Daylight Simulation in Architectural Practice: Shading Design for Hospitals in London

Md. Ashikur Rahman Joarder
Andrew Price
HaCIRIC, Department of Civil and Building Engineering,
Loughborough University
United Kingdom.
Email: ashikj2000@yahoo.com

Abstract

To achieve precision and satisfy the standards in daylight design, incorporation of computer based simulation tools during design development and decision making process could be useful. In addition to environmental factors several issues, such as construction and aesthetic, need to be considered concurrently during building projects which sometimes difficult to judge by simulation program in early stage of architectural design. To optimise time and achieve sensible design solutions this paper presents a case of therapeutic daylight shading design for an imaginary hospital in-patient room window configurations, located at London, where simulation guided results and other practical factors such as solar control criteria, line of vision, aesthetics and intuitive judgements of the authors were considered to meet the design goals. Though the simulation study is based on London climate, the principle of developing shading devices presented in this paper is also applicable for other types of building windows.

Keywords: *building simulation, architectural design, therapeutic daylight, hospital building, window shading.*

1. Introduction

To evaluate the performance of built environment, use of modelling and simulation analysis are widely recognised practice in building research. Nowadays, with the advent of personal computers (PCs) and powerful processors that can handle complex calculations and algorithms, lighting simulation techniques are extensively available to researchers and practitioners (Joarder and Ahmed 2011c). Parametric simulation can be used to isolate the exclusive effect of one single element or the small modification of the element on built environment such as daylight conditions of the spaces, keeping other elements constant (Joarder, 2007). Another significant potential of simulation study is that, it is possible to evaluate the design for any period of the year, even the whole year under present and future climate scenarios (Joarder and Price, 2012b) within a short time by simply assigning simulation parameters (e.g. location, date, time and sky condition). Nevertheless, the difficulties of incorporation of simulation analysis in architectural design process are experienced at the starting point and each step of design development process when thousands (even millions) of options are available which might alternatively be considered to lead to the next stage/phase of the design. For example, the shading requirements of a building are mostly varied for different orientations, and it is difficult to satisfy the comfort levels with sufficient daylight for different orientations with a particular design of fixed shading device (e.g. sunshade with constant depth) for the entire building, therefore, shading should vary with orientations and different configurations of shading devices should be tested to support an architectural shading system. For instance, if four (or more) types of shades (e.g. sunshade, overhang, light shelf and internal blind) are tested for four orientations (north, east, west, and south) and have four (or more) states (e.g. differ in angle, shape, size and material), the total number of simulation run will be > $(4^4)^4$, or > 4,294,967,296 experiments. It is not possible to test each option simultaneously against all combinations of every other option due to the limitations of time and parametric simulation technologies (Joarder, 2011b). Therefore, it is difficult to advance and finalise architectural design decisions entirely based on simulation study. Moreover, decisions entirely based on simulation analysis might recommend totally different design of the window shades for different orientations. The purpose of this paper is to present an example of shading design process for hospital in-patient room windows, by incorporating simulation analysis, to achieve therapeutic daylight (daylight for health) for patients at early stage of shading design i.e. conceptual level. This paper consists of major three parts. The first part contains information about therapeutic lighting concept and outlines some principle of design that was fixed prior to simulation analysis. The second part presents the analysis and results of simulation study. The third part ends the paper with a discussion on the findings of the research with conclusion.

2. Background

Most of the windows in buildings, including hospitals, are designed to satisfy the visual needs of the occupants for example light to do visual activities and enjoy outdoor views (Joarder, 2009e; 2008). To see an object light needs to fall on the item first and then reflects towards the eyes. On the other hand, to satisfy therapeutic needs, higher intensity of daylight is needed to be incident directly on individuals' retinas to start biological stimulation inside human body which regulates different functions such as maintenance of sleep and circadian rhythm; reduction of pain and appetite; and improvement of feelings and emotions (Joarder et al., 2009c). As patients are largely stationary in hospital rooms, architects and/or designers should take the opportunity to improve the design of hospital windows to concentrate higher intensity of daylight in one location (i.e. patient heads). As, traditional windows do not guarantee sufficient therapeutic daylight (Pechacek et al., 2008), Joarder (2011b) proposed a new window configurations with an specially designed 45^0 inclined high window that performed better than typical standard hospital windows in order to ensure better therapeutic daylight inside patient rooms (see Appendix A) and defined the angled window as 'Sky Window' (Figure 1). In this paper, shading devices were developed for the two windows (viewing window and sky window) for four orientations for an standard in-patient single-bed room, developed according to the guideline described in Health Building Note (HBN 04-01, 2008) published by the National Health Service (NHS), Department of Health (DH), UK (Figure 1) considering London climate.

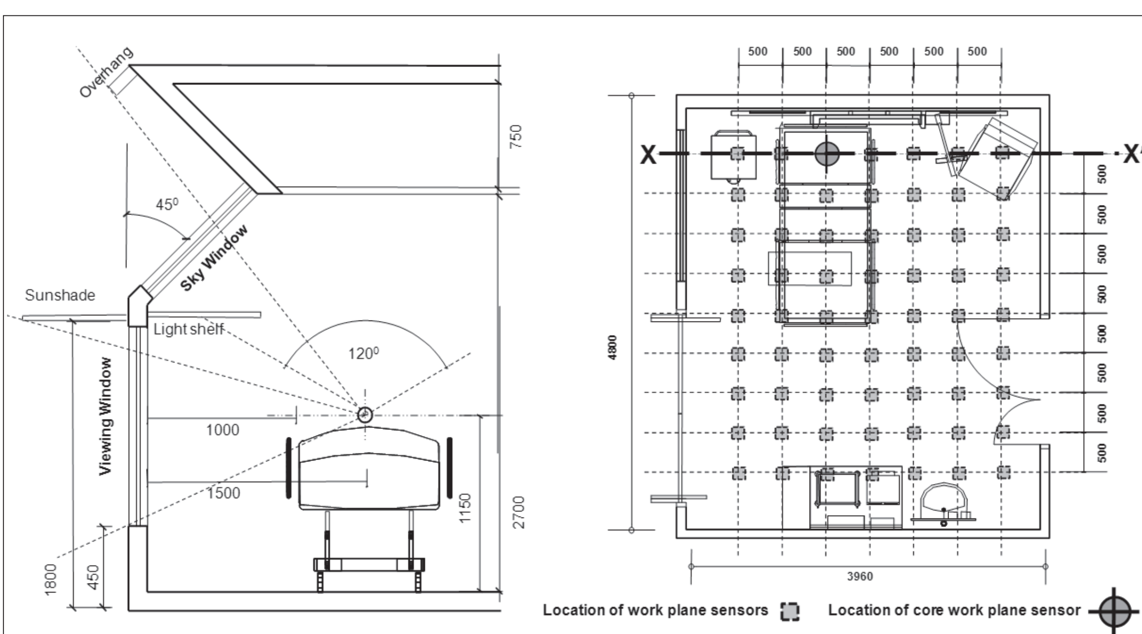

Figure 1: Section shows location and position of viewing and sky windows (left), and plan shows the location of sensors in case space for simulation study (right).

The following principle of design was set at the beginning of simulation analysis.

- To facilitate modular construction and maintain architectural uniformity, the design of a particular type of shading device (such as sunshade) will be kept constant for different orientations for the entire building and separate shades (such as overhangs/lightshelves) will be added in different levels of windows where more shades will be required, than to change the design and depth of the same shading devices in different orientations.

- For standardised recommendations, a multiple of 25mm (approximately 1 inch) will be followed for examined depths of shading devices for easy perception and implementation in both feet and meter scales.

- The designs of the shading devices will be developed to keep the DA[1] at minimum 62.5% (80% of outdoor DA) with a maximum UDI[2]>2000 of 14% (20% of outdoor UDI>2000), fixed after analysing 123 number of simulation results (Appendix B) on London's climate (Joarder, 2011a), with the help of simple passive shading devices (external sunshades, overhangs, internal light shelves, and venetian blinds) for different orientations.

3. Methodology

In this research DAYSIM, that use dynamic Climate-Based Daylight Modelling (CBDM) method (Mardaljevic, 2006), was used to calculate DA, UDI>2000 and annual illumination profile for the case space. DAYSIM use RADIANCE (backward) raytracer combined with a daylight coefficient approach (Tregenza, 1983) considering Perez all weather sky luminance models (Perez et al, 1993). Both RADIANCE and DAYSIM have been validated comprehensively and successfully for daylighting analysis (Reinhart et al., 2001). ECOTECT was used as the modelling interface to launch DAYSIM program. The 3D CAD drawings generated in ADB (2009) software for single-bed in-patient unit with furniture layouts (Figure 2) was imported to ECOTECT. Introduction and changes of window shades were done in ECOTECT. DAYSIM was then run and necessary changes were assigned to material properties (Table 1) and simulation parameters (e.g. intensity, timing and duration) described below. The location of core test plane sensor (test point) was then fixed at patient head (Pechacek et al., 2008), when patients lying with their spine on the bed, and directed towards the ceiling (Figure 1). To analyse performance metrics, the same annual illuminance profile was used based on DAYSIM calculations. The simulation time step was one hour. Figure 2 shows the flow diagram of parametric simulation study followed in this research.

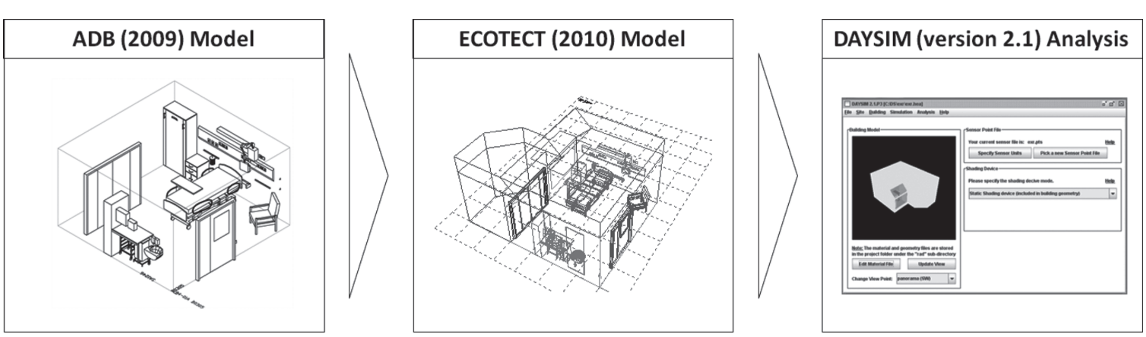

Figure 2: Flow diagram of parametric simulation study.

1 *DA (daylight autonomy) – is the percentage of the occupied times of the year when the minimum illuminance requirement at the sensor is met by daylight alone.*

2 *UDI (useful daylight illuminances) – try to find out when daylight levels are 'useful' for the user and when they are not. UDI results in three metrics, i.e. the percentages of the occupied times of the year when daylight is useful (100- 2000lux), too dark (<100 lux), or too bright (> 2000 lux).*

Table1: Material properties of the case space used for simulation analysis.

Building element	Material description	Material properties
Ceiling	Suspended plaster board ceiling	80% diffuse reflection
Walls	Brick with plaster on either side	50% diffuse reflection
Shading	Concrete with plaster on either side	50% diffuse reflection
Floor	Concrete slab on ground plus ceramic tiles	30% diffuse reflection
Door	Solid core oak timber	30% diffuse reflection
Window	Double glazed low-e aluminium frame	90% visual transmittance
Furniture	Plywood	40% diffuse reflection
Fabric	Heavy cloth	10% diffuse reflection
Metal	Stainless steel	90% diffuse and specular reflection

DAYSIM uses the same raytracer used to generate RADIANCE rendering. As DAYSIM calculate illuminances at discrete sensors, the simulation parameters needed to be modified slightly. Higher parameter settings will result in longer process time. Therefore, the art is to use parameters that are 'sufficiently high but not too high'. Table 2 summarizes the non-default RADIANCE simulation parameters for the simulation analysis recommended by Reinhart (2006) for complex geometry.

Table 2: Utilized simulation parameters in DAYSIM.

Ambient bounces	Ambient division	Ambient sampling	Ambient accuracy	Ambient resolution	Specular threshold	Direct sampling
7	1500	100	0.01	300	0.0	0.0

The quantitative and qualitative assessments for the different shading configurations were based on the following parameters.

Location: London (longitude: 00°07′29″W; latitude: 51°30′29″N).

Time: 6:00 AM – 6:00 PM (12 hour) for the whole Year.

Design illumination: minimum 190 lx daylight for south, east and west orientations and 180 lx for north orientation (Pechacek et al., 2008; Joarder and Price, 2012a).

Discomfort level: above 2000 lx (Nabil et al., 2006; Joarder and Price, 2012a).

4. Shading devices for sky window configurations

Figure 3 (left) shows dynamic daylight metrics (DA and UDI>2000) at test point without any shading devices added to the windows. In terms of achieving the simulation goals, the targeted DA (above 62.5%) was achieved for four orientations. For the climate of London, UDI>2000 increases in an order of north, east, west, and south progressively at test point for the case space. For north orientations, UDI>2000 is 0%, therefore, no shade is required for north windows. UDI>2000 is nearer to the target level (14%) for east (16%) and west (17%) orientations, but much higher (27%) for south orientations. To ensure comfort, maximum shading is required for south windows and minimum for east windows. In the next exercises, trials will be done to increase the level of shading gradually from east to west and finally for south windows to keep the DA at minimum 62.5% with a maximum UDI>2000 of 14% with the help of simple passive shading devices (e.g. external sunshades, overhangs, internal light shelves and venetian blinds).

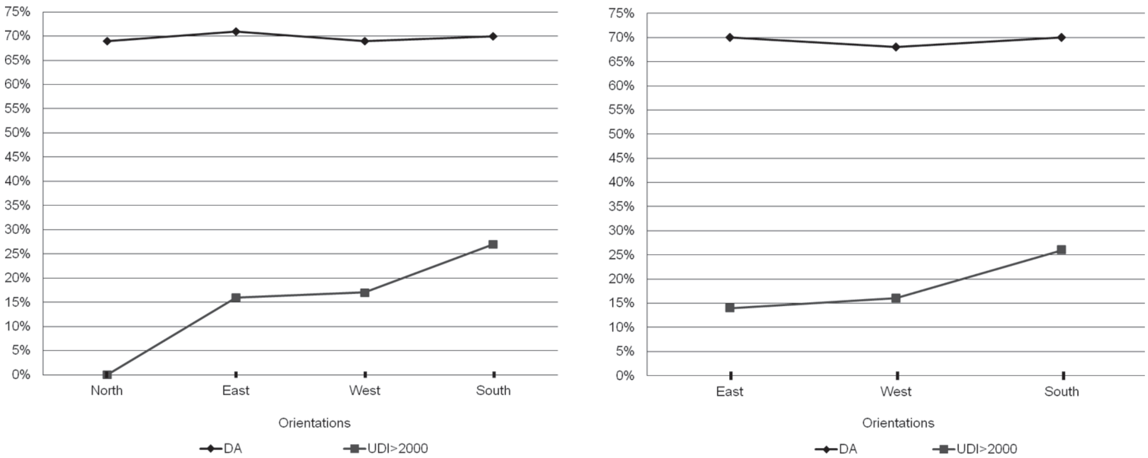

Figure 3: Daylight metrics at test point without any shading devices added to the windows (left), and impact of 825mm external sunshade in reducing the DA and UDI>2000 levels for different orientations (right).

4.1 Sunshade

External sunshades generally block direct sunlight to enter into the interior space, and reduce glare and overheating due to direct sunlight. As the sun changes its path at different times of the year, it is complicated to optimise the design of sunshade for the whole year. The requirement for shading varies with the change of seasons for same orientation. During summer when the days are hot, sunshades are very useful, but during winter when the days are too cold, the presences of sunshades are disadvantageous in terms of daylight and solar heat gain (Joarder, 2011a). In this exercise, an optimised depth of sunshade will be tried to install to shade the viewing windows (Figure 1) during summer time and impact on DA and UDI>2000 will be observed on test point for different orientations.

A rectangular sunshade was generated for the rectangular viewing window (1350mm x 1800mm) optimised for the summer time in London by using ECOTECT. The rectangular device will completely shade the viewing window from the 1 June to the 31 August, from 6:00 AM to 6:00 PM. ECOTECT uses a series of solar profiles described by the path of the sun through the sky to generate the exact shape of the sunshade required to shade the rectangular window for a given range of cut-off dates and times (Figure 4). A horizontal sunshade with a minimum 820.3mm depth was recommended by the analysis of ECOTECT for south orientation (Figure 9d), 4504mm for east orientation and 4731mm for west orientation.

In fact, horizontal shading devices are not effective in east and west orientations. Search for a 45^0 angled sunshade reduced the depth of sunshade to 1552mm for east and 1569mm for west orientations. A 1552/1569mm

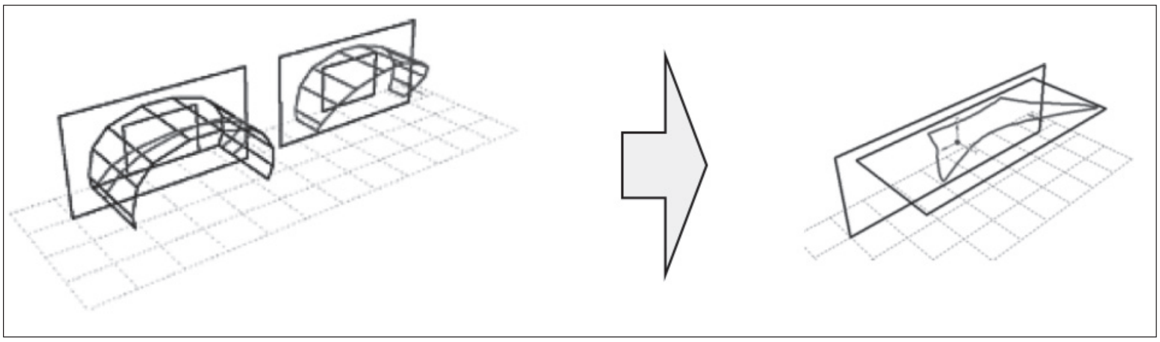

Figure 4: Concept of generating optimised rectangular sunshade by using cutting solar profiles (source: ECOTECT, 2010).

deep 45^0 angled sunshade will almost block the outside views. Vertical sunshades are most effective for east and west orientations to block direct sun, but permanent vertical shades will completely block the patients' outdoor view which is also equally important for clinical recovery (Joarder et al., 2010). It is unrealistic to provide a permanent 45^0 angled sunshade of 1552/1569mm which will block the outdoor views and daylight, and a 4504/4731mm horizontal shade, which is deeper than the width of the room itself. Due to changing position of sun during daytimes, shades are required only in east during the mornings and west in the evenings. A movable internal blind is the best solution, which can be dropped in early mornings in east orientations and late afternoons in west orientations (the impact of blind control have been analysed in section 4.6).

As the glare problem is not so prominent for east and west orientations compared to south, this simulation exercise started with 825mm deep sunshades for three orientations (east, west, and south) that will completely shade the south viewing windows and partially shade east and west windows during summer. As the north facade of the building does not receive direct sunlight, no fixed shading is required for north windows.

Figure 3 (right) compares the results of the analysis of the 825mm deep external sunshades for east, west and south orientations. Among three studied orientations, the impact of external sunshades in reducing DA and UDI>2000 were maximum for east orientation and minimum for west orientation. 825mm external sunshades were capable to reduce the UDI>2000 to the target level (14%) for east orientation, however, for west and south orientations additional shading were required. In the next exercise extra shades will be added to west and south orientations to reduce the UDI>2000 level to 14%.

4.2 Overhang

An overhang is a secondary shading usually attached to the edge of the roof slab that is projected from exterior walls of the buildings. In commercial buildings, overhangs are generally used to provide shades, break steep winds, and protect rains or snows. In this exercise, a small angled overhang was developed at the edge of the roof slab above the void space for partial shading of sky window (Figure 1) to reduce UDI>2000 at test point for west orientations at the beginning, and the performance of the shading on south orientation was observed. The shading device was placed parallel to the sky window surface (45^0 with building facade). Three alternative depths of overhangs (100mm, 200mm, and 300mm) were fixed for analysis for the west orientations in combination of 825mm external sunshades based on a primary analysis on the depth of overhangs (Appendix B).

Figure 5 shows that with the increase of the projection of the overhang, both the DA and UDI>2000 are reduced for west orientations. For the first 300mm depth both DA and UDI>2000 are reduced 1% per 100mm increase of the depth of overhangs. Overhangs with 200mm depth satisfy the requirement of UDI>2000 (14%) for west

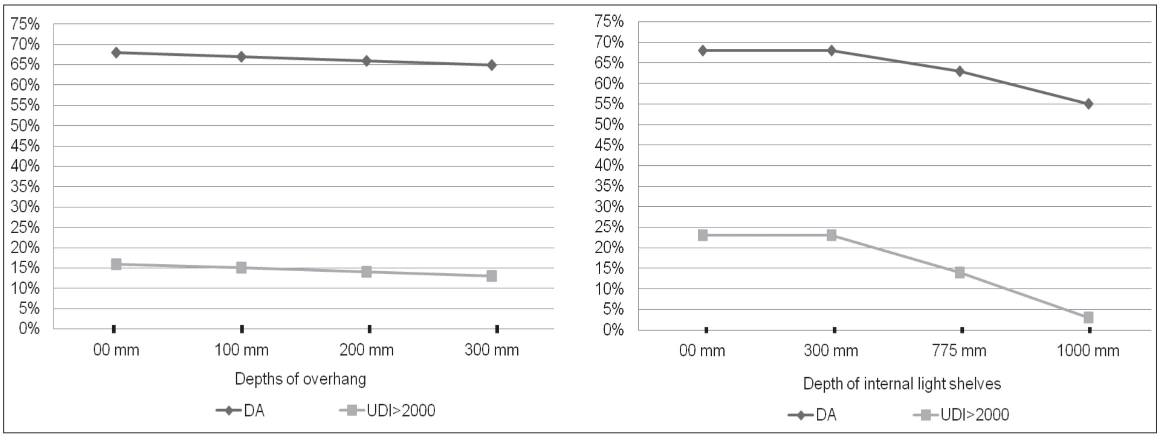

Figure 5: Increase of the projection of the overhang (left) and depth of light shelf (right) decrease both the DA and UDI>2000 for west and south orientations respectively.

orientations. A 200mm deep overhang reduces 2% DA (from 70 to 68) and 3% UDI>2000 (from 26% to 23%) for south orientation. To reduce the glare level to the target level (14%), it was necessary to reduce the UDI>2000 level another 9% for south orientation, and further shades were required for south window. In the next exercise additional shades will be added to south orientations only, to reduce the UDI>2000 levels to 14%.

4.3 Internal light shelf

Light shelves are typically placed just above eye levels to reflect daylight into the interior ceilings and to use the ceilings as a light-reflector for deeper parts of the rooms. However, light shelves are not efficient in terms of raising daylight levels under overcast sky conditions (Eagan et al., 2002), but can be used to reduce glare, and can ensure a better and uniform distribution of light throughout the interior space (Joarder et al., 2009a). As the sky conditions of London is majorly governed by overcast sky, introduction of light shelf at any height will result a decrease in daylight intensity. Therefore, light shelves can be used to reduce glare and enhance the quality of daylight in a space located at London.

In a simulation study under overcast sky condition, Joarder et al. (2009a) showed that light shelves at a height of 2000mm above floor level within a 3000mm high ceiling, performed better to enhance the quality of daylight in the interior spaces compared to other studied alternative locations, including the alternative where no light shelves were present. The light shelves were located at a two-third (2/3) height of the room height. For present case of in-patient room, the height of the ceiling is 2700mm (Figure 1), therefore, the locations of light shelves were fixed at two-third of the heights of the rooms which is 1800mm from finished floor levels and just above the viewing windows. In this exercise, the impact of the changes of the depths of internal light shelves on DA and UDI>2000 were observed at test points for south orientations.

The range of depths of the internal light shelves for this analysis was fixed by considering the viewing angle of the patients, when lying with their spine on bed in the case room at a distance of 1500mm from the window (Figure 1). The minimum depth was fixed to 300mm, so that the light shelf itself is out of the visual field of the patients, when lying with their spine on the bed and looking straight towards the ceiling (adult visual field extends to approximately 60^0 toward the nose for each eye). The maximum depth of the light shelf was fixed as1000mm, so that while patients lying on their spine on the beds, the light shelf will completely restrict the view of sky through sky windows, as a result no direct daylight will hit the test point through sky windows. A number of alternative depths of internal light shelves were studied to observe the impact on DA and UDI>2000 between 300mm to 1000mm (see Appendix B). Finally, a light shelf with 775mm depth satisfied both the requirements of DA and UDI>2000 levels.

Figure 5 shows that with the increase of the depth of light shelves, both the DA and UDI>2000 were reduced. A light shelf below 300mm have little impact on decreasing DA and UDI>2000 at test point. For a 775mm light shelf, DA reduced 5% and UDI>2000 reduced 9%. It was evident from analysis of the changes of the depths of the internal light shelves for the climate of London that light shelves reduced the direct illumination at test points more than the increase by reflection, however, there were significant usefulness of light shelves to reduce excessive illuminations (UDI>2000) near windows, which normally were much higher than target levels (190-2000 lx) (Figure 7). Therefore, light-shelves can be used to ensure a more balanced luminous environment, with less contrast, discomfort and glare for south orientations. Considering the collective performance of the light shelves for the whole year, it was evident that a light shelf with a depth of 775mm performed better among the studied alternatives and satisfied the target levels of DA and UDI>2000 for south orientations, therefore, 775mm deep light shelves were recommended in this paper for south windows.

4.4 Surfaces of internal light shelf

In the previous exercise, it was found that introduction of light shelves reduced the daylight level at test point for London climate. To observe the possibility to increase the illumination levels uniformly, highly reflective stainless steel metal sheets (with 90% specular reflectance) were added on the top of three alternative depths of light shelves (300mm, 775mm and 1000mm). From Figure 6 (left), it is evident that introduction of highly reflective materials had no impact to increase the annual DA for 775mm deep light shelf, and increases DA 2% for 300mm and 1000mm deep light shelves at the test points. As diffused plaster boards were used for suspended ceilings of the rooms and the overcast sky is dominant in London climate, reflected lights from the top of light shelves became diffused after incident on the ceiling and had little contribution on DA to the test point located on the test plane. A specular reflective ceiling could be advantageous for an office space, where the eyes are mostly directed to work plane but for in-patient rooms a specular ceiling might create discomfort, as the direction of eyes of the patients are mostly upward. Though the reflectances of light shelves might have impact on raising the illuminations on individual points near windows, when considered annually, little or no change was observed in DA, therefore, light shelves of the same material of the wall are suggested in this

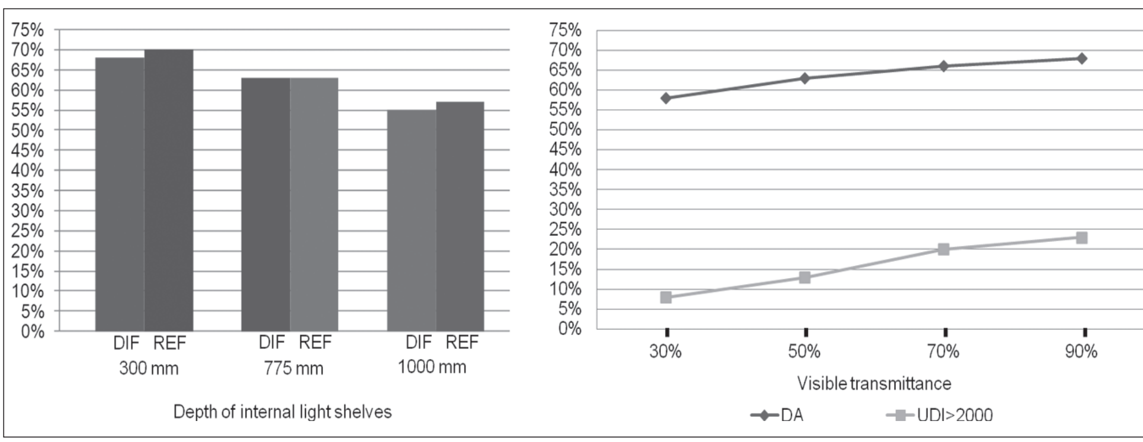

Figure 6: Introduction of highly reflective material has no impact on increasing the annual DA at test point for 775mm deep light shelf (left), however, increase of the visible transmittance of sky window glasses increases both the DA and UDI>2000 respectively for south orientation (right).

paper for London hospitals.

4.5 Material of sky window

Instead of internal light shelves, tinted glasses can be used for sky windows to reduce glare on the test points. Tinted glasses with 30%, 50%, 70%, and 90% normal visible transmittance were studied for sky windows, in this exercise. Figure 6 (right) shows the daylight performance metrics for sky windows with tinted glass with alternative transmittance value for south orientations. It is evident from the analysis that increasing the transmittance value of the glass also increases both the DA and UDI>2000. A glass with 50% transmission value meet both the requirements of the DA (63%) and UDI>2000 level (13%) for south orientations. So, a sky window with clear glass and 775mm light shelf can be replaced by a tinted glazed sky window with 50% transmittance value to achieve similar DA and UDI>2000 levels. To provide a more detailed observation on

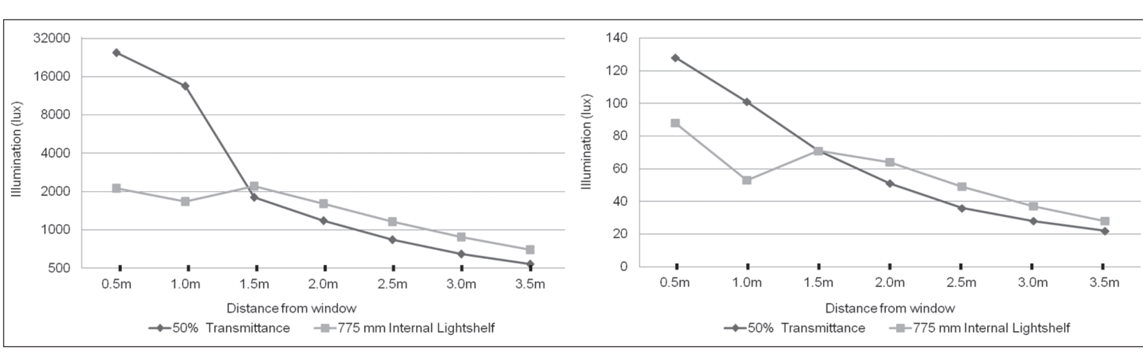

Figure 7: Comparisons of highest illuminations on an axis through the test point for the brightest sunny day (left), and most overcast day (right) for 775mm deep light shelf and tinted sky window glass with 50% transmittance.

the differences between these two options, highest illuminations on an axis through the test point (XX' axis in Figure 1) were compared for the brightest sunny day (28 June at 10:30 AM) and most overcast day (13 November at 11:30 AM) for the typical sky condition of London based on ECOTECT 2010 weather file data provided with the software.

Figure 7 shows daylight illuminations in lx from windows to the back of the rooms when the sensors were placed at 500mm interval on a line perpendicular to the window plane and go through the test points. Though the DA, UDI>2000, and illumination level at test point (1500mm from window) in sunny and overcast days are similar for two options, tinted option had a higher illumination near windows and drops gradually towards back. Light shelf had dramatic contribution to reduce higher illuminations near windows and raised illumination level at back of the rooms. Therefore, considering the individual and annual illumination of the rooms, a sky window with clear glass and light shelf was preferred compared to a sky window with 50% visible transmittance glasses.

4.6 Internal venetian blinds and operation

Venetian blinds can block or divert the direct sunlight to reduce the glare. The advantage of venetian blinds is that it can be raised when sun control is not needed. The shading requirements to protect direct sunlight vary throughout the day for south orientations and literally, no shade is required for north orientations to protect direct sun for London climate. As sun is in the east during morning and west during evening, shades are required to protect direct sunlight only in east during morning and west in afternoon. As a result, a movable internal blind is a preferable solution, which could be dropped in east orientations at early mornings and late afternoons in west orientations.

Although, the developed fixed shading devices (sunshade, overhang and light shelf) were capable to meet the target of DA and UDI>2000 recommended in Section 2 for the in-patient rooms, the scenario of a hospital in-patient room window without blinds is unrealistic. Therefore, an internal blind system was installed for four orientations in addition to the developed shading devices. The design of installed venetian blinds ensured that, it will not allow the direct sunlight into the space and will transmit 25% of diffuse daylight compared to the case when the blinds will be removed. This is a generic blind system model supported by DAYSIM under the simple dynamic shading device mode. The blinds will be fully lowered to avoid glare as soon as direct sunlight above $50Wm^{-2}$ will hit the test point and will be re-opened as soon as the sunlight will reduce below $50Wm^{-2}$. Figure 9 shows the locations of internal blinds for different orientations with fixed shading devices developed in earlier Sections.

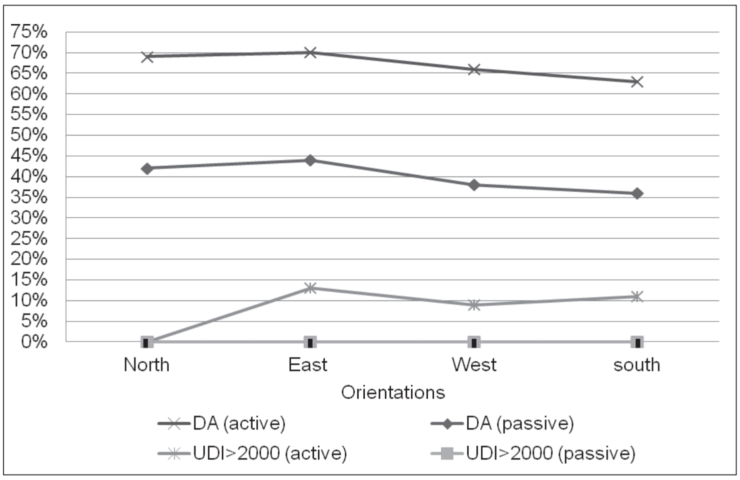

Figure 8: An active blind user can decrease the UDI>2000 levels without decreasing the DA levels.

The performances of internal blinds depend mostly on the behaviour of the users who operate and control blinds. Reinhart (2002) identified two basic user behaviour for blind control based on field studies: active user and passive user. An active user opens the blinds in the morning, and partly closes them during the day to avoid direct sunlight. A passive user keeps the blinds partly closed throughout the year to avoid direct sunlight. Both types of users were considered in this section separately.

Figure 8 shows the impact of blind operations on dynamic daylight metrics considering both active and passive users. It is evident that the impact of blind controls to reduce UDI>2000 is maximum for west orientations. An active user can decrease the UDI>2000 level, kipping the DA levels constant to a situation without any blind. At the same time, a passive user may decrease the DA level significantly and can make the space darken (Figure 8 and Table 3).

4.7 Recommendation of shading devices for sky window configurations

Figure 9 shows the developed shading designs for the sky window configurations by parametric simulation analysis for a single storey hospital building with external en-suite layout and without any surrounding obstructions. Table 3 summarises the recommendations and results of the analysis. The recommended depth of shading devices can be considered as a reference depth for NHS model space for single in-patient units with respect to London's climate. For multi-storey hospital buildings, in conjunction of mutual shading by the building itself (projected upper floors and shading of upper floors) and/or presence of surrounding obstruction (for example other buildings and trees), the depth of the shading devices can be reduced further (Joarder et al., 2009b).

To develop a module and architectural uniformity among different facades of the same building, the design (e.g. size, angle, material and operating methods) of the individual shading elements (sunshade, overhang, light shelf and venetian blind) were kept constant. That means, the sizes of the sunshades (or overhangs, or light shelves) was constant for four orientations for the same hospital building where it was used. Thus facilitates the modular and offsite construction. The various shading requirements of different orientations were satisfied by adding extra shades at different levels of the windows. It needs to be mentioned that the designs of shading devices were developed in such a manner that the fixed shading devices (sunshades, overhangs and light shelves) were sufficient to keep UDI>2000 level to 14%. Introduction of internal blinds with active control helped to reduce the UDI>2000 further without reducing the DA levels. So, if the blinds are kept open for 24 hours, it will not affect to achieve the target level; in addition to that, an active operation of internal blinds will enhance the comfort of patients.

Table 3: Recommended depth of shading devices for sky window for different orientations.

Orientation of sky window	Depth of external sunshades (mm)	Depth of 45^0 angled external overhangs (mm)	Depth of internal light shelves (mm)	Internal venetian blinds control	DA [%]	UDI> 2000 [%]
North	-	-	-	Active	69	0
East	825	-	-	Active	70	13
West	825	200	-	Active	66	9
South	825	200	775	Active	63	11

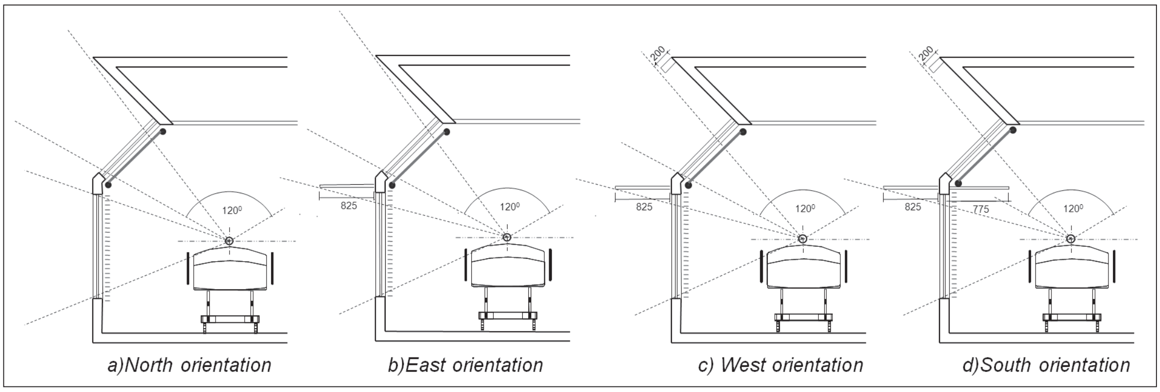

Figure 9: Sections show the recommendations of shading for the windows for four orientations

5. Discussion

To maintain uniformity and develop an architectural grammar, this paper presents a case of shading design where some principle of design was fixed at the beginning and, while progressing, simulation guided decisions were combined with some other practical factors such as solar control criteria, line of vision and aesthetics. The shading design developed for the windows in this research could be one of the way to achieve minimum 80% of outdoor DA with maximum 20% UDI>2000 for an imaginary location in central London. Based on the practicality, surrounding conditions and available outdoor natural light, both the target for indoor DA and UDI>2000 can be changed. It was evident from simulation exercise that, same DA and UDI>2000 can be achieved by a different combination of light shelves, overhangs, sunshades and internal blinds. For example to achieve the target level of DA and UDI>2000, the depth of internal light shelves and depth of external overhangs could be inversely proportional for south orientations. Means, if the depth of overhangs are increased, the depth of internal light shelves are necessary to be decreased to maintain the DA and UDI>2000 level constant. In the simulation exercise, the suitability of a 775mm internal light shelf with a 200mm overhang was shown suitable for the ground floors of single story hospital buildings for south orientations. It is possible to achieve the same DA and UDI>2000 by 275mm deep overhang with 600mm deep internal light shelf (see Appendix B). The authors preferred to maintain the depth of overhangs constant for all orientations of the same building for uniformity as a principle of design. It was evident from the simulation study that, for London climate, north and east are better orientations for in-patient units compared to south or west orientations in terms of achieving therapeutic daylight. Extra care should be concentrated for the design of south windows in hospital buildings to achieve therapeutic illumination for patients, without glare and discomfort. The occurrences of direct penetration of higher intensities of daylight through north windows are uncommon and less critical in terms of glare control and shading requirements.

The options of tinted glass (50% transmittance value) were rejected and clear glass windows with light shelves (775mm depth) was recommended in this paper. However, a lower depths of light shelf (less than 775mm) with a window glass of higher transmission value (above 50%) can also contribute the same level of DA and UDI>2000. These types of precise decisions/options/combinations can be left to the designer's/architect's individual preference. The authors prefer clear glass to facilitate outdoor view and better daylight distributions inside patient rooms. However, tinted glass might be essential to protect ultraviolet radiation (UVR) in some geographical locations where the ambient outdoor UVR is extremely high (Joarder et al., 2009d).

Among thousands (even millions) of options, the configuration of particular design elements recommended in this paper in some cases was primarily governed by authors' (with architectural/construction background) aesthetic and intuitive judgements. E.g., for the angle of the overhang, a 45^0 angle was chosen as it matches well with a 45^0 angled sky window better than other angles and it is not possible to test each degree of angle of overhang due to the limitations of time. Appendix B presents a total 123 numbers of simulation results with different shading configurations exercised in trial and error process during this research period and only 29 numbers were included in the discussions of this paper, based on which most of the design decisions were supported.

A hospital window, located at in-patient room, without blind is unrealistic. It was evident from simulation study that the concerns and benefits of window and shading design can be diminished under occupants' passive blind operations. It is difficult for a hospital patient to be active in blind control. This paper recommends hospital nurses to be active in blind operations and maintain a schedule for opening and closing the blind similar to provide timely medications to patients to maximise daylight inside patient rooms without glare (therapeutic daylight works similar to medicine). Means of operation for patients to control curtains or blinds for privacy and comfort should be included near bed (e.g. motorised curtains for non-ambulatory patients). Fully automated blind control is the least option as it uses active energy continuously i.e. electricity. Passive design and technologies should be used in the therapeutic design of hospital buildings to save energy.

6. Conclusion

Building simulation is a widely accepted research method but not widely/popularly practiced by the architects during design development process. Nowadays, building simulation technology is easily accessible to architects due to the availability of personal computers and software with impressive capability. It is necessary to incorporate or at least start to realise the prospect of simulation study in architectural design practice to conceptualise the precise performance of the design under present and future climate (e.g. climate change).

This paper focuses a research method (daylight simulation) and demonstrates its application on architectural practice in shading design for hospital windows. It was found during simulation analysis that the shading requirements varied for different orientations. With only a particular design of shading devices, it was not possible to satisfy the comfort levels with sufficient therapeutic daylight for different orientations. However, it is common in architectural design to repeat a window with same shading configuration (for example sunshade) for the entire building without considering the orientation and potential for daylighting, and in some cases totally different design of the window shading for different orientations. This paper recommends to keep the design of a particular type of shading device fixed for different orientations for the whole building and add separate shades in different levels of windows where more shades are required than to change the design and depth of the same shading devices for different orientations.

For the studied case space, the glare possibility increased in an order from north, east, west and south. Therefore, the number of shading devices were added gradually higher in north (only internal venetian blinds) to east (internal venetian blinds and external sunshades) to west (internal venetian blinds, external sunshades, and external overhangs) and finally to south (internal venetian blinds, external sunshades, external overhangs and internal light shelves). This principle for developing shading devices for a hospital window can also be used to develop shading systems for windows of other building types. The dimensions of shading devices developed in this simulation exercise can be taken as a reference for shading design for sky window configurations for London. The case presented here can be a starting point for further simulation studies to fix the dimension of shading devices for other locations. It is expected that, the example presented in this paper will help architects and designers to use simulation analysis in their practice and generate new ideas on how simulation analysis can be incorporated from the very beginning of the architectural design process.

Acknowledgements

The authors gratefully acknowledge Loughborough University, the Health and Care Infrastructure Research and Innovation Centre (HaCIRIC), and the Engineering and Physical Sciences Research Council (EPSRC), UK for funding this research project.

References

ADB, (2009). Activity Data Base [CD-ROM]. The briefing, design & commissioning tool for both new-build and refurbishment of healthcare buildings. Department of Health, NHS Estates.

Egan, M. D. and Olgyay, V. W., (2002). Architectural Lighting. New York: McGrew-Hill.

HBN 04-01, (2008). In-patient care, Health Building Note 04-01: Adult in-patient facilities. DH Estates and Facilities Division, Leeds.

Joarder, M.A.R., (2007). A Study of Daylight Inclusion in Luminous Environment of Offices in Dhaka City, Thesis (M. Arch). Department of Architecture, BUET, 7 August, Dhaka.

Joarder, M.A.R., (2008). Sick hospitals of Dhaka city. The Daily star, Agenda for Urban Concern, XVIII (5), January 18, 2008, p- 17.

Joarder, M.A.R, Ahmed, Z.N., Price, A.D.F. and Mourshed M.M., (2009a). A Simulation Assessment of the Height of Light Shelves to Enhance Daylighting Quality in Tropical Office Buildings under Overcast Sky Conditions in Dhaka, Bangladesh. 11th IBPSA Conference, 27- 30 July, Glasgow, UK, pp. 1706 -13.

Joarder, M.A.R, Ahmed, Z.N., Price, A.D.F., and Mourshed M.M., (2009b). Daylight Simulation for Sustainable Urban Office Building Design in Dhaka, Bangladesh: Decision-making for Internal Blind Configurations. 2nd SUE-MoT Conference, 22-24 April, Loughborough, UK, pp. 218-41.

Joarder, M.A.R, Price, A.D.F. and Mourshed M.M., (2009c). A Systematic Study of the Therapeutic Impact of Daylight Associated with Clinical Recovery. HaCIRIC PhD workshop, 1-3 April, Brighton, UK, pp. 25-31.

Joarder, M.A.R, Price, A.D.F. and Mourshed, M.M., (2009d). The Changing Perspective of Daylight Design to Face the Challenge of Climate Change. 3rd SASBE Conference, June 15-19, Delft, The Netherlands.

Joarder, M.A.R, (2009e). A Survey on Daylighting Potentiality in the offices of Dhaka Bangladesh, *Global Built Environment Review (GBER)*, 7 (1), pp 5-22.

Joarder, M.A.R, Price, A.D.F. and Mourshed, M.M., (2010). Access to Daylight and Outdoor Views: A comparative study for therapeutic daylighting design. *World Health Design*, 3(1), pp. 62-69.

Joarder, M.A.R. (2011a). Incorporation of Therapeutic Effect of Daylight in the Architectural Design of In-patient Rooms to Reduce Patients Length of Stay (LoS) in Hospitals. Thesis (PhD), School of Civil and Building Engineering, Loughborough University, UK.

Joarder, M.A.R., (2011b). Daylit Hospitals to Accelerate Clinical Recovery [poster]. Health and Life Sciences Research Student Conference, Loughborough University, 14 March, Loughborough, UK.

Joarder, M.A.R and Ahmed, Z.N., (2011c). Daylight for Office Buildings: Case Study Dhaka. Germany: Lap Lambert Academic Publishing.

Joarder, M.A.R. and Price, A.D.F. (2012a). Therapeutic Daylight for Hospital Patients: A Search for the Benchmarks. European Conference on Design for Health, Sheffield, UK, [In press].

Joarder, M.A.R and Price, A.D.F., (2012b). Impact of Climate Change on the Constructed Luminous Environment: An Evaluation for the Hospitals in London. *The International journal of the Constructed Environment*, [In press].

Mardaljevic, J., (2006). Examples of climate-based daylight modelling. CIBSE National Con- ference 2006: Engineering the Future, 21-22 March, London, UK.

Nabil, A., and Mardaljevic, J., (2006). Useful Daylight Illuminances: A Replacement for Daylight Factors. *Energy and Buildings*, 38(7), pp. 905–913.

Pechacek, C.S., Andersen, M., and Lockley, S.W. (2008). Preliminary Method for Prospective Analysis of the Circadian Efficacy of (Day) Light with Applications to Healthcare Architecture. *LEUKOS*, 5 (1). pp. 1-26.

Perez, R., Seals, R. and Michalsky, J., (1993). All-Weather Model for Sky Luminance Distribution – Preliminary Configuration and Validation. *Solar Energy*, 50(3), pp. 235-245.

Reinhart, C. F. and Walkenhorst, O., (2001). Dynamic RADIANCE-based daylight simulations for a full-scale test office with outer venetian blinds. *Energy & Buildings*, 33(7), pp. 683-697.

Reinhart, C. F., (2002). LIGHTSWITCH 2002: A model for manual control of electric lighting and blinds. *Energy & Buildings*, October.

Reinhart, C. F., (2006). Tutorial on the Use of Daysim Simulations for Sustainable Design [online]. National Research Council Canada. Available from: http://irc.nrccnrc.gc.ca/ie/lighting/daylight/daysim_e.html [Accessed 24 June 2007].

Tregenza, P. R. and Waters, I. M., (1983). Daylight Coefficients. *Lighting Research & Technology*, 15(2), pp. 65-71.

Appendix A: Comparison between different window configurations

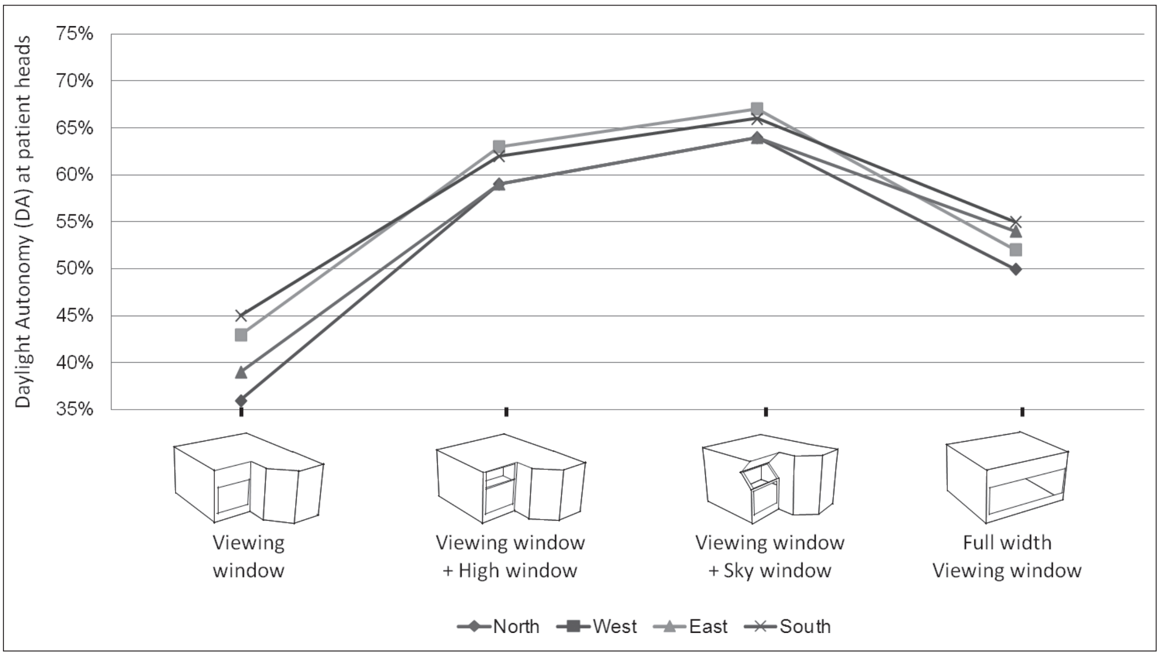

Figure A.1: DA levels at test point with upright sensor position for four types of window configurations (cited from: Joarder, M.A.R., 2011b)

Appendix B: Compilation of simulation results

Window	Location	Orientation	Window Width	Angle of Sky window	Depth of sun Shade	Depth of overhang	internal light shelf	Material of Light shelf	Material of Sky Window (visual transmitence)	Blind Control	DA(%)	DF>2%(%)	DA $_{max}$ above 5% (%)	UDI $_{<100}$ (%)	UDI $_{100-2000}$ (%)	UDI $_{>2000}$ (%)	Electric Lighting Use (kWh/unit area)	Annual lighting Energy Use (kWh)
Viewing Window	1st Floor	North	1800	-	-	-	-	-	90%	-	49	13	5	41	59	0	31.9	478.1
	1st Floor	West	1800	-	-	-	-	-	90%	-	50	14	11	40	58	2	31.7	475.2
	1st Floor	East	1800	-	-	-	-	-	90%	-	54	13	13	37	62	1	30.8	461.4
	1st Floor	South	1800	-	-	-	-	-	90%	-	53	14	13	37	61	1	31.8	477
	1st Floor	North	4500	-	-	-	-	-	90%	-	57	56	14	34	66	0	31.3	469
	1st Floor	West	4500	-	-	-	-	-	90%	-	60	56	40	32	66	3	30.5	457.4
	1st Floor	East	4500	-	-	-	-	-	90%	-	57	55	40	34	60	6	31.2	467.8
	1st Floor	South	4500	-	-	-	-	-	90%	-	60	57	41	32	64	5	31.2	467.5
Viewing window + High Window	1st Floor	North	1800	0	-	-	-	-	90%	-	65	41	11	27	73	0	30.5	458.1
	1st Floor	West	1800	0	-	-	-	-	90%	-	65	41	25	28	59	13	30.5	456.9
	1st Floor	East	1800	0	-	-	-	-	90%	-	68	41	37	26	63	11	29.8	447.5
	1st Floor	South	1800	0	-	-	-	-	90%	-	67	41	33	27	52	21	30.6	458.3
	1st Floor	South	1800	0	750	-	750	-	90%	-	59	37	27	31	58	11	31.2	468.6
Viewing window + Sky window	1st Floor	North	1800	45	-	-	-	-	90%	-	69	51	11	25	74	0	30.3	454.9
	1st Floor	West	1800	45	-	-	-	-	90%	-	69	54	30	25	58	17	30.4	455.5
	1st Floor	East	1800	45	-	-	-	-	90%	-	71	54	49	24	60	16	29.7	445.7
	1st Floor	South	1800	45	-	-	-	-	90%	-	70	54	43	25	48	27	30.5	457.1
	1st Floor	South	1800	30	-	-	-	-	90%	-	64	51	40	25	50	25	30.9	463.1
	1st Floor	South	1800	45	-	-	-	-	90%	-	70	54	43	25	48	27	30.5	457.1
	1st Floor	South	1800	60	-	-	-		90%	-	71	59	52	25	47	28	30.3	455.2
	1st Floor	East	1800	45	825	-	-	-	90%	-	70	52	43	25	61	14	30.9	463.4
	1st Floor	West	1800	45	825	-	-	-	90%	-	68	49	30	26	58	16	30.6	458.7
	1st Floor	South	1800	45	825	-	-	-	90%	-	70	51	38	25	50	26	30.2	453
	1st Floor	west	1800	45	825	-	-	-	90%	-	68	49	30	26	58	16	30.6	458.7
	1st Floor	west	1800	45	825	100	-	-	90%	-	67	49	30	26	59	15	30.6	458.3
	1st Floor	west	1800	45	825	200	-	-	90%	-	66	46	29	27	59	14	30.7	460.1
	1st Floor	west	1800	45	825	225	-	-	90%	-	65	46	27	27	59	13	30.5	457.9
	1st Floor	west	1800	45	825	250	-	-	90%	-	65	46	25	28	59	13	30.8	462.5
	1st Floor	west	1800	45	825	275	-	-	90%	-	65	46	25	28	59	13	30.6	459.5
	1st Floor	west	1800	45	825	300	-	-	90%	-	65	46	25	28	59	13	30.9	463
	1st Floor	south	1800	45	825	200	-	-	90%	-	68	46	38	26	51	23	30.7	460.8
	1st Floor	South	1800	45	825	200	300	DF	90%	-	68	44	38	26	51	23	30.7	460.2
	1st Floor	South	1800	45	825	200	650	DF	90%	-	65	43	33	28	54	18	30.6	458.5
	1st Floor	South	1800	45	825	200	750	DF	90%	-	63	43	32	29	56	15	31	465.4
	1st Floor	South	1800	45	825	200	775	DF	90%	-	63	43	32	29	56	14	30.9	463.9
	1st Floor	South	1800	45	825	200	800	DF	90%	-	62	41	32	30	57	13	31.2	467.8
	1st Floor	South	1800	45	825	200	800	SP	90%	-	62	43	33	30	57	14	31.2	467.9
	1st Floor	South	1800	45	825	200	1000	DF	90%	-	55	37	25	35	62	3	31.7	475.7
	1st Floor	South	1800	45	825	200	-	-	30%	-	58	24	22	33	59	8	31.5	471.9
	1st Floor	South	1800	45	825	200	-	-	50%	-	63	35	32	29	58	13	31.2	467.3
	1st Floor	South	1800	45	825	200	-	-	70%	-	66	44	37	27	53	20	30.8	462.2
	1st Floor	South	1800	45	825	200	-	-	90%	-	68	46	38	26	51	23	30.7	460.8
	1st Floor	South	1800	45	-	-	1000	DF	90%	-	58	37	32	33	61	5	31.2	468.4
	1st Floor	South	1800	45	-	-	650	DF	90%	-	66	43	37	28	53	20	30.7	460.9
	1st Floor	South	1800	45	-	-	600	DF	90%	-	66	43	37	27	52	21	30.6	459.6
	1st Floor	South	1800	45	-	-	550	DF	90%	-	67	44	37	26	52	22	31.2	468.4
	1st Floor	South	1800	45	-	-	500	DF	90%	-	68	46	38	26	51	22	30.6	459.7
	1st Floor	South	1800	45	-	-	300	DF	90%	-	69	51	38	25	49	26	30.6	459.4
	1st Floor	South	1800	45	-	-	250	DF	90%	-	69	49	38	25	49	26	30.6	459.5
	1st Floor	South	1800	45	-	-	225	DF	90%	-	70	49	40	25	49	26	30.6	459.3
	1st Floor	South	1800	45	-	-	200	DF	90%	-	70	51	40	25	49	26	30.7	460.4
	1st Floor	South	1800	45	-	-	None	DF	90%	-	70	54	43	25	48	27	29.7	445.5
	1st Floor	South	1800	45	-	-	1000	DF	90%	-	58	37	32	33	61	5	31.2	468.4
	1st Floor	South	1800	45	-	-	1000	SP	90%	-	59	41	33	32	58	10	31.1	467.1
	1st Floor	South	1800	45	-	-	600	DF	90%	-	66	43	37	27	52	21	30.6	459.6
	1st Floor	South	1800	45	-	-	600	SP	90%	-	67	46	37	26	52	22	30.7	460.5
	1st Floor	South	1800	45	-	-	300	DF	90%	-	69	51	38	25	49	26	30.6	459.4
	1st Floor	South	1800	45	-	-	300	SP	90%	-	69	48	38	25	49	26	30.6	459.5
	1st Floor	South	1800	45	-	900	600	SP	90%	-	57	17	13	34	63	3	31.4	470.7
	1st Floor	South	1800	45	-	600	600	SP	90%	-	59	30	24	33	63	5	31.3	468.9
	1st Floor	South	1800	45	-	300	600	SP	90%	-	64	43	33	29	55	16	30.8	461.9
	1st Floor	South	1800	45	-	275	600	SP	90%	-	64	41	33	29	55	17	30.5	458.2
	1st Floor	South	1800	45	-	250	600	SP	90%	-	64	43	33	28	54	18	30.5	458.2
	1st Floor	South	1800	45	-	225	600	SP	90%	-	65	43	35	28	54	18	30.6	459.6

Appendix B: (continued)

Window	Location	Orientation	Window Width	Angle of Sky window	Depth of sun Shade	Depth of overhang	internal light shelf	Material of Light shelf	Material of Sky Window (visual transmitence)	Blind Control	DA(%)	DF>2%(%)	DA $_{max}$ above 5% (%)	UDI $_{<100}$ (%)	UDI$_{100-2000}$ (%)	UDI $_{>2000}$ (%)	Electric Lighting Use (kWh/unit area)	Annual lighting Energy Use (kWh)
Viewing window + Sky window	1st Floor	South	1800	45	850	300	600	SP	90%	-	62	40	32	30	57	13	30.9	463.3
	1st Floor	South	1800	45	825	300	600	SP	90%	-	62	41	32	30	57	13	30.9	463.3
	1st Floor	South	1800	45	850	275	600	SP	90%	-	62	43	33	29	57	13	30.9	463.5
	1st Floor	South	1800	45	825	275	600	SP	90%	-	63	43	32	29	57	14	30.9	463.4
	1st Floor	South	1800	45	850	250	600	SP	90%	-	63	43	32	29	56	15	30.6	461.1
	1st Floor	South	1800	45	825	250	600	SP	90%	-	63	43	32	29	56	15	30.7	460.9
	1st Floor	South	1800	45	850	225	600	SP	90%	-	63	43	33	29	56	15	30.8	462
	1st Floor	South	1800	45	825	225	600	SP	90%	-	63	43	33	29	56	15	30.8	462
	1st Floor	South	1800	45	750	None	None	DF	90%	-	70	54	43	25	48	27	30.9	462.9
	1st Floor	South	1800	45	750	None	750	DF	90%	-	65	43	38	28	51	21	31	465.6
	1st Floor	South	1800	45	750	None	750	SP	90%	-	66	49	38	27	52	21	30.8	462.6
	1st Floor	East	1800	45	750	None	750	DF	90%	-	66	46	40	27	62	11	30.1	451.9
	1st Floor	South	1800	45	850	None	225	SP	90%	-	68	48	38	26	51	23	30.6	458.3
	1st Floor	South	1800	45	750	None	225	SP	90%	-	68	48	38	26	51	23	30.6	458.3
	1st Floor	South	1800	45	650	None	225	SP	90%	-	69	48	38	26	50	24	30.6	458.6
	1st Floor	South	1800	45	550	None	225	SP	90%	-	69	49	38	25	49	25	30.6	458.9
	1st Floor	South	1800	45	450	None	225	SP	90%	-	69	49	38	25	49	25	30.6	459.1
	1st Floor	South	1800	45	None	None	225	SP	90%	-	70	49	40	25	49	26	30.6	459.3
	5th Floor	South	1800	45	825	275	600	SP	90%	-	62	43	33	30	57	13	31.2	468.3
	5th Floor	South	1800	45	825	250	600	SP	90%	-	63	43	33	29	57	14	30.9	463.3
	5th Floor	South	1800	45	825	225	600	SP	90%	-	63	43	33	29	56	15	30.8	461.5
	5th Floor	South	1800	45	825	200	600	SP	90%	-	63	43	33	29	57	14	30.9	463.3
	1st Floor	South	1800	45	825	275	600	SP	90%	-	63	43	32	29	57	14	30.9	463.4
	1st Floor	East	1800	45	825	275	600	SP	90%	-	63	41	32	29	64	7	30.3	455
	1st Floor	East	1800	45	825	275	-	-	90%	-	68	46	33	26	62	12	30.1	451.3
	1st Floor	west	1800	45	825	275	-	-	90%	-	65	46	25	28	59	13	30.6	459.5
	1st Floor	North	1800	45	-	275	-	-	90%	-	66	46	11	26	74	0	30.3	454.1
	1st Floor	South	1800	45	825	200	775	DF	90%	Active	43	63	30	29	59	11	31.1	465.9
	1st Floor	South	1800	45	825	200	775	DF	90%	Passive	43	36	0	50	50	0	31.1	465.9
	1st Floor	West	1800	45	825	200	-	-	90%	Active	46	66	14	27	64	9	30.6	465.3
	1st Floor	West	1800	45	825	200	-	-	90%	Passive	46	38	0	46	54	0	30.6	465.3
	1st Floor	East	1800	45	825	-	-	-	90%	Active	52	70	37	25	62	13	30.6	465.3
	1st Floor	East	1800	45	825	-	-	-	90%	Passive	52	44	0	42	58	0	30.6	465.3
	1st Floor	south	1800	45	825	275	600	SP	90%	Active	43	63	30	29	59	12	30.8	462.5
	1st Floor	south	1800	45	825	275	600	SP	90%	Pasive	43	37	0	49	51	0	30.8	462.5
	1st Floor	East	1800	45	825	275	-	-	90%	Active	46	68	35	26	64	10	29.9	448.7
	1st Floor	East	1800	45	825	275	-	-	90%	Pasive	46	39	0	44	56	0	29.9	448.7
	1st Floor	East	1800	45	825 (45^0)	275	-	-	90%	Active	40	65	27	28	67	5	30.3	455.2
	1st Floor	East	1800	45	825 (45^0)	275	-	-	90%	Pasive	40	31	0	50	50	0	30.3	455.2
	1st Floor	West	1800	45	825 (45^0)	275	-	-	90%	Active	40	62	8	30	65	5	31	465.3
	1st Floor	West	1800	45	825 (45^0)	275	-	-	90%	Pasive	40	29	0	53	47	0	31	465.3
	1st Floor	West	1800	45	825	275	-	-	90%	Active	46	65	14	28	64	8	30.5	456.9
	1st Floor	West	1800	45	825	275	-	-	90%	Pasive	46	37	0	47	53	0	30.5	456.9
	1st Floor	north	1800	45	-	275	-	-	90%	Active	46	66	11	26	74	0	30.3	454.1
	1st Floor	north	1800	45	-	275	-	-	90%	Pasive	46	37	0	47	53	0	30.3	454.1
	1st Floor	South	1800	45	825	275	-	-	30%	-	59	24	22	32	60	8	31.3	468.9
	1st Floor	South	1800	45	825	275	-	-	50%	-	63	33	30	30	58	13	30.9	463.1
	1st Floor	South	1800	45	825	275	-	-	70%	-	66	40	35	28	53	19	30.7	460.9
	1st Floor	North	1800	45	-	-	-	-	90%	Active	52	69	11	25	74	0	30.5	457.5
	1st Floor	North	1800	45	-	-	-	-	90%	Passive	52	42	0	44	56	0	30.5	457.5
	1st Floor	South	4500	45	825	200	775	DF	90%	Active	69	98	97	25	54	21	30.4	455.6
	1st Floor	South	4500	45	825	200	775	DF	90%	Passive	48	98	0	42	58	0	30.4	455.6
	1st Floor	South	3125	45	825	200	775	DF	90%	Active	68	87	78	25	55	20	30.6	459.2
	1st Floor	South	3125	45	825	200	775	DF	90%	Passive	47	87	0	43	57	0	30.6	459.2
	1st Floor	South	1800	45	825	200	775	DF	90%	Active	66	43	35	28	57	15	30.6	458.9
	1st Floor	South	1800	45	825	200	775	DF	90%	Passive	41	43	0	46	54	0	30.6	458.9
	1st Floor	South	4450	45	825	200	775	DF	90%	-	69	98	97	25	50	25	30.5	457.7
	1st Floor	South	3125	45	825	200	775	DF	90%	-	67	87	79	26	51	23	30.5	458.1
	1st Floor	South	1800	45	825	200	775	DF	90%	-	66	43	37	28	53	19	30.6	458.9
	1st Floor	South	4450	45	-	-	-	-	90%	-	74	98	98	24	38	39	29.8	447

*DF – Diffuse surface material

*SP – Specular surface material