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VALIDATION OF BUILDING ENERGY MODELING TOOLS: ECOTECT™, GREEN BUILDING STUDIO™ AND IES<VE>™

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ABSTRACT

Building energy modeling (BEM) helps architects, engineers and green building consultants in designing increasingly energy-efficient buildings. When used in conjunction with Building Information Modeling (BIM), integration of energy modeling into the design process allows the environmental ramifications of design decisions to be tested in a relatively seamless way. While energy modeling has proven useful as a design tool, there is a need to validate the accuracy of BEM tools. A case study was conducted to compare the results of energy simulations obtained by three BEM tools (Ecotect™, Green Building Studio™, and IES<VE>™) against measured data for two academic buildings located in Gainesville, Florida. A LEED Gold-certified building and a non-LEED-certified building were investigated in the case study. Research findings showed that the three BEM tools were not able to accurately predict actual building energy consumption in the majority of analyzed cases.

1 INTRODUCTION

Building energy modeling (BEM) can be used for improving energy efficiency of a building both in design phase and operation phase of a building life cycle. As a design tool, BEM can be used to estimate the energy performance of various design iterations. In facilities management, BEM can be used to identify potential changes to system levels to reduce energy consumption. The improvement of energy efficiency in the building industry is particularly important. In the United States, the building sector comprises 8% of gross domestic product, yet accounts for nearly 39% of the nation's energy consumption (US Department of Energy 2011). While the use of BEM in building design and operation can improve energy efficiency in one of the most critical sectors of energy consumption, there is a need to assess the accuracy of the BEM tools against the actual energy performance of existing buildings.

Krygiel and Nies (2008) describe two primary ways of using BEM. BEM can be used as a design tool that employs an iterative design process in conjunction with feedback from the energy model in order to develop energy-efficient design iterations. As a design tool, BEM is useful for comparing the environmental performance of design iterations against a baseline model. BEM can also be used as a measurement tool to predict actual building energy use in later design stages and in facilities management phase. In this case there is a need to validate the accuracy of building energy models by comparing simulated results obtained by BEM with measured data for existing buildings.

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There are two primary methods to validate BEM software: 1) for idealized conditions, and 2) for realistic conditions (Ryan and Sanquist 2012). Validation for idealized conditions is outlined by the industry standards such as building energy simulation test (BESTEST) and ASHRAE Standard 140. The building energy model is created using the BESTEST guidelines, and simulation results are compared to hand calculations (Judkoff and Neymark 2006). Validation of BEM software for realistic conditions includes comparison of simulation results obtained by BEM software to measured data for an actual building. The energy model in this validation methodology tries to account for occupant behavior by implementing schedules for occupancy, lighting usage, and equipment usage. Ryan and Sanquist (2012) noted that these schedules were a common source of model errors because the behavior of occupants is highly variable and nearly impossible to model accurately.

A study conducted by Knight et al. (2007) attempted to minimize the errors associated with BEM schedules by conducting a survey of building occupants of an educational building in the UK. The survey results were used to generate detailed and accurate schedules for over 300 spaces created in an energy model of the building used in the case study. Simulation results obtained using two energy modeling tools (Ecotect™ and iSBEM™) were compared to measured data for electricity and gas consumption. Comparison of the results showed that the annual electricity use was underestimated by both software, while the annual gas consumption was slightly overestimated. Because the percentage differences between the simulation results and the measured data were not acceptable, Knight et al. (2007) were unable to recommend either BEM tool to be used for accurate prediction of building energy usage.

While the accuracy of certain BEM tools for realistic conditions remains questionable, many studies have also noted a disparity between the designed/predicted performance of buildings (and building systems) and their actual performance (Maile et al. 2012). Specifically, the study notes that it is not uncommon for HVAC systems to underperform as compared to their designed performance.

2 RESEARCH OBJECTIVES AND METHODS

The primary objective of this research was to validate the accuracy of predicting energy use by three BEM tools. The three BEM tools evaluated were Autodesk Ecotect 2011™ (Autodesk 2011a), Autodesk Green Building Studio 2011™ (Autodesk 2011b), and IES<VE> 2011™ (Integrated Environmental Solutions 2011). Simulation results obtained by each software were compared to measured energy usage for two buildings. These three BEM tools are typically applied as energy efficient design aids and are interoperable with building information modeling (BIM) platforms such as Revit Architecture™. The interoperability with BIM tools allows for the integration of energy analysis into the design process to occur in a relatively seamless manner. Since building geometry does not need to be recreated in the BEM tool, the environmental ramifications of design changes made to the BIM model can be assessed in these BEM tools relatively quickly. The three BEM tools investigated in this research were selected mainly because of their interoperability with the Revit™ BIM platform. The benefits and applications of BIM throughout the building lifecycle from early design stages to facilities management are well-known (Eastman et al. 2008). Meanwhile, the application of the three BEM tools investigated in this research has been primarily limited to early design stages. By validating each BEM tools' accuracy against measured data, this research aimed to assess the applicability of these tools for later design stages and facilities management phase when model accuracy is a necessity.

To accomplish the primary research objective, i.e., to validate the accuracy of the three BEM tools, simulation results were compared to measured data in three categories of building energy usage: heating, cooling, and overall energy usage. Percentage differences between simulation results and measured data were calculated for these three energy use categories both for annual energy consumption and for monthly energy consumption. The research aimed to validate both the precision and accuracy of the three BEM tools. In this research, the term precision refers to the degree of similarity of trends between simulated results and measured data in terms of monthly energy use; while the term accuracy refers to the percentage difference between simulated results and measured energy use data.

The case study was conducted to simulate the energy usage of two buildings using three BEM tools: Ecotect™, Green Building Studio™, and IES<VE>™. The two buildings investigated in the case study were Rinker Hall (a LEED Gold-certified building) and Gerson Hall (a non-LEED-certified building). Both buildings are academic buildings located on the University of Florida campus in Gainesville, Florida.

BIM models of the two buildings were created using the software Revit Architecture 2011™. The BIM models were exported from Revit Architecture™ as gbXML files and imported into each of the three BEM tools. Specifications pertinent to each buildings' energy performance were input in each of the BEM tools. Lighting power densities (LPD) were input for each room (based on room function) using values obtained from ASHRAE Standard 90.1 using the Space-by-Space method. The equipment power density (EPD) for all spaces was 0.48 W/sq ft based on commercial buildings energy consumption survey's (CBECS) average EPD for education building types (US Energy Information Administration 2003).

Measured monthly energy consumption for each building was provided by the Physical Plant Energy Department at the University of Florida. The energy consumption was measured for three energy usage categories: heating (steam), cooling (chilled water), and electricity. The data used in this study was collected in 2011. Based on the available outputs of each BEM tool, the simulation results obtained by each software were compared to the measured data in terms of heating, cooling, and overall energy usage. The comparisons were performed on a monthly and annual basis. The accuracy of each BEM tool was then assessed by analyzing percentage differences between simulated results and measured data. The percentage differences (PD) for every energy use category for every month of the sample time period as well as annually were calculated using Equation (1):

$$\text{Percentage Difference} = [(\text{Simulated Results} - \text{Measured Results}) / \text{Measured Results}] \times 100 \qquad (1)$$

In this research positive value of the PD meant that the software overestimated the results as compared to the measured data, while the negative value of the PD meant that the software underestimated the results. According to the previous research, the acceptable PD between computer simulation results and measured data is maximum 15% (Maamari et al. 2006). Thus, in this research, if the absolute values of the PD was equal to or less than 15% the software was considered accurate.

3 RESULTS

The results of the case study are presented in the three different categories of energy use: overall energy usage, heating and cooling. These results were used to validate each BEM tool in terms of precision and accuracy.

3.1 Overall Energy Usage

3.1.1 Rinker Hall

Overall energy usage was calculated as the sum of the three energy use types (heating, cooling, and electricity). Based on the monthly overall energy use values and the resultant line graph (Figure 1), Ecotect™ appeared the most precise with a curve that most closely resembled the form of the measured overall energy usage curve for Rinker Hall.

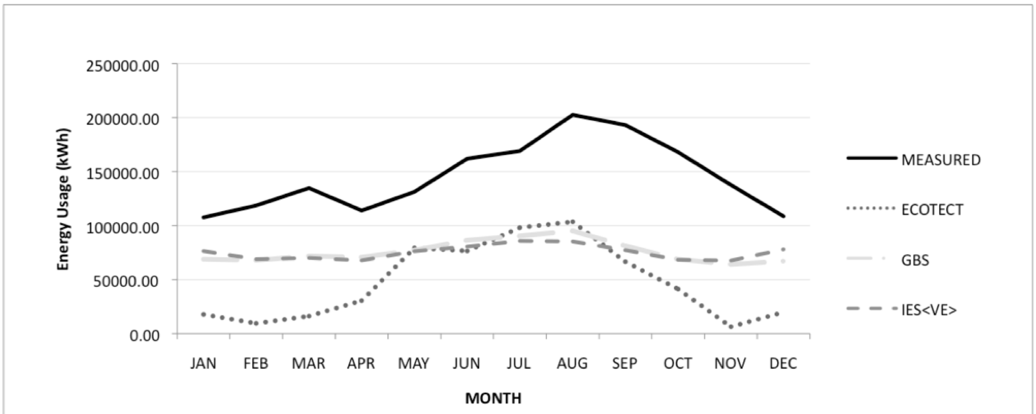

Figure 1: Comparison of measured and simulated results for Rinker Hall - overall monthly energy usage

The comparison of simulated data and measured data for Rinker Hall regarding overall energy usage showed that the simulation results obtained by Green Building Studio™ were the most accurate for annual energy consumption with a PD of -47.91% against the measured data (Figure 2). The IES<VE>™ simulation was the second most accurate (PD of -48.10%), while the Ecotect™ simulation was the least accurate (PD of -67.63%).

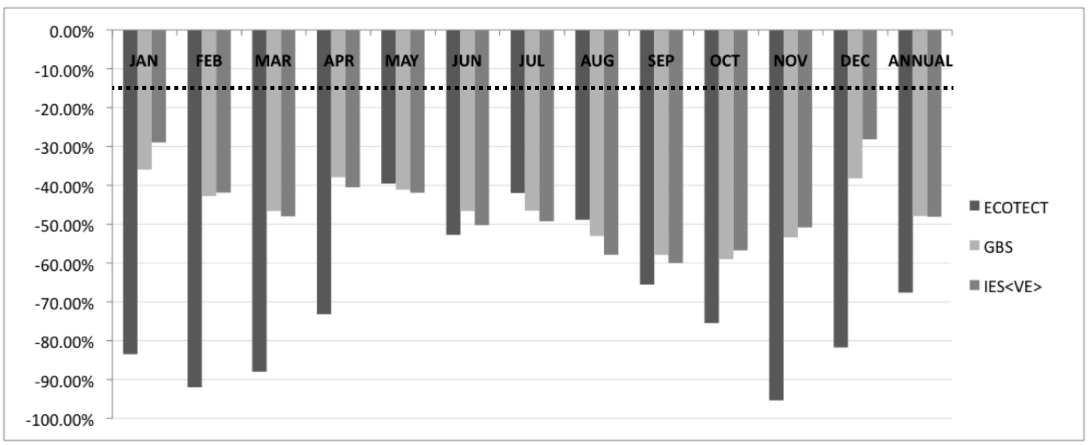

Figure 2: Percent differences between BEM simulation results and measured data for Rinker Hall - overall energy usage (dotted line indicates +/-15% accuracy tolerance)

Percent differences between measured data and monthly simulation results ranged from -39.55% to -95.36% for Ecotect™ simulation results, from -35.97% to -59.02% for Green Building Studio™ simulation results, and from -28.17% to -59.99% for IES<VE>™ simulation results. Therefore, in the case of Rinker Hall overall energy use, three BEM tools could not be considered accurate as the absolute values of the PDs between the simulated results and measured data were always larger than the acceptable 15%.

3.1.2 Gerson Hall

All three BEM tools also underestimated annual energy usage of Gerson Hall in most of the analyzed cases. In regard to the software precision, monthly energy use simulation results obtained by Ecotect™ and IES<VE>™ yielded curves that more closely resembled that of the data measured during the sample time period. However, the curve created based on the results obtained by the Green Building Studio™ simulation appeared flatter (Figure 3).

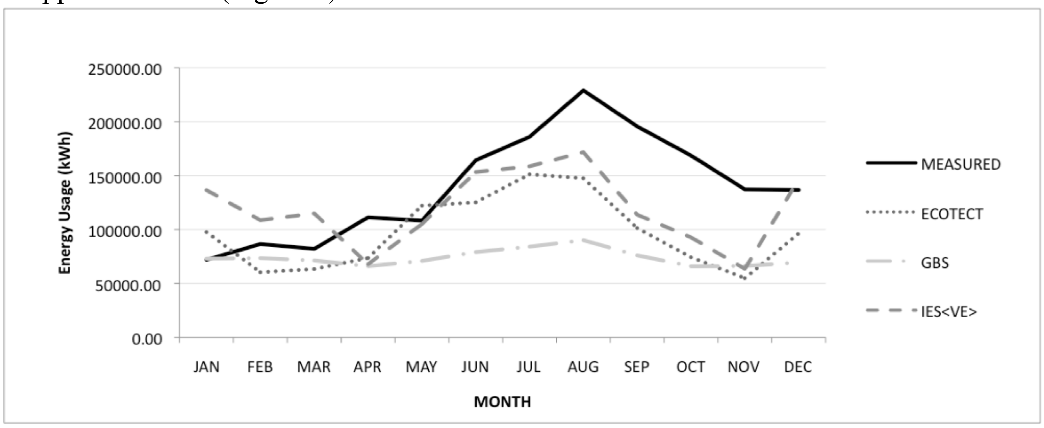

Figure 3: Comparison of measured and simulated results for Gerson Hall - overall monthly energy usage

The PDs between simulated and measured data for overall annual energy usage show that IES<VE>™ seem to be the most accurate with a PD of -14.55%; Ecotect™ the second most accurate with a PD of -28.89%; and Green Building Studio the least accurate with a PD of -47.22% (Figure 4).

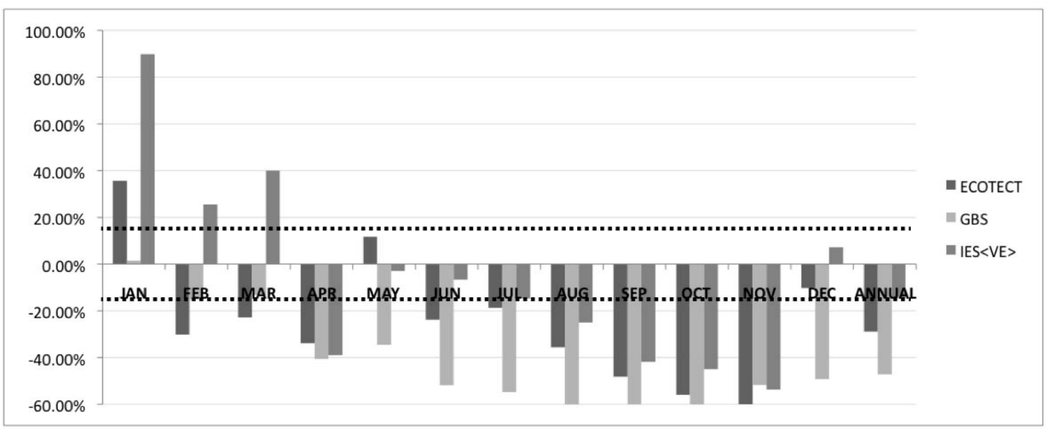

Figure 4: Percent differences between BEM simulation results and measured data for Gerson Hall - overall energy usage (dotted lines indicate +/-15% accuracy tolerance)

As the absolute value of the PD between the simulated results obtained by IES<VE>™ and measured data (14.55%) were lower than the acceptable 15%, IES<VE>™ can be considered an accurate tool for simulation of overall annual energy use in this particular case. Percent differences between measured data and simulation results per month ranged from -10% to -65% for Ecotect™ simulation results; from -1.44% to -61% for Green Building Studio™ simulation results; and from -3% to 90% for IES<VE>™ simulation results. In the case of Ecotect™ and Green Building Studio™ simulations the absolute values of the PDs were lower than acceptable 15% during two months in a year, i.e., these two software were accurate in 16.7% of the analyzed cases. Results of IES<VE>™ simulations were accurate for four months in a year (or in 33.3% of the analyzed cases).

3.2 Heating Energy Usage

3.2.1 Rinker Hall

BEM simulation results for energy consumed for heating purposes for Rinker Hall varied among the three software. Ecotect™ underestimated the amount of annual heating energy, while Green Building Studio™ and IES<VE>™ overestimated annual heating energy consumption. Regarding the software precision, the monthly heating energy use curves (Figure 5) derived from simulation results were similar to the curve that represents the measured data for all three BEM tools.

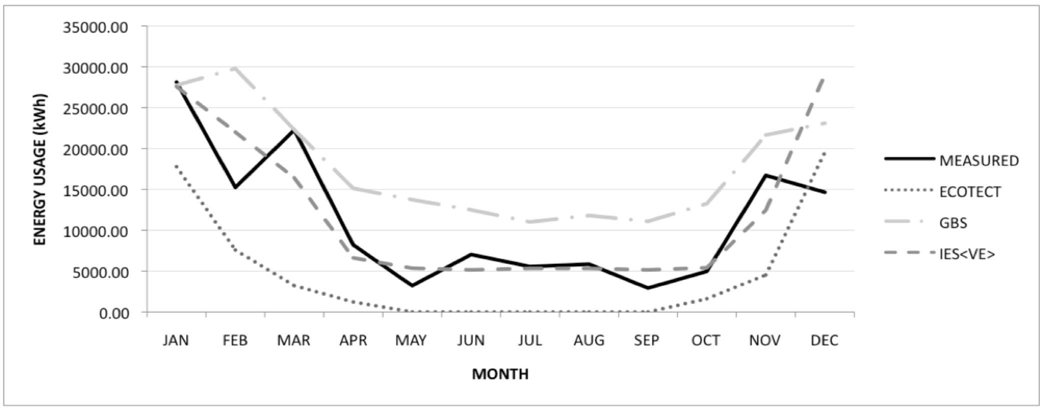

Figure 5: Comparison of measured and simulated results for Rinker Hall - monthly heating energy usage

Based on the PDs for annual heating energy consumption (Figure 6), IES<VE>™ appeared the most accurate with an annual PD of 8.22%. Green Building Studio™ (PD of 58.08%) and Ecotect™ (PD of -58.83%) simulations were less accurate by comparison.

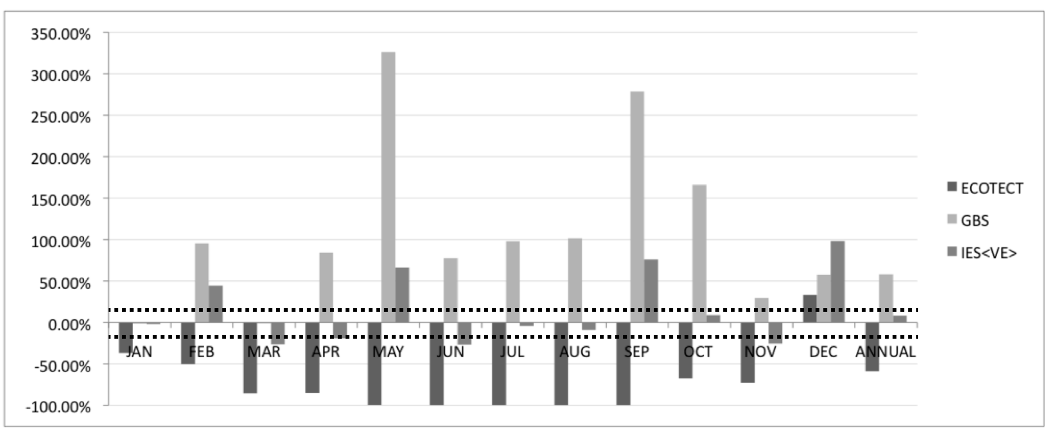

Figure 6: Percent differences between BEM simulation results and measured data for Rinker Hall - heating energy usage (dotted lines indicate +/-15% accuracy tolerance)

As the absolute value of PD between the simulated results obtained by IES<VE>™ and measured data (8.22%) was lower than the acceptable 15%, IES<VE>™ can be considered an accurate tool for simulation of annual heating energy use in this case. Percent differences between measured data and simulation results per month ranged from 33% to -100% for Ecotect™ simulation results; from -1% to 326% for Green Building Studio™ simulation results; and from -2% to 98% for IES<VE>™ simulation results. The absolute values of PDs for Ecotect™ simulations were larger than acceptable 15% for all the months in a year; thus it cannot be recommended as an accurate tool for predicting heating energy usage in the case of Rinker Hall. Green Building Studio™ was accurate for two months in the year (or in 16.7% of the analyzed cases), while IES<VE>™ was accurate for four months in the year (or in 33.3% of the analyzed cases).

3.2.2 Gerson Hall

In the case of Gerson Hall, all three BEM tools underestimated annual heating energy usage when compared to measured data. Regarding the software precision, the monthly energy usage curves were similar among the BEM simulations, but differed from the monthly energy usage curve derived from the measured data (Figure 7). The difference between the curves based on the simulation results and the measured data was most pronounced during the months of April, May, August, and September.

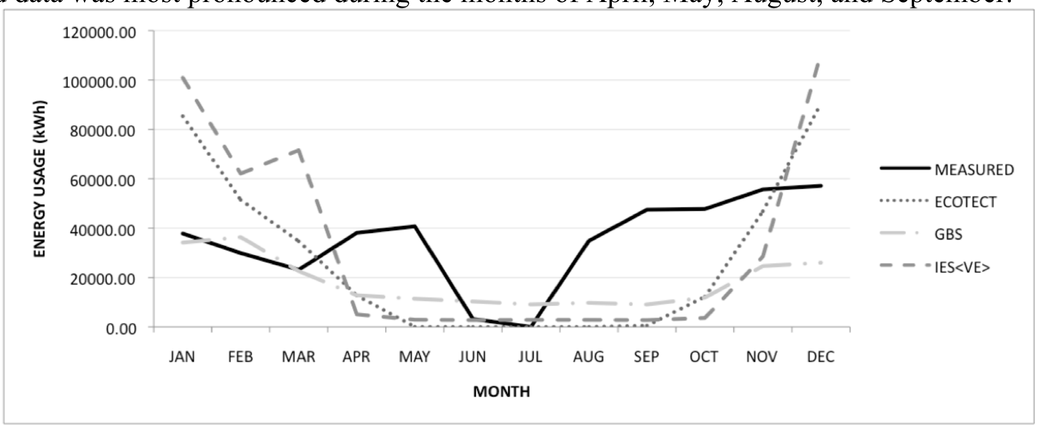

Figure 7: Comparison of measured and simulated results for Gerson Hall - monthly heating energy usage

Similar to the heating energy simulations for Rinker Hall, IES<VE>™ appeared to be the most accurate in predicting annual heating energy for Gerson Hall with a PD of -7.03% (Figure 8). Ecotect was the second most accurate (PD of -17.19%), while Green Building Studio was the least accurate (PD of -47.56%).

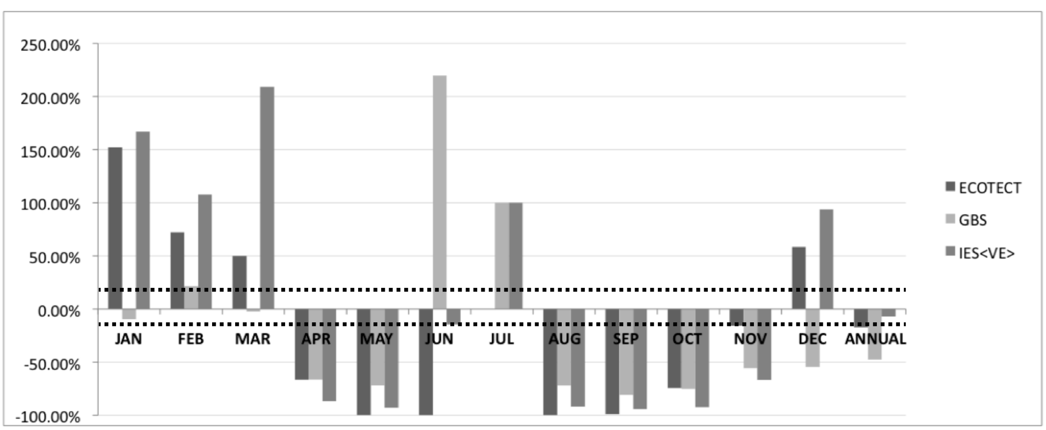

Figure 8: Percent differences between BEM simulation results and measured data for Gerson Hall - heating energy usage (dotted lines indicate +/-15% accuracy tolerance)

As the absolute values of PDs between the simulated results obtained by IES<VE>™ and measured data (7.03%) were lower than the acceptable 15%, IES<VE>™ can be considered an accurate tool for simulation of annual heating energy use in this case. Percent differences between measured data and simulation results per month ranged from 0% to 152% for Ecotect™ simulations; from -2% to 220% for Green Building Studio™ simulations; and from -7% to 209% for IES<VE>™ simulation. Analysis of absolute values of the monthly PDs that were lower than 15% shows that Green Building Studio™ was accurate for two months in the year (or in 16.7% of the analyzed cases), while IES<VE>™ and Ecotect™ were accurate for one month (or in 8.3% of the analyzed cases).

3.3 Cooling Energy Usage

3.3.1 Rinker Hall

All three BEM tools underestimated the amount of energy used for cooling purposes for Rinker Hall. The monthly energy usage curves for Rinker Hall cooling show these underestimates (Figure 9). The curve derived from the Ecotect™ simulation results appeared to more closely follow the contour of the measured data's curve. The curves created based on the Green Building Studio™ and IES<VE>™ simulation results were shallower compared to the measured data's curve. Thus, it seems that Ecotect™ is more precise in this case when compared to the other two BEM tools.

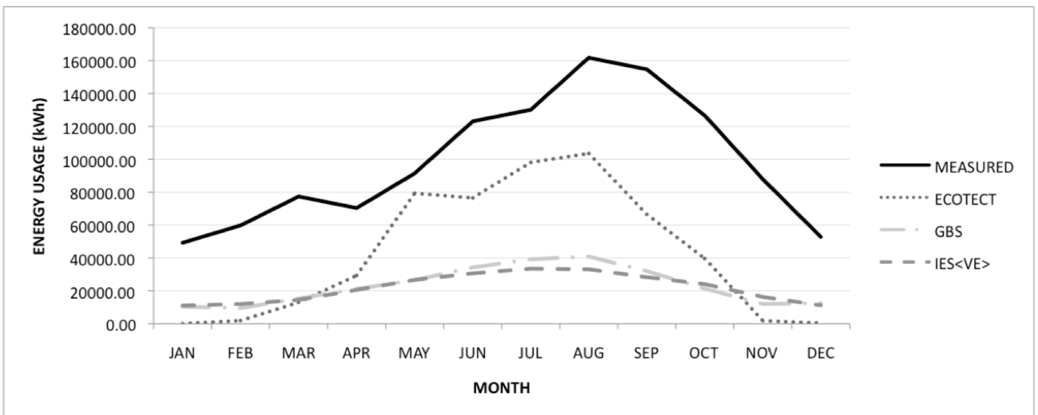

Figure 9: Comparison of measured and simulated results for Rinker Hall - monthly cooling energy usage

Regarding annual cooling energy use, Ecotect™ simulations were the most accurate with a PD of -56.97%; Green Building Studio™ simulations were the second most accurate at -76.81% difference; while IES<VE>™ was the least accurate at -77.92% difference (Figure 10).

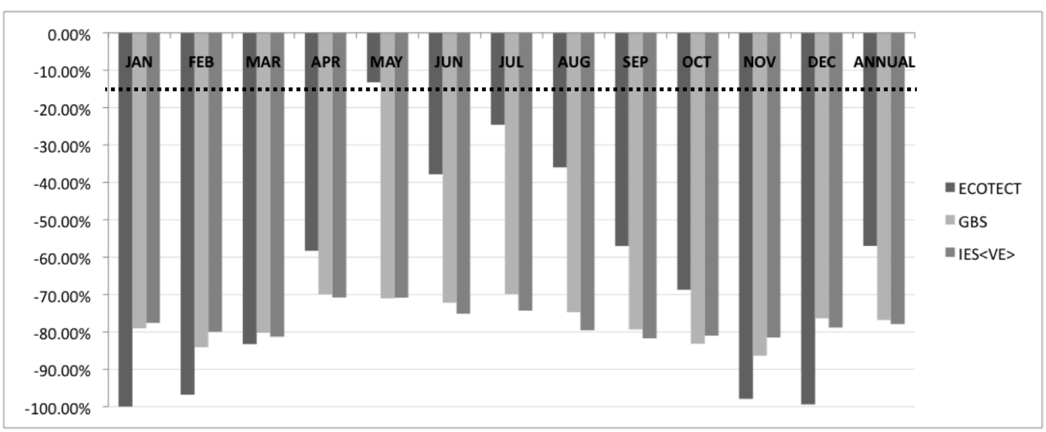

Figure 10: Percent differences between BEM simulation results and measured data for Rinker Hall - cooling energy usage (dotted lines indicate +/-15% accuracy tolerance)

Percent differences between measured data and simulation results per month ranged from -13% to -100% for Ecotect™ simulation results; from -70% to -86% for Green Building Studio™ simulation results; and from -71% to -82% for IES<VE>™ simulation results. The analysis of the absolute values of the PDs shows that Ecotect™ simulations were accurate for one month of the year, that is, the PDs were lower than acceptable 15% in 8.33% of the analyzed cases. Green Building Studio™ and IES<VE>™ simulations did not provide accurate results for any month.

3.3.2 Gerson Hall

Cooling energy simulations for Gerson Hall yielded similar results. All three BEM tools underestimated the amount of energy that Gerson Hall consumes for cooling purposes. Ecotect™ simulation results yielded a monthly energy use curve that most closely resembled the contour of the curve created based on the measured data, that is, Ecotect™ can be considered more precise tool in this case when compared to the two other BEM tools (Figure 11).

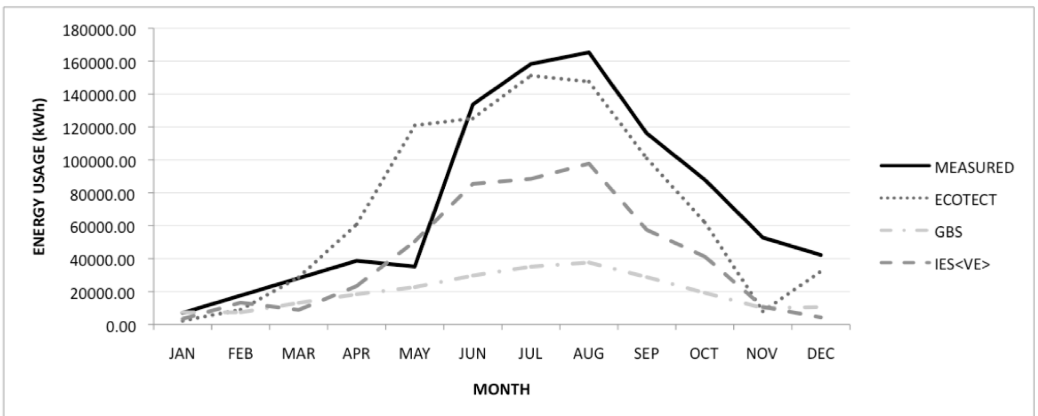

Figure 11: Comparison of measured and simulated results for Gerson Hall - monthly cooling energy usage

Simulation results of annual cooling energy obtained by Ecotect™ were also the most accurate at -3.86% difference, followed by IES<VE>™ simulation results at -45.10% difference, and Green Building Studio™ simulation results at -72.83% difference (Figure 12).

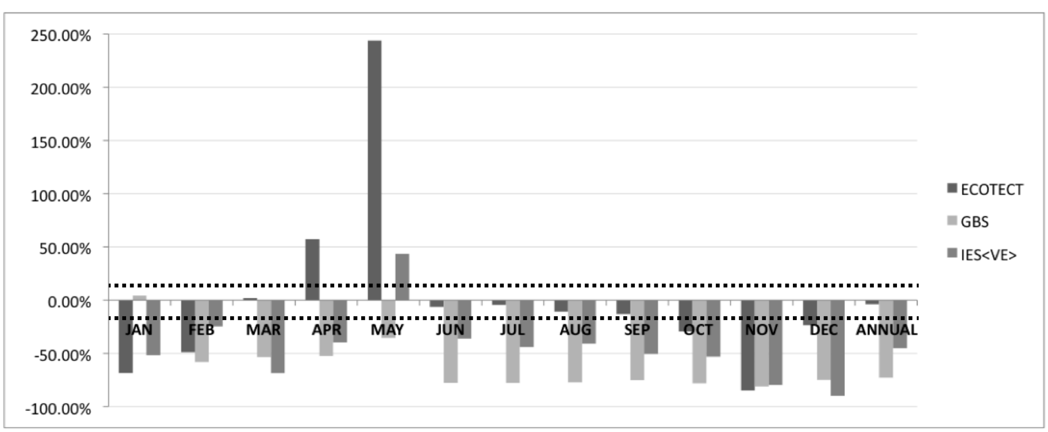

Figure 12: Percent differences between BEM simulation results and measured data for Gerson Hall - cooling energy usage (dotted lines indicate +/-15% accuracy tolerance)

As the PD between the simulated results obtained by Ecotect™ and measured data (3.96%) was lower than the acceptable 15% Ecotect™ can be considered an accurate tool for simulation of annual cooling energy use in this particular case. Percent differences between measured data and simulation results per month ranged from 2% to 244% for Ecotect™ simulation results; from 4% to -81% for Green Building Studio™ simulation results; and from -25% to -90% for IES<VE>™ simulation results. Analysis of the absolute values of the PDs for each month show that Ecotect™ simulations were accurate (that is, absolute values of PD were less than 15%) for five months in the year (or in 41.7% of the analyzed cases), Green Building Studio™ simulations were accurate for one month in the year (or 8.3% of the analyzed cases) while IES<VE>™ simulations did not provide accurate results for any month.

3.4 Summary of Results

The annual percent differences for the two buildings used in the case study were analyzed for the three categories of energy use. Regarding overall energy use, the only result which absolute value fell within the acceptable PD range (0-15%) was the IES<VE>™ simulation of Gerson Hall (-14.55% difference). Regarding heating energy use, IES<VE>™ simulations were accurate for both Rinker Hall (8.22% difference) and Gerson Hall (-7.03% difference). Regarding cooling energy use, only the Ecotect™ simulation of Gerson Hall may be considered accurate (-3.86% difference). Based on the results for annual energy consumption in the three different energy use categories and for the two buildings, Ecotect™ simulations were accurate in 16.67% of the analyzed cases (1 out of 6 simulations), Green Building Studio™ simulations were never accurate, while IES<VE>™ simulations were accurate in 50% of the analyzed cases (3 out of 6 simulations).

The monthly PDs for each BEM tool for each of the three energy use categories and for the two buildings used in the case study were additionally analyzed. Ecotect™ simulations were accurate in 11.11% of the analyzed cases (8 out of 72 simulations). Ecotect™ simulations were never accurate in case of Rinker Hall. In the case of Gerson Hall, Ecotect™ provided an accurate prediction of overall energy use in 16.67% of the cases (2 out of 12 simulations), an accurate prediction of heating energy use in 8.33% of the analyzed cases (1 out of 12 simulations) and an accurate prediction of cooling energy use in 41.66% of the analyzed cases (5 out of 12 simulations).

Green Building Studio™ simulations were accurate in 9.72% of the analyzed cases (7 out of 72 simulations). In the case of Rinker Hall, Green Building Studio™ simulations were never accurate in predicating overall energy use and cooling energy use. The prediction of heating energy use of Rinker Hall was accurate in 16.67% of the cases (2 out of 12 simulations). In the case of Gerson Hall, Green Building Studio™ provided an accurate prediction for both overall energy use and heating energy use in 16.67% of the cases (2 out of 12 simulations), and an accurate prediction of cooling energy use in 8.33% of the analyzed cases (1 out of 12 simulations).

IES<VE>™ simulations were accurate in 12.5% of the analyzed cases (9 out of 72 simulations). In the case of Rinker Hall, similarly to Green Building Studio™ simulations, IES<VE>™ was never accurate in predicating overall energy use and cooling energy use. The prediction of heating energy use of Rinker Hall was accurate in 33.3% of the cases (4 out of 12 simulations). In the case of the Gerson Hall, IES<VE>™ provided an accurate prediction of overall energy use and heating energy use in 33.3% of the cases (4 out of 12 simulations), and an accurate prediction of cooling energy use in 8.3% of the analyzed cases (1 out of 12 simulations). IES<VE>™ was not able to accurately predict the cooling energy use for either building.

In conclusion, the three validated BEM tools were not able to accurately predict energy use for both buildings in the majority of analyzed cases.

4 CONCLUSIONS

This research validated the precision and accuracy of three BEM tools (Autodesk Ecotect 2011™, Autodesk Green Building Studio 2011™, and IES<VE> 2011™) in three energy use categories: heating, cooling, and overall energy use. Precision of the BEM tools was validated by comparing the monthly line graphs (see Figures 1, 3, 5, 7, 9, and 11) of each BEM tools' monthly energy usage against one another in order to determine the BEM tool curve that most closely resembles the curve of actual monthly energy usage. Validation of precision showed that Ecotect™ was the most precise of the three BEM tools. The curves created based on monthly Ecotect™ simulation results appeared to be similar to the measured data curves in five of the six analyzed cases (three energy use categories for two buildings). Thus, Ecotect™ may be considered precise in all the cases except in the case of heating energy usage for Gerson Hall. In comparison to the other BEM tools, Ecotect™ simulations appeared to be the most precise, that is, most similar to measured data, in three of the six cases: Rinker Hall overall energy usage, Gerson Hall overall energy usage, and Rinker Hall cooling energy usage. In the other three cases, the most precise BEM tool was more ambiguous. IES<VE>™ simulations appeared precise in three of the six cases (overall energy usage for Gerson Hall, heating energy usage for Rinker Hall, and cooling energy usage for Gerson Hall). Green Building Studio™ appeared similar to the line graph of actual data for Rinker Hall heating energy usage. In all other cases, Green Building Studio™ simulations yielded monthly energy use curves that appeared flatter in comparison to the curves based on simulation results provided by the other two BEM tools.

In this research, a BEM tool was considered accurate if the absolute values of the percent differences between simulation results and measured data were less than or equal to the acceptable percent difference of 15% (Maamari et al. 2006). Validation of the accuracy of three BEM tools showed that the three BEM tools were not able to accurately predict energy use for both buildings in the majority of analyzed cases. The three BEM tools were never accurate in predicting overall energy usage in the case of Rinker Hall (the LEED Gold certified building). In the case of Gerson Hall (the non-LEED-certified building), the BEM tools were able to accurately predict overall energy uses in 16.7-33.3% of the cases. In heating energy usage category, IES<VE>™ simulations were accurate in 8.3% of the cases for Rinker Hall and 33.3% of the cases for Gerson Hall, while Green Building Studio™ simulations were accurate in 16.7% of all the analyzed cases for both buildings. In cooling energy usage category, Ecotect™ simulations were accurate for only Gerson Hall in 42% of the cases, Green Building Studio™ simulations were accurate for only Gerson Hall in 8.3% of the cases, while IES<VE>™ was not accurate in any of the cases for either building.

Comparison of the percentage differences between simulation results and measured data for the two buildings showed that each software was overall more accurate in the case of Gerson Hall (the non-LEED-certified building) than in the case of Rinker Hall (the LEED Gold certified building) for all three energy use categories. This suggests that the energy models may overestimate the effectiveness of some of the LEED Gold certified building's energy efficient characteristics, and that Rinker Hall is not performing at its desired level.

Software incapability to accept input of accurate/realistic schedules for occupancy, electrical lighting use, and equipment use is a likely source for error for all simulations. As noted by Ryan & Sanquist (2012), these inputs are highly variable in actual building use. The schedule inputs along with the tendency for buildings and building systems to underperform makes the prediction of actual energy usage during later design stages very difficult. When applying BEM for facilities management or retrofit analysis, users can finely tune the schedule inputs to calibrate the energy model with metered data to obtain more accurate results. Future research could investigate further why the BEM tools underestimated energy consumption as well as why the values of the simulation output varied among the three BEM tools.

ACKNOWLEDGEMENTS

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