Building Energy Benchmarking with Building Information Modeling and Wireless Sensor Technologies for Building Retrofits

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ABSTRACT

Opportunities for improving energy efficiency can be recognized in many different ways. Energy benchmarking is a critical step of building retrofit projects because it provides baseline energy information that could help building stakeholders identify energy performance, understand energy requirements, and prioritize potential retrofit opportunities. Sub-metering is one of the important energy benchmarking options for owners of aging commercial buildings in order to obtain critical energy information and develop an energy baseline model; however, it oftentimes lacks baseline energy models collecting granular energy information. This paper discusses the implementation of cost effective energy baseline models supported by wireless sensor networks and Building Information Modeling (BIM). The research team focused on integrating the theories and technologies of BIM, wireless sensor networks, and energy simulations that can be employed and adopted in building retrofit practices. The research activities conducted in this project provide an understanding of the current status and investigate the potentials of the system that would impact the future implementation. The result from a proof of concept project is summarized in order to demonstrate the effectiveness of the proposed system.

INTRODUCTION

Over the last decade the construction industry has experienced extreme ups and downs. During the mid-2000s, the industry celebrated record levels of growth, but over the last four years, many incidents have reversed the prosperity of the construction industry. This economic downturn has strongly influenced the decision makers of construction projects. While new construction projects decreased sharply due to inadequate funding and economic uncertainty, major retrofit and renovation projects continued to increase. In 2010 retrofit and renovation projects comprised nearly 70% of all construction projects, while new construction projects comprised less than 30% (Bernstein and Lusso 2011).

The American Recovery and Reinvestment Act (ARRA) also stimulated the growth of retrofit and renovation projects. ARRA funded over $30 billion in energy efficiency retrofits of buildings operated by several federal agencies; including the U.S. General Services Administration, Department of Defense, Department of Energy, and Department of Veterans Affairs. The building stakeholders have also realized that energy efficiency is the pivotal approach in reducing operating costs and increasing asset value, while at the same time improving occupant comfort.

Opportunities for improving energy efficiency can be recognized in many different ways that range from low-hanging fruits, such as changing lighting fixtures, to deep retrofit solutions involving whole building design perspectives. Deep retrofits can offer more than 30% of energy savings (Liu et al. 2011). The opportunities are magnified using recent innovations in energy management tools for greater access to energy use data, analytics, and increased intelligence to optimize systems. These tools enable the quantifying of benefits gained from the application of energy technologies and control systems. Furthermore, the emerging trend of "Internet of Things" – particularly the commercialization and adoption of devices such as smart meters, smart thermostats, and home automation networks – are advancing the opportunities for a higher level of energy savings (Gomez and Paradells 2010).

RESEARCH PROBLEM

While the opportunities for energy efficiency retrofits in existing buildings are significant, the process of identifying, planning, and implementing these retrofits is not always straightforward. It is critical for building owners to select the best available solution and materialize it in a cost-effective manner. As aging buildings get worn out, the building stakeholders need to make a set of retrofit decisions to confirm up-to-date energy standards and functional requirements while maintaining daily functions without compromising the integrity of the existing structure.

Energy benchmarking is the first critical step of a building retrofit process because it provides baseline energy information that can help building stakeholders identify energy consumption, energy waste, understand energy requirements, set performance goals, create energy management plans, and prioritize potential retrofit opportunities. Most importantly, it helps to avoid excessive peak energy use. Sub-metering is one of the most important benchmarking options for owners of the aging commercial buildings to implement in order to obtain critical energy information (Granade et al. 2009, Liu et al. 2011). Recent advances of sensing and wireless network technologies make sub-metering a cost-effective approach to obtain critical energy information (Pesovic et al. 2012). The lack of energy baseline models currently impedes making the optimal decisions on retrofit projects. There is a need for an integrated information platform in order to manage energy benchmarking and provide necessary information for successful design and decision making.

GOALS

This paper discusses the implementation of cost effective energy benchmarking supported by sub-metering with a wireless sensor network and Building Information Modeling (BIM) technologies. The main goal of this research is to improve retrofit decision-making by providing accurate building energy data from a computational platform managing a broad range of energy-related data in interoperable data format. This paper in particular focuses on the technical requirements, system architecture, and functionality. A case study approach is used to describe the outcomes from a one-year long proof of concept (POC) project at the Technology Innovation Center (TIC) building located at Milwaukee, WI.

RESEARCH METHODS

A POC project was conducted to test the proposed benchmarking system and to demonstrate its feasibility. The major tasks included installing a wireless sensor network, prototyping of a BIM-based baseline energy model, and conducting a calibrated energy simulation.

Task 1: Installing a wireless sensor network. Granular information for selected spaces has been collected using a Wi-LEM™ sensor network. A set of sensing devices, data loggers, and controllers were installed to capture temperature, humidity, CO_2, and power consumption data from each room for use in analyzing building performance at a more aggregate level.

Task 2: Prototyping of BIM-based Baseline Energy Model. A BIM-based baseline energy model of the TIC building was developed based on a BIM approach, which is a set of technologies and processes related with the generation and management of digital building models. The resulting building information model became a shared information repository to support retrofit decision-making of a building by means of a BIM-compliant database.

Task 3: Calibrated Energy Performance Simulation. BIM-based building energy models are capable of acquiring real-time energy performance data such as energy consumption, temperature, CO_2 emissions, occupancy, and humidity. As it captures energy-related data, accurate operating conditions can be simulated and regenerated as the operating conditions are updated. Once the simulation model is matched with measured data, the simulation model can be used to estimate the energy savings of the different combinations of retrofits and to measure and verify energy savings accurately. Finally, a BIM-based energy model could pass decision-relevant information to various energy simulation programs in order to assist facility managers in maximizing energy efficiency. Simulation results are to be used in prioritizing the retrofit candidates based on energy efficiency.

OUTCOMES

Wireless Sensor Network. The sensors and associated equipment such as energy meters, gateway, repeaters, and temperature/humidity/CO2 sensors were installed at the TIC building. The research team conducted two site visits prior to the installation in order to decide sensor locations and develop a list of required equipment. Energy meters were installed in the power panels by clipping voltage taps with the CTs/Rogowski coils around the conductors. The research team decided to focus on the electrical energy metering specifically in the offices on the second floor because these rooms represent typical office spaces in the TIC building. Power consumption due to air conditioning use was measured at one of the main panels on the fourth floor. Photos in Figure 1 show energy meters in the power panels that contains the branch circuits to the rooms.

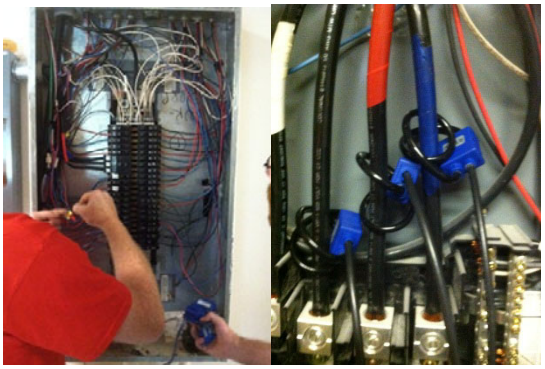

Figure 1. Installations of Power Meters

The BIM-Based Baseline Building Model. The BIM-based baseline building model consists of two parts: an as-built virtual building model and a baseline energy model. Firstly, the virtual building model of the TIC building was created using Autodesk Revit software. The model represented the existing conditions of the building's architectural, structural, and mechanical systems. The virtual building model was created by interweaving three types of information including 3D point clouds, 2D AutoCAD files, and building pictures. The 3D point clouds of building exteriors were captured using a Leica High Definition Scanner. Then, Cyclone software was used to transfer 3D point clouds to Revit. When modeling the interior layouts of the building, 2D AutoCAD files were imported directly into Revit and used as a background for trace over. The building pictures were used to confirm the interior layout models. The 3D images of architectural and mechanical models are shown in Figure 2.

Secondly, a baseline energy model was built by storing up-to-date energy information from the wireless sensor network into the Revit model. Sensor data was exported to a MS Access database, and then stored in the Revit model of the TIC building through Revit API called DB Link. This interface allowed Revit to refresh updated information to the database and vice versa. Additional parameters were added on the Revit model environment to store energy-related information (See Figure 3). The completed baseline energy model intends to capture and store energy consumption data of the building into a single repository.

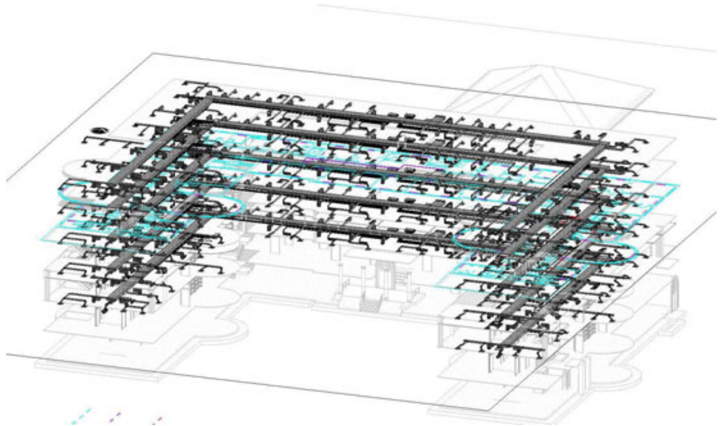

Figure 2. Revit Model of the TIC building

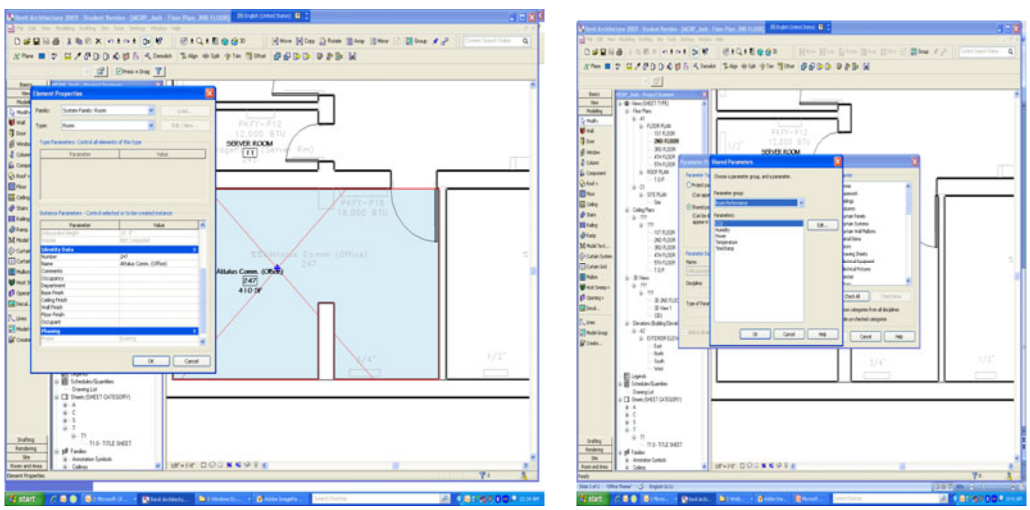

Figure 3. Adding Energy-Related Parameters on the Revit Platform

Energy Consumption Data. A wireless sensor network was placed in the Technology Innovation Center at Milwaukee, WI, which then collected data on the air conditioning, lighting, air handling units (AHU), and plug loads, or wall outlets. The data was collected from May 30, 2012 through September 30, 2012. The data collected by the sensors was put into a delimited format and then converted into useful data in Microsoft Excel. Analysis was done according to the sum and average of the active energy (Wh) data collected by the sensors. The weather data was obtained from Weather Underground (http://www.wunderground.com/).

Air Conditioning. The air conditioning units are standard window units. There was no central system in place and the units were controlled by the occupants each space. This system may lead to periods of time where the system was run even if occupants were not present, such as on the weekends or at night. The results of the data show that the energy usage was similar to the temperature (See Figure 4).

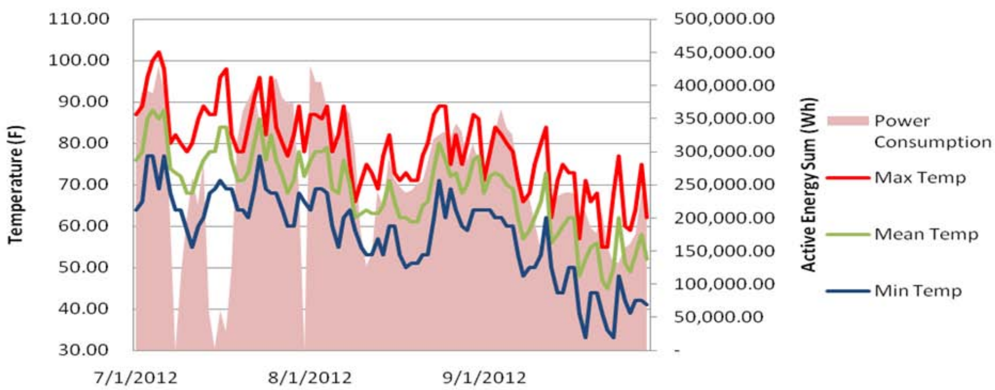

Figure 4. Air Conditioning Power Consumption vs. Temperature

Lighting. The lighting load was analyzed based upon the amount of energy used during normal working hours, 9 am to 5 pm Monday through Friday, versus non-working hours. In the figure below, the working hours are shown in red, and the total energy consumption for the day is shown in blue. The data is stacked on top of each other, so where ever the blue bar is showing above the red bar lights were on outside of normal working hours. It can be seen that the largest days for energy consumption were actually on a Saturday and Sunday (August 11-12). If occupancy sensors were in place, then instances such as this would not have occurred. Occupancy sensors are one way aging commercial buildings can be easily retrofitted to reduce energy costs.

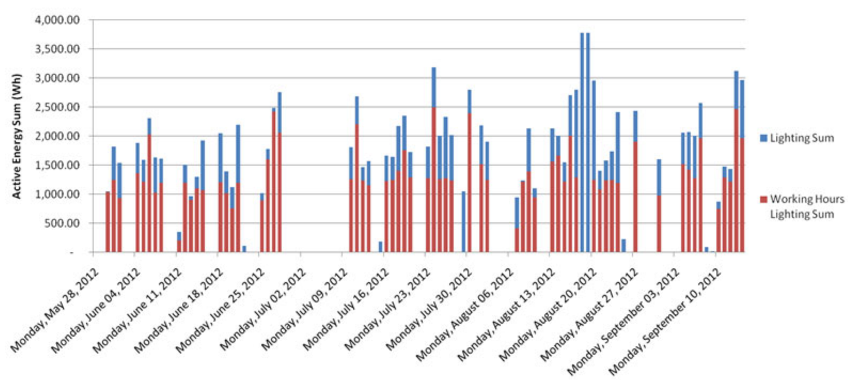

Figure 5. Lighting Energy Usage - Working Hours vs. Total Consumption

Calibrated Energy Performance Simulation. In previous research activities, the BIM-based building baseline model was developed to acquire real-time energy performance data such as consumption, temperature, CO_2 emissions, occupancy, and humidity. As it captured energy-related data, accurate operating requirements were regenerated as the operating conditions were updated. Once the simulation model was matched with measured data, the simulation model was used to estimate the energy savings of the different combinations of retrofits and to measure and verify energy savings accurately. Finally, the BIM-based building baseline model provided decision-relevant information to various energy simulation programs. Figure 6 and 7 depict the simulation results of the three HVAC retrofit options (Alt. 1: Variable Refrigerant Flow, Alt. 2: Current System, and Alt. 3: ASHRAE 90.1) for the TIC building.

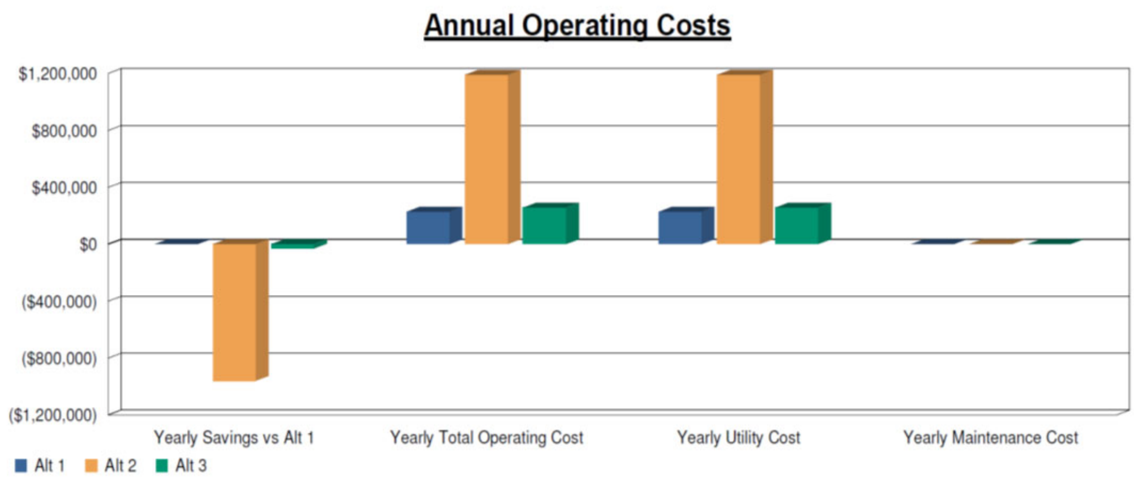

Figure 6. Comparisons of Annual Operation Costs

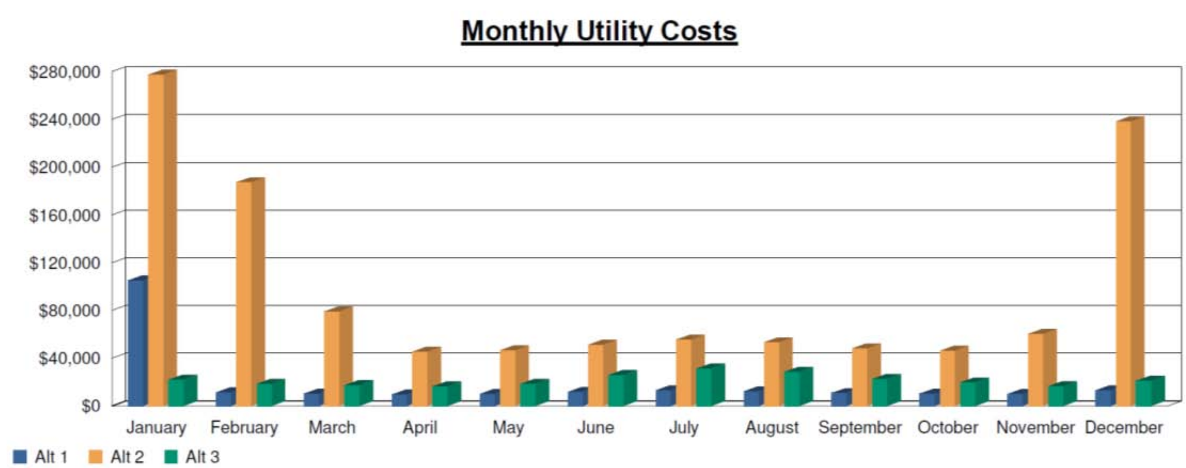

Figure 7. Comparisons of Monthly Utility Costs

CONCLUSIONS

This research project developed a BIM-based benchmarking system for supporting decision making and cost-effective retrofits of aging commercial buildings. A POC project was conducted to test the effectiveness of the proposed system on the retrofit decision process for the TIC building. The research team focused on integrating the theories and technologies of BIM, wireless sensor networks, and energy simulations that can be employed and adopted in building retrofit practices. The research activities conducted in this project provide an understanding of the current status and investigate the potentials of the system that would impact the future implementation. The outcomes of this project revealed that the system is capable of helping building stakeholders make accurate decisions by delivering accurate energy-related data. Facility operations can be improved based on the data collected. The system also provides necessary data to produce more accurate building energy simulation models. This will enhance the accuracy of energy-saving verification by utilizing real-time energy-related data from sensors and associated data collection methods.

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