Lighting Performance of Virtual Natural Lighting Solutions with a Simplified Image in a Reference Office Space

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Introduction

Virtual Natural Lighting Solutions (VNLS) are systems that can artificially provide natural lighting as well as realistic outside view, with properties comparable to those of real windows and skylights. The benefit of installing VNLS in a building is the ability to use more space which has no access to daylight, i.e. located underground or faraway from the façade. VNLS is a new concept and does not yet exist in reality. The currently available virtual windows and skylights are considered not suitable for meeting the whole expectation, since they are only able to meet part of the natural light expectation (Mangkuto et al., 2011). Some user perception studies on view and light aspects of virtual windows have been reported by, e.g., IJsselsteijn et al, 2008, de Vries et al, 2008, and Shin et al, 2012.

In a bigger scope, it is intended to have an overview of the potential of VNLS system application in various building types. This will be done by using computational building performance simulation, which has the ability to predict the performance of such a non-existing solution. However, little is known about the technique to model an ideal virtual window, including a realistic outside view, to predict its potential for application in buildings.

The objective of this study is to describe the approach of modelling VNLS and using the Radiance lighting simulation package to compare the lighting performance of various VNLS configurations in a defined reference office space. Prior to incorporating a realistic view component in the performance assessment, a simplified image is included in the simulation.

The lighting performance is described in terms of the ability to meet the space availability demand, the illuminance uniformity on the workplane, and the ability to meet visual comfort demands, e.g. to produce minimal glare at predefined observer's positions in the given space. Space availability is defined as "the percentage of workplane (at height of 0.75 m from the floor) meeting a certain minimum illuminance criteria".

The building type discussed in this study is a reference office space with dimensions of 5.4 m × 3.6 m × 2.7 m (L×W×H). There are four vertical window configurations chosen from the earlier studies of Diepens et al (2000) and LBL (2010), see Figure 1. Each window configuration is modelled with a simplified viewed image on its surface. No real windows are present in the modelled spaces.

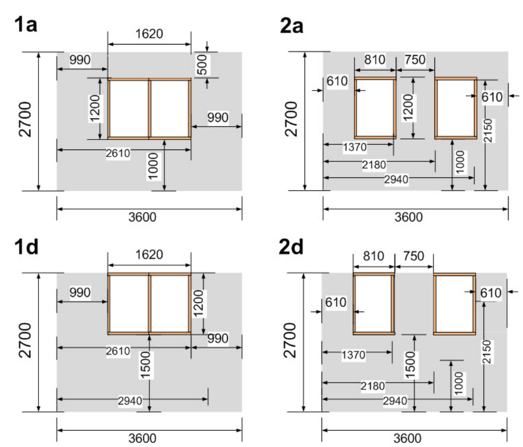

Fig. 1: Elevation view of the VNLS window configuration on the wall

Methods

Modelling

A VNLS surface is expected to resemble a real window, including the direct and reflected components. For this study, it is therefore modelled as arrays of light sources.

The VNLS in this study is modelled to fit two individual vertical windows, each with the size of 0.8 m × 1.2 m (*W*×*H*). Each light emitting areas in each individual window has the size of 0.05 m × 0.05 m and resembling a blue sky. The sources have a beam angle, i.e. the angle between the two directions opposed to each other over the beam axis for which the luminous intensity is half that of the maximum luminous intensity, of 76°. At the lowest row, there are 4 (for configura-tions 1a and 2a) or 8 (for 1d and 2d) light emitting areas resembling a green ground surface. Since the windows' position in configurations 1d and 2d is higher, smaller number of green ground surface are used to make it invisible from the observer's position.

In order to model the directionality of the entering light, the sources at the highest row are tilted with a 40° angle (refers to vertical line) pointing downward. The sources at the row below are tilted with a 38° angle pointing downward, and so on with an interval of 2°. The "ground" sources are tilted with a 40° (for 1a and 2a) or 60° (for 1d and 2d) angle pointing upward. See Figure 2 for details.

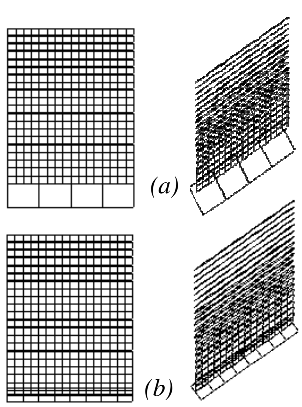

Fig 2: Front and perspective views of the individual VNLS in configurations: (a) 1a and 2a, (b) 1d and 2d

The luminous intensity distribution of each light source is written in IES format file, based on the character of downlights with a large beam angle. The distributions have similar patterns, but different values, as shown in Figure 3. Each source in the highest row has maximum intensity of 14.8 cd at 0° angle. Each "ground" source has maximum intensity of 354 cd (for 1a and 2a) or 122 cd (for 1d and 2d, due to smaller size of individual source), with a similar pattern of luminous intensity distribution.

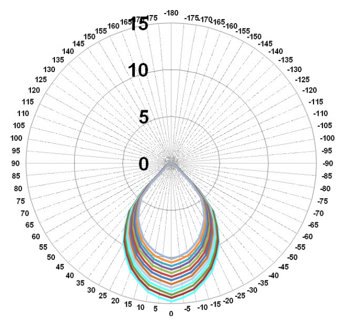

Fig 3: Polar diagram of luminous intensity of the light sources resembling the sky

Settings

In the given space, VNLS are put on the front wall (*W* 3.6 m × *H* 2.7 m). Frames of 5 cm wide are given at the perimeters of the windows. Reflectance values of the room's interior are: ceiling: 85%, walls: 50%, floor: 20%, door: 50%, window and door frames: 50%; all based on the IEA Task 27 reference office (van Dijk, 2003).

Three different observers' positions, namely A, B, and C, are defined at the eye height of 1.2 m above the floor. The view directions at positions A and B are parallel to the window plane, while C is directly facing the window plane, as shown in Figure 4.

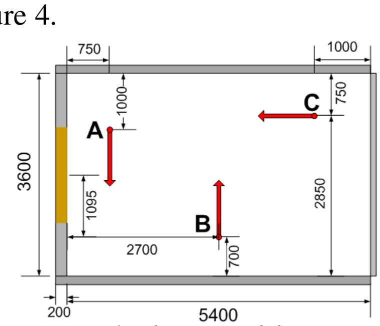

Fig. 4: Plan view of the space

For all simulations, ambient parameters in Radiance are set as shown in Table 1.

Table 1: Radiance ambient parameters

Parameter	Description	Value
-ab	Ambient bounces	4
-aa	Ambient accuracy	0.15
-ar	Ambient resolution	128
-ad	Ambient divisions	512
-as	Ambient super-samples	256

Assessment

The assessment for this study is based on the selected performance indicators of interest, which are:

- *Space availability* [*%A*]: percentage of workplane area (h = 0.75 m, equal size to the floor area) with illuminance ≥ 500 lx (typical criteria for office work). Calculation is performed for 1944 (= 54 × 36) points which are evenly distributed on the workplane. The *%A* is the percentage of the number of points with illuminance ≥ 500 lx, compared to the total number of points.
- *Uniformity* [U_0]: ratio between the minimum illuminance to the average; based on the defined calculation points.
- *Glare indices*: since it is not a priori clear which glare indices are most suited to use for VNLS, we calculate all potentially relevant ones, i.e. DGP, DGI, UGR, and CGI, in Evalglare. The results are also normalised as suggested by Jakubiec and Reinhart (2012) to determine the "probability of discomfort glare", by multiplying DGI value with 0.01452, and multiplying UGR and CGI values with 0.01607.

As a mean of comparison, the VNLS in all configurations are replaced with real windows (double clear glass 6 mm, transmittance 88.5%) under a CIE overcast sky condition giving approximately the same average window luminance (3200 cd/m^2). The same assessments are then performed.

Results

The space availability, uniformity, and probability of discomfort glare for all configurations and positions with VNLS and real windows are summarised in Tables 2 and 3, respectively.

Table 2: Summary of %A, U_0, and probability of discomfort glare for all configurations and positions in VNLS scenes

Con.	*%A*	U_0	DGP	DGI_n	UGR_n	CGI_n
1a, A	29.3	0.28	0.25	0.23	0.37	0.40
1a, B			0.21	0.19	0.32	0.35
1a, C			0.27	0.33	0.45	0.47
1d, A	25.4	0.26	0.20	0.12	0.26	0.27
1d, B			0.20	0.16	0.29	0.31
1d, C			0.26	0.31	0.44	0.45
2a, A	32.2	0.31	0.21	0.17	0.32	0.34
2a, B			0.21	0.21	0.31	0.34
2a, C			0.27	0.34	0.45	0.47
2d, A	26.2	0.29	0.19	0.12	0.23	0.26
2d, B			0.20	0.19	0.28	0.31
2d, C			0.26	0.33	0.43	0.45

Table 3: Summary of %A, U_0, and probability of discomfort glare for all configurations and positions in real windows (overcast sky) scenes

Con.	*%A*	U_0	DGP	DGI_n	UGR_n	CGI_n
1a, A	27.9	0.16	0.24	0.21	0.35	0.39
1a, B			0.21	0.19	0.31	0.33
1a, C			0.26	0.31	0.43	0.45
1d, A	25.0	0.24	0.22	0.17	0.32	0.33
1d, B			0.20	0.16	0.28	0.31
1d, C			0.26	0.30	0.42	0.44
2a, A	29.5	0.15	0.22	0.26	0.36	0.39
2a, B			0.21	0.22	0.32	0.34
2a, C			0.26	0.33	0.43	0.45
2d, A	25.1	0.19	0.21	0.23	0.33	0.35
2d, B			0.20	0.20	0.30	0.32
2d, C			0.26	0.32	0.42	0.43

To give a visualisation of the simulated space, the rendered images with their corresponding luminance false colour map at the three positions in configuration 1a are shown in Figure 5.

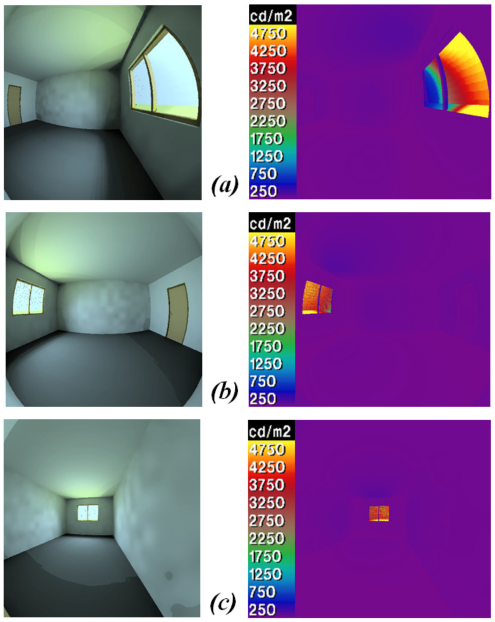

Fig. 5: Rendered image of the space with the corresponding luminance false colour map in configuration 1a, viewed from (a) position A, (b) position B, and (c) position C

Discussion

Based on the simulation results, the space availability obtained is 29% in VNLS configuration 1a, 25% (1d), 32% (2a), and 26% (2d). These values are slightly larger than those obtained in real windows scenes. The uniformity in all VNLS scenes (0.26 ~ 0.31) are also larger than those in real windows scenes (0.15 ~ 0.24). The glare indices are largely determined by the observer position. Position C experiences the worst glare perception. In the configurations 1d and 2d, where the VNLS are raised up to the ceiling, the glare perceptions are better than those in configurations 1a and 2a.

By definition, DGI and DGP may be the better indicators, since VNLS is meant to emit virtual daylight. However, viewed from position C (Figure 5c), the VNLS surface on average gives luminance of 3200 cd/m^2, while the immediate surrounding wall surface gives around 35 cd/m^2. This indicates a risk of glare, which is underestimated in both DGI and DGP calculations. The probability of visual discomfort results show that UGR and CGI values are found in the middle range, and in no case are larger than 0.50, suggesting that glare problems can be expected in less than 50% of the time. In general, the question to find the most appropriate glare indicators for VNLS remains open until it is validated with users experiment. Nevertheless, the results indicate that the probabilities of discomfort glare in VNLS scenes are comparable to those in real windows scenes.

In this simulation study, we model a VNLS configuration composed of light emitting sources with the size of 0.05 m × 0.05 m. It shows the possibility to model the direction of light from the “ground” to the ceiling and from the “sky” to the floor. We also show that the simulated VNLS can give generally larger space availability and uniformity, compared to similar scenes with real windows, while main-taining the discomfort glare comparable to the real windows scenes. In reality, the VNLS configuration can possibly be built by employing arrays of small light sources such as LEDs. Alternative configurations and source parameters will be studied to further improve the visual comfort characteristics.

Acknowledgements

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