A Framework for Building Energy Model to Support Energy Performance Rating and Simulation

Jamal A. Abdalla[1] and Kincho. H. Law[2]

[1]Department of Civil Engineering, American University of Sharjah, P.O. Box 26666, Sharjah, United Arabs Emirates; PH (971) 6515-2959; FAX (971) 6515-2979; e-mail: jabdalla@aus.edu
[2]Department of Civil and Environmental Engineering, Stanford University, Stanford, CA, USA; email: law@stanford.edu

ABSTRACT

Recent advances in Building Information Modeling (BIM) and the emergence of mandatory building energy codes and specifications encouraged the integration of energy performance rating and energy analysis and simulation in building design and operation. Building Energy Performance (BEP) ratings and simulations and the Architecture, Engineering and Construction/Facility Management (AEC/FM) disciplines are converging. However, current BIM databases contain data that support, mainly, AEC/FM tasks. Few attempts had been made to include data that support BEP rating and simulation. In this study, a conceptual framework for a Building Energy Model (BEM) that captures the data needed for building energy performance rating and simulation has been presented. A case study, using a warehouse, is used as a test-bed for proof of concept and for validation of the developed framework. The ultimate goal is to develop a data model that supports the integration of BEP rating and simulation to facilitate building design and operation.

INTRODUCTION

Buildings consume large amount of energy and contribute significantly to the carbon footprint by causing environmental pollution and emission of greenhouse gases that adversely affect the climate. It is estimated that buildings consume approximately 40% of the global primary energy and contribute roughly to about 30% of the global carbon footprint (Wang et al. 2012, Costa et al. 2013). Therefore, reduction in building energy consumption is vital for achieving sustainability and for reducing the green house effect. Energy consumed by buildings can be in the form of either embodied energy or operational energy. Embodied energy is the energy expended in the processes of building material production (resource extraction, manufacturing), transportation of materials and on-site delivery, prefabricated components, construction and assembly on-site, renovation and final demolition, end-of-life reuse, recycling, or disposal (Dixit et al. 2012). Operational energy in buildings is the energy use over a period of time (hourly, daily, monthly, yearly) for lighting, cooling, heating and ventilation loads for achieving certain thermal comfort and performance in buildings. This includes the performance of HVAC equipment in response to these loads and calculation of utility costs using the energy use results. Figure 1 shows a classification of energy consumption in buildings.

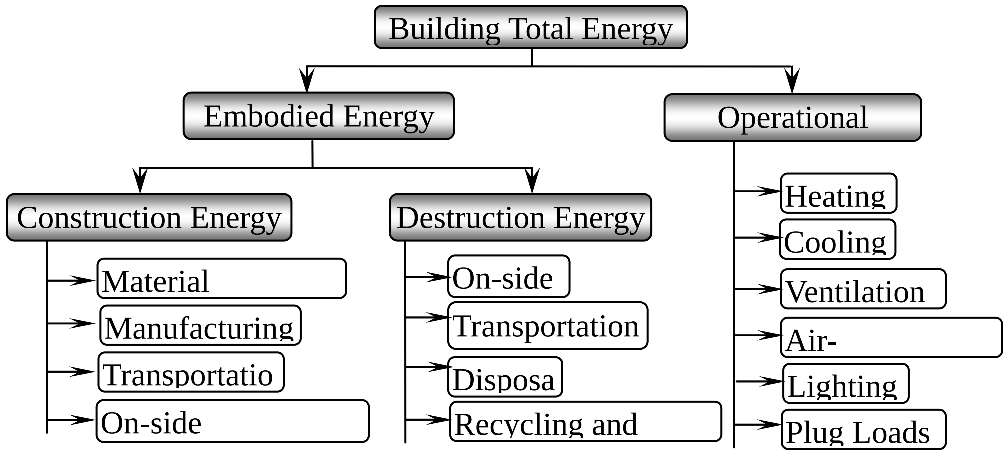


Figure 1. Embodied and operation energy in buildings.

There are several building energy rating systems that have been used internationally and within the U.S. In the US there are several rating systems used by individual states. Nationally, many energy rating systems are in use including EPA Energy Star Portfolio Manager (ESPM 2013), the U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) program (USGBC 2013) for sustainability rating, the Building Energy Quotient (bEQ) program developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (ASHRAE 2013) and the Green Building Initiative (GBI) Green Globes for environmental sustainability (GBI 2013). A review of quantitative energy performance assessment methods for new and existing buildings is given in Wang et al. 2012.

Several studies have been conducted to assess and evaluate building energy performance to improve in building design, building operation/life-cycle and building remodeling or retrofitting to reduce energy consumption. Energy analysis and thermal load simulation combines building's structural components and simulated operations and incorporates the basic framework of the building, building use, occupant behavior and operations and maintenance to analyze energy use and carry out thermal simulation taking into consideration occupants' comfort, among others (McCabe and Wang 2012). There are several different methods of energy analysis and simulation, some are based on statistical analysis others are table based or hybrid/mixed. Simulation of building energy performance requires the use of large amount of data that describes the building geometry, occupancy, lighting and electrical systems, HVAC equipment and systems, weather conditions and the schedules of use.

There are numerous building energy simulation tools and several energy performance rating ones as well. The energy simulation tools are generally used to simulate the energy of existing buildings and to size the plants for new buildings. Among the commonly used energy simulation tools in the U.S. is DOE *EnergyPlus* (Crawley et al. 2001) and among the widely used energy rating system in the US is

Energy Star Portfolio Manager (ESPM 2013). Unfortunately, energy performance rating systems and energy simulation systems were not integrated into the design process of new buildings. For integration of these systems into building design and operation, the BIM must support data related to energy performance rating and energy calculation and simulation.

Therefore there is a need for developing energy data model to be integrated with existing BIM to capture the data needed for building energy modeling.

BUILDING INFORMATION AND BUILDING ENERGY MODELING

Recent advances in BIM, energy measuring and sensing technology and energy modeling encouraged the integration of energy performance rating and energy analysis and simulation in building design, operation and maintenance. The AEC/FM disciplines are moving towards convergence and there is clear evidence that building service disciplines are merging (Attia 2010). This move is partially triggered by the mandatory codes and energy rating systems. The rapid emerging confluence of multidisciplinary integrated building design process and building performance simulations will accelerate the use and development of building energy simulation tools within the architectural and engineering practice and education (Attia 2010).

However, current BIM contain data that mainly support the tasks of AEC/FM. Few attempts have been made to include data that support energy performance rating, energy analysis and thermal load simulation that enable the use of building energy performance to be used in the decision making of the building design (Bazjanac 2008, Schlueter et al. 2009, Tantisevi et al. 2010, O'Donnel et al. 2012, O'Donnel et al. 2013, gbXML 2014). Usually, energy performance simulation and analysis take place only after architectural and HVAC design have been completed to provide the needed input for energy calculation and simulation. Nevertheless, there are some attempts to integrate energy performance ratings into BIM.

Bazjanac 2008 proposed a methodology to eliminate human intervention and to automate the energy performance modeling and simulation process as much as possible. The goals of his methodology are to make the process and its results consistently reproducible and to enable the integration of energy performance simulation and analysis tools into suites of interoperable tools that are routinely used in building design. Schlueter et al. 2009 extended the capability of building information model to store multi-disciplinary information and parameters necessary for energy performance calculations to optimize the building design at the early stage. They developed a tool that has been integrated into a building information modeling software to enable instantaneous energy and exergy calculations and the graphical visualization of the resulting performance indices. Tantisevi et al. (2010) investigated the use of commercially available building information model software to extract data needed for evaluating energy performance of buildings and calculate the overall thermal transfer value of building envelope. They concluded that data related to building shell element and areas needed for energy performance can be extracted from BIM, however, they suggested BIM software capabilities need to be extended to enable other types of analytical approaches for the evaluation of the building energy used to support exchange of energy information throughout the project life cycle.

O'Donnel et al. 2012 developed an interoperable XML-based data model named Simulation Domain Model (SimModel) for the building simulation domain that provides a consistent data model across several aspects of the building simulation process. The model captures both geometric and Mechanical, Electrical and Plumping (MEP) simulation data and it is a general tool that is not tied to specific input schema and aligned with Industry Foundation Classes (IFC). O'Donnel et al. 2013 developed a semi-automated process that extracts building geometry from existing BIM and convert it into format of a BEM tool. Specifically, they developed a semi-automated geometry data transformation from ArchiCAD (BIM) to EnergyPlus (BEM). Green Buildings (gbXML 2014) developed gbXML schema that provides interoperability by allowing 3D BIM architectural models to be imported and to facilitates the generation of heating, cooling and air conditioning systems' sizes and other data for building energy modeling as used in DesignBuilder (DesignerBuilder 2014).

In this paper, a conceptual framework for a building energy model (BEM) that captures the data needed for BEP rating and simulation has been suggested. The developed framework will establish the relationship between BIM and BEP rating and simulation processes. A case study, using a warehouse, is used as a test-bed for proof of concept and for validation of the developed framework.

FRAMEWORK FOR BUILDING ENERGY MODEL (BEM)

A framework for building information modeling that incorporates data for building energy modeling is shown in Figure 2. Besides the well defined BIM data, BEM data is added to support energy performance rating and energy analysis and thermal load simulation. The BEM data will be extracted from the common BIM database. Details of the extracted data are shown in Figure 2. Such data includes, architectural data, envelope data, HVAC data, among others. The extracted BEM data, in addition to the weather data and the operational data will be sufficient to carry out BEP simulation using *eQuest* (DOE-2 2013) or DOE *EnergyPlus* (Crawley et al. 2001) for example and BEP rating using EPA *Energy Star Portfolio Manager* (ESPM 2013). A brief description of these programs is given.

Energy performance analysis and simulation. Energy analysis and thermal load simulation are intended to provide needed information including the heating and cooling loads necessary to maintain a certain set level of thermal comfort. It takes into consideration the description of the building geometry and layout, constructions data, operating schedules, conditioning systems (lighting, HVAC, etc.), plug loads, weather data and the energy consumption of primary plant equipment and utility rates provided by the user to perform an hourly simulation of the building and to estimate utility bills. Such information can be used by the design engineer or architect that wishes to size appropriate HVAC equipment, develop retrofit studies for life cycling cost analyses, optimize energy performance, etc. (EnergyPlus 2013). There are several energy analysis and thermal load simulation programs in use. Details of these tools are given in Crawley et al. 2008. The major energy simulation software packages that are widely used in the U.S. is *DOE-2* and its derivative *EnergyPlus* and *eQuest* (Crawley et al. 2001, DOE-2 2013).

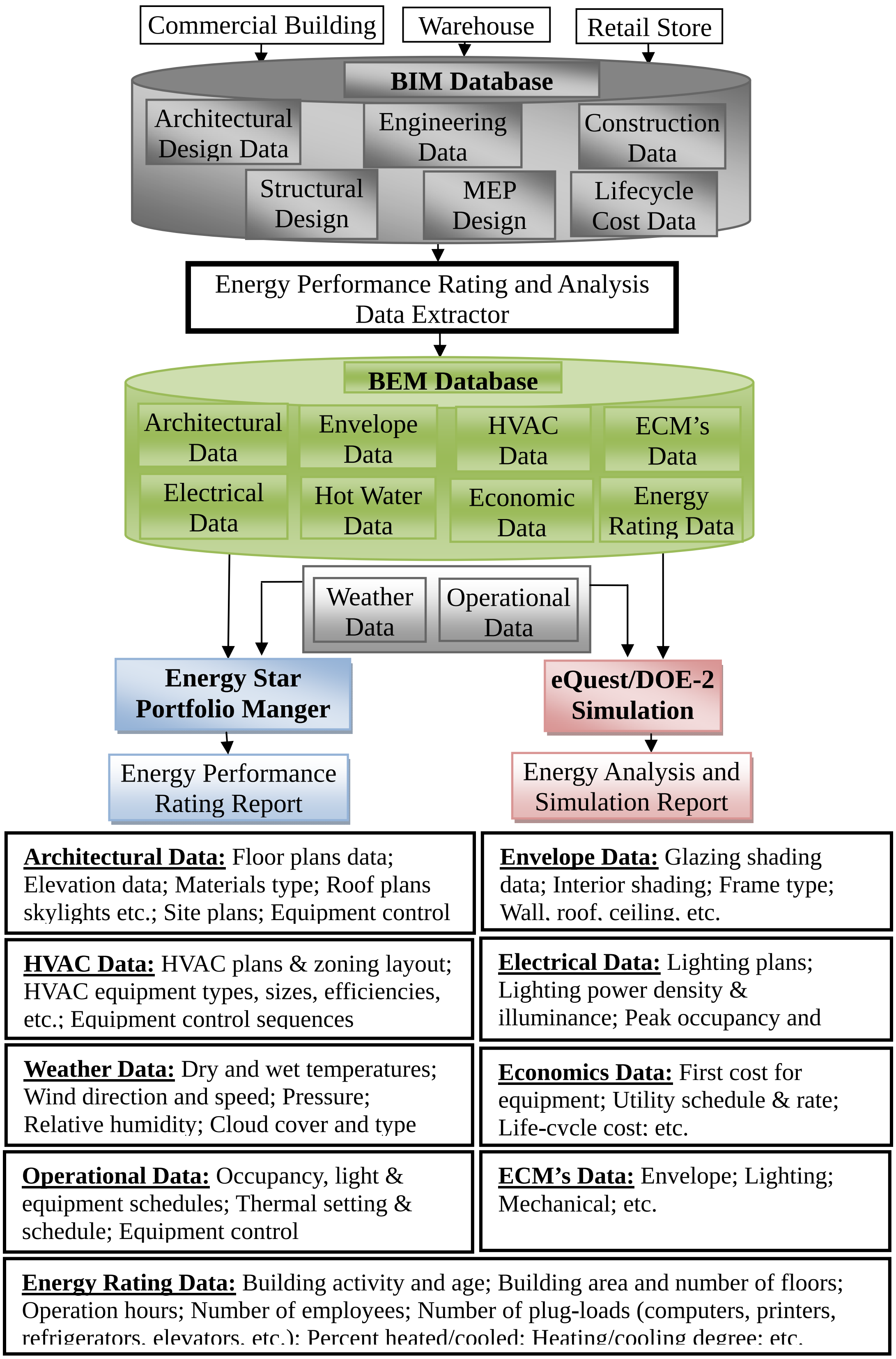
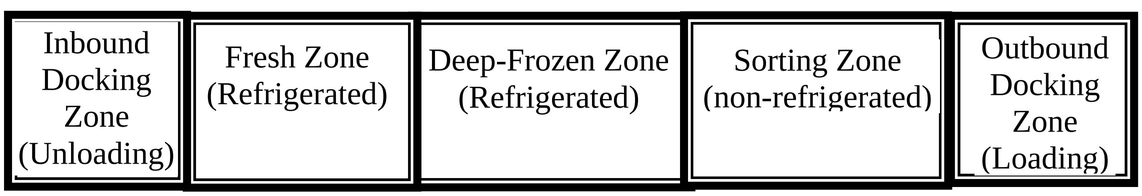


Figure 2. A framework for energy data model.

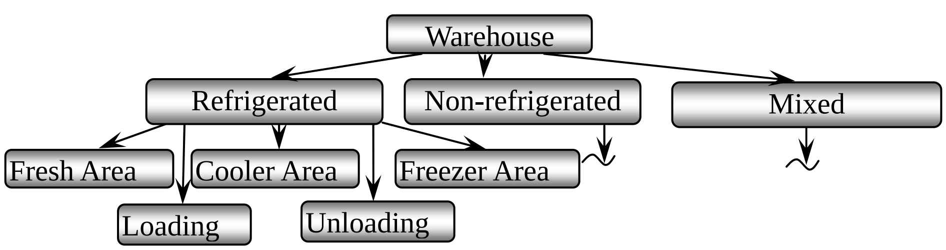
Energy performance rating. There are several software tools that have been used for energy operation ratings. The most commonly used tool is the EPA energy performance rating called *Energy Star Portfolio Manager* (ESPM). It is an operational energy rating tool that allows building owners or operators to compare their actual building energy use with energy use in similar buildings in the same climate zone, as derived from the U.S. Department of Energy's (DOE) CBECS. Energy Star Portfolio Manager provides an accurate and equitable assessment of a building's energy performance. It evaluates energy performance for the whole building, reflects actual billed energy data, normalizes for operation and provides a peer group comparison, i.e., it generates a percentile score against the mean of existing buildings (ESPM 2013). It relies on a statistically robust set of data that is based on a nationally representative sample of buildings with collected and verified actual billed energy data at the whole building level together with information on key operational characteristics.

CASE STUDY: A WAREHOUSE

A warehouse is a lightweight construction that usually consists of a rectangular or square single story building with few windows in the four sides of its walls and can be modeled as three zones (refrigerated, non-refrigerated and conditioned or mixed) with or without interior partitions (DOE 2013, ESPM 2013). There are many sections and subsections within each area. Figure 3(a) shows a mixed/hybrid warehouse with refrigerated and non-refrigerated areas and Figure 3(b) shows a class hierarchy of the warehouse. Figure 4 shows energy use in a warehouse. Energy use can be classified into two major categories – indoor energy use and outdoor energy use.



(a) Mixed (Refrigerated and Non-refrigerated) warehouse



(b) Class hierarchy of a warehouse

Figure 3. Zones and class hierarchy of a warehouse.

ENERGY SIMULATION AND RATING FOR A WAREHOUSE

Input data and modeling information for warehouse energy simulation using *eQuest* include: (1) architectural data such as floor plans space layout/areas, surface orientations, elevations surface areas (windows, doors), building/wall/roof sections materials composition, site plans adjacent structures and landscape, roof plans skylights and overhangs, gross area & net (conditioned area); (2) envelope materials data (glazing shading coefficient, frame type, interior shading); (3) mechanical data (HVAC plans approximate and zoning layout, equipment types and sizes, design conditions, etc.); (4) electrical/internal loads (lighting plans, lightening power density, peak occupancy, peak equipment all by HVAC zone, occupancy, equipment, light and thermostat schedules, chilled and hot water temperature, etc.); (5) economic data such as first costs of equipment and systems, applicable and optional utility rates. Energy data and information for a warehouse energy performance rating using *Energy Star Portfolio Manager* include total area, heated area, cooled area, weekly operation hours, number of employees, computers, printers, copiers, refrigerators, elevators, etc. Figure 5a and 5b show screen shots of *eQuest* and *Energy Star Portfolio Manager* for energy performance simulation and rating of the warehouse.

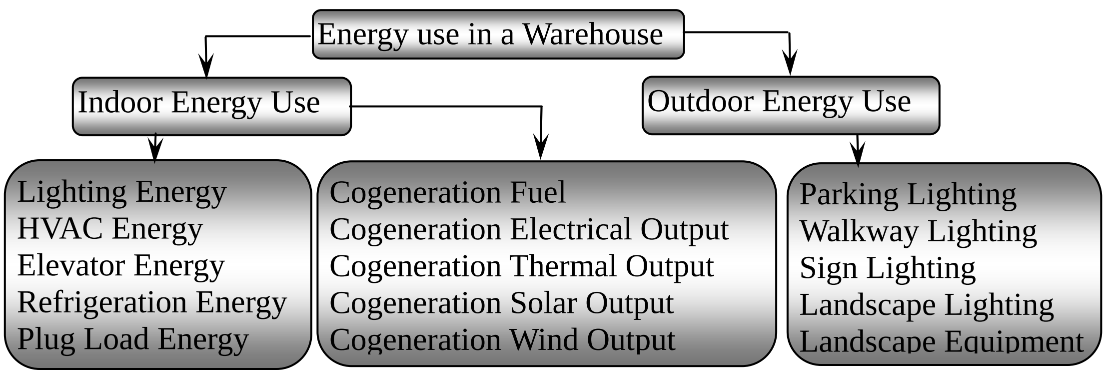
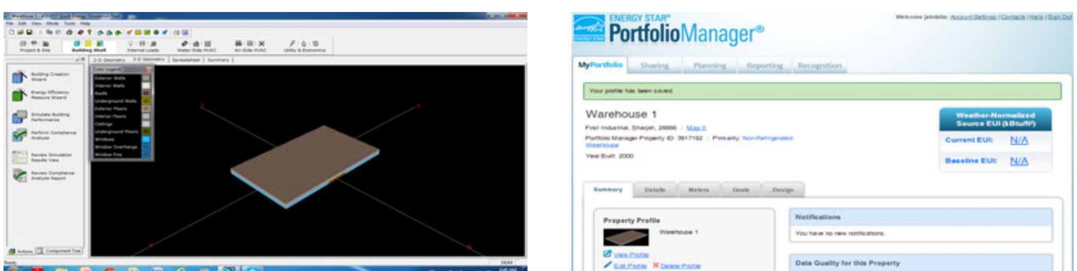


Figure 4. Energy use in a warehouse.



(a) eQuest Energy Simulation (b) Energy Star Portfolio Manager

Figure 5 Energy performance simulation and rating for a warehouse

CONCLUSION AND FUTURE WORK

This paper presented a conceptual framework for a building energy model that captures data needed for building energy performance rating and simulation. A case study of a warehouse has been presented as a proof of concept for validating the framework. The proposed framework established the relationship between BIM and

BEP rating and simulation processes and outlined the parameters that need to be extracted and transferred among them. This framework can be extended to develop a full-fledged BEM that can be incorporated into existing BIM to facilitate full integration of building design and operation.

REFERENCES

Attia, S. (2010). "Building Performance Simulation Tools: Selection Criteria and User Survey." Research Based Report. Architecture et climat, Université catholique de Louvain, Louvain La Neuve, Belgium.

ASHRAE (2013). www.ashrae.org (May 10, 2013).

Bazjanac, V. (2008). "IFC BIM-Based Methodology for Semi-Automated Building Energy Performance Simulation." Lawrence Berkeley National Laboratory.

Costa, A, Keane, M. M., Torrens, J. I., and Corry, E. (2013). "Building operation and energy performance: Monitoring, analysis and optimisation toolkit." *Applied Energy* 101, 310–316.

Crawley, D. B., Hand J. W., Kummert M., and Griffith B. T. (2008). "Contrasting the Capabilities of Building Energy Performance Simulation Programs." *Building and Environment* 43, 661–673

DesignBuilder (2014). http://www.designbuilder.co.uk (February 10, 2014).

Dixit, M. K., Fernández-Solís J. L., Lavy S. and Culp C. H, (2012). "Need for an embodied energy measurement protocol for buildings: A review Paper." *Renewable and Sustainable Energy Reviews* 16: 3730– 3743.

DOE-2 (2013). http://www.doe2.com/equest/ (October 12, 2013).

EnergyPlus 2013. http://apps1.eere.energy.gov/buildings/energyplus/(April 20, 2013).

ESPM (2013). http://www.energystar.gov/ (December 14, 2013).

GBI (2013). www.thegbi.org April 10, 2013).

gbXML (2014). http://www.gbxml.org/index.php (February 10, 2014).

McCabe, M. J. and Wang N. (2012). "Commercial Building Energy Asset Rating Program –Market Research." PNNL-21310. Richland, WA.

O'Donnell, J. T., See, R., Rose, C., Maile, T., Bazjanac, V. and Haves, P. (2012). "SIMMODEL: A Domain Data Model for Whole Building Energy Simulation." Environmental Energy and Technologies Division. LBNL-5566E.

O'Donnell, J. T., Maile, T., Rose, C., Mrazović, N., Morrissey, E., Regnier, C., Parrish, K. and Bazjanac, V. (2013). "Transforming BIM to BEM: Generation of Building Geo. for NASA Ames Sustainability Base BIM." LBNL- 6033E.

Tantisevi, K, and Sornsuriya, K. (2010). "Building information model for evaluating the building energy performance: a case study." ICCCBE 2010. Nottingham 30 June - 2 July 2010, UK.

Schlueter, A., and Thesseling, F. (2009). "Building information model based energy/exergy performance assessment in early design stages." *Automation in Construction* 18, 153–163.

USGBC (2013). www.usgbc.org (April 6, 2013).

Wang, S., Yan, C., Fu Xiao, F. (2012). "Quantitative energy performance assessment methods for existing buildings." *Energy and Buildings* 55: 873–888.