Energy and Buildings 80 (2014) 424–435

Contents lists available at ScienceDirect

Energy and Buildings

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

Virtual Retrofit Model for aging commercial buildings in a smart grid environment

Jeong-Han Woo[a,*], Carol Menassa[b]

[a] Civil and Architectural Engineering and Construction Management, Milwaukee School of Engineering, 1025 N. Broadway, Milwaukee, WI 53202, United States

[b] Department of Civil and Environmental Engineering, University of Michigan, 2350 Hayward Street, Ann Arbor, MI 48109-2125, United States

ARTICLE INFO

Article history:
Received 9 February 2014
Accepted 5 May 2014
Available online 28 May 2014

Keywords:
Building energy efficiency
Building retrofit
Building Information Modeling
Interoperability
Multi-criteria decision making
Agent-based modeling
Stakeholder survey

ABSTRACT

The economic and environmental benefits of building retrofits have been acknowledged. However, there is a series of barriers that threaten to impede implementing successful retrofit projects such as: lack of funding, lack of interoperability, and unstructured decision making. This paper aims to address these barriers by providing the framework of the Virtual Retrofit Model (VRM), an affordable computational platform that supports streamlined decision making for building retrofit projects. An occupant survey was implemented to identify the primary requirements and perceptions from different types of stakeholders of the buildings. The responses were analyzed to identify the most important criteria of the future retrofit projects to focus on if it were to be renovated in the future. A case study approach was used to describe the outcomes from a year-long demonstration project that has been conducted at an aging commercial building. The research activities focused on integrating theories and technologies of Building Information Modeling (BIM), energy simulation, agent-based modeling, multi-criteria decision support system, and software application that can be employed and adopted in building retrofit projects. The software prototype is designed to connect buildings to a smart grid environment where building energy data should be shared for intelligent decision making.

1. Introduction

The urgent need for a viable response to energy security and global warming has become more acute. In the United States, existing buildings have a profound impact on the natural environment, economy, human health, and productivity. Statistics show that commercial and residential buildings account for approximately 70% of electricity consumption, 40% of energy use and 40% of CO_2 emissions [1–3]. In commercial buildings nationally, 36% of the energy is consumed for space heating, 21% for lighting and 8% for cooling [4]. In 2010, commercial buildings consumed roughly 20 percent of all energy in the U.S. Economy [4]. Reducing energy use by retrofitting aging commercial buildings for energy efficiency became one of the greatest opportunities for energy saving and is now considered as a high priority for the building stakeholders.

Despite the economic and environmental benefits of building retrofits, there is a series of barriers that threatens to impede implementing successful retrofit projects. The funding for building retrofit projects is typically limited, but the building stakeholders are required to achieve significant energy saving and carbon footprint reduction goals with less monetary resources and constrained schedules. Furthermore, it is hard for the building owners to make informed retrofit decisions. Energy benchmarking of aging commercial buildings are rarely performed due to the lack of energy meters and building energy management systems. Each retrofit project is typically unique and reinvented on a case-by-case basis. Despite the recent development of the energy technologies and renewables to reach the energy conservation goals, it is often difficult to identify optimal solutions and gain synergistic benefits from the installations.

Conflicting needs among opposing stakeholders (e.g., owner, tenant, or building operator) is another main barrier that limits the increase in the number of sustainably retrofitted buildings. The decision to retrofit has become extremely complicated and unstructured due to the conflicting expectations of the different building stakeholders, variety of proposed solutions by different engineers, and uncertainty about the expected economical and environmental benefits of the proposed retrofits.

This paper aims to address these barriers by providing the framework of the Virtual Retrofit Model (VRM), an affordable computational platform that supports streamlined decision making for

* Corresponding author. Tel.: +1 414 277 7595.
E-mail addresses: woo@msoe.edu, jeonghan.woo@gmail.com (J.-H. Woo).

http://dx.doi.org/10.1016/j.enbuild.2014.05.004
0378-7788/

building retrofit projects. Another goal of this research is to develop a software prototype linking buildings to a smart grid environment where building energy data should be shared for intelligent decision making such as fault detection and demand response. The main function of the software is for the buildings (considered as end nodes in the smart grid) to have the capability to communicate with the smart grid by deploying advanced sensing technologies, control methods, and information technologies coupled with BIM and EMCS (Energy Management Control System). It is noteworthy that, whenever possible, the software can be interfaced with existing relevant software components such as energy sensors, energy simulation tools, and BIM software. In particular, to maximize its interoperability with existing smart grid standards, the research team built it in a way that interfaces with the modular, open-source, and leading map software, Google Maps™.

2. Theoretical background

Many of today's aging commercial buildings fail to satisfy performance expectations and oftentimes consume more energy due to inefficient HVAC systems, lack of energy control systems, deteriorating building envelops, and occupant behavior. The national challenge is to reduce resource (energy fuels, water, and materials) consumption and achieve the net zero-energy building (ZEB) goal in the commercial building sector in the United States [5]. The significant number of retrofit projects have been undertaken in order to improve energy efficiency in existing buildings. Several studies claim that a typical office building can cut energy use by up to 25–45% by implementing moderate to deep retrofit solutions [4]. Gellings et al. [6] also stated that the commercial building sector is likely to offer the highest potential for energy-saving opportunities from the demand-side management perspectives. The benefits of such projects also include reduced operating costs, improved occupant comfort, and other related benefits.

However, the energy savings actually achieved after retrofits in commercial buildings are often disappointing [7], and many Leadership in Energy and Environmental Design (LEED) certified buildings oftentimes show poor energy efficiency [8,9]. Several studies reveal that the difference between predicted and actual energy consumption in buildings is estimated to be greater than 30 percent [10–12]. Menassa [13] also asserted that the value of the investment in sustainable retrofits for existing buildings tends to be doubtful due to uncertainties associated with the life cycle costs and perceived benefits of the investment. A previous research done by the authors has also found that aging commercial buildings may exhibit unpredicted energy consumption patterns. It is clearly shown that some occupants of the building waste a significant amount of electricity on air conditioning over the holidays or weekend periods [11]. The number of claims against architects/engineers is increasing as expectations for lowered energy costs go unmet [14].

Although there is a consensus about the potential of innovative energy technologies, renewables, and net-zero-energy buildings, it is still unclear how the retrofit decisions could be optimized and what the technical requirements are needed for successful implementations of the retrofit project. This issue has received significant attention from the research and the professional communities [15]. Asadi et al. [16] developed a multi-objective optimization model to assist stakeholders in identifying the most appropriate retrofitting options. Alanne [17] used a multi-criteria "knapsack" model in order to help architects select the most feasible retrofit solutions in the conceptual phase of a renovation project. Although previous studies tested several decision-support methods considering various decision criteria, limited studies reported technical interfaces supporting decision makings for building retrofits.

3. Project goals

The primary goal of this research is to develop a framework of Virtual Retrofit Model (VRM) that provides an affordable computational platform for data integration to support decision making for retrofit projects. VRM integrates and analyzes multiple layers of energy information such as physical characteristics, energy usages, building performances, and user inputs. It includes a BIM-based building baseline model which is used to store diverse energy information and physical characteristics of the buildings. A wireless sensor network is also deployed to collect energy-related data and store in a BIM-compliant database. This paper also discusses the effectiveness of VRM with measured performance data. The research activities focus on integrating theories and technologies of Building Information Modeling (BIM), energy simulation, agent-based modeling, multi-criteria decision support system, and software application that can be employed and adopted in building retrofit practices.

A year-long demonstrate project was conducted at the Technology Innovation Center (TIC) of the Wisconsin County Research Park in order to test the effectiveness of VRM with measured performance data and to evaluate impacts on building occupants. A software interface was also developed to test its commercial feasibility and capability of capturing and exchanging real-time energy information with smart grid operators. The research team also developed a broad and qualitative survey instrument in order to identify the primary requirements and perceptions from different types of stakeholders of the buildings. In addition, the information is necessary to develop a decision framework that allows building stakeholders to decide on the most efficient, economic and environmentally sound retrofit solutions for the building. This research takes a holistic approach by not only accessing existing conditions and measuring energy consumption, but also analyzing building stakeholders' opinions, outdoor environmental data, and indoor environmental data (luminance levels, temperature, humidity, CO_2 concentration, etc.) that enable us to identify the cause-effect relations between occupants' behavior and energy consumption in the building.

Finally, this research developed a software prototype linking buildings to a smart grid environment. The buildings (considered as end nodes in the smart grid) need to have the capability to communicate with the smart grid by deploying advanced sensing technologies, control methods, and information technologies coupled with BIM and EMCS (Energy Management Control System). It is noteworthy that, whenever possible, the software can be interfaced with existing relevant software components such as energy sensors, energy simulation tools, and BIM software. In particular, to maximize its interoperability with existing smart grid standards, the research team built the software in a way that interfaces with the modular, open-source, and leading map software, Google Maps™.

4. Research methods

This section describes the research methods employed to meet the stated research goals. Three primary research methodologies were employed: survey for the building stakeholders; case study of a public building project; and software prototyping. Outcomes of each research procedure are to be triangulated toward the final conclusions as validation efforts [18]. Each of these methodologies is described in detail below along with the contexts and the procedures which the research activities implemented.

Task 1: identifying potential retrofit options of Heating, Ventilation, Air Conditioning (HVAC) system