Energy and Buildings 89 (2015) 76–86

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A comparison of scale-model photometry and computer simulation in day-lit spaces using a normalized daylight performance index

Riad Saraiji[a,*], M. Yaman Al Safadi[a], Najat Al Ghaithi[a], Richard G. Mistrick[b]

[a] United Arab Emirates University, Al Ain, United Arab Emirates
[b] Department of Architectural Engineering, The Pennsylvania State University, USA

ARTICLE INFO

Article history:
Received 15 August 2014
Received in revised form
15 December 2014
Accepted 18 December 2014
Available online 26 December 2014

Keywords:
Daylighting
Building energy
Renewable energy
Lighting
Building simulation

ABSTRACT

A process to compare results of building daylighting computer simulations to the results obtained using scale-model photometry under real skies is outlined. The process uses the illuminance values in a subject space under study and normalizes the values with those obtained in a space considered to be the base case. The normalized factor is termed Normalized Daylight Performance Index (NDI). An example on how this can be done is applied to an open plan office space with two different furniture layouts. Sources of experimental errors are outlined. NDI was found to be a viable metric for comparing daylighting simulations with scale-model photometry.

1. Introduction

To study how design variables in a particular space affect daylight distribution, a number of daylight performance indices are available. The following daylight performance indices have been studied by various researchers:

1- Daylight factor
2- Coefficient of utilization
3- Horizontal illuminance
4- Vertical to horizontal illuminance ratio [1]
5- Daylight autonomy and spatial daylight autonomy
6- Useful Daylight Illuminance (UDI)
7- Vector to scalar ratio

The daylight factor is equal to the ratio of daylight illuminance at a point within a space to the exterior illuminance under an unobstructed overcast sky. Daylight factor has significant limitations [2]; the most obvious is that it only deals with an overcast sky based on the standard CIE model, which is symmetric across all orientations. Therefore, clear sky performance cannot be evaluated using this index, and furthermore, the effect of different model and fenestration orientations cannot be modelled.

The coefficient of utilization (CU), on the other hand, is defined as the ratio of the illuminance at a point within a space to the vertical illuminance on the window [3]. The CU values have been used in the lumen method of sidelighting and top lighting [4]. A more recent metric is daylight autonomy (DA) which is the percentage of occupied times of the year when a minimum illuminance requirement is met at an analysis point by daylight [5]. The Illuminating Engineering Society of North America has developed DA into Spatial Daylight Autonomy (sDA) [6] which is defined as the percent of an analysis area that meets a minimum daylight illuminance level for a specified fraction of the operating hours per year. For example, sDA $_{300/50\%}$ is reported as the percentage of the analysis points across the analysis area that meets or exceeds 300 lx for at least 50% of the analysis period (which is typically 8 AM–6 PM).

The Useful Daylight Illuminance (UDI), on the other hand, aims at an illuminance range (minimum to maximum) within which the daylight at an analysis point is labelled as “useful” [7]. Both the DA and UDI consider the fraction of operating hours (occurrences) throughout the year that the target value (minimum value in the case of DA and a range in the case of UDI) has been fulfilled. To acknowledge that even a partial contribution is beneficial, Continuous Daylight Autonomy (cDA) was developed [8–10]. An example of how daylight autonomy is used to study daylight utilization in perimeter office spaces can be found in Mc Dubois and Flodberg

* Corresponding author at: Department of Architectural Engineering, PO Box 15551, Al Ain, United Arab Emirates. Tel.: +971 3 7135190.
E-mail address: r.saraiji@uaeu.ac.ae (R. Saraiji).

http://dx.doi.org/10.1016/j.enbuild.2014.12.033
0378-7788/

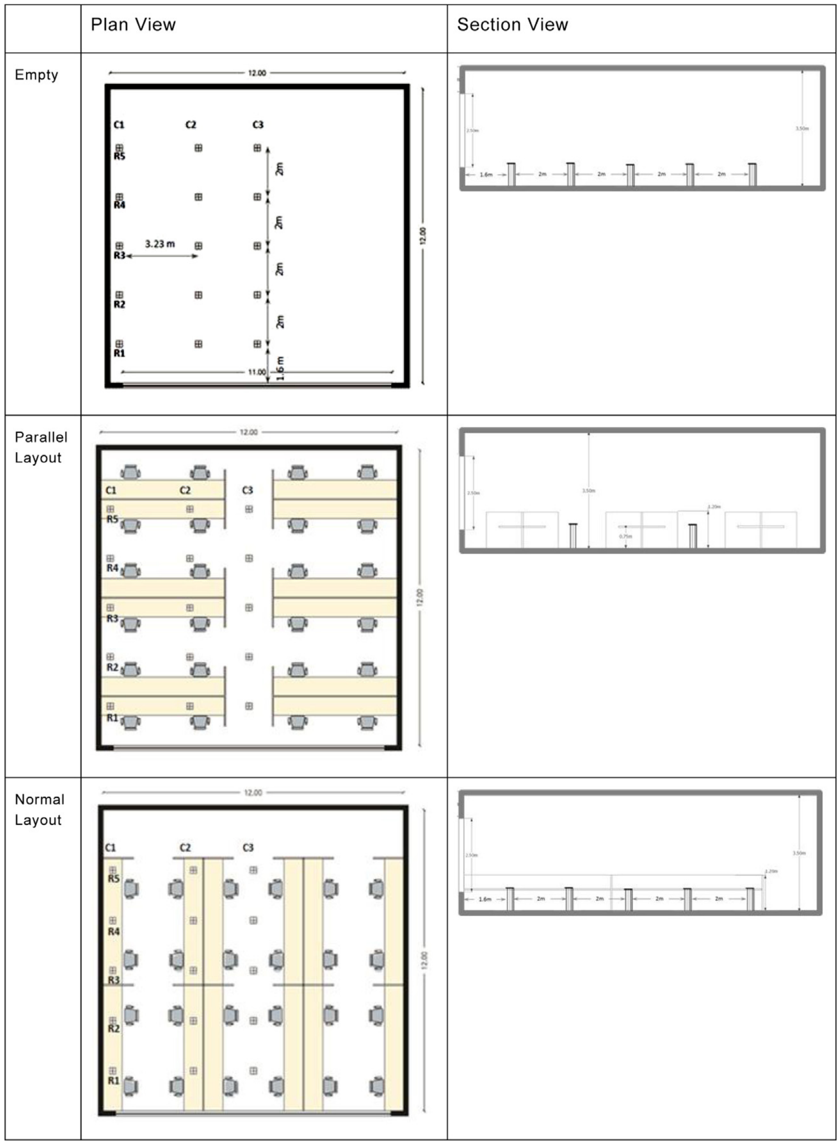

Fig. 1. Configuration of various spaces and the location of the illuminance sensors.

[11]. Space availability as a metric can also be found in the literature [12]. Whereby space availability is defined as the percentage of points on a horizontal grid that meet or exceed a target illuminance. Leslie et al. [9] and Reinhart [10] showed how a daylighting dashboard could be used to represent more than one daylighting design metrics.

The above indices focus more on the quantitative aspect of daylighting rather than qualitative aspects. The visual comfort in day lit spaces can be assessed by a metric known as daylight glare probability (DGP) [13]. The DGP evolved into a dynamic annual metric (DGPs) [14], which provides a comprehensive yearly analysis of glare. Two new metrics were proposed by Rockastle and Andersen [15]; annual spatial contrast and annual luminance variability. These were proposed to establish a comparative framework and method for evaluating how much contrast or variability is in a scene or space over time. These two new metrics communicate information about the spatial and temporal quality of daylit spaces. A critical investigation of common lighting design metrics for predicting human visual comfort can be found in Wymelenberg and Inanici [16].

The search for daylight performance indices continues to be an important subject in daylighting research. The reader is referred to Reinhart et al. [17] and Mardaljevic et al. [2] for useful insight regarding the above mentioned daylight performance metrics.

Comparative daylighting analysis between computer simulations and scale-model photometry under real skies can be found in the literature [18–21]. In the bulk of the above-mentioned work, the comparison was based on the horizontal illuminance or daylighting factor. Discrepancies between the values obtained in virtual models and scale models were attributed to factors such as; sky luminance distribution function, the illuminance sensor size, sensor placement and levelling and the fidelity with which the model replicates the space [20]. Love and Navvab [20] found that scale-model photometry provided generally good estimates of the sky component of daylight under a clear sky relative to the full-scale space. Computer simulation estimates did match scale-model measurement. The authors attributed the discrepancy to the luminance distribution of real clear skies relative to the standard functions used by the software.