Mangkuto R.A, Aries M.B.C, Loenen E. J. van & Hensen J.L.M., 2014.
Simulation Study of a Virtual Natural Lighting Solutions Prototype: Validation and Analysis.
In Proc. EXPERIENCING LIGHT 2014, Eindhoven, 10-11 November.

Simulation Study of a Virtual Natural Lighting Solutions Prototype: Validation and Analysis

R. A. Mangkuto, M. B. C. Aries, E. J. van Loenen, & J. L. M. Hensen

Building Physics and Services, Eindhoven University of Technology, Eindhoven, the Netherlands

Introduction

The benefit of natural light and view from windows in buildings has been widely reported (e.g. Berman et al., 2008; Aries et al., 2010). However, there are some situations in which natural light is absent, for example, due to hygienic or safety reasons. To answer this challenge, the concept of Virtual Natural Lighting Solutions (VNLS), which are systems that can artificially provide natural lighting as well as a realistic outside view with properties comparable to those of real windows and skylights, is proposed.

This study aims to find how a certain VNLS prototype influences the indoor lighting condition and visual comfort. In particular, this study focuses on lighting measurement and simulation of a 'second generation' VNLS prototype. Two objectives are defined: (1) to validate the illuminance distribution results obtained from *Radiance* simulation (Ward & Shakespeare, 1998) with the ones obtained from measurement, by evaluating the interior lighting condition inside the test room; and (2) to determine the effect of various prototypes configurations on the space availability, uniformity, and visual comfort in the test room.

Case Description

A VNLS prototype has been built in the new ExperienceLab of Philips Research at the High Tech Campus in Eindhoven, the Netherlands. The light sources of this prototype were eight *Philips Origami BPG762* luminaires (Figure 1), each measured 0.595 m × 0.595 m × 0.050 m, incorporated to provide the light as well as to construct the view of the prototype. Each luminaire housed four smaller tiles consisting of 108 *LUXEON RGB* power LEDs, and were able to display colours in red, green, and blue (RGB) components.

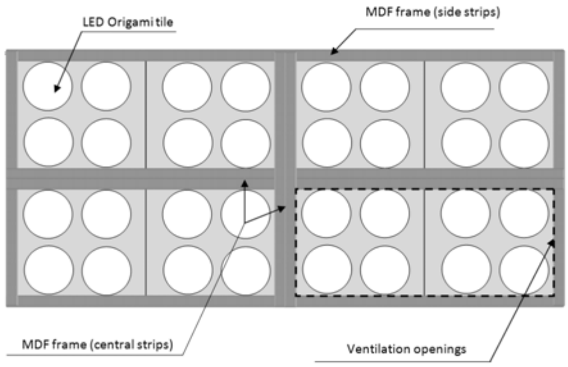

Figure 1. *Rear view illustration of the 2 × 4* Origami *BPG762 arrays in the prototype; taken from Mangkuto et al. (2014)*

The prototype was set to display a diffuse view by applying a diffuse panel. The original displayed view was a scene of nature, composed of a green ground and a bluish, cloudy sky. The horizon was set at the eye height; therefore the 'ground' elements occupied only 0.25 of the total view height. Using an image processing software, a mosaic filter was applied to turn the image into 32 pixels.

Figure 2 displays the appearance of the prototype from inside the test room, at the 'on' condition, after applying the diffuse panel and window glass.

Figure 2*. The prototype appearance from inside the test room at the 'on' condition; taken from Mangkuto et al. (2014)*

Measurement Protocol

The prototype was placed in a test room of 6.81 m × 3.63 m × 2.70 m (L×W×H). There were two openings for the prototype; each had a dimension of 0.90 m × 1.20 m (W×H), while the height of the window bottom was 0.93 m from the floor. The distance between the frames of the two openings was 0.14 m. Figure 3 illustrates the floor plan of the test room.

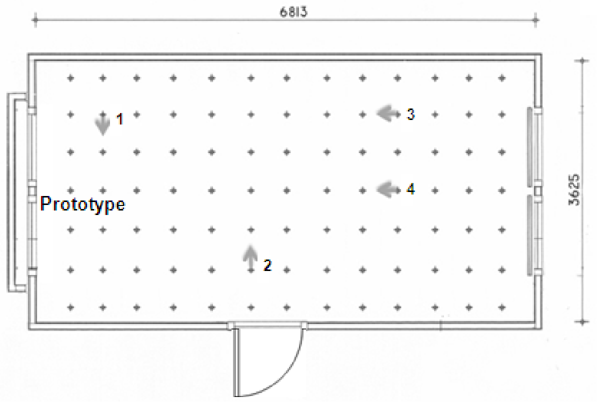

Figure 3. *Floor plan view of the test room*

Data were collected at three settings: 25%, 62.5%, and 100% of the maximum. Horizontal illuminance on the workplane (0.75 m from the floor) were measured at 91 points (see Figure 3), using *Lutron LX-1118* light meter (instrument error ± 5%). Vertical illuminance were measured at four positions (see Figure 3), at a height of 1.20 m from the floor. Reflectance of interior surface materials data were measured using *Konica Minolta CM-2600D* spectrophotometer (instrument error ± 0.1%). The horizontal illuminance data were post-processed to obtain the average illumi-nance values (E_{av} [lx]), uniformity (U_0), and space availability (*%A* [%]). The latter is the percentage of measuring points satisfying the criterion of minimum illuminance value. The Daylight Glare Probability (DGP) (Wienold & Christoffersen, 2006) was used as an indicator for visual discomfort.

Simulation Protocol

The first objective of this study is to validate the illuminance distribution results obtained from simulation using *Radiance* with the ones obtained from measurement. *Radiance* itself has been validated against CIE test cases (CIE TC-3-33, 2005) with a good accuracy (Maamari et al., 2005). Therefore, the actual conditions under the three lighting scenes were modelled and simulated. Comparison was made between the simulated and measured values of horizontal illuminance at the measurement points in Figure 3, as well as between the simulated and measured values of the space availability and uniformity.

Each *Origami* tile was modelled as a box of 0.30 m × 0.30 m × 0.05 m, constructed with a 'light' material. Each lamp had various red, green, and blue radiance components, in proportion to the actual DMX settings.

To validate the model, simulations were run for the settings of 100%, 62.5%, and 25%. One-to-one comparison between measurement and simulation was done for the values of horizontal illuminance at all measurement points.

There is no definitive agreement on an acceptable degree of accuracy whether a simulation result is fit for the purpose of reproducing the actual scene (Ochoa et al., 2012). Fisher (1992) suggested an acceptable criteria range of 10% for average illuminance calculations and 20% for measured point values. Moreover, the European Standard EN 12464-1 (CEN, 2002) mentions that "a factor of approximately 1.5 represents the smallest significant difference in subjective effect of illuminance", as given in the recommended scale of illuminance for various conditions in work places. This is roughly in agreement with the findings of Slater et al. (1993), which suggested that illuminance ratios of minimum 0.7 (or maximum 1.4 if inversed) between two work stations were 'generally acceptable'. In other words, the ratio of simulation and measurement values at any measuring point should not be less than 2 : 3 (or approximately 0.67) and not more than 3 : 2 (or 1.50), so that the values do not lead to a significant difference in their subjective effect. This criterion is applied in the following sections to evaluate the simulation results.

Configurations Setting

The second objective of this study is to determine the effect of various configurations of the prototype inside the test room. Two prototypes were modelled inside the test room, and were placed either on the short walls or on the long walls. Seven configurations (namely 1 until 7) were introduced, see Figure 4. In most configurations, the prototype was split into two equal parts; each consisted of 4 × 4 tiles. Each opening had a dimension of 0.90 m × 1.20 m, and the height of the window bottom in all configurations was 0.93 m from the floor, i.e. the same as in the tested configuration.

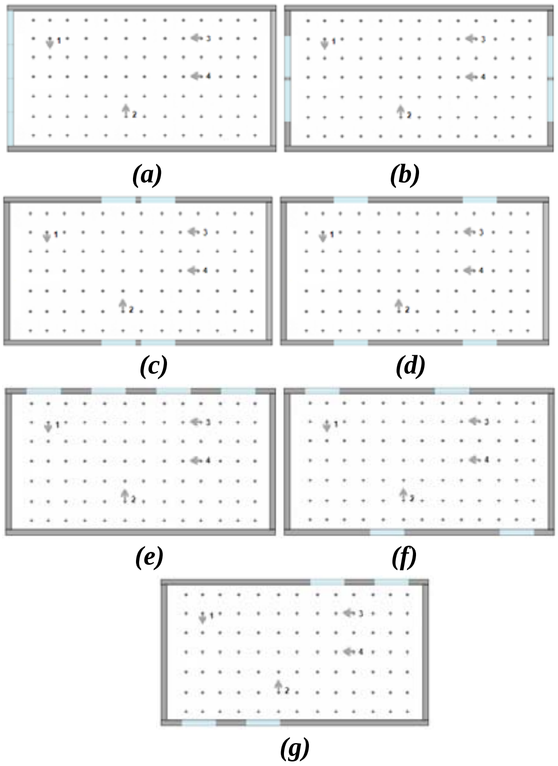

Figure 4. *Floor plan of the test room with the prototypes in configurations (a) 1, (b) 2, (c) 3, (d) 4, (e) 5, (f) 6, and (g) 7; adapted from Mangkuto et al. (2014)*

Simulations in *Radiance* and *Evalglare* were run to obtain the space availability, uniformity, and DGP at the defined four observer's positions. For this analysis, the space availability was evaluated for the minimum criteria of 500, 300, and 200 lx.

Results

The lighting simulation and measurement results of the prototype generally show a good agreement, as shown in Figure 5, for all measurement points and settings. The maximum relative difference was 28% at the farthest point under the 25% setting, possibly dominated by measurement accuracy limits. Ratio of the simulated value to the measured one at all points is always found to be within the range of 0.67 ~ 1.50, suggesting that the computational model is sufficient to reproduce the scenes without yielding a significant subjective difference.

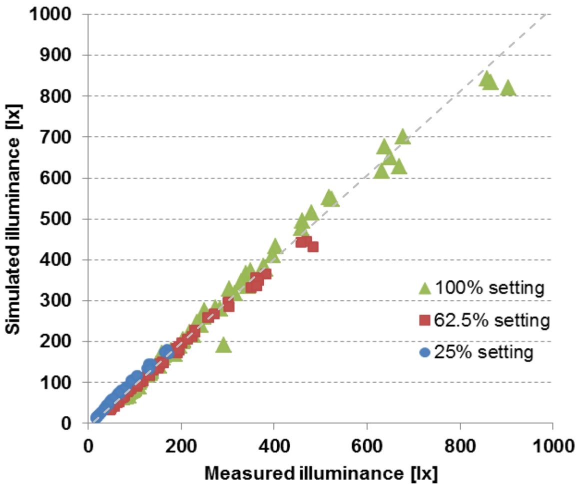

Figure 5. *Graphs showing the relationship between simulated and measured horizontal illuminance under 25%, 62.5%, and 100% of the maximum setting*

Table 1. *Space availability, uniformity, and maximum DGP in the test room, under all simulated configurations at 100% setting*

	C1	C2	C3	C4	C5	C6	C7
%*A* 500lx	34	29	48	31	34	25	33
%*A* 300lx	52	93	67	89	92	84	81
%*A* 200lx	68	100	96	100	100	100	100
U_0	0.28	0.59	0.35	0.51	0.55	0.48	0.55
DGP max	0.30	0.29	0.27	0.25	0.26	0.25	0.26
Pos.	1	1	3	1	2	2	1

The results of space availability, uniformity, and maximum DGP in the test room under all simulated configurations at 100% setting are illustrated in Table 1, for all measurement points. Taking 200 lx as the criterion for minimum workplane illuminance, nearly all of the configurations yield a space availability of 100%, except Configuration 1 in which all of the four openings are placed on a short wall. Taking 300 lx as the criterion, the largest space availability (92 and 93%) is found in Configurations 2 (two openings on each short wall facing each other) and 5 (four openings on a long wall). Taking 500 lx as the criterion, Configuration 3 (two openings on each long wall facing each other, 0.14 m distance between openings on the same wall) yields the highest space availability of 48%.

Regarding visual discomfort, the largest maximum DGP is found in Configuration 1 (0.30), whereas the smallest one is found in Configurations 4 and 6 (0.25). DGP values of less than 0.35 are considered ‘imperceptible’ (Wienold, 2009; Reinhart & Wienold, 2011). Hence, it is expected that the observers will experience a very minimum amount of discomfort glare, when viewing the prototype configurations.

Conclusions

A VNLS prototype has been constructed in a test room to provide blurred view, diffuse and directional light. The prototype consists of an array of LED tiles and an array of LED linear fixtures. Based on the performed measurement and simulation, computational model of the prototype is considered sufficient for the purpose of reproducing the test room scene.

Seven configurations of two prototypes with equal total opening size in the test room were modelled and compared to each other. Space availability in the test room can be optimised by placing a prototype on each short wall facing each other, or by placing two prototypes on a long wall.

This work aims to assess how VNLS influence the indoor lighting performance and visual comfort in the early design stage. Therefore, it is based on measurement and computational modelling and simulation of the relevant prototypes. Future works should be focused on assessing user’s perception of the prototypes. A thorough study and analysis on how people actually appraise VNLS in reality would turn be the pre-requisite before implementing the design in the real world application.

Acknowledgements

This work is supported by the Sound Lighting research programme of the Intelligent Lighting Institute, Eindhoven University of Technology. The setup and testing of the prototype were assisted by S. Wang, MSc and B.W. Meerbeek, MSc, PDEng, and were accommodated in the ExperienceLab of Philips Research.

References

Aries, M.B.C., Veitch, J.A., Newsham G. 2010. Windows, view, and office characteristics predict physical and psychological discomfort. Journal of Environmental Psychology, 30(4): 533-541.

Berman, M.G., Jonides, J., Kaplan, S. 2008. The cognitive benefits of interacting with nature. Psychological Science, 19(12): 1207-1212.

Commission Internationale de l’Eclairage (CIE), TC-3-33. 2005. Test cases to assess the accuracy of lighting computer programs. Commission Internationale de l’Eclairage.

Comité Européen de Normalisation (CEN). 2002. EN 12464-1: Light and Lighting - Lighting of work places, Part 1: Indoor work places. Comité Européen de Normalisation.

Fisher, A. 1992. Tolerances in lighting design. In: Proceedings of CIE Seminar on Computer Programs for Light and Lighting. Vienna: Commission Internationale de l'Eclairage.

Maamari, F., Fontoynont, M., Tsangrassoulis, A., Marty, C., Kopylov, E., Sytnik. G. 2005. Reliable datasets for lighting programs validation – benchmark results. Solar Energy, 79(2): 213-215.

Mangkuto, R.A., Aries, M.B.C., van Loenen, E.J. Hensen, J.L.M. 2014. Analysis of various opening configurations of a second-generation virtual natural lighting solutions prototype. LEUKOS, 10(4): 223-236.

Ochoa, C.E., Aries, M.B.C., Hensen, J.L.M. 2012. State of the art in lighting simulation for building science: a literature review. Journal of Building Performance Simulation, 5(4): 209-233.

Reinhart, C.F., Wienold, J. 2011. The daylighting dashboard — a simulation-based design analysis for daylit spaces. Building and Environment, 46(2): 386-396.

Slater, A.I., Perry, M.J., Carter, D.J. 1993. Illuminance differences between desks: Limits of acceptability. Lighting Research and Technology, 25(2): 91-103.

Ward, G., Shakespeare, R.A. 1998. Rendering with Radiance: The Art and Science of Lighting Visualization. San Francisco: Morgan Kaufman Publishers.

Wienold, J., Christoffersen, J. 2006. Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras. Energy and Buildings, 38(7): 743-757.

Wienold, J. 2009. Dynamic daylight glare evaluation. In: Proceedings of Building Simulation 2009 – the 11th International IBPSA Conference, Glasgow.