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Technical note

Comparison of radiosity and ray-tracing techniques with a practical design procedure for the prediction of daylight levels in atria

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Abstract

Designers are often facing prescribed requirements concerning daylight in atria. For the accurate prediction of the illuminances the designers should employ either computer simulations or apply empirical equations. This study compares results obtained by a practical design procedure and simulated results using Radiance and Lightscape 3.2.

Keywords: Daylight; Algorithms; Atria

1. Introduction

Limitations in the scope and reliability of conventional daylight factor models for the calculation of illuminance within atria prompted a number of investigations into the daylighting of atria in the 1980s. Details of these studies are given in the paper of Wright and Letherman [3]. Today there are quite a number of computational methods to simulate building features with a good degree of accuracy under a range of sky luminance distributions. While these methods can be accurate, they are subject

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to a number of limitations such as high complexity, long timescale and high cost. Thus the question arises at this point as to whether they are suitable replacements for a generalized analytical—and practical—design method. Comparison between real illuminance values and simulated ones in heavily obstructed buildings in Hong Kong [1] show differences between –27% and +36% for Lightscape and −6.5% and +49% for Radiance.

In the present paper three methodologies are considered. The first one is a practical design procedure for the estimation of illuminance on the floor and the walls of atria. It was developed by Tregenza [2] by using the exponential attenuation of light flux and presents a fair fit to equations derived from measured data. The second method is radiosity (Lightscape) while the third one is ray tracing (Radiance).

2. Practical design procedure

The illuminance on the walls of a top lit atrium decreases from the top to the base of the well. Measurements in real and model buildings have led to empirical equations for daylight illuminance that often take the form of an exponential decay where one of the parameters is the 'well index'. Tregenza presented a simple method for the calculation of illuminance in atria by using the exponential method.

Eq. (1) gives the illuminance on a horizontal plane lying across an atrium at a distance h from the top while Eq. (2) gives the vertical wall illuminance at the same level:

$$E_{\mathrm{htotal}} = E_{\mathrm{h0}}\,[(2a-R_1)\exp(-akWI) + R_1]/[2a(1-R_1R_2)] \tag{1}$$

$$E_{\mathrm{vtotal}} = E_{\mathrm{htotal}}k(1 + R_1)/4 \tag{2}$$

where $a = 1-\rho_{vd}/2-\rho_{vs}$ is the fraction of light incident on walls that is not reflected downwards. The variables ρ_{vd} and ρ_{vs} represent the diffuse and specular reflectance of the wall surfaces accordingly. The variable k is given in the following equation:

$$k = (4E_{\mathrm{v0}}/E_{\mathrm{h0}})(1-WI/8) \tag{3}$$

where E_{v0}, E_{h0} are the vertical and horizontal illuminance while WI is the well index of the atrium which is defined as follows:

$$WI = H(l + w)/2Hw \tag{4}$$

with l, w, H the length, width and height of the atrium, respectively.

Variables R_1 and R_2 in Eq. (1) and (2) represent the cavity reflectances of the atrium from the top to the distance h and from the distance h to the bottom, respectively. Cavity reflectance is the proportion of flux emerging from a cavity to the flux entering. It depends on the reflectance of the internal surfaces and on the cavity shape.

By using the above equations the horizontal and the vertical daylight factor s are estimated as follows:

$$DF_{\mathrm{htotal}} = [(2a-R_1)\exp(-akWI) + R_1]/[2a(1-R_1R_2)] \tag{5}$$

$$DF_{\mathrm{vtotal}} = DF_{\mathrm{htotal}} k(1 + R_1)/4 \tag{6}$$

3. Radiosity

With this method the space is divided into a mesh of patches. Each patch is considered as a Lambertian reflector, which means that it has a constant luminance, independent of the viewing direction. The flux that leaves each patch is given by Lampert's cosine law. Therefore each patch receives and reflects light back to into space. The whole process is iterative and proceeds until all reflected flux has finally been absorbed. The calculation of view factors between different patches is one of the most difficult parts of this method. As view factors have to be stored, the amount of data storage required increases as a function of the number of patches. It is evident that this method cannot model specular reflection effectively. Different models have been developed using the radiosity method [5]. In the present study Lightscape 3.2 software, commonly available to building professionals, was used.

4. Ray-tracing

Ray tracing methodology can easily deal with complex building forms more simply. Rays are emitted from the light source (forward ray-tracing) striking surfaces in space, contributing to the luminances of these surfaces. An inverse process can be used in which the rays are emitted from a point in the scene trying to trace the light sources (backward ray-tracing). Each ray carries a 'weight' which is proportional to the intensity of the corresponding ray. After an intersection with a surface, new rays are generated and their weight depends on the reflection. When the weight of one ray falls below an arbitrary value, it is taken to be absorbed and the process is repeated with a new emission.

The emission of the rays to different directions is time consuming and demands large processing time. To reduce the time, ray tracing is often combined with a statistical method of calculating the ray emission (Monte Carlo). Ray tracing techniques excel in the rendition of point light sources, specular reflection and refraction effects.

In this study RADIANCE [4] simulation package was used. This tool is a physically based rendering program. It uses a light backward ray tracing method that is capable of solving the rendering equation under any kind of reflection or transmission, in geometrically complicated environments. For the estimation of lighting levels, deterministic and stochastic ray-tracing techniques are used to achieve the best balance between speed and accuracy.

5. Methodology

The tests involved the modeling of a simple 100 m^2 square atrium. The atrium has a horizontal opening and the Daylight Factor estimation have taken place on the center of the floor and on the vertical wall, $H/4$ meters above the floor, with H the atrium height. This is a very simple model which was not used in order to test the validity of the results of the simulation packages but to show the differences among the different methodologies and to provide an indication if these methodologies are of full assistance to the designer. The atria modeled have Well Indexes between 0.5 and 2.5 and as mentioned above commercially available software was used. Sky conditions were chosen to be overcast according to the CIE overcast sky. Concerning Radiance, five ambient bounces have been used while the parameter −ad was set to 3000. For Lightscape, a medium coarse grid was used.

Two sets of simulations were conducted: (a) case 1: atrium wall and floor reflectances 0.4 and 0.2 respectively, and (b) case 2: atrium wall and floor reflectances 0.8 and 0.2. The results are presented in Figs. 1–4.

6. Conclusions

1. As a general trend the relative differences tend to increase with the reflectance of the wall surfaces of the atrium. This is to be expected since the reflections deep in the atrium put more stress on the software.
2. Concerning case 1, the practical design procedure (Tregenza's method) overestimates the values of daylight factors in comparison with the results from the other two simulation programs. The relative difference increases with the increase in Well Index. The average relative difference between Tregenza's method and Radiance is 13%.
3. Case 2 presents higher reflectances which in turn increases the differences even more. The average relative difference between Radiance and Tregenza's method is 30% while the difference between Lightscape and Tregenza's method is 38%.

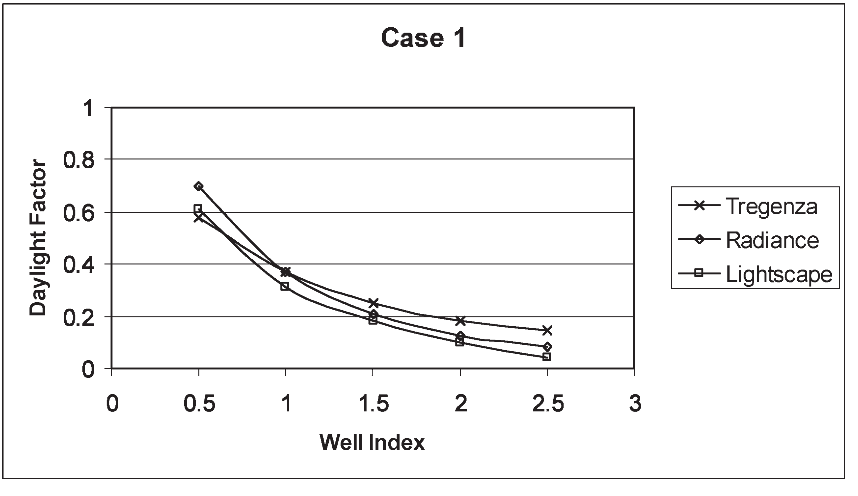

Fig. 1. Comparison of horizontal DF for case 1.

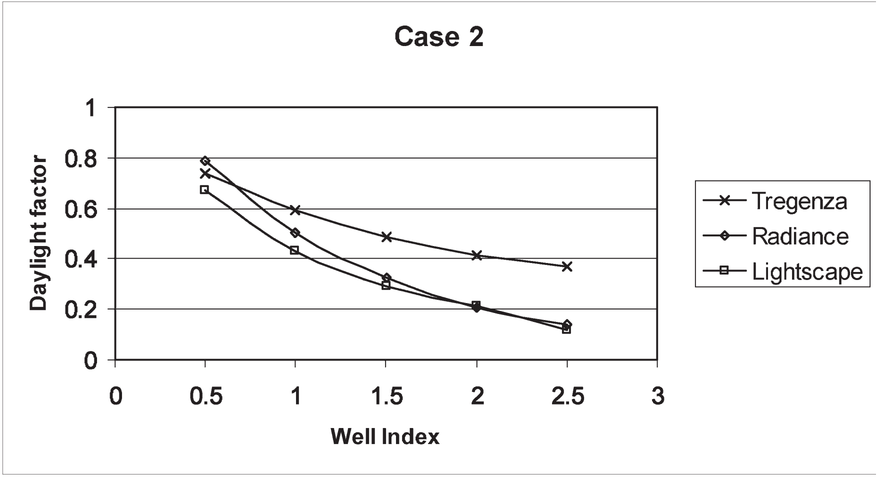

Fig. 2. Comparison of horizontal DF for case 2.

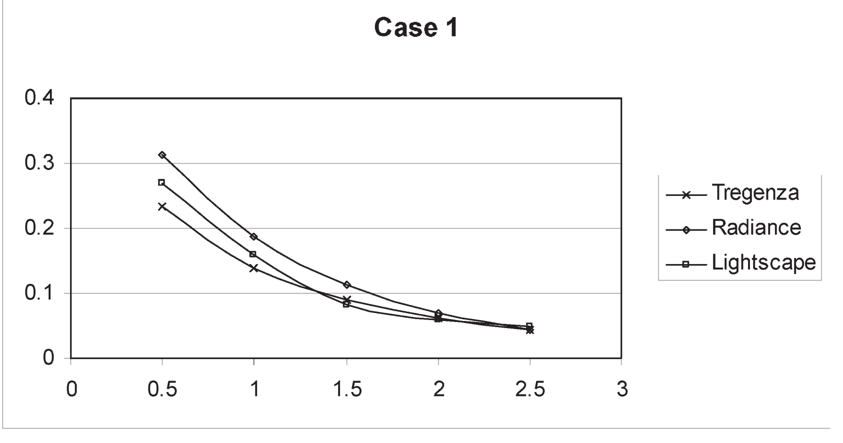

Fig. 3. Comparison of vertical DF for case 1.

4. Figs. 3 and 4 show a relatively good comparison of the vertical daylight factors between the three methods. The relative difference is decreasing with the well index. This is a very interesting result since the daylight levels in the spaces adjacent to atrium are mainly affected by the vertical illuminance on the window façade.
5. During the last decade the poor daylighting performance of some atria could be assigned in part either to the poor availability of suitable design models or to the poor quality of information within such models [3]. In general, there is an absence of performance data although there is an effort for a thorough and systematic comparison [6]. In recent software tools some tradeoffs have to be made mainly related with the experimentation with their parameters selection.

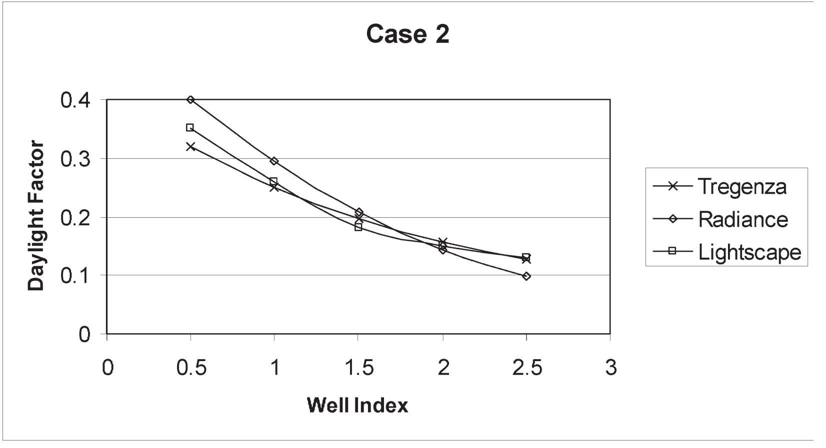

Fig. 4. Comparison of vertical DF for case 2.

6. It is evident that during the early phases of design a practical method should be used, since the time required for data input and program running is not prohibitive. Nevertheless, if energy savings estimation due to daylight is the objective—especially at the bottom floor—a more detailed methodology (ray-tracing) should be adopted due to the higher accuracy of the results.

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