EVALUATION OF FOUR ARTIFICIAL LIGHTING SIMULATION TOOLS WITH VIRTUAL BUILDING REFERENCE

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ABSTRACT

There are number of software environment available to conduct lighting simulations to support researchers and designers. This paper compares and analyses performance of four lighting simulation programs (AGI32, DIALux, RADIANCE and RELux), which are dedicated to provide physically accurate lighting calculation. Along with the evaluation of modeling ability and software features two significant aspects focussed in this study are accuracy in calculating illumination level and luminaire number for interior spaces. Illumination level calculation is validated by Commission International de Eclairage (CIE) recommended methodology known as CIE test cases. Another virtual space is used to evaluate luminaire number calculation capability. Modelling and simulation were conducted by all four packages. Validation were done by comparing simulation results with analytical and manual method calculation.

INTRODUCTION

Lighting is a significant built environment design criteria, and architects/designers always keen to expend efforts to deliver optimal lighting solution. Along with the day-lighting, artificial or electric lighting is now obligatory to meet building lighting requirement. Computer simulation packages exist to support lighting designers through facilitating prediction and evaluation ability of design decisions. A number of lighting simulation packages exist to support designers and their capabilities vary in modelling, calculation and output features.

A comprehensive review of few earlier validation studies can be found in Roy (2000). Beside academic researchers, assessment of simulation accuracy also found form individual organizations engaged with tool development (DIALux, INTEGRA). Comparatively more validation studies are focused on day lighting as variability of natural light intensity made it more complex to model appropriate daylight environment (Ashmore and Richens 2001). However considerable interest also exist in modeling and simulating artificial lighting, and it can be suggested that simulation tools play vital role in designing artificial lighting

environment. Li and Tsang (2004) studied the agreement of lighting simulation output with daylight and artificial lighting with RADIANCE and achieved satisfactory results. They also concluded that computer simulation can play important role in designing energy efficient lighting design. Evangelos and David (2005) reviewed four lighting simulation tools includes Desktop RADIANCE, RAyfront, RELux 2004 Vision and Lightscape based on measured daylight data, user interface and help manuals. A systematic study under International Energy Agency (IEA) Task 31 (IEA 2005) evaluated two lighting computer programs (RELux Professional and Lightscape) and introduced the application of the CIE test cases methodology. This study included 32 test scenario to evaluate accuracy of lighting calculation programs for artificial and day lighting (Maamari et al. 2006). The study is based on theoretical principles and reference data, and established the test scenarios as a strong methodology to evaluate lighting computer programs. Most of the studies primarily focused on assessing illumination level (Li and Tsang 2004; Evangelos and David 2005; Maamari 2006), few studies also attempted to evaluate luminance environment (Roy 2000) with measurement. Apart from the simulation tools mentioned above newer tools are also developed with the advancement of software and hardware technology. A list of existing lighting simulation programs with brief description can be found in Department of Energy - Building Technologies Program (DOE 2008) website.

This paper studies and compares four contemporary lighting simulation programs. Evaluation criteria included the accuracy of calculation output (illumination level and luminaire number); ability to model light source and scene geometry; and flexibility in data manipulation.

SELECTION OF SIMULATION PACKAGES

Overview

For this study primary focus in considering simulation programs were ability to model and calculate artificial lighting. Four simulation tools were selected based on wide use, acceptability, availability and previous references.

Selected Packages

Selected lighting simulation packages for this study are:
- AGI32 v2.04

- DIALux 4.6
- Ecotect 5.5 + Radiance
- Relux Professional 2007

AGI32 is a lighting simulation tool for daylight and artificial lighting developed and distributed by Lighting Analyst. This dedicated program has integrated 'raytrace' and 'radiosity' based calculation engine to produce lighting calculations and photorealistic images. Ecotect is a building simulation program introduced by Square One Research. The program is a building performance analysis tool to be used at the earlier stage of design; it can perform lighting calculations beside energy and thermal simulations. The program is capable of using RADIANCE for lighting calculations and provide illuminance and luminance values over a customized analysis grid, or image output. Ecotect and RADIANCE combination are more used in academic research rather than professional lighting design. Radiance is a radiosity based lighting simulation program and uses backward raytracing process for simulation developed in Lawrence Barkely Laboratory (Larson 1998). Developed by DIAL GmbH DIALux is a widely used commercial package in lighting design, which is available for free through lighting manufacturers' websites. This program is customized for interior and road lighting. The program provides output in customized pdf format and additionally uses POV Ray to produce photorealistic images. Relux Professional is developed by Informatik AG, can be used both for interior and exterior. This program uses average indirect fraction methodology for calculation and can produce photorealistic image output by RADIANCE through Relux Vision interface.

COMPARISON OF SIMULATION TOOLS

Scene Modeling

Generally simulation packages are able to create 3D models with built in facilities and interface. All packages used in this research are capable of modeling 3D environment. RADIANCE, which does not provide any 3D modelling interface. Ecotect is capable modelling of 3D geometry and compatible to export to RADIANCE format precisely. DIALux, Relux and AGI32 provides their own library for preset 3d objects. In some cases preset object libraries are an advantage; on the other hand they can limit number of polygons and detail definitions.

Table 1: Acceptability of standard 3d formats.

	Ecotect	DIALux	Relux	AGI32
Dxf	√	-[1]	√	√
Dwg		-[1]		√
3ds	√	√	√	
VRML Object	√		√	

[1] Imports as lines only, no 3d surface or object.

Another important aspect is importing ability of 3D models from standard formats, because there is a considerable interest found among the users to use models built for other purposes. In some cases complex models are desired to be modelled by standard CAD packages (Roy 2000). Differences are found in importing and handling ability of these formats among the packages. A comparison is shown in Table 1 of standard 3D model importability among the packages. Images demonstrated in Figure 5 are rendered by importing same models in all four packages developed in a standard CAD package. Important aspect identified while importing 3D definition to the simulation programs is, defining 3D surface normals appropriately while modeling to make readable by simulation tools.

Luminaire Modeling

One of the significant aspects for artificial lighting simulation is defining the luminaire shape and light output appropriately. Along with the capability of accurately reading photometry files, it is desired to get enough opportunities to modify parameters separately to model the desired luminaire, such as, lamp colour, lamp loss factor or correction factor etc. In this case all four programs evaluated in this study well accept IESNA photometric format. AGI32, DIALux and Relux can take luminaire definition in greater detail by online or downloadable catalogue from manufacturers.

In case of Ecotect + RADIANCE the IESNA photometric profile file needs to be converted by 'ies2rad.exe' program to be readable by RADIANCE. Ecotect v5.5 itself can import photometry files but unable to import intensity distribution of multiple horizontal axis. Also it fails to import luminous flux and dimensional form from the photometry. These inabilities can be resolved by converting IESNA photometry by 'ies2rad.exe' program and use from external RADIANCE readable light definition file.

DIALux, Relux, AGI32 also afford opportunity to modify the parameters of luminaire definition like, luminous flux output, lamp colour, dimension, mounting height etc. The output multiplier can be modified by 'correction factor' in DIALux and 'Lamp Loss Factor' parameters in AGI32.

Output Features

Comparisons of few output features are given in Table 2 desired by a standard lighting simulation package which helps in lighting design. These selections of features are referred by Ashmore and Richens (2001). Two significant output features are generation of photorealistic rendered image and data visualization.

The selected packages use radiosity and raytrace based rendering technology to generate simulated images, where appropriate use of parameters can produce photo-realistic images. A comparison of rendered images by four simulation programs are presented in Figure 5 with a test case of single bed patient room.

Visualization of data is possible over reference grid points for all the packages with graphically rendered iso-illuminance contours. In case of AGi32, DIALux and RELux this data is not exportable to other formats. Ecotect is

capable to save analysis grid data in delimited text format, which provides further opportunity in data handling through external applications. Along with this Ecotect also provides opportunity to save multiple data in one analysis grid, which provides improved manipulation ability of simulation data.

Table 2: Comparison of output features of different simulation packages.

Output features	Ecotect + RAD	DIALux	Relux	AGI32
View of working plane with iso-illuminance contours	√	√	√	√
View iso-illuminance contours in scene	√	√	√	√
False colour in camera view	√	√	√	√
Illuminance at a reference point	√	√	√	√
Photorealistic renderings	√	√	√	√
Luminance at a reference point	√	√	√	√
Virtual Reality Markup Language	√		√	
Walkthrough animation (rendered)				√
Luminance and illuminane level with pointer scene or camera	√			
Simulation data manipulation in scene	√			
Simulation data export	√			

Calculation of Illumination Level

Illumination level calculation is one of the primary objectives of lighting simulation programs and is required while lighting configuration design. In this paper we presented validation of illuminance value calculation by four selected packages by applying CIE test case. Detail methodologies are described in the following sections.

Application of The CIE Test Case
Commission Internatiole de Eclairage (CIE) established an evaluation procedure of the output performance of lighting simulation packages published as IEA SHC Task 31 (Maamari 2005). The validation approach is based on testing different aspects of lighting simulation by individual test scenarios. The approach includes validation procedure for both artificial and day-lighting and based on theoretical principals where comparison is done with analytically calculated reference data to avoid uncertainties (Maamari et al. 2006).

In this study we have conducted two experiments with CIE test case scenario those validate performance of artificial lighting. Selected simulation packages are already discussed in previous section.

Simulation Parameters
Following simulation parameters are used for this test, some of the parameters stated here does not affect illuminance level calculation but radiosity/raytrace based image generation.

Ecotect + Radiance:
RADIANCE export parameters:
Model detail: High
Light variability: High

Image quality: High
Indirect reflections: 4

AGI32:
Mesh level: 1.1 - 3.2 (depending on the size of the plane)
Calculation mode: full
Radiosity Convergence: Maximum Steps: 1000
Stopping Criterion (Convergence): 0.01
Display Interval: 10
Electric and Day lighting for All other surfaces
Maxium Subdivision Level: 5 (level 3 is adequate in most cases)
Minium Element Area (Sq.M.): 0.0465
Element Luminance Threshold: 1.5

DIALux:
Calculation options: very accurate
Calculation method: standard
POV Ray settings:
Smooth edges: On
Indirect calculation: High
Radiosity settings: Count 70; error bound 1.800; pretrace_start 0.800; pretrace_end 0.040; gray_threshold 0.200

Relux:
Calculation parameters:
Precision: High indirect fraction
Raster: 0.7
Active Dynamic Raster: on, fine

Artificial direct lighting – point light source
Scenario used for this test is used as same as described in CIE test case conducted by Maamari (2006) and illustrated in Figure 1. The virtual space is a 4m x 4m in dimension with height of 3m. A point light source is located at the centre at 3m high and analytical reference data were calculated in horizontal surface at floor level.
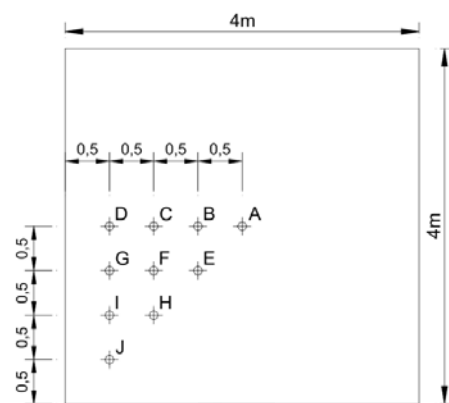

Figure 1: CIE test case suggested reference points' position for point light source as described by IEA (2005).

Analytical reference data are calculated by the equation:

$$E = I \frac{\cos\theta}{d^2}$$

Here, *E* is the horizontal illuminance (lux), *I* is the intensity (candela) of the point light source in the direction of the

reference point; θ is the incident angle of the light arriving to the reference point from the light source (radians); d is the distance between light source and the reference point.

Simulation esults are presented in Figure 2, which demonstrates very identical results among four simulation programs with analytical reference data and maximum deviation is found within 0.46%.
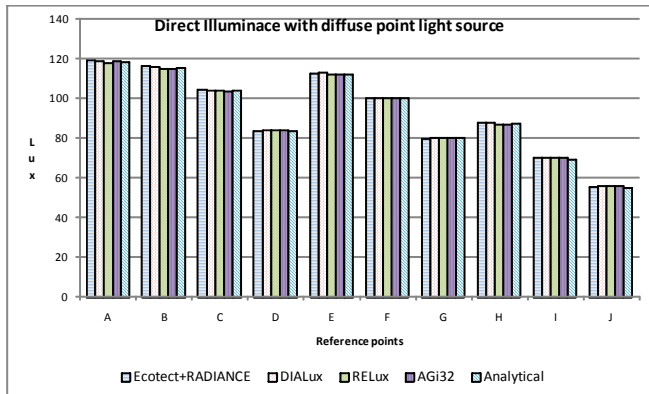

Figure 2: Comparison of illuminance level simulation with with analytical results by point light source.

Artificial direct lighting – area light sources
This test evaluates capability of the lighting program to calculate illuminance level from an area light source. Test scenario is a square space (4mx4mx3m), where analytical reference data is calculated horizontally as explained in Figure 3. Light source is a 1m x 1m in size with uniform intensity distribution.
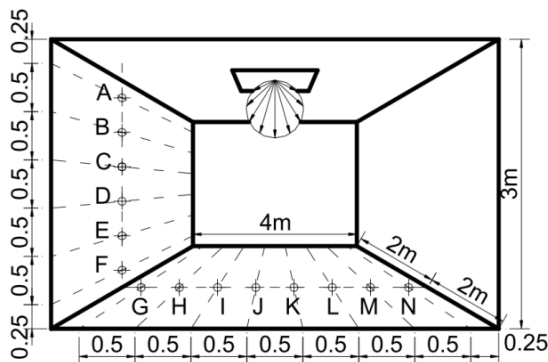

Figure 3: Model description of CIE test case for area light source as described by IEA (2005).

Reference values are calculated by following equation:

$$E_1 = M_2 \times F_{12}$$

Here, E_1 is the direct illuminance at any reference point received from the area light source; M_2 is the luminous existence or emittence of the area light source (lumen/meter^2); F_{12} is the configuration factor between the receiving area and the light source. More details of the calculation is explained in Maamari (2006). Figure 4 represents the result of this test where simulation programs are well equivalent with the analytically derived reference data.
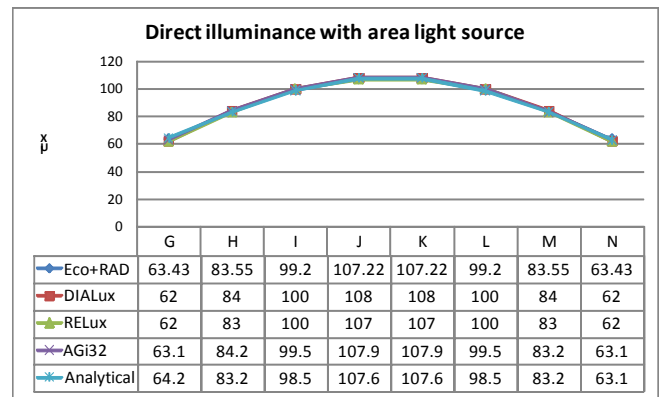

Figure 4: Comparison of illuminance level simulation with analytical calculation by area light source.

Calculation of Luminaire Number

Calculating required number of luminaires takes place during lighting design of interior spaces. AGI32, DIALux and RELux are facilitated with calculation opportunity of required number of luminaires for a defined space. Lumen Method is recommended by Chartered Institute of Building Services Engineers (CIBSE 2002) to calculate required number of luminaires. Also Zonal Cavity method is described as another recommended procedure of luminaire number calculation by Illuminating Engineering Society of North America (IESNA 2000). A comparison of these three computer programs and manual Lumen Method calculation in generating number of luminaires is accomplished to evaluate authenticity of the lighting programs. This test is conducted in a virtual space for one luminaire.

Virtual Space Definition
The virtual space dimension is 15m(length) x 25m(width) x 2.7m (height). Surface reflectance are: Wall 0.50, Floor 0.20, Ceiling 0.70. Target maintained illuminane level is 500 lux (horizontal) over working plane height (0.75m).

Computer and ManualMethod Calculation
Luminaire model used for this study is QuattroC 3x18w T26 HF EFL Dif manufactured by Thorn Lighting. Utilisation factors were taken from luminaire manufacturer's catalogue available in Thorn Lighting website. IES photometry of this luminaire is used in all programs to derive required luminaire number in all lighting programs. Results are described in Table 3 and discussed in section 4. Manual calculation by Lumen Method (CIBSE 2002) is described in the following section:

Room definition:
Length (L) = 25 m; Width (W) = 15 m;
Height (H) = 2.7 m
Height of working plane = 0.75m;
h_m (ceiling height – working plane height)= 1.95
Room index (K) = L*W/{(L+W)* h_m} = 4.807
Target Illumiance level (E)= 500lux
Area (A) = 375 sqm
Flux output of one lamp (F) = 1350
Number of lamps (n) = 3

Maintenance Factor (MF) = 0.80
Utilisation factors (UF) = 0.58 [derived from datasheet using Room Index]
Numbe of luminaires, n = E x A / F x n x MF x UF
n = 99.78 ~ 100

Table 3: Comparison of luminaire number calculation between different packages and manual methods.

Name of the program	Calculation method	Luminaire number calculated	Luminaire used in design	Configuration	Consider ceiling grid in arrangement
RELux	Average Indirect Fraction	102	110	11x10	No
DIALux	Efficiency Method	Not showing	110	11x10	No
AGi32	Zonal Cavity Method	104	104	13x8	Yes
Manual Calculation	Lumen Method (CIBSE)	100	104	13x8	N/A

RESULTS AND DISCUSSIONS

Illumination Level Calculation

Simulated illuminance values are found very identical with the analytically calculated values, which authenticates the acceptability of lighting calculation for similar types of scenarios. This study only covered two CIE test cases particularly focused on point and area light sources without inter-reflections. Opportunity remains to validate with other test cases and with more complex circumstances. Important aspect noticed is influence of simulation and design parameters on output, like Maintenance Factor, Lamp Loss Factor, etc. which must be considered in real case simulation.

Luminaire Number Calculation

All programs demonstrated similar results compared to Lumen Method calculation. RELux calculated number of luminaires were 102, suggested to use 110, arranging 11 in one axis and 10 in the other. Results of other programs are shown in Table 3. A manual Lumen method calculation derived required number of luminaires 100 and an arrangement of 104 luminaires (13 x 8) showed both average illuminance (above 500 lux) and uniformity of illuminance (Minimum Illuminance / Average Illuminance, UG1 > 0.5) were able to maintain. This suggestion is also verified by theories of spacing-to-height ratio (CIBSE 2002). This finding suggest automated arrangement of luminaires is not always precisely ensuring the most efficient power density, however it achieves a near result. Another limitation identified, RELux and DIALux were not considering ceiling tile grid in automated luminaire arrangements. Even though ability to customize position of luminaires are available but this can raise complexity and include extended manual arrangement process. AGI32 considers 600x600mm or customised ceiling tile grid arrangements for luminaires.

However, in this test output failed to meet criteria in some points to ensure recommended average illuminance and uniformity of illuminance.

Automated calculation of required number of luminaires are not always found most energy efficient, but meets uniformity of illuminance criteria. However, disability to consider ceiling tile grid is found a primary disadvantage for DIALux and RELux. Even though AGI32 showed potentiality in considering ceiling tile but further modification is desired for more acceptable result. Application of simulation tools reduce calculation steps and able to take all necessary information directly from photometry to calculate luminaire number, where in manual calculation sufficient luminaire data like Utilisation factors, Lamp lumen output etc. must be derived from technical sheets or light definitions.

None of the programs are considering multiple type luminaires in configuring number and arrangement as they are focused on similar type of output available from manual calculation methods. Newer calculation/optimization methodologies using advanced computer simulation techniques can play role in supporting lighting design decisions through automated calculation of multiple luminaire types.

General Discussion of The Packages

AGi32 is found able to handle complex models with its built-in modelling and importing ability from other formats. For radiosity calculation it provides opportunity to control some advanced parameters like 'mesh level' of surfaces, 'maximum subdivision level', 'minimum element area' etc. Also ability to control detail luminaire definition is found in this program. The program is found as a complete package to provide opportunity to model and calculate lighting, but few limitations found in manipulating and visualizing data in scene, which could be a drawback for analysis and design.

Ecotect is found compatible for modelling and exporting environment geometry for RADIANCE calculation, which includes preparing 3D models, positioning luminaires, setting cameras and setting initial material properties. Using of RADIANCE from Ecotect can be complicated for some users as it is not providing any separate interface for handling RADIANCE materials including luminaire profiles. The use of photometry requires additional use of other RADIANCE commands and demands supplementary knowledge over that.

Customizable analysis grid provides option to use the grid in several ways for analysis and visualization. Analysis grid allows multiple data to be saved in one and can provide customized output (e.g. difference between two sets of data) with graphical representation. The program also exports analysis grid data and allow extended analysis through external programs. The program can be found complicated for some users, as this is a building performance simulation program and contain many other operations other than lighting calculations.
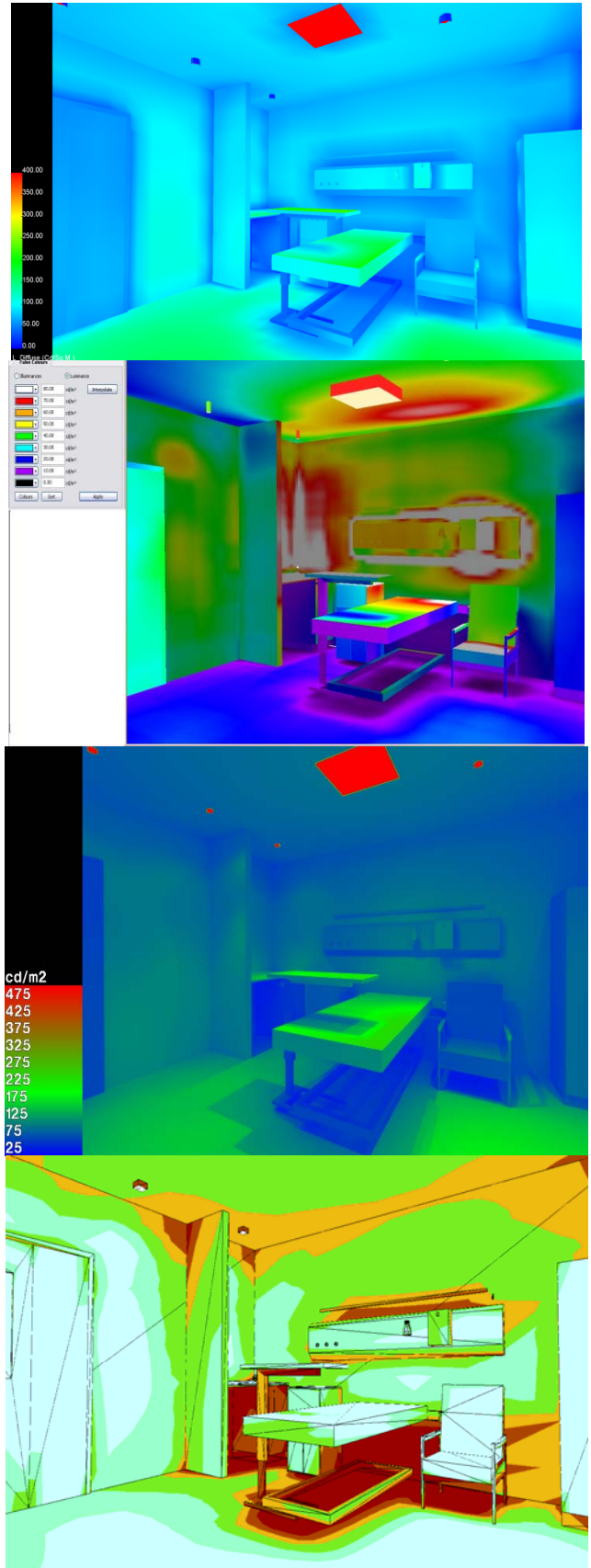
Figure 5: Radiosity and raytrace based rendered images (left) and pseudo colour views of luminance distribution (right) by four packages of a patient room. Image order (from top): AGi32, DIALux, RADIANCE (from Ecotect) and RELux Vision.

In DIALux some users can find complications in building complex geometry for its limited model building and 3D object import ability. This is a qualified package for quick calculation with good results with photorealistic image.

Relux can be found prospective in defining complex scene description with ability to import 3D geometry from other standard formats. The program also provides limited opportunity to customize material properties and uses RADIANCE to produce photo realistic image.

CONCLUSIONS

The scene modelling and luminaire defining ability found rational enough for all the packages where DIALux showed possible lack in building complex geometric description. Illuminance value calculation is found within acceptable precisions for all programs in case of simple geometric descriptions and direct lighting. Opportunity still remains for complex geometrical scenarios with inter-reflections to validate. Also it can be suggested that output result is largely dependent on influential physical properties of the environment and light source, so it is advisable to gather sufficient and appropriate space definition and calibrate packages before running simulation. Disability in luminaire number calculation considering ceiling grid can imply limitations or complexity in applying the tools in design practice. More intelligent computation ability is expected in this case. Futhermore application of simulation can be extended to automated luminaire number and arrangement design considering multiple types of luminaires, which demands further study in lighting calculation and optimization methodologies.

Another aspect distinctly lagging in all programs is manipulation and handling ability of output data. Ecotect shows some advanced features for data manipulation and visualization with wider interactivity while other programs found limited in visualizing and exporting output data that is desired for analysis and design. Considering all these AGI32 and Relux found to be potential complete packages dedicated to lighting simulation though some modifications are desired. Combination of Ecotect and RADIANCE gives flexibility in defining scene geometry, creating advanced material and visualization of data; but complexity in operation can make it more applicable in research and development work rather than supporting design decisions.

This study assessed calculation output of illumination level and luminaire number by the programs and used virtual building reference. Lighting environment design involves other aspects like glare evaluation, luminance distribution and moreover energy calculation. Scope remains for future studies to evaluate the programs' ability to manipulate these parameters and in real building reference.

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