

LIGHTING/DAYLIGHTING ANALYSIS: A COMPARISON

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ABSTRACT

This paper will explore both the advantages and disadvantages of several daylighting simulation programs. A number of criteria were established to help measure the efficacy of these programs, especially as they relate to understanding the fundamentals of daylighting performance. The question, is learning enhanced by one program over another will be given particular attention. In addition, these programs will be compared as to their accuracy. For example, we have found that several of these programs inaccurately use an isotropic model to describe the clear sky condition. Recommendations will also be made as to how these programs can be improved, for example, how well the results of these programs can be linked to other tools for further manipulation. Our paper concludes with a matrix that highlights the results of our comparison.

1. INTRODUCTION

Daylighting simulation tools have been available for some 20 years, however their use has been mostly restricted to researchers or lighting specialists. During this same period computer rendering programs also emerged and today are widely used by designers. These rendering programs usually give a photo-realistic output, but often have inaccuracies in their light rendering, especially natural light. The daylighting programs on the other hand were mostly concerned with accuracy. Most of these programs initially did not output any rendered images of the scene, giving only numerical or iso-lumen output. In addition, these programs involved a lengthy effort to learn that limited their use, especially among designers. The latest generation of these programs is attempting to bridge the gap between

lighting simulation and photo-realistic rendering. In some cases, this has been done by compromising the accuracy of the lighting simulation.

2. METHODS OF DAYLIGHTING ANALYSIS

Three types of design tools have been used to predict interior daylight illumination: physical scale models, graphic techniques, and calculations. A detailed discussion of each is beyond the scope of this paper; we focus here on computational approaches.

Calculations can provide a fast and accurate assessment of illumination levels for typical room and glazing design. Present procedures for calculating illumination can be divided into two categories: simplified procedures, which often make simplifications and assumptions that may reduce flexibility and accuracy; and computer programs, which although they may be more flexible and accurate, require the preparation of detailed input data.

2.1 Simplified Calculation Programs

As microcomputers began to emerge in the early 1980s, a number of manual calculation procedures were introduced into this environment. Several of these programs were just automated versions of the popular lumen method (which is a coefficient of utilization method), while others utilized first principles models such as using the CIE sky luminance distribution functions for the overcast and clear skies. Of these Microlite was one of the most popular. Microlite predicted daylight illumination at any point within a room. The program utilized sky luminance distribution functions that are consistent with the CIE overcast and clear sky functions. The light reaching the interior point being

considered is separated into two components. Light arriving directly from the sky (Sky Component or SC) is calculated using a source area formula. Light reflected from external and internal surfaces (Reflected Component or RC) is calculated using the split flux approach. The total of these two components is given as either the daylight factor (the ratio of illumination at the reference point to the illumination on an unobstructed horizontal surface) or as illumination (in footcandles) for the point being considered. Microlite output was very advanced for the time, in addition to traditional tabular output it generated a number of graphical formats in the familiar architectural representations of plan, section and 3D axonometric projection. While fast and easy to use, the split flux approach used for calculating internal surfaces did not prove accurate enough for detailed daylighting analysis.

2.2 Computer Simulation Programs

Detailed lighting simulation began in the late 1970's with the introduction of Lumen II and around 1980 a daylighting feature was added. Lumen II could analyze internal reflectivity and complex external obstructions very well. However, it required a main frame or service bureau for accessing, which limited its use to the illuminating engineering community. In the mid-1980's, Superlite emerged as a powerful daylighting simulation tool which could analyze complex spaces such as L-shaped rooms. Initially, it required a very powerful operating environment. Later a version for MS-DOS environment was developed. However, the DOS version did not receive the support it needed and has been eclipsed by Windows based programs. In the later 1980's Radiance was developed using a new radiosity model in combination with a powerful graphic package. It was able to produce highly rendered analyses. Unfortunately, this version of Radiance required an expensive graphic workstation which limited its application. Today's desktop computers are equivalent to the graphic workstations of a decade ago, thus a desktop version of Radiance has been developed (it will be discussed below). In the early 1990's Adeline was developed. Though not a daylighting program, in essence it was a CAD interface that formatted input data for either a Superlite or Radiance analysis. Thus, Adeline was an early attempt at interoperability of design information.

There are several programs that are often misrepresented as daylighting programs; the most common of these are DOE-2 and Building Design Advisor. The daylighting analyses that these programs do perform are in support of energy analysis and do not lend themselves to detailed daylighting studies.

Today, there are several commonly used programs that claim to have the ability to simulate distribution of light

from natural and artificial sources. The four that have been chosen for investigation in this study are:

Lightscape 3.2: (www.lightscape.com)

Lightscape is a specialized visualization tool for artificial and natural light. The program is Windows based and since being purchased by AutoDesk, has started incorporating features from the company's other products (AutoCAD, 3d MAX etc.). The next planned version of AutoDesk's rendering program 3d VIZ, called VIZ4 will incorporate all the functionality of Lightscape.

Desktop Radiance 1.02: (<http://radsite.lbl.gov/deskrad>)

Desktop Radiance is a Windows version of Radiance that was specifically designed to integrate a realistic rendering package with a CAD input environment. Desktop Radiance also facilitates data entry by creating libraries of materials, glazings luminaires and furnishings. It was developed in combination with the Lawrence Berkeley National Laboratory, Pacific Gas & Electric and the California Institute of Energy Efficiency.

Lumen Micro 2000: (<http://www.lighting-technologies.com/Products/LM.htm>)

Lumen Micro is the successor of Lumen II and is recognized as the industry standard by the lighting design and engineering communities. It operates in a Windows environment and is capable of detailed indoor, outdoor and daylighting analysis. It has an extensive product library with over 70 manufacturers contributing luminaire data, which makes it a powerful electric lighting analysis tool.

FormZ RadioZity 3.80: (www.formz.com)

FormZ RadioZity is the version of formZ that includes radiosity based rendering. FormZ is a general-purpose solid and surface modeler. According to their website, this program can simulate the distribution of light in an environment in a physically accurate manner. Although not commonly known as a daylighting simulation program, it is being analyzed because the ability of the program to do accurate sunshading and radiosity rendering lead to the claim that it simulates daylighting accurately.

3. THE PARAMETERS

The parameters used for comparing the daylighting programs are as follows:

3.1 Modeling & Input

Most of the daylighting programs do not have geometric modeling capabilities, but rather allow the importation of CAD data modeled in some other program. Often this transfer process is not smooth, because of incompatibility

with peculiar model geometries (like 3d-solids, meshes etc.), surface normal orientation problems, and problems with layers and object groupings (blocks).

Lightscape: The program can import dwg, dxf, 3ds and lws formats. The import process is fairly smooth through the import wizard, which allows some tweaking. The surface orientation wizard identifies and corrects incorrectly oriented.

Desktop Radiance: Since the program works inside AutoCAD, the modeling process is built-in and doesn't create any major problems. All the surfaces in Desktop Radiance are considered infinitely thin (zero thickness) and cannot have different materials on front and back surfaces. This makes the surface normal orientation of materials irrelevant, except for transparent surfaces, which should have their normals aligned properly. The program has a good feature for checking and reversing normal orientations.

Lumen Micro: Although the program can import dxf and dwg file formats, these models can only be used as a background for the Lumen Micro modeler to construct the model. This modeler has serious limitations. Only simple orthogonal geometries are allowed. Sloping or curved surfaces have to be approximated by orthogonal surfaces.

FormZ RadioZity: It is a fairly sophisticated modeling program with advanced features. It can also import most other CAD formats.

3.2 Daylighting Set Up

One of the most important components of the daylighting setup is a sky model. Sky condition is a dynamic entity dependant on time and location. Most daylighting simulation programs do estimation by choosing a standard sky model. The most common sky models are the ones developed by the Commission Internationale de l'Eclairage (CIE), for clear and overcast skies (see Fig.1).

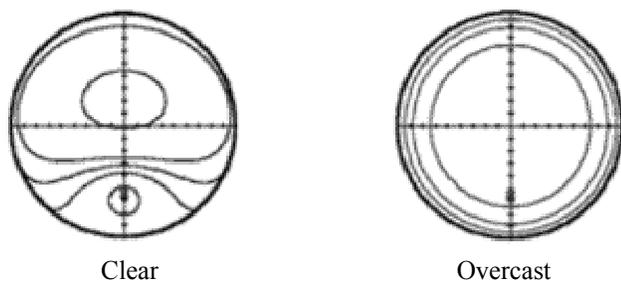


Fig. 1 CIE Sky Luminance Distribution Functions

Correct sky models are necessary to accurately simulate daylighting. Custom sky models can be defined for the required locations using some third-party programs like the SDF-Web client (<http://eng-sun3.murdoch.edu.au/~geoff/webpages/>).

Lightscape: The sky condition setup can be done by selecting one of three sky conditions (Clear, Intermediate and Overcast) or by typing a numeric value. The sun can be set up by selecting a location or through direct input of altitude and azimuth. For a direct input, sun illuminance has to be typed in. The daylighting wizard can be used to quickly set up the meshing and simulation parameters depending on the kind of geometry and light conditions. Alternately, these values can be typed in manually. Our tests with the program showed that it does not use an accurate clear sky model. This is clear in the images in Fig.2, which are simulated for a south-facing window with sun being due east, with clear sky conditions. The clear sky illuminance is asymmetrical in this case and should result in an asymmetric distribution of light in the room, as seen in the Lumen Micro example.

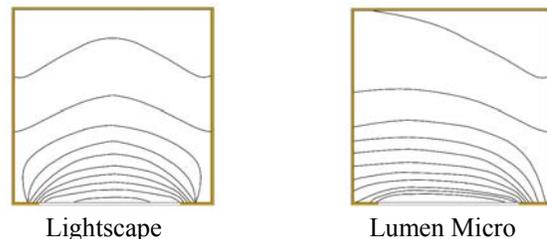


Fig 2. Iso-lumen contour plans for similar atmospheric conditions

Desktop Radiance: The program has just six locations built in. New locations can be fed in by supplying latitude, longitude, time zone and turbidity. Apart from the three sky conditions, a uniform sky can also be selected. The simulation can be set up for luminance, illuminance or daylight factors. According to the Desktop Radiance website, later editions of the program will allow custom sky settings based on TMY weather data.

Lumen Micro: The program was primarily aimed at artificial lighting design and analysis. This fact is clearly seen by its inability to process daylight without addition of a luminaire, although the wattage can be set at 0.

FormZ: The program does not have any daylight setting options. The sun can be set up through the location window.

3.3 Surface Properties

Lightscape: Any source of daylight has to be represented by a plane, which is defined as an opening or as a window. The material assignment can be done from a limited set of built-in materials or from material libraries. The built-in materials are categorized according to the surface type (wall, floor etc.) The wizard shows some safe or typical values of reflectance, transmittance etc. for each of these. An unusual input results in a warning message appearing in the window. Procedural textures can also be generated and applied to surfaces.

Desktop Radiance: The program has a substantial collection of materials in its library. The material assignment dialog box has useful find and sort functions. Custom materials can be easily defined using the Materials Editor.

Lumen Micro: The program does not have any material assignment feature. Surfaces can only be assigned color, spectral properties and reflectances. A very useful feature of the program is its ability to setup a work plane height without physically making a surface. The final lighting levels are laid out on this imaginary surface. Similarly, the exterior ground is also calculated for reflectance, without the presence of a physically constructed surface.

FormZ RadioZity: The program has an extensive materials library. New materials can be defined easily.

3.4 Simulating/ Rendering

The two most common rendering techniques used by most programs are raytracing and radiosity

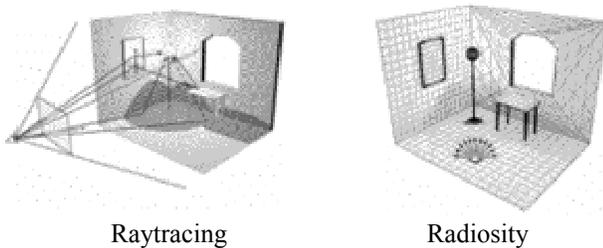


Fig. 3. Rendering Techniques (www.lightscape.com)

The raytracing technique tracks the path of a light ray as it bounces off or is refracted through the surface. The technique known as "backward raytracing" starts off with a ray from the eye towards the light source. This technique is best suited for surfaces having specular reflections and refractions.

Radiosity is a much more accurate and process-intensive technique than raytracing. The original surfaces are divided into a mesh of smaller surfaces. In the radiosity process, the amount of light distributed from each mesh element to every other mesh element is calculated. The final radiosity values are stored for each element of the mesh. These values are retained even when the viewpoint is changed, making it possible to render numerous views with the same initial radiosity calculation. The radiosity technique is best suited for diffused reflections and shadows.

Lightscape: Lightscape has a radiosity-based renderer with capability to do a raytrace render for the final output. The user has the control over the mesh density, through direct input or through the wizard. The initial perspective view can be set up by identifying the camera and target points. The radiosity rendering is an iterative procedure, which is visible all the time, allowing the user to stop the calculations if the result is not suitable. Light leaks along joining or intersecting planes have been observed even with apparently accurate positioning of the planes in the model.

Desktop Radiance: The program uses a combination of Monte Carlo and backward raytracing methods of rendering. The most common way of setting up a view is to define a camera within the space and simulating for its viewpoint. The simulation can either be done in an interactive mode, batch mode or no-image mode. The interactive mode opens up a window where the user can see the draft rendered image and change the render settings, if required.

Lumen Micro: The program uses a radiosity rendering technique. The program gives options for detailed and quick calculations. The quick calculation method calculates only the direct component and is therefore not suitable for daylight calculation. The user can choose the calculation grid (for which the simulation will be performed) in a variety of manners, including by defining a custom polygon.

FormZ RadioZity: The program has several rendering options, with radiosity giving the best results among them in most cases.

3.5 Output

Each program has a different approach to the final output of the simulation and rendering process. Depending on the program's focus, the output is either image intensive or data intensive. Some programs generate tools like graphs, tables, isolumen contours, and false color images for the final analysis.

Lightscape: The rendered model can be analyzed by converting to false colors representing various light intensities. Alternately, any surface can be divided up into a grid showing numeric values at predetermined spacing. Clicking the mouse within the image also shows the luminance/illuminance at that particular point. The program also provides a summary for the surface selected, giving its average luminance/illuminance and also the minimum and maximum values. The program apparently has no feature to save these false color and grid images, except by doing a screen capture. Since Lightscape uses radiosity rendering, once the calculations are done, the view can be changed without the need for rendering again. Animations can also be set up easily. The output can be saved in a variety of formats, including VRML, QuickTime VR and even a special stereoscopic format for viewing with 3d-glasses.

Desktop Radiance: The output from Desktop Radiance can be viewed and saved as a rendered image, isolumen contours, false color images or tabular data.

Lumen Micro: The program plots isolumen contours and textureless rendered images. It can also generate detailed reports of the input as well as the output figures. These reports can be customized and also saved in HTML format. Lumen Micro can save the radiosity calculations and export this model to Lightscape for photo-realistic rendering.

FormZ RadioZity: The only output generated by this program is a rendered image or animation.

3.6 User Interface

Lightscape: The program utilizes wizards to enable non-expert users of the program to set up the simulation settings. Many other settings needed for an accurate simulation are not very explicit, and might be overlooked by such a user. For example, the surface normals orientation procedure might be missed, and if the user realizes that after starting the radiosity calculations, the file has to be reopened to make the changes.

Desktop Radiance: All the necessary commands for the program are within one drop-down menu, which is added to its host AutoCAD's interface. The setup interface screens are mostly self-explanatory, but the later screens are not. For example, the review window offers numerous options for fine-tuning the final output, but tends to be a bit confusing to the new user.

Lumen Micro: The Lumen Micro interface is extremely simple to learn and use. It utilizes a checklist toolbar which lists the step to be done in the correct order. Clicking on these steps opens up the required dialog boxes. The whole

process takes considerably less time than any other program used for this comparative study.

FormZ RadioZity: The FormZ interface is mostly mouse-driven. Most of the icons on the toolbars are not self-explanatory and need familiarization before use.

3.7 Online Help etc.

Lightscape: Although the program comes with a detailed help file, some specific daylighting related issues are not clearly dealt with. The web site has some additional information available and hosts a user forum as well.

Desktop Radiance: The help files and tutorials are fairly detailed and supplemented well by the information on the active Radiance and Desktop Radiance user groups.

Lumen Micro: The program has limited help available which is usually sufficient considering the simplicity of the interface.

FormZ RadioZity: The program help files are limited to a brief explanation of the menu and toolbar commands.

4. SUMMARY

The requirement for a daylighting simulation program that is simple to use, yet accurate and capable to photo-realistically render the scenes is still not met completely by any of the programs. Whereas Lightscape renders most photo-realistically, Desktop Radiance is the most accurate and Lumen Micro the simplest. Therefore, one needs to select the program according to the requirements and priorities.

To summarize each program's deficiencies, one could say that Lightscape has inaccurate sky models and doesn't have a suitable report generation procedure. Users of Desktop Radiance have had numerous problems with the program's stability and the complexity of the interface. Lumen Micro is limited by its inability to model complex room geometries. FormZ doesn't really fall into the realm of daylighting programs, since its daylighting algorithm is approximated. Thus, claims made by software vendors need to be carefully evaluated. A more detailed comparison of the programs is presented in the Tables 1 and 2.

5. CONCLUSION

An ideal daylighting simulation program would combine the best features of the existing programs and avoid their

deficiencies. For example, a program with the Lumen Micro interface and reporting structure, with the accuracy of Desktop Radiance and the rendering capabilities of Lightscape would be ideally suited for most professionals requiring daylighting simulation. The future might also see an easy to use simulation environment emerge based on a data model that can be extendible to and shared by other analysis applications. Such an interoperable model will enable designers and researchers to not only design efficient daylit environments, but a whole host of environmental and user sensitive strategies.

6. REFERENCES

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TABLE 1: COMPARISON OF SETUP FEATURES

	Modelling				Daylight Setup				Surface Properties	
	Exchange of CAD Data	Surface Orientation	Layers and Blocks	3d Solids	Different Sky Covers	Accuracy of sky model	Wizard available	Geographic locator	Materials Wizard	Inbuilt Material Library
Desktop Radiance	✓✓	✓	✓✓✓	*	✓✓✓	✓✓✓	✓	✓✓✓	✓✓✓	✓✓✓
Lightscape	✓✓✓	✓	✓✓✓	✓	✓✓✓	*	✓✓✓	✓✓✓	✓✓✓	✓✓
Lumen-Micro	*	✓✓✓	✓	*	✓✓✓	✓✓✓	✓✓	✓✓✓	✓	*
FormZ	✓✓✓	✓✓✓	✓✓✓	✓✓✓	*	*	*	✓✓✓	✓✓✓	✓✓✓

TABLE 2: COMPARISON OF PROCESSING FEATURES

	Simulating/Rendering					Output						User Interface	Online Help
	Radiosity	Raytracing	Iterative procedure	Viewpoints	Memory Requirement	Isolumen Contours	Numeric Output	Photorealistic rendering	Animation	Glare Analysis	Daylight factors	Ease of Use	Extensive Help
Desktop Radiance	✓✓✓	✓✓✓	*	✓✓✓	✓	✓✓✓	✓✓✓	✓✓✓	*	✓✓	*	✓	✓✓
Lightscape	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	*	*	✓✓	✓✓✓
Lumen-Micro	✓✓✓	*	*	✓✓✓	*	✓✓✓	✓✓✓	✓	*	*	*	✓✓✓	✓
FormZ	✓✓✓	✓✓✓	*	✓✓✓	✓✓✓	*	*	✓✓✓	✓✓✓	*	*	✓✓	✓✓