who are also usually occupants of these buildings and, thus, hold one of the keys to reduced energy consumption. It has been shown that energy-conscious behaviour of building occupants presents a significant opportunity to save energy. Human behaviour is, however, very complex and hard to predict, and there needs to be a set of conditions satisfied for occupants to cooperate on the energy efficiency level. Majority of commercial buildings' occupants are not directly affected by their energy-consumption related behaviour due to the non-obvious/-direct incentive to reduce energy use and no access to their levels of consumption. In this paper we present a framework for a building energy management decision support system that is motivated by these findings, and therefore, centres the occupants and motivates them to both achieve business-wise and improve their energy-related behaviour.

Keywords. Buildings, energy, decision support system, framework, human factors

1. Introduction

Energy efficiency is becoming an increasingly critical issue and one of the major cost drives for existing buildings [1, 2], is known as a very complex matter because it is affected by factors of various natures [3]. Commercial buildings, as focus of this paper, are specific for the following reasons. Commercial buildings typically host businesses or organizations that have their own business performance goals, whose rate of success depends, to a large extent, on employees. Employees are usually building occupants, meaning they hold the key to one of the most cost-efficient ways of enhancing energy performance of existing buildings, i.e. through exhibiting a more energy-conscious behaviour. The common problem is that occupants are not generally motivated to behave in an energy-conscious way due to the non-obvious/-direct incentive to reduce energy use and no access to their levels of consumption. Furthermore, energy management of a building can also influence employees' productivity, both positively and negatively. Based on this observations, occupants' behaviour, energy performance and business

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performance are all dependent on each other, whereby occupants/employees hold one of the keys to enhancing both energy and business performance [4] [5].

Based on the afore-described features, we detail a framework for an Occupant-Centered Building Management Decision Support System in which we aim to emphasize the importance of placing building occupants in the focus of building energy management systems. Our motivation stems from the following two facts:

- Occupants' behaviour can significantly affect the energy efficiency of existing buildings [6, 7],
- Employees content with the work environment significantly affects their productivity [8], and
- Buildings ultimately exist to serve their occupants and keep them satisfied [9-11].

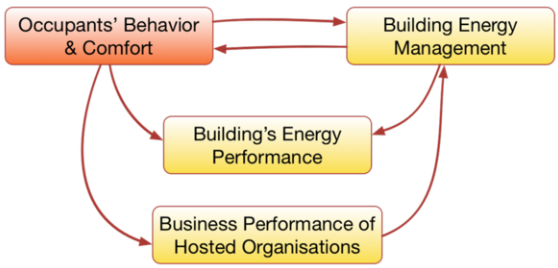

Fig. 1. Influence diagram of behaviour/energy performance/business environment-productivity/ energy management

In Figure 1 we present an influence diagram of energy performance and business performance of commercial buildings. The diagram shows that the influence goes in almost all directions. Namely, the way that occupants behave affects the energy performance of a building, as well as the building energy management and business performance. On the other hand, building energy management also affects behaviour of occupants, and here we include the complex behaviour that can occur due to feelings of not being taken care of or being ignored (it can literally make them frustrated and even angry). This, in turn, can negatively impact productivity, i.e. possibly imply a loss in profit or inability to meet business performance goals. Building energy management also affects, as expected, building's energy performance, and additionally, business performance can influence the way in which energy management is performed. It is apparent that the factor that directly influences all relevant aspects are the building occupants. Finally, the goal of this paper is twofold:

a) to argument, based on existing literature, why occupants need to be actively involved and placed in the centre of the building management to increase the overall building performance, and
b) to present a framework for an occupant-centered decision support system that would guide building energy managers in making decisions related to energy performance.

The framework that we present is based on findings from research done in the areas of building management, decision support systems and occupants' importance in buildings energy management.

The paper is structured as follows. In Section 2, we explore the current state-of-the-art in the relevant problem domains: decision support in the building energy domain and importance of occupants in energy management of buildings. We use these advances and findings as inspiration and motivation for the framework that we present in Section 3, where we detail all modules and the way they interact. In Section 4, we discuss our approach, and in Section 5, we conclude the paper.

2. Related Work

Building energy management decision support systems (DSS) can assist building managers in managing buildings in an energy-efficient manner. We claim that DSS need, besides other technical aspects, to significantly consider the contentment level of building occupants and provide them with a perception that their comfort is important. To support this view, in the following we provide an overview of the state-of-the-art in decision support and importance of occupants in the energy performance of buildings, as well as the impact of workplace on productivity.

2.1. Decision Support in the Building Energy Domain

Decision support systems (DSS) have been utilized in the energy domain for a long time, focusing on different aspects of the energy efficiency. On one hand, there have been DSS that are utilized during the building processes, such as to ensure that the building has been built as a zero energy building [12], or that the selection of materials is done in a sustainable manner [13]. With respect to existing buildings, there is research on decision support in retrofitting existing buildings to improve their energy efficiency [14], as well as DSS focused on the energy management of existing buildings. In one of the relevant works on the energy management of existing buildings [15], the authors introduce a decision support model for the identification of needs for intervention and further evaluation of energy saving measures in a typical existing building. The model that is introduced in this paper is based on the systematic incorporation of building energy management systems (BEMS) data (loads, demands and user requirements) that are used to calculate building performance indicators, which are then compared to the corresponding standards performance indicators. Finally, the outcome is a priority list of energy saving measures.

Due to the multitude of factors that influence buildings energy performance, DSS for energy planning often utilize multi-criteria decision-making approaches. A good overview of multi-criteria methods can be found in the works presented in [16, 17].

In one of the latest works on this subject [18], a decision support system for energy consumption and renewable energy utilization in rural China is presented. The work refers to dominantly residential areas, and it utilizes a Geographical Information System (GIS) as portal and is based on a production rule system. The authors claim that the system can generate a reasonable energy plan for the government by predicting the future trends in energy consumption and possibilities of renewable energy alternatives to conventional energy.

However, none of the existing building management DSS that we have encountered have considered occupants' contentment level in an active manner, as we intend to. This has further motivated us in researching this issue, as we are confident that it could make a significant difference in both energy performance of commercial buildings and, productivity of businesses that these buildings host.

2.2. Occupants in Management of Buildings

The comfort of occupants in commercial buildings has an increased importance as it is tightly linked to their productivity. Some of the comfort aspects, however, can only be tackled during the design phase. Therefore, there has been a vast amount of research on the effect of lighting, furnishing, space management, etc. on the productivity of employees [19-21]. A significant amount of research has also focused on the effect of materials that are being used [22].

We are interested in the way that energy management can affect occupants, and that, in turn, can affect business performance. Therefore, we are interested in the modes of communication with occupants to develop cooperative energy-conscious behaviour. Some of the most significant approaches are feedback and education [23, 24], whereby feedback is a better opportunity to actively involve occupants. It has also been noted that occupants' behaviour changes have potential to achieve about 25% energy use reduction [25], which is a very significant saving.

Active communication with occupants can enhance their awareness of their energy-related behaviour. In [26] Vikhorev et al. present an energy management framework to promote energy awareness in commercial buildings. The conclusion of their research is that the visualization of energy data is highly important in raising awareness about energy-related behaviour of occupants. In a work with similar goals [27], Carrico and Riemer evaluate group-level feedback and peer education and information dissemination on energy consumption, achieving 4% and 7% reduction in energy consumption, correspondingly. In [18] Hall presents a tool to assist building stakeholders identify key energy performance issues with their buildings. The tool explores 5 key areas in buildings that influence energy performance: design elements, building management, occupant experience, agreements and culture and indoor environment quality. One of the conclusions is that occupant feedback needs to be harnessed more in building rating tools, as a major factor for sustainability of buildings.

The existing work in this domain shows the importance of active communication with building occupants. It confirms the importance of feedback and the different types of visualization of feedback. However, communication with occupants needs to be customized, as there is nothing like "one size fits all" approach.

2.3. Workplace Impact on Productivity

There have been numerous studies that assess the impact of the workplace ambient on productivity. In one of the most recent works [28] analysis of working environment of a foreign private bank in Turkey is presented and the relationship between the workplace physical conditions and employees' productivity is examined. They conclude that the overall workplace environment significantly impacts employees' performance. In a similar study [29], the thermal comfort was being observed, and it was found that there is a tight link between employee's behaviour, his/her thermal comfort and productivity. Air quality is also seen as a significant factor to productivity, and it has been shown that poor indoor air quality can significantly decrease productivity, apparently to the size of 6-9 % [30]. Many studies go even further and claim an average relationship of 2% decrement in work performance per degree ^{o}C when the temperature is above 25^{o}C [31]. In the same work, the study performed showed that the productivity increase by using nighttime fans during work was 32 to 120 times greater than the cost of energy to run the fans. Therefore, the strong link between workplace ambient and employees' productivity is more than evident, and energy consumption savings have to be viewed in light of utilizing this connection.

3. Decision Support System for Occupant-Centered Building Energy Management

Managing buildings in an energy-efficient manner is a complex problem. To simultaneously address the human factor and business performance only further aggravates this complexity. To tackle this problem we have designed a framework for a building energy management decision support system that positions occupants in the centre and highly prioritizes their contentment level to optimize both energy consumption and business performance.

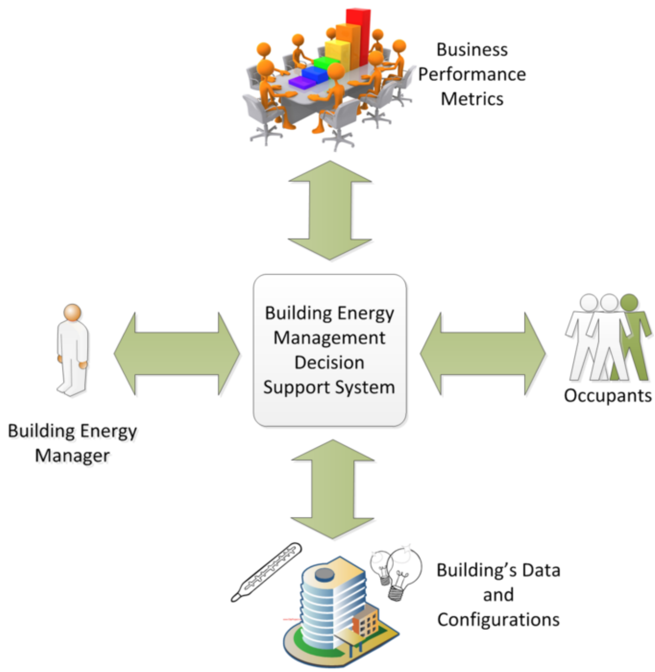

Fig. 2. High level representation of the DSS for building energy management

Our building energy management decision support system is meant to interact with the building energy manager and occupants, as well as with the building subsystems for lighting, HVAC, feedback and maintenance. Furthermore, it is also meant to receive input from various business performance metrics of hosted businesses. This is illustrated in Figure 2. This active bi-directional communication with occupants is essential to support the holistic approach of our proposed system framework, as it is meant to register feelings and perceptions of occupants and consider them as parameters in the decision-making processes.

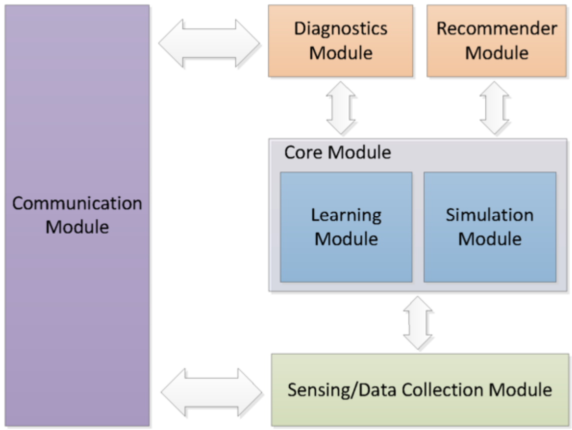

Fig. 3. High level representation of the DSS framework for building energy management

In Figure 3 we illustrate the architecture of our DSS framework. The system consists of six modules: two core modules (Learning and Simulation modules), Sensing/Data Collection Module, two modules that rely on the core modules and process their results to either diagnose or recommend (Diagnostics and Recommender modules) [32], and finally, a module that is responsible for making building occupants involved and delivering the actions in a user-friendly and user-cooperative manner, i.e. the Communication Module. In the following we elaborate each of the modules separately. To begin with, we first describe the remedial actions that can be delivered as an output of the system.

3.1. Remedial Actions

In the following we describe the remedial actions that can get recommended by the DSS to the building manager. We limit them to 4 possible types of actions that can be taken:

- Lighting
- HVAC
- Maintenance
- Inform/Explain

The last type of remedial actions (Inform/Explain), that we found to be usually neglected, is to ensure communication between the system, the building manager and occupants. The actuators associated with the different remedial actions are modelled as various modules, as detailed below.

An example for a remedial action would be “Reduce temperature in room X by 2°C”. In addition to technical types of actions, the DSS can also inform/explain to occupants. An example for this would be “Display to occupants ‘Please use warmer clothes, the outside temperature is too low.’” or “Display image X to occupants”, which could be displaying a rewarding image to occupants after their positive action towards energy preservation.

3.2. Communication/Feedback Module

The first module to be described is the module that enables and supports centralization of occupants. The Communication/Feedback Module is responsible for successful bi-directional communication with occupants. The communication from DSS's side is meant to be either explanation or request for feedback. This module will ensure that the system runs in coordination with needs of occupants and it is perceived as caring towards their wellbeing. The module will incorporate various interaction models, and is meant to be highly customizable, as not all occupants can be effectively communicated in the same way. It would also feature various visualization modes, to enhance the different interaction models. An example for feedback on how occupants feel with respect to office conditions would be a simple perception, such as “I am hot” or “It is dark”, from which the Learning Module would learn and build a model of how occupants perceive certain configurations. Furthermore, this perception might vary if the occupant has Scandinavian or Middle East background, so our DSS framework intends to take this into consideration as well. A configuration would consist of occupant's description, heating/cooling level, outside temperature, time of the day, date in the calendar, etc. This will help in classification and future decision-making processes. The Communication/Feedback Module relies to a great extent on the Sensing/Data Collection Module, as described in the following subsection.

3.3. Sensing/Data Collection Module

The Sensing/Data Collection Module's task is to sense, collect, filter, and process data from building, occupants, and businesses. These would include movement (room enter/exit), window/door open/close, lighting, temperatures, business performance indicators, etc. It would also signal obvious outliers and obviously abnormal behaviour. This module is tightly coupled with the Communication/Feedback Module, which acts as a more sophisticated and higher level module.

The Sensing/Data Collection module would act independently if it only needs to automatically sense certain data, without explicit communication with occupants. Otherwise, its actions will need to be coordinated by the Communication/Feedback Module. It will also serve to store historical data that has been collected, which would further be utilized and processed by the core modules (Learning and Simulation modules).

3.4. Diagnostics Module

Diagnostics Module's task would be to diagnose issues and energy gaps when the energy systems do not behave as predicted by the Simulation and Learning Modules. The Learning Module will support the Diagnostics Module by learning models from data that would be utilized to determine causes of deviations in system's behaviour. Input to the Diagnostics Module would be deviations and problems in the energy management system, and the output would be the list of possible causes, ordered by probability. Depending on the nature of the cause, the Recommender Module could be communicated to calculate a list of possible remedial actions.

3.5. Learning Module

The task of the Learning Module is to learn from collected data and build models and classifiers that could further be used by the Diagnostics Module and the Recommender Module. The Learning Module would utilize machine learning and data mining algorithms, such as Support Vector Machines or Bayes Networks. To consider occupants' comfort, the module will also incorporate occupants' perceptions gathered through the Communication/Feedback module and utilize them for classification of conditions that contribute to having content occupants and achieving optimal energy efficiency without compromising occupants' satisfaction and, in turn, residential businesses' productivity.

3.6. Recommender Module

The task of the Recommender Module is to further process the results obtained by the Learning and Simulation Modules and wrap them up into a set of recommended actions, ordered by priority. Each of the recommended actions would be assigned a value that would assess the level of improvement that it would offer if implemented. The recommender module would generate a set of recommended actions based on a set of predefined goals, which could be assigned different weights based on their relevance for the building management. If there were multiple goals defined, then the value associated with a recommended action would actually be a vector of values that would indicate the level of improvement towards each relevant goal, along with an overall score, normalized based on each goal's weight. The building energy manager can then, either automate some of the processes and allow the system to proceed with the most favourable action, or intervene by manually selecting one of the suggested remedial actions. Thus, the system is meant to operate in either fully- or semi-automated manner.

3.7. Simulation Module

The Simulation Module would be running various what-if scenarios for further optimization of parameters for parts of the system that have been associated with models. The Simulation Module would be utilized either by the Recommender Module, the Diagnostic Module, or by the building manager directly to test and evaluate various scenarios. The Simulation Module would gather data from the Data Collection Module, and utilize this to build prediction models for both optimization and diagnostics.

4. Discussion

The goal of our presented framework is to provide a systematic way of actively involving occupants in building management systems, and thus, utilize the opportunity that they carry for optimal commercial building energy management, in support of the *overall* building performance. Our framework focuses on positioning occupants in centre, as one of the key players for improved energy performance of existing commercial buildings. We are confident that contented occupants can make a significant difference, as productivity (supported by a productive building ambient) is a substantial parameter of the overall building performance, and it should not be compromised for energy efficiency.

The real challenge of our proposed decision support system framework lies in developing effective modes of communication with building occupants. This is so because of the increasing diverse educational and cultural background of occupants. Therefore, psychologists, as well as experts in user experience and human computer interaction need to be highly involved in its further development. Establishing a common language among the various expert profiles that need to be involved in the design and implementation of the proposed DSS would be one of its main challenges.

5. Conclusions

Motivated by findings in decision support and importance of occupants in buildings energy management, as well as impact of workplace on productivity, we have presented a framework of a decision support system that utilizes the potential that lies in occupants. The potential that occupants of commercial buildings carry is twofold: a) opportunity for reducing energy consumption, and b) opportunity for increased business performance. If not carefully managed, these two importance metrics can develop a trade-off. Our proposed framework represents a way to actively involve occupants and motivate them to achieve in both targets, thereby not compromising either of them.

6. Acknowledgment

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