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Full Length Research Paper

Simulation of strategic placement of luminaries for energy efficient lighting using daylight

Bangali Jayashri A[1*], Shaligram Arvind D[2]

[1]Kaveri College of Science and Commerce, Erandwane, Pune-411038
[2]Department of Electronic Science, University of Pune, Pune-411007

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Lighting simulation is increasingly gaining importance as a tool for energy optimization of modern buildings. Lighting simulation tools are used to see illumination distribution. This paper reviews lighting simulations tools available in market and presents an optimal procedure of obtaining strategic placement of Luminaries, for energy efficient lighting systems, taking advantage of daylight. A 'Room model', accommodating the dynamic features of a daylighting project is built in lighting simulation software DIALux 4.10. Using this tool outputs such as 3D representation, energy evaluation, luminance distribution and table outputs are obtained. These are then used in evaluating the candidate illumination system designs for a room model. Results of three alternative candidate designs or arrangements of commercial available luminaire are presented. Some issues and challenges related to the simulation tools such as time complexity, challenges of sky models, real time control application, validation and time taken by simulation process are discussed in this paper.

Keywords: Daylighting, lighting simulation, DIALux, room model, energy efficient, CIE sky models

INTRODUCTION

Today, there are many lighting simulation tools are available in market. U.S. Department of Energy - Energy Efficiency and Renewable Energy listed these tools alphabetically in Building Energy Software Tools Directory (USDOE,2010a). It includes a short description of their capabilities, weaknesses and strengths. Lighting simulation tools are used to see how light behaves in a building. These tools have the powerful features and also related issues such as challenges of sky modeling, time complexity of software towards real time control applications, validation and energy simulation. These tools play an effective role in daylighting projects thus contributing to creating energy efficient buildings. To design effective and intelligent lighting control systems, which responds to user inputs and environmental conditions, the advanced computer simulation softwares need to be carefully chosen. Though the array of choices is plenty in the market, the designers constantly look for solutions to reduce the degree of complexity in the algorithms. This is because the high levels of complexity and long computation times make the tools unsuitable to be deployed in model-based building control domains. A brief review of the lighting simulation tools available in the market is presented in this paper. This study presents a comprehensive review of related issues of lighting simulation tools. The paper demonstrates the systematic procedures of simulation along with the corresponding values and parameters using DIAlux simulation software. A room model is developed using DIALux 4.10 which

*Corresponding Author's E-mail: jayashri789@yahoo.com

was further used to simulate the scenes in the room that helped to obtain the internal illuminance values at the task surface. The brief review of commercially available lighting simulation tools available today is presented in next section.

Review of Lighting Simulation Tools available today

From the online list presented by USDOE, the most influential model among the lighting simulation research and computer graphics communities continues to be Radiance (Ward 1994, LBL 2010a).The RADIANCE is a stochastic, deterministic backward ray tracing simulation engine developed by Ward, at Lawrence Berkeley National Laboratory (Larson and Shakespeare, 1998). RADIANCE has some of the advanced current calculation techniques available in most lighting simulation models (Ward et al. 1988). Radiance has been incorporated as a limited lighting simulation engine within other tools, such as ADELINE (FIBP 2002, unsupported), Desktop Radiance (LBL 2000, unsupported), Rayfront (Mischler 2003, unsupported), Daysim (NRC 2009) and RadianceIES (IESVE 2010).

DIALux (DIAL GmbH 2010) is widely used for calculation of indoor and outdoor electric lighting systems. There is an external radiosity and raytracing model, POV-Ray (Persistence of Vision 2010). Some noteworthy scientific studies that used DIALux include determining criteria for energy efficient lighting (Ryckaert et al. 2010) or simulating luminaire arrangements for a study of patients suffering dementia (van Hoof et al. 2009). Relux (Relux Informatik 2010) includes links to photometric databases from manufacturers. It calculates lighting arrays, daylighting, and some energy consumption data. The raytracing module is also used for rendering. Its accuracy has been validated by Maamari et al. (2006a). It has been used to evaluate comfort conditions of traditional architecture (Ruggiero et al. 2009), and to provide an electric lighting basecase for comparison with daylighting systems (Linhart and Scartezzini 2010). Relux is also free of charge, but not open source. Some lighting simulation tools are listed in table 1.1.Some issues concerned with today's lighting simulation tools are discussed ahead.

Issues related to simulation software

The space and time complexities associated with radiosity and ray tracing methods also pose some issues related to simulation. For example, ray tracing softwares takes too long time since the law of physics demand complex calculations for precision.

Since the entire control process is very dynamic, results or predictions by models should be done within reasonable time limit. However, some simulation software take too much time for each simulation.

While modeling daylight, rendering is another important feature which is to be done properly. In many simulation softwares, sunlight and skylight are rarely rendered correctly in computer graphics because of high computational expense and lack of precise atmospheric data.

Issues in validation

Most comparisons under this category examine lighting simulation models for use by architects in the production and evaluation of designs. Ubbelohde and Humann (1998) studied four programs for use in daylighting studies (Radiance and three programs now discontinued: Lumen Micro, Super Lite, and Lightscape). They found that results are affected by choice of sky model and input detail. They simulated two floors of an existing San Francisco building with an atrium. A physical model was an additional benchmark. However, their choice of simulated skies was deliberately simplified, differing from existing weather conditions at measurement time. Input was more detailed for Radiance and Ligthscape than for the other programs. Therefore, these two followed more closely real measurements.

Ashmore and Richens (2001) also studied four simulation programs (ADELINERadiance and three programs now unsupported: Lightscape, RadioRay, and Microstation 7). A scale model under two artificial overcast skies was used as benchmark. Programs had to replicate real-life measurements of a small room next to a very large courtyard, using reflectances from the model. Simulation programs gave good results except close to the window. These authors acknowledged their scale model and choice of two artificial skies were error sources.

The lighting simulation softwares require large amount of empirical data for validation. This is a very inconvenient, cumbersome, costly and complex process. Lighting simulation is normally done to arrive at the most favorable control scenario in terms of optimum energy usage with lighting and heating or cooling. The control action taken and its corresponding output can be verified only if the actual scenario is available in a real building under operation. So, a complete perspective on building usage and the corresponding data of real buildings are prerequisites for simulation validation.

Issues in modeling sky

For day lighting purposes, the Commission International de Eclairage (CIE) declares a number of sky conditions as standard skies. Those are defined by functions, depending on the solar altitude, even when the sun is hidden. Sunny sky is any sky condition where the sun happens to shine (through the clouds, if there are any).

This can be combined with any of the following three conditions. Clear sky has less than 30 % cloud cover, or none. This sky is most likely to be combined with sun. Partly cloudy sky has between 30 % and 70 % cloud cover. This sky can be combined with sun in some cases. Cloudy sky has more than 70 % cloud cover. This sky normally excludes the sun. Overcast sky has a completely closed cloud cover (100 %). Obviously, this sky can't be combined with sun in a meaningful way. This is the sky condition applied in daylight factor calculations.

When modeling sky, the variability of daylight presents a challenge along with the calculation of interior light, solar gain and glare. This is due to the fact that a part of the sky component of light reaching a given space can be diffused or reflected by neighboring buildings or some other objects before coming indoors. The standard sky models such as clear and overcast alone cannot describe sky luminance conditions for all locations.

A Room Model in DIALux

The room model consists of information about room geometry, pillar, partition, door, furniture, the placement and size of windows as well as the physical properties of room components such as reflectance and transmittance. The luminaire library of various manufacturers that comes along with the simulation software can help to choose the wattage and number of devices needed for a given room for an adequate and glare-free illumination. A room model can also build using CAD tool and then can be imported into DIALux simulation software. This room serves as a platform for system's internal representation and hence sometimes simply referred to as model. The designer can then input surface, geometrical, date and time and various sky conditions to find the energy efficient luminaire arrangement with the maximum use of daylight.

Simulation of a 'Room Model' in DIALux 4.10

A 'Room model', accommodating the dynamic features of a daylighting project is built in lighting simulation software DIALux 4.10. The simulation procedure is demonstrated with the help of a room model. The analysis is based on following output of DIALux:

- Artificial light according to the standard DIN 18599
- Energy saving potential of artificial light by the use of daylight
- Artificial and daylight combined
- Daylight as per CIE sky conditions (overcast, clear)
- Calculations using daylight factors
- Energy evaluation (standard EN 15193)

DIALux can display output in anyone of the following forms: Illuminance on the reference plane in the form of a table, room's floor plan, 3D rendering, False Color rendering, Workplane Photometric chart and Workplane Isolines , 3D representation of the light distribution and 3D view.

DIALux has many output options to help you visualize and understand data from your simulation. Output options include 3D rendering, False Color rendering, Workplane Photometric chart, and Workplane Isolines. Considering the input of environmental factors (sky conditions, solar radiation etc.), building factors (type of the building, window orientation, presence of neighboring structures etc.), room layout factors (partition, irregular floor plan, configuration change, presence of furniture etc.) and occupancy factors, the simulation of daylighting is done.

To create a room model for daylighting calculations, the project location has to be specified by entering the geographical longitude and latitude along with the corresponding time zone. It is also possible to make allowance for daylight saving time and the start and end of daylight saving time. The north angle shows the orientation of the room compared with geographic north corresponding to the project and this alignment is important for daylighting calculations.The location of a room model and their values along with the room dimensions are given in table 1.2

For room model standard floor, standard wall, standard walls are selected. So reflelection factors for ceiling: 80%, Walls : 50% and for Floor: 20%. The maintenance plan method selected is: very clean room, low yearly usage

The room model build for simulation is shown in figure 1.1.

The shortest day, winter solstice and midwinter are the colloquial terms used to describe the 24 hours around an annual astronomical event which occurs around the 22nd December. The winter solstice is the shortest day of the year in the sense that the length of time elapsed between sunrise and sunset on this day is minimum for the year. This is the worst case situation for a lighting system which looks forward for daylight contribution in energy efficient lighting. So, the daylight simulations are done on this day. It is assumed that the room is in office building and working hours are 10 a.m. to 6 p.m.. The luminaire LZA 2/35W T16 EVG LME (75W) is selected from the database of DIALux. All three luminaire arrangement consists of four luminaires, so total wattage is 300 W. Three different arrangements of selected luminaries are designed as shown in fig. 1.2

The illuminance diagrams or luminaire (LZA 2/35W T16 EVG LME) of arrangements 1, 2 and 3 are shown in fig1.3. It shows the light distribution of artificial lights only; the daylight is not included in it.

RESULTS AND DISCUSSIONS

The daylight simulation assuming overcast and clear sky models as per CIE are done at different timings of the

Table 1.1. Lighting Simulation Tools

Tool	Method used	Availability/Details
Radiance	Ray Tracing	Global illumination using Monto Carlo method
AGi32	Radiosity, limited ray tracing	Paid, Luminaire design, Daylight integration
DIALux	Integrated Ray tracing	Free, Luminaire design, daylight integration
Inspirer	Bidirectional Ray tracing	Paid, General purpose
mental ray	Radiosity, ray tracing	found within paid modelling software General purpose
Relux	radiosity and modified Radiance ray tracing	Free, Luminaire design, daylight integration
Velux Daylight Visualizer	Bidirectional ray tracing	Free, Conceptual stages in daylight application
ADELINE	Radiosity	CAD interface, the lighting tools UPERLITE and RADIANCE
Lightscape	Radiosity	Made by Autodesk possible to change viewpoints without recalculating the scene
Rayfront	Ray tracing	Makes use of radiance engine and has interfaces for enhancement of geometry and complexity issues
Light works	Ray tracing	fast preview of the image of lighting and materials within the scene
DAYSIM	Ray tracing	Precise sky modeling taking into account the sun position and real sky distribution

Table 1.2.Location of a Room Model

Parameter	Values
Longitude	73.51˚
Latitude	18.32˚
North Alignment	0.5˚
Room Dimensions	L=12 ft W=12 ft H=12 ft
Time	5h deviation from GMT

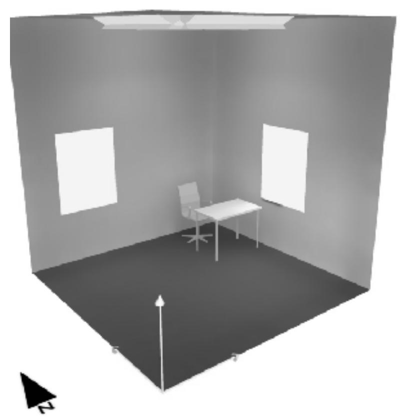

Fig. 1.1. 3D representation of a 'Room Model'

day (22nd December, 2013). The average energy in foot candles evaluated from these simulations is given in table 1.3

It is recommended that minimum light intensity required in test space is 40 FC. From table 1.3, it is observed that in the morning hours (from 9 a.m. to 3 p.m.), sufficient daylight is available in the room (up to 40FC). After 3 p.m. artificial lighting is required. So to find the energy efficient luminaire arrangement, simulations are done from 3 p.m. to 6 p.m. According to the availability of daylight in the room, the luminaires are dimmed. The energy saving (in percentage) of these luminaire arrangements assuming overcast sky model are given in table 1.3.

Total average energy consumed is calculated using the formula given below:

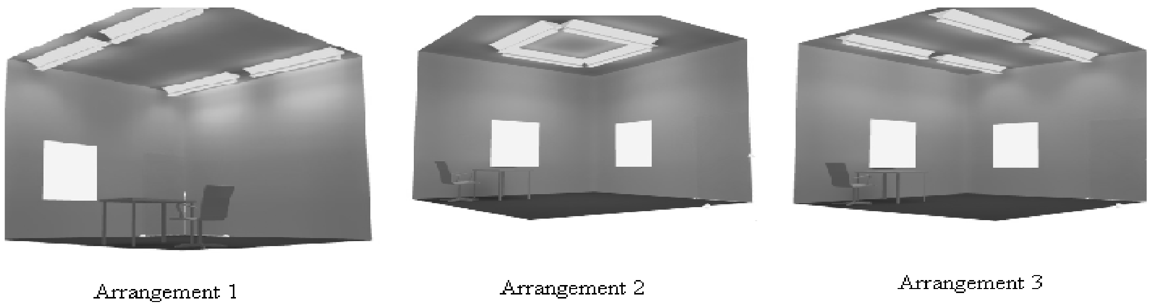

Fig 1.2. Luminaire Arrangements

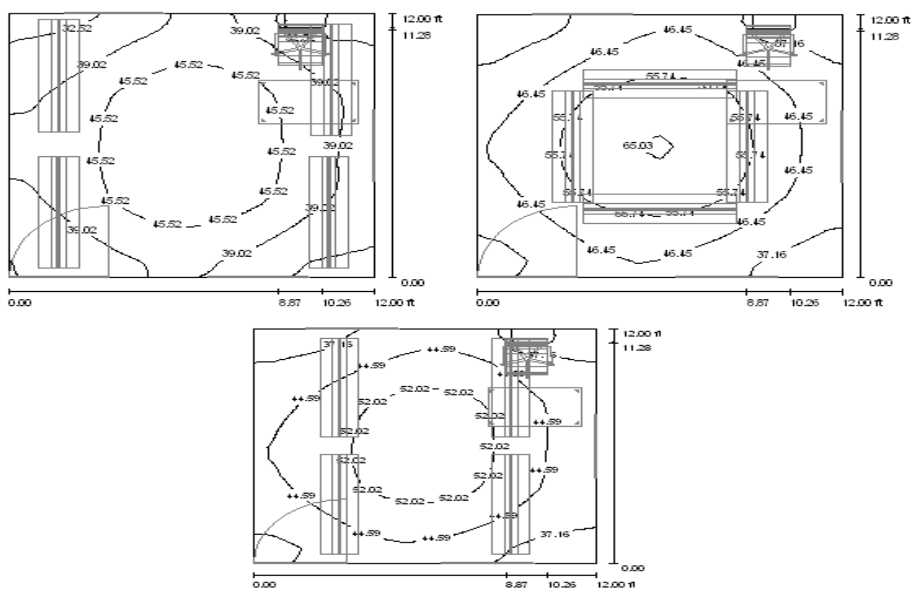

Fig1.3 Illuminance diagrams of Luminaire Arrangements 1, 2 and 3

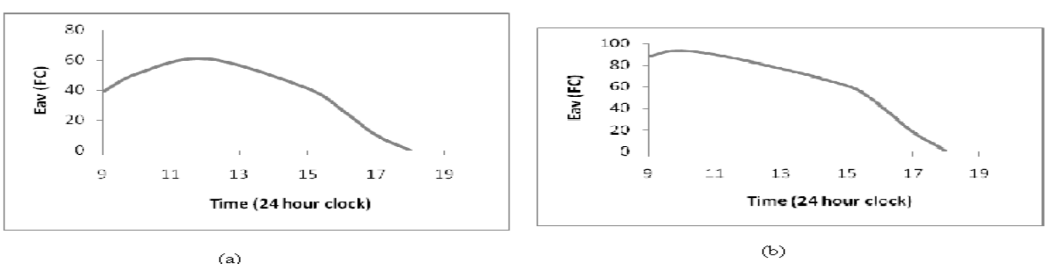

Fig1.4 Daylight simulation graphs (on 22nd December, 2013)
a. Overcast Sky Model b. Clear Sky Model

Table 1.3 Energy saving (%) for three luminaire arrangement

Time	Lumianire Arrangement 1	Lumianire Arrangement 2	Lumianire Arrangement 3
3.30 p.m.	87%	88%	85%
4.00 p.m.	70%	72%	68%
4.30 p.m.	53%	58%	55%
5.00 p.m.	35%	40%	28%
5.30 p.m.	15%	20%	8%
6.00 p.m.	0%	0%	0%

Total energy consumed = time duration X energy consumed by luminaire.
The calculations were carried out for above mentioned luminaire arrangement. It was found that arrangement 1, 2 and 3 saves 78%, 80%, 77% energy respectively. So, energy, arrangement 2 is more energy efficient arrangement as compared to other two arrangements. As the dimensions of the room are small, there is no

much scope for the luminaire arrangements. However, applying the same method, the energy efficient luminaire arrangement can be found out by forming the different luminaire arrangement for any space or in a whole building.

For real time control, the simulation runs that are needed for energy efficient lighting have to be practically less and the time taken by each run has to be small. In addition, seasonal simulations require large amount of runs. It was observed that DIALux calculations are remarkably fast and hence it becomes an attractive proposition under such scenarios.

CONCLUSIONS

Lighting simulation tools play an important role in finding the energy efficient lighting for a given space. There are two major light processes employed in lighting simulation tools, namely radiosity and ray tracing. Some tools made use of either one of these processes. However most of today's tools model lighting combining both these techniques. This paper reviews lighting simulation tools available today and discussed issued related to these tools.

A 'Room Model' is build using DIALux 4.10 simulation software. Daylighting is very dynamic because of the environmental factors such as sky conditions, cloud cover and solar radiation; building factors such as type, window orientation, neighboring buildings etc.; room layout factors such as partition, irregular floor plan, configuration change, presence of furniture etc. along with occupancy fluctuation. For finding the energy efficient lighting arrangement of luminaire for a given room model, artificial light and daylight has to into account while performing the simulations.

In this paper, the systematic procedure of simulation in DIALux is presented and the corresponding results are discussed. The method to find the optimized luminaire arrangement is described taking the example of room model. The same procedure can be use to find energy efficient luminaire arrangement for a building or for any space.

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