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VALIDATION OF AUTODESK ECOTECT™ ACCURACY FOR THERMAL AND DAYLIGHTING SIMULATIONS

Prasanthi R. Vangimalla
Svetlana J. Olbina
Raymond R. Issa
Jimmie Hinze

University of Florida
304 Rinker Hall, P.O. Box 115703
Gainesville, FL 32611, U.S.A.

ABSTRACT

Autodesk Ecotect™ is an environmental analysis software which according to the U.S. Department of Energy, has not been validated yet. Therefore, the objectives of this research were to validate accuracy of Ecotect™ for thermal and daylighting simulations of buildings and provide recommendations to the Architecture, Engineering and Construction community on application of Ecotect™. Analysis of thermal performance of an institutional building was conducted for one year while the daylighting performance was studied from January to September. The thermal loads and illuminance levels of the building were first measured in the field. The field measurements were then compared to the simulated thermal loads and illuminance levels obtained by Ecotect™. The validation results showed that Ecotect™ underestimated thermal loads in all the analyzed cases and overestimated illuminance levels in 98% of the analyzed cases. Therefore, these findings show that Ecotect™ cannot be used for accurate simulations of thermal loads and illuminance levels.

1 INTRODUCTION

Recent studies signify the need for sustainable energy-efficient buildings which pose minimal threat to the environment. Use of artificial heating, cooling, ventilation, and lighting which were introduced through industrial revolution, weakened if not nearly eliminated attention to the local climate or to consumption of natural resources. This instigated a rapid development of buildings which were completely dependent on artificial methods to maintain their usability. Thus, a major part of the total energy consumed serves to maintain a comfort level through artificial heating or cooling, use of lighting, appliances, and building service systems (Krygiel and Nies 2008).

Developed countries tend to consume more energy to maintain a comfort level and standard of living (WBCSD 2009). In the United States, building sector is responsible for 40% of energy consumption, 39% of CO_2 emissions and 13% of water consumption per year, making green building a source of significant economic and environmental opportunity (USGBC 2010). Space heating accounts for 12% of the total energy consumption in commercial buildings, space cooling for 8% and lighting for 18% (U.S. Department of Energy 2010). Therefore, the total thermal loads can be decreased by minimizing heating and cooling loads. In addition to this, application of daylighting strategies decreases not only the use of electrical lighting, but also internal heat gain from lighting, cooling loads and, thus, total energy consumption.

Given the need for design and construction of energy-efficient buildings, the construction industry has seen a surge in the development of new software tools that can be used to evaluate the energy-efficiency of a building in its early conceptual design stages. According to the U.S. Department of Energy (DOE) (2010) there were 374 software tools for evaluating building energy efficiency. One of these software tools, Autodesk Ecotect™, has numerous features that can be employed for environmental analysis. Ecotect™ has been widely used by the Architecture, Engineering and Construction (AEC) community in conjunction with the Building Information Modeling (BIM) tools such as Autodesk Revit suite. However, according to the DOE (2010), Ecotect™ has not been validated for the accuracy of its results.

Therefore, the objectives of this research were to: 1) validate accuracy of Autodesk Ecotect™ for thermal and daylighting simulations of buildings, and 2) provide recommendations to the AEC community on whether or not Ecotect™ can be used as a thermal and daylighting analysis tool in the design and construction of buildings.

2 LITERATURE REVIEW

2.1 Energy Performance

Energy performance and indoor environment have become increasingly important in building design. Building developers and designers are straining to produce buildings with low energy consumption and high indoor environmental performance. The energy a building consumes for its operation and maintenance is directly linked to amount of its carbon emissions. This attention to energy performance has led to a growing awareness that, in order to achieve low energy buildings with satisfactory indoor climate, the designer must be aware of the consequences of critical design decisions as early as possible in the design process (Hviid et al. 2008).

Maintaining the comfort level of a building through artificial heating or cooling accounts for a major portion of the total energy consumption. The most cost-effective reduction of thermal loads occurs during the design process. By employing design strategies such as orientation of the building, massing of the built structure, using proper building materials, photovoltaic systems, natural ventilation, and shading devices designers can significantly reduce thermal loads of a building (Krygiel and Nies 2008).

Even though daylight is recognized as an effective means to reduce the artificial lighting requirements of buildings, daylight is still an underexploited natural resource (Nabil and Mardaljevic 2006). Artificial lighting not only consumes electrical energy but also adds to the cooling loads as a result of the heat generated by the lighting appliances. Daylight factor is one of the metrics used to assess daylighting performance. The daylight factor is defined as the ratio between the internal illuminance in a building at a certain point and the external horizontal illuminance (Reinhart et al. 2006).

2.2 Building Information Modeling (BIM)

Building information modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A building information model is the shared knowledge resource for information about a building that helps in making decisions during building lifecycle from its start to finish (NIBS 2007). Unlike the computer aided drafting (CAD)-based drawings, a BIM model contains the buildings' actual constructions and assemblies rather than only a two-dimensional representation of the building. A BIM model can accelerate the design process by allowing parametric changes to the building design. Recent studies have shown that BIM is an emerging technological and procedural shift within the AEC community (Succar 2009).

2.3 Building Information Modeling (BIM) and Sustainability

CAD tools lacked the ability to analyze a building energy performance. This resulted in evaluating a building energy performance after the completion of the design and construction documents. This process proved to be inefficient and time consuming. With the advent of BIM, the designer has the capability to perform sustainability analyses in the early stages of design development. BIM also allows the designer to incorporate and monitor sustainable features throughout the entire design process (Azhar et al. 2011).

As stated earlier design strategies such as orientation of the building, massing of the built structure, building materials, photovoltaic systems, natural ventilation, and shading devices that reduce the thermal loads can be incorporated in the design and tested using BIM. Evaluation of orientation by using BIM tools significantly reduces energy costs (Schueter and Thessling 2008, Azhar et al. 2011). The massing of the built structure can be analyzed by BIM tools to optimize the building envelope. Energy analysis tools not only help in measuring the energy loads but also in analyzing the building's carbon footprint and in recognizing potential renewable energy options (Krygiel and Nies 2008, Azhar et al. 2011).

2.4 Autodesk Ecotect™

Autodesk Ecotect™ is a BIM environmental simulation tool that can be used for analysis of thermal loads, lighting design, shadows and reflections, shading devices, and solar radiation. Ecotect™ was developed by architects with its application in architecture and the design process in mind. Ecotect™ can also be used by engineers, local authorities, environmental consultants, building designers, owners, builders, and environmental specialists. Ecotect™ uses the CIBSE Admittance Method to calculate heating and cooling loads and daylight factor method to calculate illuminance levels (Autodesk 2010). The results of a survey conducted by Attia et al. (2009) showed that 64% of the architects that responded to the survey used Autodesk Ecotect™ as building performance simulation tool. The study also showed that Ecotect™ was mostly used during conceptual phase and design development phase of the project (Attia et al. 2009).

3 RESEARCH METHODS

The objective of this study was to validate the accuracy of the simulated measurements of thermal loads and illuminance levels obtained by Autodesk Ecotect™ (from now on this software will be mentioned herein as "Ecotect™"). Rinker Hall, an institutional building at the University of Florida, located in Gainesville, Florida, was used as a case study to accomplish the research objective. Rinker Hall is a LEED Gold certified building with a total area of 46,530 sq. ft. The Rinker Hall building facilitates classrooms, teaching laboratories, offices, computer labs, and campus support services.

3.1 Field Measurements

The field measurements of the thermal loads were provided by the Facilities and Planning Department at University of Florida. This Department measures the daily energy consumption of Rinker Hall. The data used in this study was collected in 2009. The chilled water, steam, and energy recovery loads were summed up to obtain the total thermal loads for each month and the entire year.

The illuminance levels were measured in the two west-oriented classrooms (220 and 225) and one east-oriented classroom (238), under the skylights and in the corridor on the third floor of Rinker Hall. Sensor points (SPs) were marked on the tables adjacent to the walls in the classrooms, under the skylights, and in the corridor. Figure 1 shows an example of the location of SPs in the classroom 220.

Blinds and louvers in all the classrooms were kept open. The electrical lights in the classrooms were turned off because the goal of this research was to measure illuminance levels from daylight only. Few electrical lights in the corridor had to be turned on for the safety of the building occupants. An Extech Instruments light meter was used to measure the illuminance levels every hour from 8:00 a.m. to 5:00 p.m. on January 17th, February 27th, March 20th, April 17th, May 22nd, June 21st, July 24th, August 28th, and September 18th, 2010. Sky illuminance levels were simultaneously measured at the same time periods. Weekends or holidays were chosen as the appropriate days to take measurements in order to avoid conflicts with classes scheduled in the selected classrooms.

3.2 Simulations by Autodesk Ecotect™

A BIM model of Rinker Hall was created in the Autodesk Revit Architecture™ software and then exported as a gbxml file into Ecotect™. Figure 2 shows a 3D view of Rinker Hall and the daily sun-path diagram for April 17th, 2010 created in Ecotect™. Project information such as site location, orientation, altitude, and terrain were input into the model. The weather file for Gainesville was imported from the DOE website in .epw file format and was converted to .wea file format. Materials specific to the building components of Rinker Hall were created and added to the Ecotect^{TM} element library.

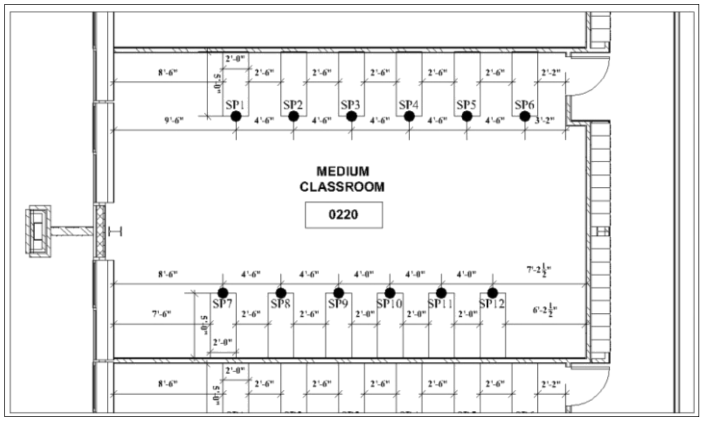

Figure 1: Location of the sensor points in the classroom 220

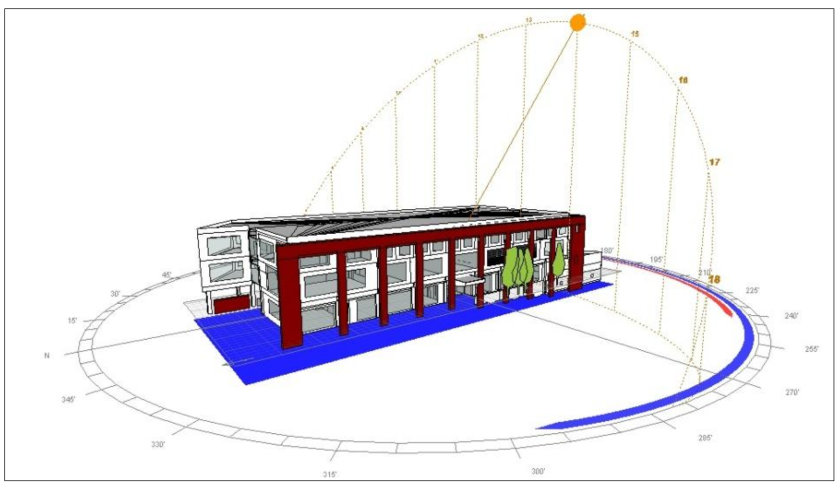

Figure 2: A 3D view of Rinker Hall created in Ecotect^{TM}

The additional input into the Ecotect^{TM} model included modeling: blinds and louvers in the windows, glass in the doors, and tables in the classrooms. SPs were marked on the top of the tables at the height of 2' 5" from the floor (see Figure 3). Electrical lights in the corridor that were turned on for the field measurements were also created in the Ecotect^{TM} model.

The actual occupancy and operation schedule of Rinker Hall was input into the Ecotect^{TM} model. The properties of each building zone were defined in the model in accordance with the actual usage of the particular zone. The general settings for each zone included the following parameters: shadow and reflection, internal design conditions, and occupancy and operation settings. The HVAC system operation and performance details of the HVAC system were obtained from the Physical Plant Department at the University of Florida. Based on this information, the thermal properties of each zone were assigned in Ecotect^{TM} by defining HVAC system settings and HVAC system operation schedule settings.

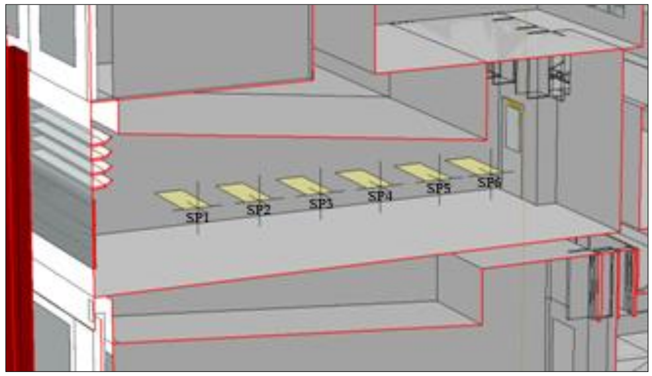

Figure 3: A 3D cross-section of the classroom 220 created in Ecotect^{TM}

The HVAC operation schedule of Rinker Hall had two possible settings: 1) for the peak time (from 6 a.m. to 11:05 p.m. on weekdays and from 8 a.m. to 7 p.m. on weekends), and 2) for the off-peak time (from 11:05 p.m. to 6 a.m. on weekdays and from 7 p.m. to 8 a.m. on weekends). The indoor temperatures were set at 74˚F for cooling and at 71˚F for heating for the peak time, and at 88˚F for cooling and at 64˚F for heating for the off-peak time. However, Ecotect^{TM} does not allow such specific input of the time periods for each operation setting. Therefore, two separate simulations were conducted: one set of simulations for the peak time and another set of simulations for the off-peak time. After that, the results of these two sets of simulations were summed up to obtain the total heating and cooling loads per month.

The Ecotect^{TM} lighting analysis tool was used to simulate the daylighting performance. The illuminance levels were calculated for all the 40 SPs marked in the classrooms, under the skylights, and in the corridor. The Sky Luminance distribution model in Ecotect^{TM} has two possible values: CIE Overcast Sky Condition and CIE Uniform Sky Condition. Therefore, in this research the Clear and Partly Cloudy actual sky conditions were categorized as CIE Uniform Sky Condition while the Mostly Cloudy and Overcast actual sky conditions were categorized as CIE Overcast Sky Condition. An average value of 0.90 was used for window cleanliness. The increased accuracy mode was chosen as the more effective way to calculate the illuminance levels as compared to the regulatory compliance mode. The increased accuracy mode considers both the transparency and refractive index of window glazing and the actual surface reflectance of external obstructions instead of the standard Building Research Establishment (BRE) design values used by the regulatory compliance mode.

3.3 Research Limitations

In this research, illuminance levels were measured only from January to September. Field measurements of illuminance levels were taken only during weekends and holidays in order to avoid conflict with classes conducted in the classrooms. On the other hand, the simulated illuminance levels were neither date-dependent nor time-dependent. These illuminance levels obtained by Ecotect^{TM} simulations represented the worst-case design conditions based on an "average" cloudy or uniform sky distribution during mid-winter. Although varying sky conditions were noted during the field measurements, these values could not be input into the Ecotect^{TM} model because Ecotect^{TM} allowed only two types of sky conditions; "uniform" and "overcast", to be assigned to the model for illuminance simulations. Ecotect^{TM} did not use the imported weather file for the calculations of the illuminance levels. This study focused on measuring illuminance levels from daylight only. However, during the field measurements of illuminance levels, few electrical lights in the corridor on the third floor had to be turned on for the safety of the students and faculty working over the weekend or on holidays. These electrical lights were also added to the Ecotect^{TM} model for validation purposes.

Ecotect^{TM} does not allow the user to select a particular type of HVAC system or to specify operation schedules of the system. Thus, Ecotect^{TM} selects the most efficient HVAC system from its library rather than the HVAC system actually designed for the building. The thermal analysis tool in Ecotect™ simulates only monthly heating and cooling loads and does not allow for the calculation of hourly and daily heating and cooling loads. Therefore, in this research the field measurements of thermal loads were summed up for each month to compare these field measurements with the simulated results.

4 RESULTS

To validate the accuracy of Ecotect™, the results obtained by Ecotect™ simulations and by field measurements were compared by analyzing percentage difference between the measurements. The percentage difference (PD) between the Ecotect™ measurements (EM) and field measurements (FM) for both thermal loads and illuminance levels was calculated by using the equation (1):

$$PD = ((EM-FM)/FM)/100 \quad (1)$$

Based on the literature review, the acceptable percentage difference between computer simulation results and field measurements is maximum 15% (Maamari et al. 2006). Thus, in this research, if percentage difference was less than or equal to 15%, the software was considered accurate.

4.1 Analysis of Thermal Load Calculations

The field measurements of thermal loads obtained in 2009 were used in this study. Thus, the Ecotect™ measurements of thermal loads were also simulated for the year 2009.

The field measurements of the thermal loads of Rinker Hall show that the highest total thermal load (4,466 MBtu) was recorded during September while the lowest total thermal load (1,621 MBtu) was recorded during May. The annual thermal load of Rinker Hall was 29,209 MBtu. Figure 4 shows the monthly loads for chilled water, steam, and energy recovery of Rinker Hall.

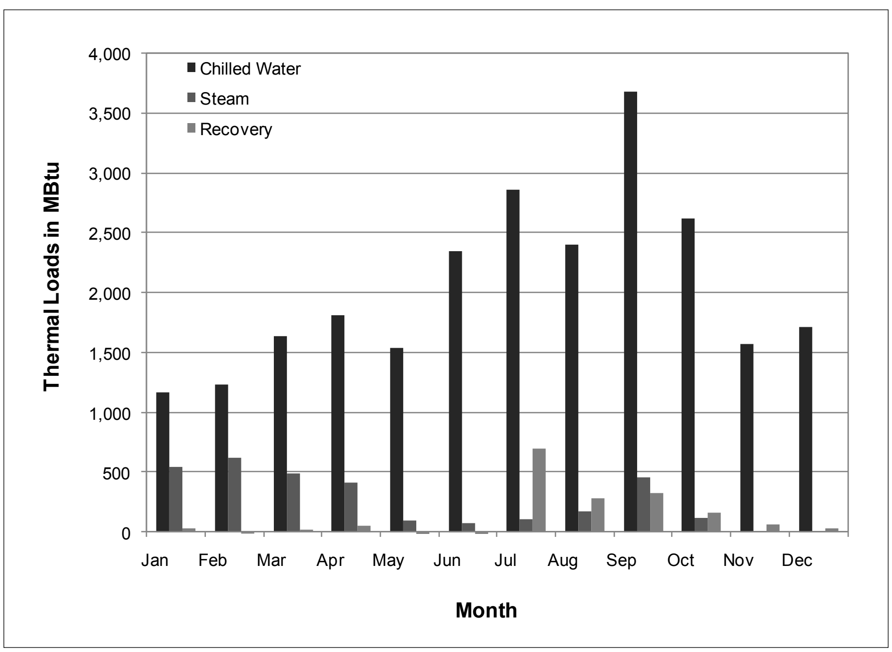

Figure 4: Field measurements of thermal loads of Rinker Hall in 2009

The Ecotect^{TM} measurements of the thermal loads show that the largest heating load (517 MBtu) was recorded in January while the largest cooling load (411 MBtu) was recorded in August (see Figure 5). The largest total thermal load (518 MBtu) was recorded in January, while the lowest total thermal load (241 MBtu) was recorded in October. The simulated annual thermal load was 4,184 MBtu.

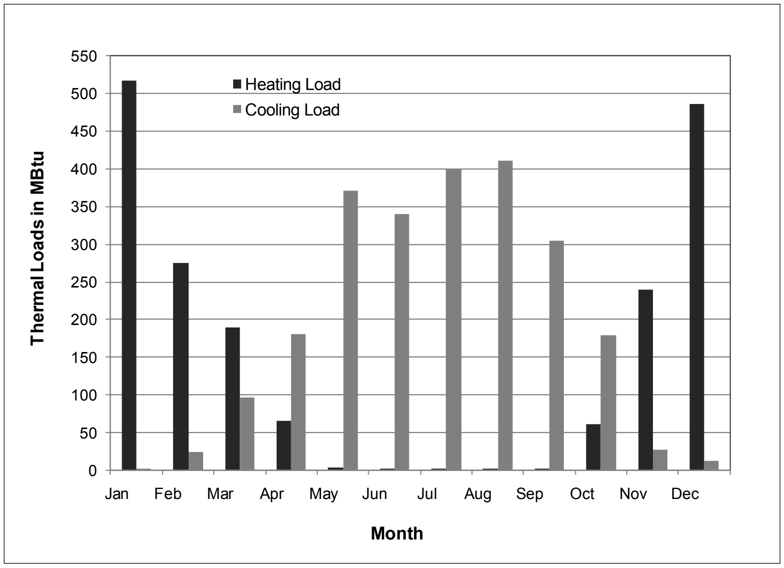

Figure 5: Ecotect^{TM} measurements of thermal loads of Rinker Hall in 2009

The comparison of these results show that both the highest and the lowest thermal loads were obtained in different months (e.g. the highest loads in January for Ecotect^{TM} measurements and in September for field measurements, and the lowest loads in October for Ecotect^{TM} measurements and in May for field measurements). Also, the comparison between the monthly Ecotect^{TM} and field measurements of thermal loads showed the thermal loads simulated by Ecotect^{TM} had constantly lower values than the thermal loads obtained by the field measurements (see Figure 6).

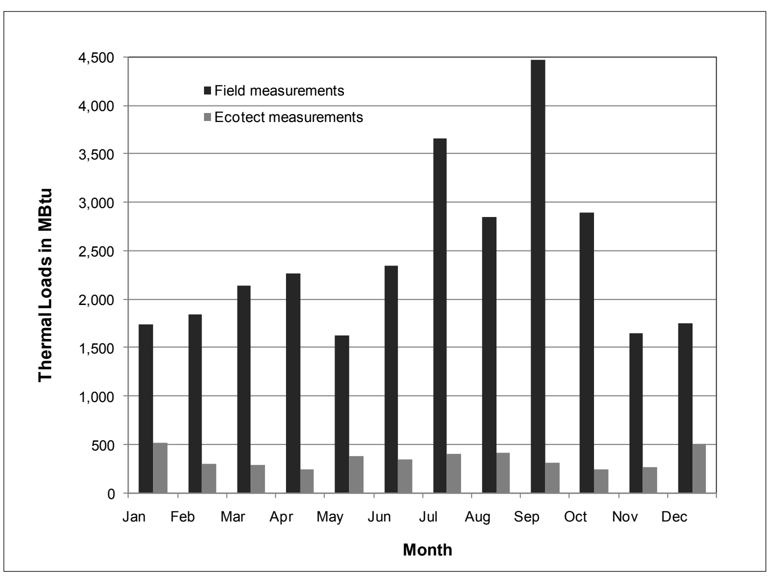

Figure 6: Comparison of thermal loads obtained by Ecotect^{TM} measurements and field measurements

Figure 7 shows the percentage difference between the Ecotect™ measurements and field measurements of the monthly thermal loads. The percentage difference was higher than acceptable 15% for all the months. The largest percentage difference (93%) was noted in September while the lowest percentage difference (70%) was observed in January. Therefore, these results show that Ecotect™ cannot be considered as an accurate tool for simulations of thermal loads.

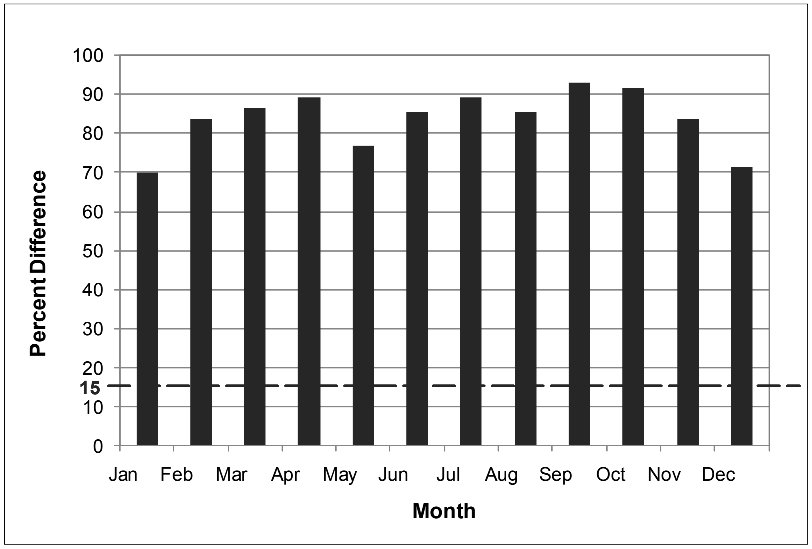

Figure 7: Percentage difference between Ecotect™ measurements and field measurements of the monthly thermal loads

4.2 Analysis of Illuminance Level Calculations

The field measurements of illuminance levels were taken from January 2010 to September 2010. Thus, the Ecotect™ measurements of illuminance levels were simulated for the same time period.

Figure 8 shows the Ecotect™ and field measurements of illuminance levels in the classroom 220 on May 22nd at 8.05 a.m. SP 1 and SP 7 were the sensor points closest to the window while SP 6 and SP 12 were the sensor points farthermost from the window. SP 6 was the sensor point closest to the door (for the location of the SPs see Figure 1). The field measurements showed that the highest illuminances levels were always recorded at the sensor points close to the window (SP 1 and SP 7).

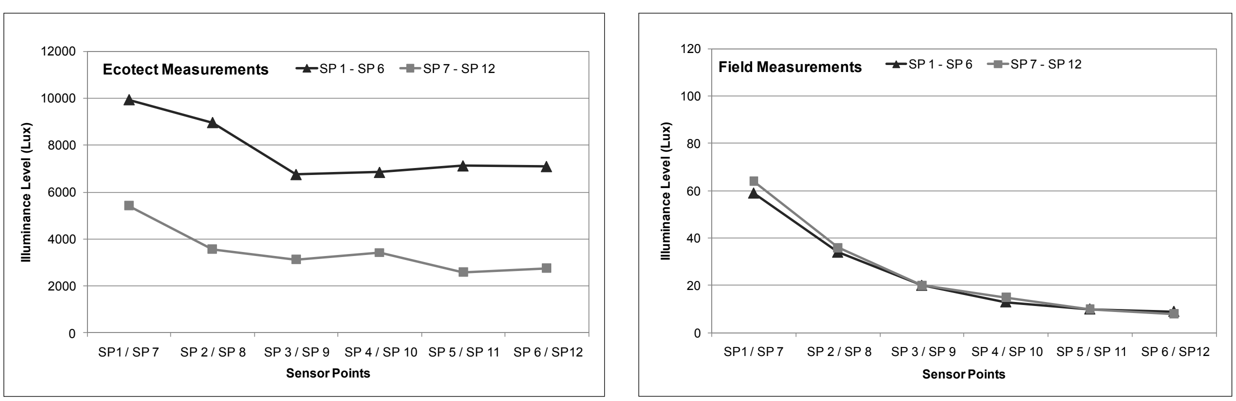

Figure 8: Ecotect™ and field measurements of illuminance levels in the classroom 220, on May 22nd at 8:05 a.m.

However, in the case of the Ecotect™ results, only one of the sensor points (SP 1) that was close to the window had higher illuminance levels when compared to the remaining sensor points. On the other hand, another sensor point (SP 7) that was close to the window had lower illuminance level than, for example, sensor points SP 2 – SP 6 that were farther away from the window. The reason for this might be that Ecotect™ overestimated the amount of light entering through the opening in the door; thus, the illuminace levels at the sensor points SP 1 – SP 6 were higher than those at the sensor points SP 7 – SP 12. As a result, the percentage differences between Ecotect™ measurements and field measurements were also larger at SP 1 – SP 6 than at SP 7 – SP 12 (see Figure 9). Even though the same percentage differences would be expected at the SPs that were at the same distance from the window (such as SP 1 and SP 7), this was not the case in this study. Thus, these results point out inaccuracy of the Ecotect™ for the illuminance simulations.

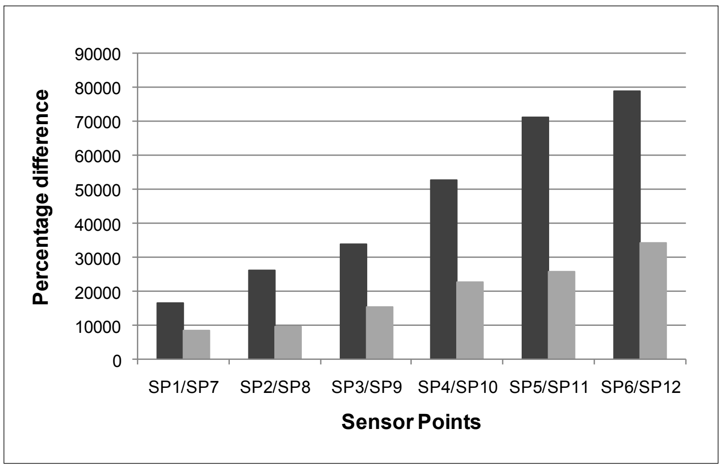

Figure 9: Percentage differences between Ecotect™ measurements and field measurements of the illuminance levels in the classroom 220 on May 22nd at 8:05 a.m.

On each analyzed date 400 illuminance measurements were taken, except on January 17th when 366 measurements were recorded. The number of cases that had a percentage difference of less than or equal to 15% or larger than 15% are shown in Figure 10. The most cases with the acceptable percentage difference of less than or equal to 15% were observed on March 20th (25 out of 400 cases). The least number of cases (1 out of 400 cases) that achieved the acceptable percentage difference of less than or equal to 15% were noted on May 22nd. The total number of cases that had a percentage difference of less than or equal to 15% were 72 (out of 3566 total analyzed cases or 2.01%).

Table 1 presents the lowest and highest percentage differences between Ecotect™ measurements and field measurements for each analyzed day and in each analyzed spce. The highest percentage difference (111,445%) was observed at SP 6 in the classroom 225 at 8.05 a.m. on June 21st. The lowest percentage difference (0%) occurred in three cases. It was noted that in all the nine months the highest percentage differences were recorded at SP 6 in the classrooms 220 and 225 when compared to the other sensors points in the same classrooms. However, in the classroom 238, in eight out of nine months the highest percentage differences were recorded at SP 10 .

Since Ecotect™ simulations of illuminance levels were accurate in only about 2% of all the analyzed cases, it can be concluded that Ecotect™ cannot be considered as an accurate tool for simulations of illuminance levels.

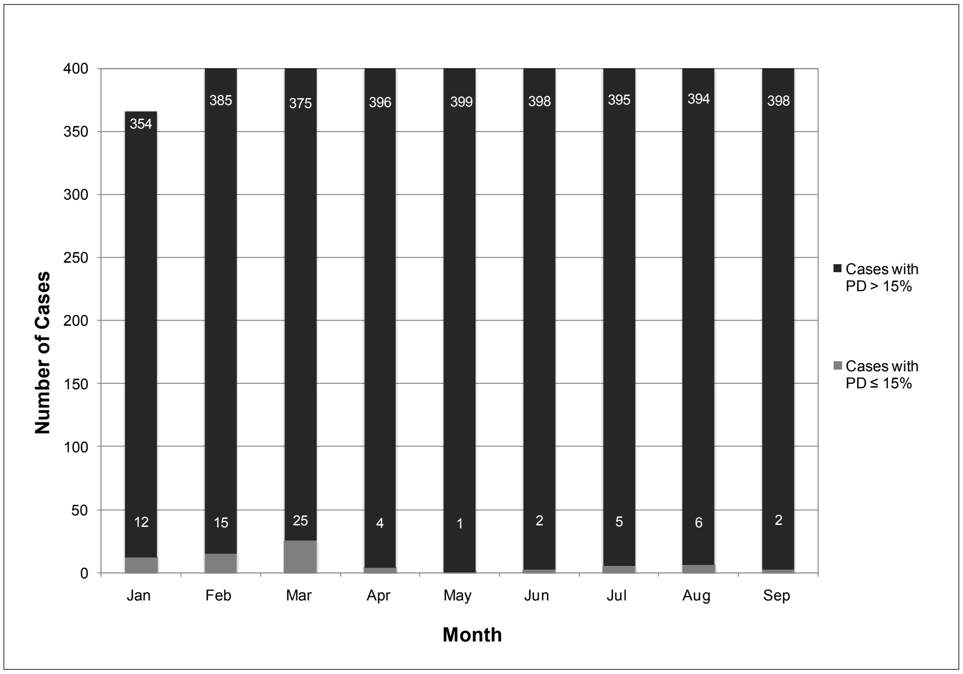

Figure 10: Comparison of number of cases with percentage difference of less than and equal to 15% and those with percentage difference of more than 15%

Table 1: Range of percentage differences between Ecotect™ measurement and field measurements.

Date	**PD**	**Classroom**			**Skylights**	**Corridor**
		220	**225**	**238**		
January 17, 2010	Lowest	15%	0%	1%	76%	309%
	Highest	11894%	16307%	1069%	2979%	6501%
February 27, 2010	Lowest	3%	1%	0%	37%	170%
	Highest	90084%	92658%	6638%	2477%	6821%
March 20, 2010	Lowest	6%	3%	1%	63%	184%
	Highest	54093%	25693%	413%	1954%	4811%
April 17, 2010	Lowest	186%	32%	3%	45%	250%
	Highest	40807%	36846%	2372%	1598%	3405%
May 22, 2010	Lowest	340%	162%	10%	1352%	2176%
	Highest	78810%	69655%	4211%	4426%	8068%
June 21, 2010	Lowest	38%	2%	20%	72%	50%
	Highest	48193%	111445%	3446%	6643%	13872%
July 24, 2010	Lowest	173%	28%	2%	75%	761%
	Highest	44753%	69906%	3508%	3136%	5307%
August 28, 2010	Lowest	7%	36%	0%	324%	884%
	Highest	22787%	51537%	1458%	1302%	2629%
September 18, 2010	Lowest	315%	152%	8%	738%	1463%
	Highest	104866%	103495%	4995%	8187%	17168%

5 CONCLUSIONS

Although most of the actual building conditions can be input in Autodesk Ecotect^{TM} for simulation of thermal loads, the inability to specify the type of HVAC system seemed to be a major drawback in obtaining accurate results. The selection of the most efficient HVAC system for the building from the Ecotect^{TM} library rather than using the actual HVAC system might also affect the accuracy of the results. Other limitations of the software regarding the thermal analysis include the inability to input the accurate operation schedule of the HVAC system as well as the inability to simulate hourly and daily thermal loads. The research results show that Ecotect^{TM} constantly underestimated thermal loads for more than 15%. Therefore, it can be concluded that Ecotect^{TM} should not be used for simulation of thermal loads if high accuracy of results is desired.

The accuracy of the illuminance results simulated by Ecotect^{TM} was affected by various software and research limitations as discussed in the limitations section. Limitations of the software which might affect the accuracy of the illuminance results include: not using the weather file, using limited sky conditions, and not being able to specify date/time of the simulations. The research results show that Ecotect^{TM} overestimated illuminance levels for more than 15% in nearly all the analyzed cases. Therefore, it can be concluded that Ecotect^{TM} should not be used for simulation of illuminance levels if high accuracy of the results needs to be achieved.

Based on validation of accuracy of Ecotect^{TM} for simulations of the thermal loads and illuminance levels, this research results suggest that the Architecture, Engineering, and Construction (AEC) community should not use Ecotect^{TM} as a thermal and daylighting analysis tool in the design and construction of buildings if accuracy of results is needed. The quality and quantity of input information that can be entered in Ecotect^{TM} should be improved in order to achieve more accurate simulations of thermal loads and illuminance levels. Another major improvement to the software would be to make the lighting analysis both date and time-specific.

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AUTHOR BIOGRAPHIES

PRASANTHI VANGIMALLA is a former Building Construction graduate student in the M. E. Rinker, Sr. School of Building Construction at the University of Florida. She received Bachelor of Architecture degree from Anna University, India. Her research interests include Building Information Modeling (BIM) and sustainable design and construction. Her email address is p.reddy@ufl.edu.

SVETLANA OLBINA is an Assistant Professor in the M. E. Rinker, Sr. School of Building Construction at the University of Florida where she teaches the course related to Building Information Modeling (BIM). She received a B.S. and M.S. in Architecture from University of Belgrade, and a Ph.D. in Building Construction from Virginia Tech. Her research interests are in Building Information Modeling (BIM); sustainable design and construction, particularly daylighting and thermal performance of buildings; and construction safety. Her email address is solbina@ufl.edu.

RAJA R.A. ISSA is a Holland Professor and Director of the Center for Advanced Construction Information Modeling in the Rinker School of Building Construction at the University of Florida. He has over 30 years of industry and academic experience in computer science and construction engineering and management. He received a B.S., M.S. and Ph.D. in Civil Engineering from Mississippi State University and a JD from the University of Memphis, where he also did post-graduate work in computer science. His areas of research are in construction law, information systems and advanced construction information modeling. His email is raymond-issa@ufl.edu.

JIMMIE HINZE, Ph.D., P.E. is a Professor of the M. E. Rinker, Sr. School of Building Construction and is the Director of the Fluor Program for Construction Safety at the University of Florida. He received a B.S. and M.S. in Architectural Engineering from the University of Texas and a Ph.D. from Stanford University. His primary research interests are construction safety, contracts, productivity, scheduling, and subcontracting. He has written three textbooks and over 150 journal articles and conference papers. His email is hinze@ufl.edu.