COMPARISON OF SIMULATION TOOLS MOSTLY USED IN DAYLIGHTING PERFORMANCE STUDIES

TUĞÇE KAZANASMAZ[1], PELİN FIRAT[2]

ABSTRACT

In recent years, sustainable architecture shows great interest into the daylighting design of buildings, regarding energy saving strategies and user comfort. Increasing usable daylight and creating efficient daylighting strategies help to decrease the total energy consumption and enhance user comfort in the buildings. There are many factors and considerations that need to be taken into account in the process of daylighting design; such as, solar heat gain, glare, artificial lighting control—dimmers and sensors— and predictable or unpredictable variations in sky conditions. Therefore, commencing the daylighting design in the first steps of the designing process is needed. Computer-based daylighting simulation tools help the designers to make time and cost effective pre-tests before the construction stages and understand how their buildings act under different sky conditions throughout the year. This paper presents the basic principles and the discussion of four daylighting simulation programs that have been more commonly used in daylighting design in the recent years. These programs are Desktop Radiance, DesignBuilder, Autodesk Ecotect Analysis and Velux Daylight Visualizer. In this study, the basic working principles of these programs are discussed and a comparison is made regarding the differences in potential quality of the tools in terms of physical correctness of the results, adaptability for new technologies and usability for design decision support. Other criteria that are taken into account in the comparison are compatibility with third party programs, working as a plug-in or as standalone in nature, user interface, ease of use, characteristics of output data, existence and source of climatic data, daylighting analysis and calculation methods, 3D modeling capability. The paper ends with the discussion of the overview literature results.

Key words: Daylighting, Simulation, Performance

---

[1] Assoc. Prof. Dr. Izmir Institute of Technology, Department of Architecture, İZMİR
[2] Res.Assist. Izmir Institute of Technology, Department of Architecture, İZMİR

1. INTRODUCTION

Simulation tools have become essential in the design and evaluation process of buildings. Specifically, they assist in daylighting performance studies and design with a growing interest (Kim and Chung 2011, Reinhart and Fitz 2006). Well-proposed daylighting strategies may decrease the buildings' total energy consumption and enhance user comfort. Thus, it is necessary to evaluate the quantity and quality of daylight in a space both in the early design stage and during occupation (Kim and Chung 2011; IEA 2010). This has recently become a considerable component of sustainable design. Thus, it is expected that, simulation software tools provide accurate visual and quantitative outcomes in the preliminary steps of design.

To examine what kind of deficiencies about daylighting systems and components exist in occupied buildings, we may use simulation tools. They provide this for various climatic conditions. Several daylighting software are integrated in the comprehensive energy performance calculation methods and legislations. Thus, it is necessary to obtain daylighting numerical outputs and visual outcomes close to the real situations. The question related above is how their physical correctness, adaptability and usability are determined and which one is more suitable in design decision support and evaluation process than others.

This can be examined by comparing recently-used daylighting simulation software in daylighting design with the ones integrated in analysis process. Thus, this paper includes an overview of four software; namely, Desktop Radiance, DesignBuilder, Ecotect, Velux Daylight Visualizer. It based on the review of literature mentioned about studies of these tools. The most reliable, adaptable and usable one would become the prevalent one to develop new daylighting technologies. The major deficiencies pointed out as a result of a comparison among software would be inputs to improve such software technologies in future. The best accuracy obtained from one software would assist professionals to design high energy saving potential buildings, and high user comfort in interiors, and low construction and operating costs. The consideration is to seek the proper tool to predict the daylighting performance and take precautions against deficiencies in the early design stage. The objective is to determine the appropriate tool to propose daylighting technology decisions such as innovative shading and light guiding devices as building components. This determination will depend on pointing out their strengths and weaknesses. Consequently, several criteria such as, compatibility with third party programs, working as a plug-in or as standalone in nature, user interface, ease of use, characteristics of output data, existence and source of climatic data, daylighting analysis and calculation methods, 3D modeling capability are examined.

2. OVERVIEW OF DAYLIGHTING SIMULATION TOOLS

2.1. Desktop Radiance

Radiance is developed to assist designers in the prediction process of the lighting levels and the appearance of a space before application. The lighting simulator engine of the Radiance uses a hybrid approach of Monte Carlo and deterministic ray tracing in lighting calculations. The software is initially developed for the Unix environment and works on a text-based input format (Bhavani and Kahn 2011; Kim and Chung 2011; Minstrick 2000). On the other hand, Desktop Radiance is a more user-friendly version of Radiance in terms of its graphical interface and ease of reach through the integrated pull-down menus within other programs such as AutoCAD, Autodesk Ecotect Analysis and DesignBuilder. It works under the Windows operating system through these programs and its graphical user interface also allows using most of the key operating features of Radiance. It is also possible to reach the remaining Radiance features by modifying the original text-based inputs (Minstrick 2000; Lim et.al. 2010). The 3D model used in Desktop Radiance is created either in Radiance or in the above programs. It is also possible to import the model from other 3D modeling tools in compatible 3D formats.

To obtain proper photometric analysis, the model should include appropriate amount of details and the exterior should be modeled closely enough to calculate amount of daylight striking an opening adequately. Before proceeding to simulations, the complete 3D model should be edited by assigning Radiance materials onto each surface. These materials can be chosen from the Desktop Radiance Library or the Material Editor can be used for creating user-defined materials (Minstrick 2000). The site location (entering longitude-latitude values or choosing from one of the available cities), the date, the time and sky condition should also be defined too, before running a simulation. The sky models used by the Desktop Radiance are the models of International Commission on Illumination (CIE) which are CIE clear sky, CIE intermediate sky, CIE overcast sky and uniform sky. It is also possible to discard daylight computations by entering the time as the middle of the night (Kim and Chung 2011; Minstrick 2000). The Desktop Radiance can make analysis on "single reference points" or "grids of reference points"; the latter is used to compute the horizontal illuminance. It is also possible to produce "detailed renderings" of the 3D model through which the illuminance or luminance values of each rendered surface can be learned. The Desktop Radiance has two alternative rendering modes; batch processing and an interactive mode that utilizes the rview program. (Minstrick 2000)

2.2. DesignBuilder

DesignBuilder is a building simulation tool which carries out the analysis on energy consumption, carbon emissions, occupant comfort and daylight availability and works as an evaluation tool on determining the current conditions of the buildings with regard to several building regulations and certification standards.

DesignBuilder was launched as the first Graphical User Interface to the EnergyPlus simulation engine and the latest version of the program (Version 3) includes the first advanced Graphical User Interface to EnergyPlus HVAC systems and a daylight evaluation tool that uses the advanced Radiance ray-tracing engine (DesignBuilder 2012)

The 3D model used in DesignBuilder can be created by an integrated OpenGL solid modeler or can also be imported from 3rd party BIM tools supporting the gbXML standard like ArchiCAD, Microstation and Revit. Imported 2D CAD floor plan data can be traced by DesignBuilder and used as a base for modeling. DesignBuilder provides three types of daylighting calculations; "daylight contour plots, average daylight factor and uniformity outputs by using the Radiance simulation engine", "reduced electric lighting and consequent energy and carbon savings through EnergyPlus simulations" and "photo-realistic renderings by Radiance" (DesignBuilder 2012) By using the Radiance simulation engine, it is possible to calculate daylight factors and illuminance as well as to generate high quality illuminance contour plots within the zones, the blocks or for a slice through the whole building. The sky models are similar to the ones used by Radiance (DesignBuilder 2012). DesignBuilder uses also EnergyPlus simulations to determine the impact of daylighting strategies (decrease in electric lighting usage) on energy and carbon savings based on analysis of available daylight, site conditions, window management regarding solar gain and glare, and various lighting strategies (DesignBuilder 2012).

2.3. Autodesk Ecotect Analysis

Autodesk Ecotect Analysis is a sustainable design analysis tool that provides a wide range of simulation and building energy analysis functions by using desktop and web-service platforms. The program uses Green Building Studio web-based service to carry out whole-building energy, water and carbon analysis and integrates them with desktop tools for visualizing and simulating building's performance. The program aims to help the designers in the schematic phases of their designs and guide their design decisions on orientation, floor plan depth, glazing sizes, etc. Regarding this purpose, the 3D model used in the software needs to be as simple as possible with no non-essential details; almost like a massing model with defined zones for air-conditioning or daylighting (Ecotect 2012; Green Building Studio Manual 2011). Ecotect Analysis together with Green Building Studio can produce data on whole-building energy analysis, thermal performance, water usage and cost evaluation, solar radiation, daylighting and shadows and reflections. (Ecotect 2012)
Ecotect Analysis carries out lighting analysis by several different methods. The program can create daylighting information by using the BRE daylight factor calculations integrated into Ecotect Analysis or by exporting the model to Radiance. Autodesk Green Building Studio also performs daylighting calculations using the LEED prescriptive method for evaluating the buildings for LEED Daylighting Credit Potential. It is also possible to calculate electric lighting as footcandle levels by BRE daylight calculation or by Radiance exports (Ecotect 2012).

2.4. Velux Daylight Visualizer

Velux Daylight Visualizer is a daylighting design and analysis tool aiming to increase the use of daylight in buildings and help designers to predict the daylight quality of their designs before construction stages. The program runs on both Mac OSX and Windows7 platforms. The integrated modeling tool of Velux Daylight Visualizer can be used for creating quick and simple 3D models. The modeler only

Table 1. An overview of daylighting simulation tools

	Desktop Radiance	**DesignBuilder**	**Autodesk Ecotect Analysis**	**Velux Daylight Visualizer**
References	Kim and Chung 2011; Minstrick 2000; Bhavani and Kahn 2011; Lim et.al. 2010; Acosta et al. 2011; Ng 2001; Christakou and Silva 2008.	DesignBuilder 2012	Ecotect 2012; Green Building Studio Manual 2011, Acosta et al. 2011, Attia et.al. 2009; Christakou and Silva 2008.	Velux 2012; Labayrade et al. 2010.
Available daylighting calculations	reference points detailed renderings	reference points detailed renderings	reference points detailed renderings by Radiance; evaulation for LEED Daylighting	reference points detailed renderings
Daylighting Outputs	illuminance, luminance, daylight factor, photo-realistic renderings, daylighting contour plots	daylighting contour plots, average daylight factor, illuminance, and photo-realistic renderings by Radiance; electric and carbon savings by EnergyPlus	daylighting contour plots, average daylight factor, illuminance, uniformity outputs and photo-realistic renderings by Radiance; results for LEED Daylighting Credit potential	daylighting contour plots, average daylight factor, illuminance
Available sky models for daylighting calculations	CIE clear sky, CIE intermediate sky, CIE overcast sky and uniform sky	CIE sunny clear day, CIE clear day, CIE sunny intermediate day, CIE intermediate day, CIE overcast day, CIE overcast day (10000 lux) and uniform cloudy sky.	CIE clear sky, CIE intermediate sky, CIE overcast sky and uniform sky	CIE Standart Overcast Sky, Partly Cloudy Sky, CIE Standard Clear Sky
3D Modeling	in Radiance or in the programs DR is a plug-in. Importing is allowed.	by integrated OpenGL solid modeler or importing from programs	in Ecotect or importing in compatible formats	by the integrated modeler or by importing

permits creating orthogonal shapes as well as the exception of the rotatable custom object entity, so it can be inflexible and inadequate when trying to model complex geometries. By using the 3D importer feature, it is possible to import 3D models. The imported 3D models should only be made of polygons and to prevent light leaks, the polygons should be attached together properly. Furniture created with other programs can be used in the imported models if they are inserted before importing the model to Daylight Visualizer. There are some other restrictions in Daylight Visualizer like the textures can only be applied to horizontal surfaces and there is no undo function in the program. In the simulations, Velux Daylight Visualizer uses sky types defined by CIE. By utilizing Velux Daylight Visualizer, the simulation outputs that can be acquired are; luminance, illuminance, daylight factor and daylight animation (Velux 2012)

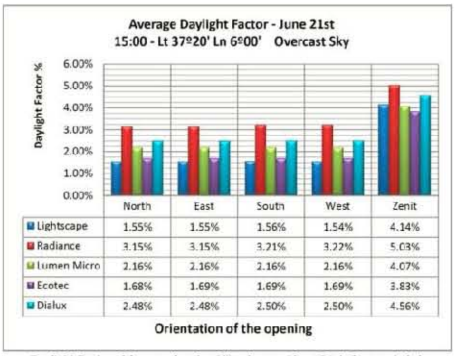
3. PHYSICAL CORRECTNESS AND ADAPTABILITY FOR NEW TECHNOLOGIES

In recent years, daylighting simulation tools have become commonly used by lighting designers and professionals. Increasing trust in their accuracy and decreasing use of scale models may result in their wider use. However, their users still remain less than the others using other building simulation software. Since, users may tend to use easy, practical and reliable daylighting tools and when they cannot reach adequate information, self-teaching materials, convenient databases, practical user-interface or reliable analysis results; they avoid using them. (Reinhart and Fitz 2006; Reinhart and Wienold 2010) In this section, "physical correctness" and "adaptability to new technologies" and in the following chapter, "usability" of four programs; Desktop Radiance, DesignBuilder, Ecotect and Velux Daylight Visualizer, were discussed through a review of related previous studies.

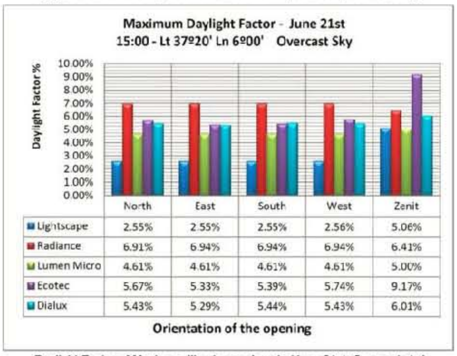
Physical correctness depends on competence of 3D models, the various characteristics of materials, sky conditions and external obstructions. Various sky model types are used by these tools to indicate different sky conditions. However, it is almost impossible to cover all real sky conditions since they vary unpredictably due to time, location and occlusion. This inconsistency between the real sky conditions and the sky models of daylighting tools cause simulation errors and affect physical correctness of the tools.

To show these dependencies, a study by Acosta et al. (2011) tried to identify how the sky models of the different tools affect daylighting calculations. To achieve this, a simple room with a square opening on one side was modeled identically in five tools; Lightscape, Desktop Radiance, Lumen Micro, Autodesk Ecotect Analysis and Dialux. Overcast sky conditions and a common day were selected for each simulation. Firstly, the researchers changed the opening orientation in each simulation (North, East, South, West, Zenith) to understand how each tool responded to this variation. Findings showed significant differences in daylight factor results, illuminance levels, and coefficients of uniformity for each simulation tool (Figure 1 and 2). Highest illuminance levels were obtained by Desktop Radiance for all orientations. Ecotect results were almost half of them. But they were in acceptable limits for all software. The understanding of overcast sky by each tool was differed from each other. So, physical correctness of each tool varies due to their sky interpretation.

Secondly, distribution of light according to time was analyzed in the same study. Only the uniformity coefficients of Desktop Radiance varied with the time remarkably. Thus, Desktop Radiance was sensitive to time variation due to the addition of sky-turbidity-factor in its algorithms. Ecotect resulted very small shifts in daylight factor values for the same time interval, but Desktop Radiance showed inconsistent and relatively greater values when compared to the other tools (Figure



Daylight Factor of Average levels of Illuminance (June 21st, Overcast sky)

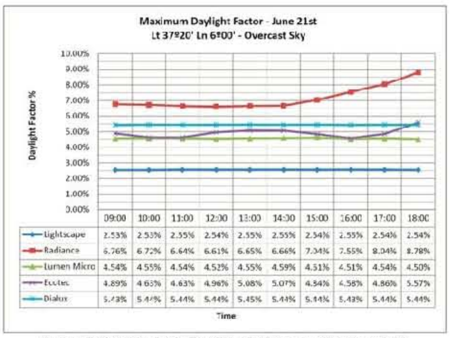


Daylight Factor of Maximum Illuminance Levels (June 21st, Overcast sky)

Figure1. Distribution of daylight factors obtained from each software due to orientation. (Acosta et al. 2011)

2). Consequently, in overcast sky conditions, Desktop Radiance was found to be more sensitive to time when compared to Ecotect and other tools. Its daylight factor values tend to be higher than Ecotect in all conducted simulations in that study.

Coefficients of Uniformity (Max/Min illum. levels) (from 9:00 to 18:00 on June 21st, Overcast sky)



Maximum Daylight Factor Levels (from 9:00 until 18:00 on June 21st, Overcast sky)

Figure 2. Coefficients of uniformity and daylight factors due to time (Acosta et al. 2011)

With a similar purpose, another study compared Desktop Radiance results with scale-model measurements conducted under intermediate and overcast tropical sky conditions in Malaysia. The simulated results showed high mean differences from the scale-model measurements such as 81.63%, 71.06% and 49.71% with external illuminance, absolute work plane illuminance and absolute surface illuminance respectively (Lim et al. 2010). Daylight factor and luminance ratios were better comparisons with 26.06% and 29.75% mean differences. These errors basically based on the inconsistencies between the tropical sky and CIE sky models. Desktop Radiance failed to predict the external illumination in acceptable limits, though results were closer to the actual conditions under the CIE overcast sky when compared to CIE intermediate sky. According to Lim et al, this was due to the luminance distribution of the tropical sky being more uniform during overcast conditions.

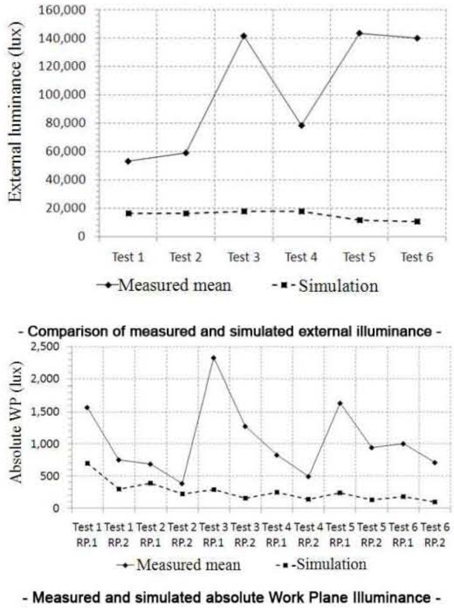


Figure 3. Comparison of measured and simulated illuminance (Lim et al. 2010)

It is challenging for daylighting simulation tools to use sky models that are in complete harmony with extreme and rapidly changing real sky conditions. One reason for that may be the tendency of the software developers to constitute sky models that imitate general sky characteristics worldwide. Using these sky models for extreme sky conditions like tropical sky, the inconsistencies in the simulation results are inevitable.

High external obstructions affect the amount of daylight striking to openings. In some cases that may lead computational errors due to the distorted local sky conditions, and affect the physical correctness of daylighting tools. Regarding these concerns, in a research by Ng (2001), the simulation abilities of Radiance and Lightscape under conditions with high external obstructions were tested. Simulations carried out with the two software were compared with the calculated results and the on-site measurements in an extremely dense urban environment in

Hong Kong. The on-site measurements were carried out in three apartments located at different levels in a building block between June – October 2000 on cloudy days. For the simulations, the CIE Standard Overcast Sky was used. It was concluded that, on-site measurements substantially matched with the calculation results. Desktop Radiance simulations were similar to the calculation results at higher floor levels and with obstructions less than 30 degrees angles. At lower floor levels or with greater obstruction angles, both Desktop Radiance and Lightscape overestimated the daylight availability. The Desktop Radiance errors increased when the angle was greater than 35 and the error was close to 50% at 60 degrees. It was derived from trial-error simulations that, by lowering the reflectance to 0.2 from 0.4, Desktop Radiance could minimize the errors.

It was proved that external obstructions caused remarkable inconsistencies on daylighting simulation results and affected physical correctness. The obstruction angle and height of the simulated environment does also affect the results and may increase the errors. Under overcast sky conditions Desktop Radiance simulation results can be remarkably manipulated by external obstructions. Desktop Radiance overestimates daylight availability with an increasing error at lower floor levels and with obstruction angles higher than 35 degrees.

The comparison and validation studies of simulation programs in the literature that we could be able to attain were mainly included Radiance, testing it alone or among other simulation tools or simulation results were validated with measurements. We could hardly reach any studies of validation or comparison neither with Velux Daylight Visualizer nor with Ecotect and DesignBuilder, apart from the ones that are testing the two programs with their Radiance based simulation capabilities. The dominance of Radiance on these studies can be explained by the previously mentioned survey (Reinhart and Fitz 2006) results. Among 42 different daylighting simulation programs that the survey participants routinely used; over 50% of these programs were the ones that operated with the Radiance simulation engine.

However a study by Labayrade et al. (2010) aimed to validate Velux Daylight Visualizer against CIE 171:2006 test cases. The validation results showed an average error of 1.8% and a maximal error of below 6% with respect to the reference for eight identified settings proving the accuracy of Velux Daylight Visualizer.

In designing low-energy buildings, material selection becomes an important criterion. By modifying the material characteristics like transparency, reflectivity or absorptivity, architects aim to design high energy performance buildings. To evaluate their daylighting performance, such tools should be adaptable to accurately simulate these complex new materials. For example, Thanachareonkit et al. (2006) conducted an error analysis on the complex fenestration systems (prismatic films and laser-cut panels) simulation techniques by using Radiance. A 1:10 scale model under a scanning sky simulator and an identical Radiance model under CIE overcast sky were compared while both equipped with conventional glazing, laser-cut panel and prismatic film on the side opening respectively. With conventional glazing, the results showed a relative divergence of 1-9.2 % proving high accuracy of Radiance. With a laser-cut panel mounted to the window, it was 0.5-16%, while with prismatic film; it was 2.2-35%. Secondly, a sensitivity analysis of surface reflectance was carried out. 10 -50% overestimation of surface reflectance caused 5-52 % relative deviation above the scale model values, while a similar underestimation range of surface reflectance caused 10-40% lower values. Laser-cut panel and prismatic film results were slightly differed from each other and both results were comparable with the glazing model. Thus, simulation techniques of laser-cut panels and prismatic films by using Radiance were validated. A similar research was conducted aiming to validate trans and transdata Radiance material types and to constitute corresponding Radiance material from a translucent panel by using goniophotometer and integrating sphere measurements. After adjusting indoor illuminance simulation results with a ratio of measured to simulated façade illuminances, the errors were under 8% and 10% for transdata (Reinhart and Andersen 2006).

As mentioned above, daylighting designers have been rapidly using the complex materials and advanced daylighting systems in their designs recently. Apart from the design decisions like orientation, amount of openings, floor plan depth, etc; using these modified materials and advanced daylighting systems provide remarkable energy savings. To evaluate the daylighting performance of the buildings with these new technologies, simulation tools should be adaptable to these consistent changes. As can be derived from the mentioned studies, simulation techniques of Radiance for complex fenestration systems (in this case laser-cut and prismatic panels) as well as the trans and transdata Radiance material types has been verified recently. Also, the ability of Radiance; constituting corresponding Radiance material from a translucent panel by using goniophotometer and integrating sphere measurements has been validated. With the new technological progresses in daylighting systems, materials and co-elements like paints or isolative films; the adaptability of the simulation tools to new technologies is crucial.

4. USABILITY OF SIMULATION TOOLS

Researchers pointed out that, professionals, in general, prefer to learn such daylighting software by themselves. The ones which are easily understood by intuition and provide easy operation decrease learning period of time. Even, the longer the time spent in self-teaching, the faster to avoid from using these software. Daylighting simulation software should offer efficient tutorial options and simple simulation environment (Reinhart and Fitz 2006; Reinhart and Wienold 2010). User interface is the center of interest for architects, since it is the link between them and digital processes (Christakou and Silva 2008). Related studies mostly based on users' opinion and preferences, and the concept named here as "usability"(or user-friendly) involved such criteria as being intuitive, less learning time, user manual options, being simple and data output options. This term mainly depends on the interface operation (graphical based or text based) and capability. Menus, on screen clickable items which are perceived immediately are requisite. Usability secondly based on information management of interface (Attia et.al. 2009). In relation to this, Reinhart and Wienold (2010) define barriers such as the misleading interpretation of simulation results or outdated evaluating schemes. Visually accessible simulation results are preferable.

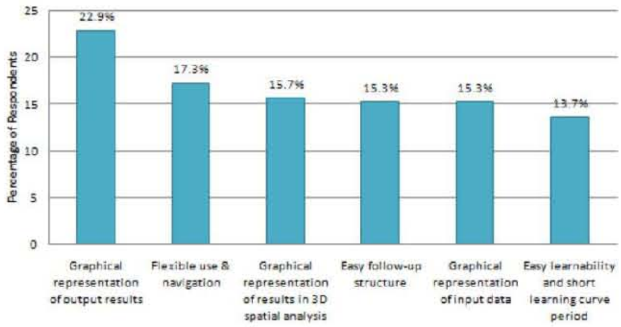


Figure 4. Criteria concerning usability and graphical visualization usage pattern (Attia et.al. 2009)

According to the research conducted among users' opinion about simulation software, usability is related to "better graphical representation, of simulation input and output, simple navigation and flexible control. Ecotect and Design Builder fully matched these criteria except easy follow up structure for the former and graphical representation of results in 3D spatial analysis for the latter. Due to the criteria concerning information management, users considered Ecotect as insufficient in creation of comparative reports and Design Builder as unsuccessful in the quality control of simulation input (Attia et.al. 2009). (Figure 4,5). On the other hand, Radiance's interface was not defined as friendly by a reference cited in Christakou and Silva (2008). Their research included both users' opinion and the application of software in a design process. Findings showed that Ecotect was not the most suitable software and not intuitive when compared to Relux, but had user friendly interface (Christakou and Silva 2008).

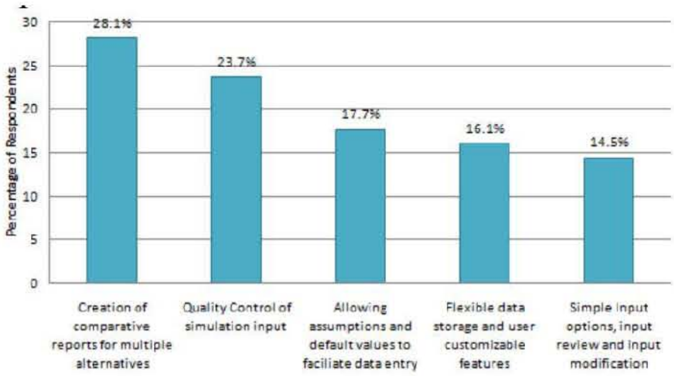


Figure 5. Criteria concerning information management (Attia et.al. 2009).

Table 2. Strength and weaknesses of Ecotect, Radiance and DesignBuilder due to their usability

	strength	weaknesses
Ecotect	Less learning time and simple navigation (simulation tips for instructors) user friendly interface better graphical representation	inappropriateness in flexible data storage and input options (Limitations in 3D modeling) not easy follow up structure not intuitive
Design Builder	simple navigation flexible control	graphical representation of results in 3D spatial analysis
Radiance		Not user friendly Not preferred by beginners

The study by Reinhart and Ibarra (2009) supported the usability of Ecotect due to users' preferences. According to this study about beginners' choice for using a software (Ecotect versus Radiance), it was stated that none of them preferred to run simulations by exporting to Radiance, but they used Ecotect analysis. However, a large number of students imported their model into Ecotect after modeling it with another program due to limitations of modeling capabilities of Ecotect. This showed that inappropriateness in flexible data storage and input options were the cause of this. Users in this study also paid attention to simulation tips which can be useful for the instructors. So, this approved that easy learnability and simple navigation were suitable features in Ecotect. Unfortunately, literature about the usability of Velux was not cited.

5. CONCLUSIONS

This paper is an overview of four recent simulation tools mostly used in daylighting design and performance studies. It is based on contemporary researches cited in literature and on inspection of simulation characteristics. When compared to the scale models and mathematical calculations; the number of users of the daylighting simulation tools is higher. Their priority depends on being less-time consuming, providing various visual scenes for various physical and sky conditions. It is possible to detect any deficiency in the design phase and provide solutions before its construction. So it is cost-efficient. In this paper, the discussion is based on the physical correctness and usability of these tools for daylighting design decisions and performance analysis. A majority of the studies analyzed Radiance as the mostly used daylighting tool. Output results by Radiance were found to be within acceptable limits, although its physical correctness might fail due to real sky conditions (such as tropical). However, it is sensitive to time variation when compared to Ecotect. In regard to usability, Ecotect seems to be a practical tool because of its shorter learning time and simple navigation, user friendly interface and better graphical representation. Desktop Radiance also uses Ecotect's user interface as a plug-in. The authors concluded that, this is a complex task to determine the most accurate simulation tool. Each one has its own strengths and weaknesses. And it is obvious that the developments in the field of simulation technologies will continue with a growing acceleration aiming to improve these weaknesses. This study suggests that; among the analyzed simulation tools, Radiance and Ecotect together might be preferred in daylighting calculations, especially when designing and examining the effects of advanced daylighting technologies such as laser-cut or prismatic panels in glazing.

REFERENCE

Acosta, I., Navarro J. and Sendra J. J. 2011. Towards an Analysis of Daylighting Simulation Software, Energies, 4, pp. 1010-1024.

Aizlewood M E and Littlefair P J. 1994. “Daylight Prediction Methods: A Survey of their Use”, Garston Watford, UK, British Research Establishment.

Attia S., Beltrán L.,Herde A. and D. Hensen J. 2009 “Architect Friendly: A Comparison Of Ten Different Building Performance Simulation Tools”, Eleventh International IBPSA Conference, Glasgow, Scotland, July 27-30, 2009.

Bhavani, R.G. and Kahn, M.A. 2011. Advanced Lighting Simulation Tools for Daylighting Purpose: Powerful Features and Related Issues, Trends in Applied Sciences Research, 6 (4), pp. 345 – 363.

Christakou, E. and Silva, N., A. 2008 Comparison of Software for Architectural Simulation of Natural Light, T. Sobh (ed.), Advances in Computer and Information Sciences and Engineering, pp. 136–141. Springer Science + Business Media B.V.

DesignBuilder, Simulation Tool, Manual, 2012 (http://www.designbuilder.co.uk/)

ECOTECT, Autudesk Ecotect Analysis Sustainable Building Design Software, (http://usa.autodesk.com/ecotect-analysis/)

International Energy Agency (IEA), Daylight in Buildings, Project Summary Report, 2010, Ed. Johnsen, K., Watkins, R., AECOM, United Kingdom.

Labayrade, R., Jensen, H.W. and Jensen C.W. 2010. An Iterative Workflow to Assess the Physical Accuracy of Lighting Simulation Programmes, Light & Engineering, Vol. 18, No. 2, pp. 60-70

Lim, Y., Ahmad, M.H. and Ossen, D.R. 2010. Empirical Validation of Daylight Simulation Tool with Physical Model Measurement, American Journal of Applied Sciences 7 (10): pp. 1426-1431

Kim, C. and Chung, S. 2011, Daylighting Simulation as an Architectural Design Process in Museums Installed with Toplights, Building and Environment 46 (2011) pp. 210-222.

Mistrick, R.G., Desktop Radiance Overview. 2000. The Pennsylvania State University, , Pasific Gas & Electric. http://radsite.lbl.gov/deskrad/drad-overview.pdf

Ng, E., A Study on the Accuracy of Daylighting Simulation of Heavily Obstructed Buildings in Hong Kong, Seventh International IBPSA Conference, Rio de janerio, Brazil, August 13-15, 2001

Reinhart, C. F. and Andersen, M. 2006. Development and Validation of a Radiance Model for a Translucent Panel, Energy and Buildings 38, pp. 890-904.

Reinhart, C.F. and Fitz, A. 2006. Findings From a Survey on the Current Use of Daylight Simulations in Building Design, Energy and Buildings 38, no. 7, pp. 824-835.

Reinhart, C.F. and Ibarra D.I. 2009. Daylight Factor Simulations – How Close Do Simulation Beginners 'Really' Get? , Eleventh International IBPSA Conference, Glasgow, Scotland

Reinhart, C.F. and Wienold, J. 2011. The Daylighting Dashboard - A Simulation-Based Design Analysis for Daylit Spaces, Building and Environment 46, 386-396

Thanachareonkit, A., Scartezzini J.L. and Robinson D., Comparing the Accuracy of Daylighting Physical and Virtual Models for Complex Fenestration Systems, PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 6-8 September 2006.

VELUX, Daylight Visualiser, 2012 (http://viz.velux.com/daylight_visualizer/about).