Improving Energy Efficiency using BIM-based Basedline Building Models

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Abstract

Due to the urgent need for a response to energy security, aging commercial buildings are required to conform to increasingly stringent environmental standards, particularly with regard to energy and water consumption. Solutions to reach the energy-related goals seem to exist. However, it is often difficult to gain synergistic benefits from the installations. The energy savings actually achieved are often disappointing. The building owners typically invest on “low-hanging fruit” energy efficiency measures including window replacement or light fixture replacement. Systematic measurement and verification are rarely available due to the high initial cost of such studies. Therefore, there is a significant chance that misunderstandings and unrealistic expectations will affect decision making related with building sustainability. The ability to synthesize emerging technologies into a robust computational platform for monitoring coupled human-building environments is lacking. This paper disscusses developing a prototype of BIM-based Baseline Building Model (B^3M) for aging commercial buildings. As-built BIM of a public building was employed as a platform for delivering user-actionable information to building occupants, maintaining healthy environments, and achieving further energy savings. Initial testing was conducted at the Technology Innovation Center with data collected for four months. The results of this study showed that B^3M provides a robust computational platform for monitoring coupled human-building environments. B^3M would be a useful system when aging commercial buildings need to measure and verify accurate benefits of the installations.

Keywords

BIM, energy efficiency, baseline building model, XML parser, sensor network

1. INTRODUCTION

The urgent need for a response to energy security and global warming has become more acute. Existing commercial buildings in the United States consume 71% of electricity, 39% of all energy, and 12% of water; they produce 40% of nonindustrial waste and 38% of CO_2 emissions (U.S. Green Building Council 2009). Demand for electricity is expected to grow 30% by 2030, and electricity

prices are forecast to increase 50% over the next 7 years (Conti and Sweetnam 2008). Achieving a net-zero-energy (NZE) building (Torcellini, et al. 2006) and building energy efficiency coupled with healthy and sustainable work environments are nationwide challenges for local, state, and federal governments (National Science Foundation 2009).Therefore, buildings are required to conform to increasingly stringent environmental standards, particularly with regard to construction waste recycling and energy and water consumption. Policies and incentives such as federal and state tax credits; utility rebates and pricing structures; and government-backed research to develop energy-efficient technologies gradually mitigate energy consumption (US Department of Energy, 2008).

However, there are still opportunities to improve energy efficiency of the existing buildings. Due to the limited resources, building owners of aging commercial buildings typically do not keep track of energy performance. They typically invest on "low-hanging fruit" energy efficiency measures including window replacement; light fixture replacement; heating, ventilating, and air conditioning (HVAC) system upgrade; or building envelope improvement. Life cycle assessments and systematic sustainability initiatives are rarely available due to the high initial cost of such studies. Therefore, there is a significant chance that misunderstandings and unrealistic expectations will affect decision making related with building sustainability.

Energy measurement and verification of aging commercial buildings also remains difficult because such buildings rarely acquire actual operating conditions and analyze builsing subsystems interaction. Subsequently, there is a lack of accurate baseline energy models of the existing buildings (Whole Building Design Guide, 2009). Federal, state and local government adoption of sustainable guidelines such as LEED™ and Green Globes™ calls for improved baseline building models describing existing consumption, as well as for indoor air quality, water consumption and solid and hazardous waste management. Simulation models typically are used to identify energy efficiency measures and evaluate the energy performance of a new building compared to an energy baseline model. However, simulation results often are compromised by uncertainty and vague assumptions used in baseline models.

The need to develop an integrated baseline building model for future sustainable buildings becomes more and more urgent. A building baseline for intelligent, self-maintaining buildings (Fiatech 2009) should be capable of delivering user-actionable information to building occupants, maintaining healthy environments, measuring peak load reductions, and achieving further energy savings. The baselines should communicate with all of the subsystems such as smart meters, building automation system, renewable energy, HVAC, lighting, and waste management. The lacking is the ability to synthesize emerging technologies into a robust computational platform for monitoring coupled human-building environments (Granade, et al. 2009).

2. USE OF BIM IN BASELINE BUILDING MODELS

Building Information Modeling (BIM) is one of the most significant recent innovations in architecture, engineering and construction. It integrates the description of static building data such as 3D geometries, materials, building structures, Mechanical, Electrical, and Plumbing (MEP) systems, occupants, etc. into an intelligent format. The use of BIM has been focused on building design rather than building operations and facility management. Although the potential of using as-built BIM for facility management (Ezell 2007) is well known, a systematic approach to provide the necessary information for sustainable buildings is yet to be developed (Young, Jones and Bernstein 2009). Construction Operations Building Information Exchange (COBIE) has been developed to automate the handover and commissioning process of a facility at the end of the construction (East 2008). However, it does not provide continuous support for building operation and maintenance for the entire building life cycle.

Comprehensive baseline models should be able to acquire and analyze actual operating conditions and measure and verify energy savings accurately. If a building baseline model is created directly from an up-to-date BIM, the energy model can be regenerated as the operating conditions are

updated. Facility management processes can be improved significantly through the use of an as-built BIM that can integrate real-time building performance data. Expanded use of BIM would allow for more detailed analysis of building systems. BIM-based building energy models can be designed to store energy performance data such as consumption, temperature, CO2 emissions, occupancy, and humidity. In addition, the connection to the BIM allows facility managers to simulate occupancy changes, facility upgrades, or energy management strategies based on potential energy demands. Integrating environmental and energy data and metrics within BIM tools would reduce data and input errors. Furthermore, a BIM-based energy model could pass decision-relevant information to various energy simulation programs to assist building owners in optimizing building energy efficiency.

However, there has been no attempt to link BIM with building automation systems or energy management systems. As more information is accumulated in as-built BIM, a higher level of design and construction expertise can be contributed, as required, for sustainable design solutions in the future. As-built BIM also can be used for studying various aspects of building performance. The recent development of National BIM standards promotes the use of BIM for integrating building information during the entire building life cycle. Previous studies (Eastman, et al. 2008) also showed that an accurate as-built BIM should be used for managing facilities and analyzing potential retrofit projects.

This paper addresses this need by describing an approach for developing as-built BIM coupled with various energy data acquisition tools. Existing as-built technologies, such as 3D laser scanning, are also demonstrated and future uses for as-built BIM are suggested. The implementations presented in this paper are part of an ongoing research project involving a local governmental agency building with significant renovation needs. This paper also addresses serious gaps in the scientific research on monitoring, verifying and enhancing energy savings and performance of existing buildings. Previous research has been limited by the lack of interoperability amongst various data resources such as utility bills, one-time inspection or metering activities and a lack of data integration for energy performance analysis (e.g., actual real-time data was not integrated into energy baseline models). This research removes these limitations by developing a BIM system linked with a sensor network to provide stakeholders with better data on building performance and better methods for making appropriate sustainable energy-related decisions.

3. PREVIOUS RESEARCH

Very little research has been done on the topic of comprehensive baseline models describing not only existing energy consumption, but also indoor air quality (IAQ), renewable energy, and water consumption (Bharvirkar, et al. 2008). Models for waste management and recycling are also important since transforming waste into valuable resources is to contribute to sustainability (Kunde and Newenhouse 2002). Environmental Protection Agency (EPA) has developed IAQ models to calculate risks associated with indoor air problems. Botic and Diggelman's environmental risk model (2007) calculated Environmental Risk Value (ERV) to identify potential risks associated with air pollutants such as Volatile Organic Compounds (VOCs) from off-gassing hazardous construction materials. However, these models need a variety of data from ventilation, occupancy, and emissions and take a significant amount of time to produce the intended analysis due to labor-intensive data collection processes. Comprehensive building baseline models should capture IAQ data from various systems to maintain up-to-date IAQ models.

The focus of previous research on building baseline models has been limited to the measurement and verification of energy consumption in accordance with the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) Standard 90.1. Various building simulation models have been developed to assess energy savings accurately. However, it remains difficult to accurately measure and verify energy savings because the data acquired and analyzed rarely reflects actual operation conditions for the building (Sylvester, et al. 2002). The unfortunate result is a significant chance of misunderstanding of building energy performance which impacts

decision making. One of the most time-consuming and labor-intensive tasks in building energy modeling is reconstructing building geometries and setting the operating conditions necessary to accurately represent the working environment in a simulation tool. The simulation often deviates from actual building conditions and, in turn, decreases the accuracy of building energy models (Whole Building Design Guide 2009).

4. BUILDING

The Technology Innovation Center (TIC) of the Milwaukee County Research Park (MCRP) was used as a test bed. The TIC is a 138,000 sq. ft. solid masonry structure built in 1913 as the Muirdale Tuberculosis Sanitarium. It generates and nurtures start-up technology-based businesses, driving development, innovation, and job creation. Since its inception in 1993, the TIC has served over 120 companies which created 866 jobs and graduated 72 companies, 80% of which relocated in Southeastern Wisconsin.

The TIC still uses wall-mounted air conditioning units. There is no central energy management and control system. With Milwaukee County's Department of Public Works, Johnson Controls, Inc., and other design, engineering, and construction professionals and contractors, MCRP has developed a comprehensive capital improvement plan, centered on a complete upgrade of the building's mechanical and energy systems which promised significant energy savings to the MCRP. The owners also had ambitious goals regarding other dimensions of sustainability such as water management, waste recycling, or obtaining a LEED™ certificate.

5. BIM-BASED BASELINE BUILDING MODELS

A prototype of a BIM-based Baseline Building Model (B^3M) was developed in order to provide a technological plaform for measuring accurate energy consumption and linking energy-related data with as-built BIM of the TIC. The key components of B^3M is sensor network, as-built BIM, XML parsing engine, and integrated database as shown in Figure 1.

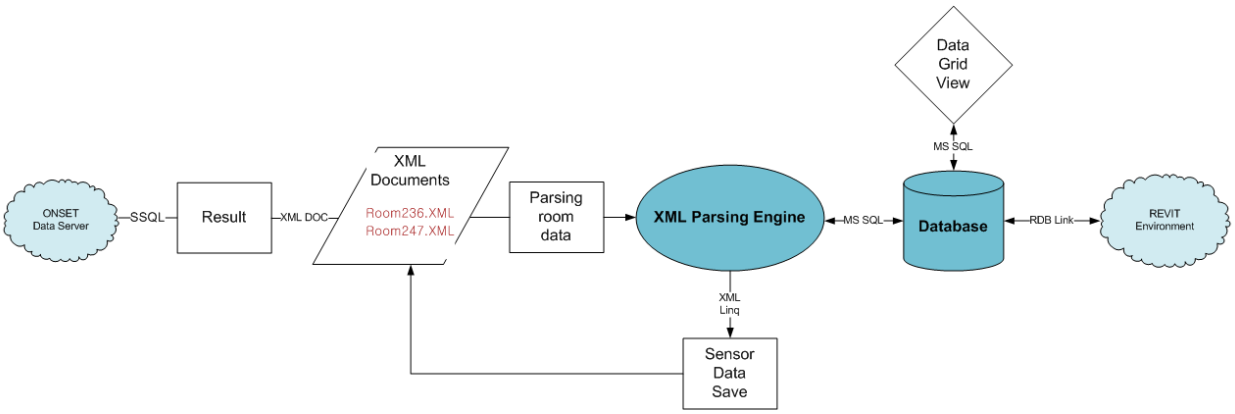

Figure 1 Concept diagram of BIM-based Baseline Building Model

The sensors and data loggers acquire and store energy data such as power consumption, temperature, CO_2 emissions, occupancy and humidity while BIM captures static data about the size and location of HVAC equipment, building materials, geometries and envelope performance. B^3M also acts as a central data repository achieving data integration among the different components of building management systems. The focus is on integrating data sets from the seperate proprietary building systems in open formats and collecting data related to the energy performance and environmental aspects of the building.

5.1 Sensor Network

The research team instrumented two offices, room 264 and 273, on the northwest corner of the TIC with sensors and data loggers to capture data which include indoor dry bulb temperature; relative

humidity; indoor CO2 (as a surrogate for occupancy); lighting electricity consumption/demand; receptacles electricity consumption/demand; cooling electricity consumption/demand; outdoor dry bulb temperature; relative humidity; solar radiation; wind speed; and wind direction. A weather station was installed on the building roof. The objective of the installations was to collect accurate energy consumption data and store the data set into Onset's database server for use in analyzing building performance at a finer level. Seven temperature sensors, three CO_2 sensors, twelve power sensor modules, and two data loggers interfacing with Onset HOBOlink and HOBOware Pro were installed in the winter of 2009. All sensors are wired and battery-powered. The list of equipments is shown in Table 1.

Table 1 Equipment List for Room 236 and 247

Equipment	Measurement	Room 236	Room 247
Sensors			
TEL-7001	CO2 Level	1	2
S-THB-M008	Temperature / Humidity	4	3
T-MAG-SCT-050	A/C 1 (Window Type) Current Transformer	2	2
S-UCC-M006	A/C 1 (Window Type) Pulse Input Adapter	2	2
T-MAG-SCT-20	Lighting Current Transformer	1	1
S-UCC-M006	Lighting Pulse Input Adapter	1	1
T-MAG-SCT-20	Receptacles Current Transformer	3	1
S-UCC-M006	Receptacles Pulse Input Adapter	3	1
T-WNB-3D-240	kWh logger (WattNode)	1	1
Data Loggers			
U30-ETH	Energy Logger	1	1

Data from the sensors were recorded on Onset's HOBO® Ethernet Communications Data Loggers, model U30-ETH, in 5-minute intervals and were transmitted to the Onset's database server via data organization software HOBOware Pro. Examples of output from the system can be seen at the website: https://www.hobolink.com/p/691f87a78e34150be0d0a0f905f0c6b6. The equipments were installed and calibrated on January 22, 2010. Some minor problems were identified and fixed by April 14, 2010. An example of monitored energy consumption data is shown in Figure 2.

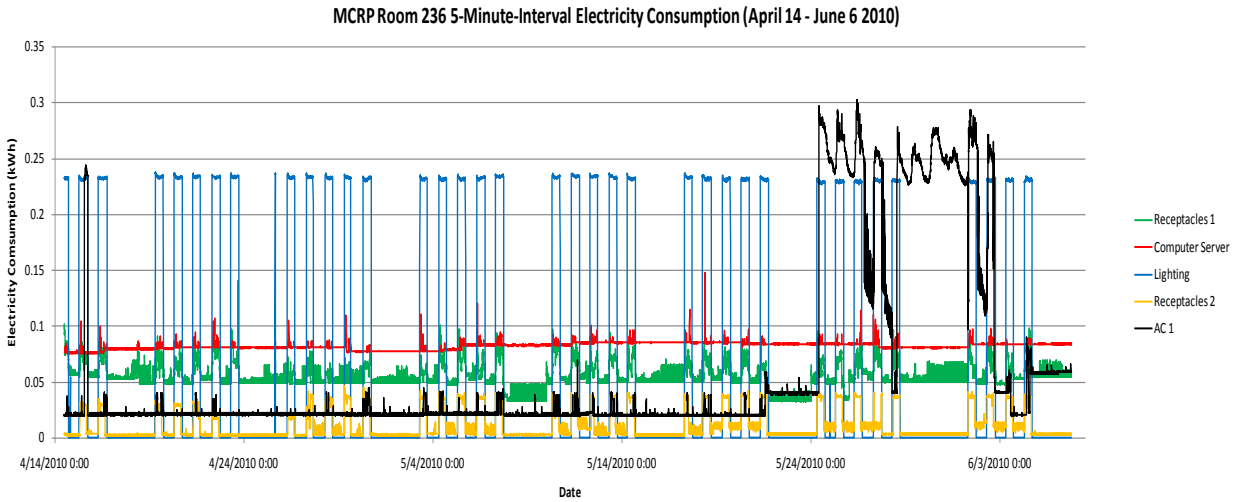

Figure 2 Power Consumption in Room 236

5.2 As-built BIM

The research team developed an as-built BIM of the TIC using Autodesk Revit™ software. Revit data was stored in a MS Access database through Revit APIs using Visual Basic (VB). This interface allowed Revit to refresh updated information to the database. Additional parameters were added to the Revit software environment to store energy-related information. The research team captured necessary information for as-built BIM from three different resources: CAD files, old drawings, and 3D Point Clouds. An on-site survey was conducted as well. The two dimensional CAD files was imported directly into Revit and used as a background for trace over to develop Revit models. This process simulates the steps that would be required to create an as-built BIM of a building when the original CAD drawings are available. The exterior of the buildings was scanned by engineers from Excel Engineering, Inc from Fon Du Lac, WI and modeled from the point clouds (Figure 3). The interior of the buildings was modeled from CAD drawings. The research team used Leica High Definition Scanner and Cyclone software, which was used to transfer 3D point clouds to Revit™.

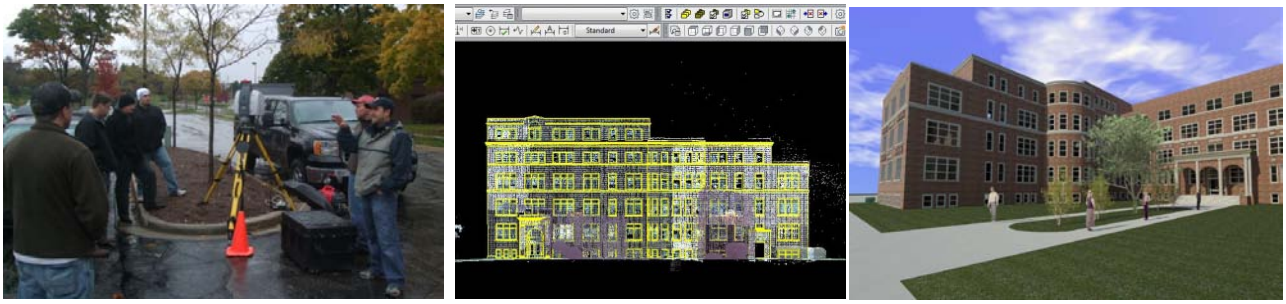

Figure 3 3D Modeling Prcess using Point Clouds

5.3 Data Import/Export from BIM and Sensor Network

After the TIC was virtually constructed in Revit™, the building model was extended as a baseline database management system (DBMS) via RDBLink, an open database connectivity (ODBC) protocol which is provided in 2009 Revit application programming interface (API). RDBLink is capable of pushing a variety of property values that are made in the DBMS back to their corresponding elements in Revit. In addition, the RDBLink application can create a new Revit Family based on added records in the DBMS. Figure 8 shows that ODBC links the external DBMS database and Revit's database system.

A MS Access database was used to host the BIM data and energy data retrieved from Onset database server. This environment allowed B^3M to update with the latest conditions of the TIC. In addition to centralizing the data flow, the database enables real-time collaboration, as changes to the model are reflected on all clients each time their view of the data is refreshed.

5.4 Prototype: MCRP PRO

Building data from the as-built BIM were unified with monitored data to provide accurate building baseline conditions. As a part of this effort, a parsing engine was developed to translate Sensor ML data to be used in a .NET and Revit API environment. The Parsing Engine, called MCRP PRO, is designed to access to the Onset's database server to extract recorded sensor data. The functions of the Parsing Engine are as follows: receives data, decrypt, parse, send to data grid view, and insert data into MS Access database. MCRP PRO was developed using .NET programming languages, including Visual Basic and C#. Visual Studio.NET was chosen as the development platform to establish the internet-based application via ODBC protocol (Figure 4).

The datasets are delivered in SensorML, an industry standard XML schema, defining the geometric, dynamic, and observational characteristics of sensors. Authentication is achieved via a "token" which is provided by Onset. The parsing engine used pre-defined algorithms to parse the data and to

send and receive data from different data protocols, normalize the data, and exchange it in an XML format. It also converts the SensorML data to open XML/SOAP Services so that it can be used in .NET environment. Finally, it mapped data to .NET applications which store the data into the database. Figure 5 shows that MCRP PRO was used in temperature monitoring for the TIC.

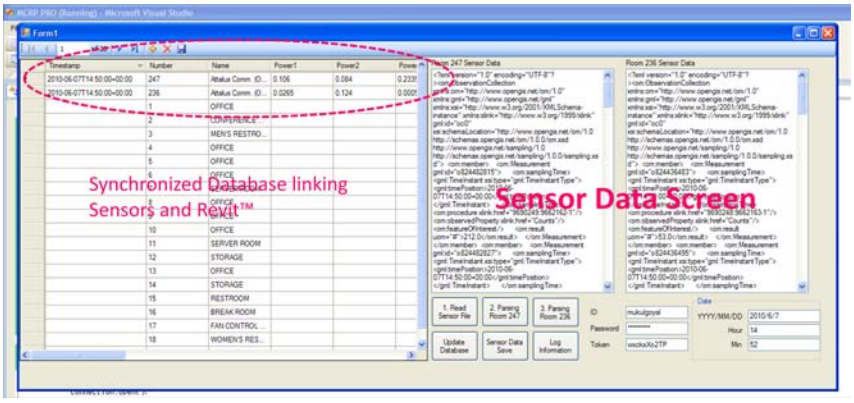

Figure 4 Prototype Parsing Engine

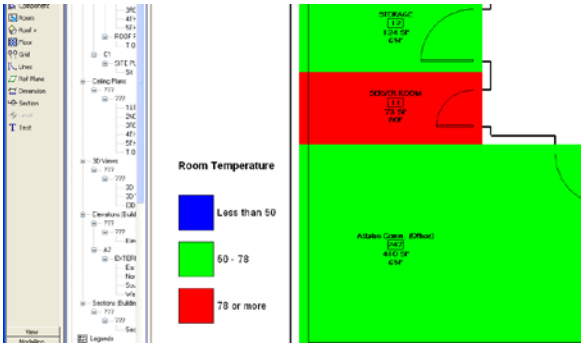

Figure 5 Temperature Monitoring for the TIC

6. CONCLUSION

This paper have focused on developing B^{3}M. As-built BIM of the TIC was employed as a technological platform to deliver user-actionable information to building occupants, maintaining healthy environments, measuring peak load reductions, and achieving further energy savings. Initial testing was conducted at the TIC with data collected for four months. The results of this study showed that B3M provides a robust computational platform for monitoring coupled human-building environments. B3M would be a useful system when aging commercial buildings need to measure and verify accurate benefits of the installations. The integratred data framework have a potential to create substantially more interconnected building systems and reduce operational and environmental risks. The future research will develop a set of exemplary B^{3}M-based applications to test and verify its ability to meet user needs. The verification approach with real data will provide stronger evidence of how B^{3}M contributes to sharing building information within the context and scale of real facility management practices.

7. ACKNOWLEDGEMENTS

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