

# **Consequences of Climate Change on the Therapeutic Impact of Indoor Illumination on Hospital Patient: Assessment for an Imaginary In-Patient Room Located at London**

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## **ABSTRACT**

Due to a global climate change, individual environmental variables are expected to be changed, for example changes in indoor and outdoor daylight levels are expected in future. The diurnal and annual daylighting performance of a window analysed by computer based daylight simulation programs with historical data, which is a widely accepted research method, is also expected to be different under projected future climate data. The objective of this paper is to identify the difference in indoor daylight level at a particular point (patient retina) inside in-patient rooms due to the use of predicted climate change weather data instead of historical weather data, and its probable impact on the therapeutic needs of hospital patients. Change of daylight levels inside in-patient room is analysed by prospective daylight simulation analysis using a dynamic annual climate based daylight modelling (CBDM) method (i.e. DAYSIM), where the TMY2 weather data provided with ECOTECH

2010 is replaced by climate change data defined by UKCIP02 under different future emissions scenarios for an imaginary hospital in-patient room located in London, UK. The analysis shows that there is a possibility to increase the average indoor room illumination at the location of patient retina by a maximum of 8% in the future (2080-2100) compared to the present (1983-2004). It is also evident that windows, with integrated shading systems with active blind control, are capable to keep the annual dynamic daylight metrics (i.e., DA and UDI>2000) at the location of patient retina nearly constant in case of the increased level of indoor daylight illumination due to climate change, but internal blinds will be needed to shut down more often/time during day hours, which might create a negative impact on patient psychological health due to lack of outdoor view. This paper presents a case of the difficulties/uncertainties of using computer based daylighting simulation programs to achieve the design goal based on historical data and, also highlights the necessity for the consideration of future climate data while do daylighting simulation analysis.

Keywords: climate change, hospital patient, daylight, in-patient room, indoor illumination, therapeutic impact, CBDM simulation.

## INTRODUCTION

Assessment of existing buildings shows that many buildings are at the risk of being uninhabitable in the future without additional protection in building service design. This can be expected to have significant impact on the building industry; therefore, refurbishment might be necessary for the existing buildings to meet the challenge of the climate change. During new construction, additional consideration should be taken, so that the design must satisfy the demand to cope with the climate change. In this regard, computer based building simulation method could be a useful tool to assess and conceptualise the performance of present and future constructions.

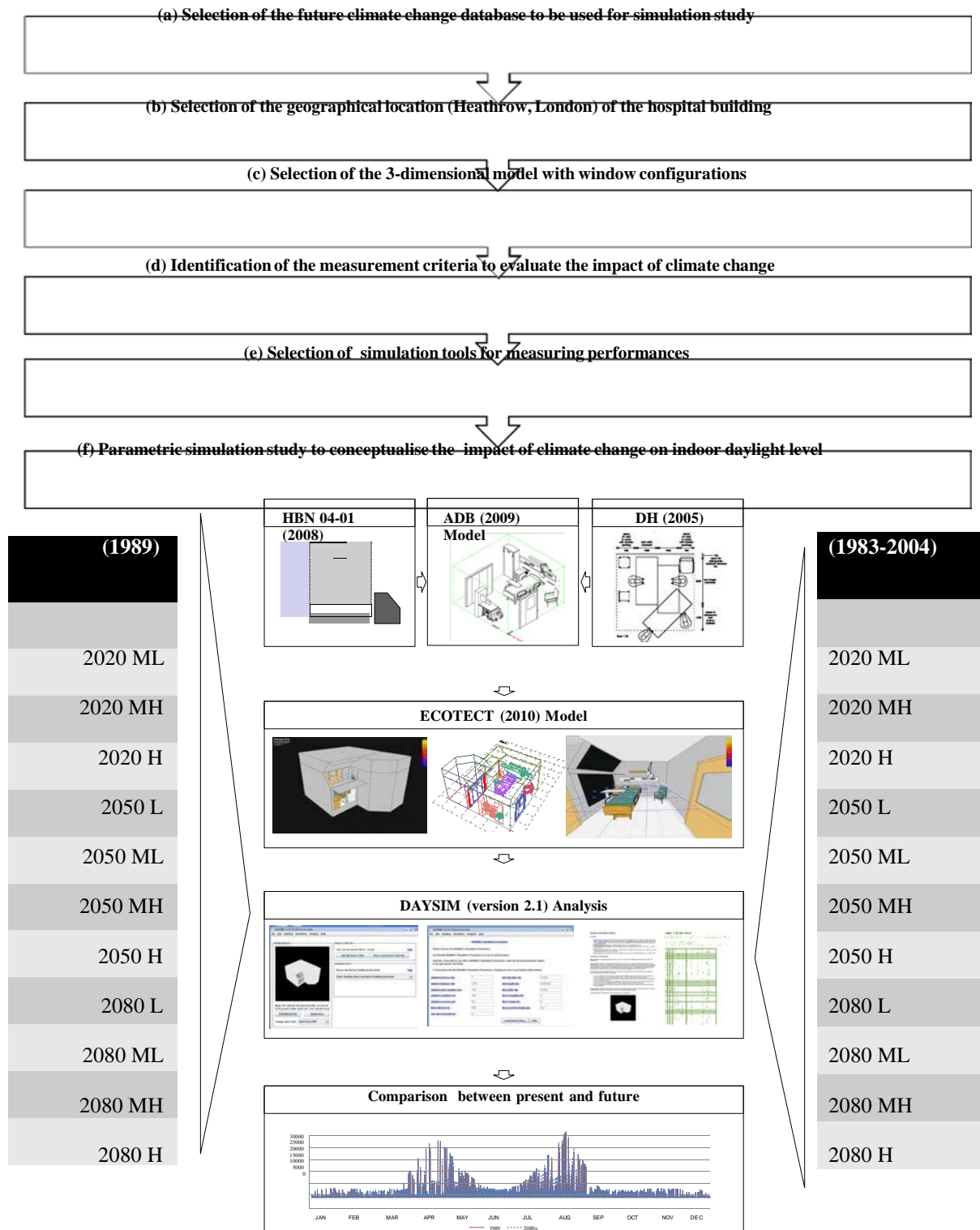
Rapid climate change, which is mainly associated with greenhouse gas (GHG) emissions, is responsible for many dangerous regional and global environmental events. Climate change has the potential to decrease cloud cover (HPA, 2002) and change in sunshine duration. According to United Kingdom Climate projection 2009 (UKCP09), the changes in mean cloud amount during summer can be decreased up to -18% (-33 to -2%) in some parts of UK (southern) which will result an addition of  $+16\text{W/m}^2$  (-2 to  $+37\text{W/m}^2$ ) in downward shortwave radiation over the 21st century (Jenkins et al., 2009). Similar type of impact is also expected to visible radiation (i.e. daylight). Climate change thus introduces several new issues to the knowledge gap in daylighting research (Joarder and Price, 2009d; 2012a) and daylight design strategies should not only meet the current requirements but also should take accounts of any future changes.

A previous study (Joarder and Price 2012c), shows that the average global radiation can rise by a maximum of  $8.3\text{W/m}^2$  at London (Heathrow), UK, in the future (2080-2100) compared to the present (1983-2004) based on the Chartered Institution of Building Services Engineering, UK (CIBSE, 2008) database. As a result, for the first time, the evaluation of the daylighting performance of a single bed in-patient room under different future emissions scenarios revealed that there is a possibility to increase the average indoor room illumination by a maximum of 5% (average 16.58 lx considering 24 hours, and 33.23 lx considering 12 hours of daylighting from 06:00 AM to 06:00 PM) in the future compared to the present with a difference from -595.54 lx to 579.03 lx. It is important to consider how this large amount of variation will be incorporated in the design of indoor daylighting in the future, because the level of indoor illumination is associated with occupants' health and visual comfort (Joarder et al., 2013, 2009c, 2010; Pechacek et al., 2008). This study aim to contribute further to this literature by examining the impact of this increased indoor daylight level relevant to the therapeutic needs of hospital patients, and to discuss few strategies to incorporate the changing level of daylight in future.

To make an object visible, light is needed to fall on the object first and then needed to be reflected towards the eyes. On the other hand, to satisfy therapeutic needs, higher intensity of daylight is needed to be incident directly on individual retinas to start biological stimulation inside human body (Lockley et al., 2006) which regulates different functions, such as maintenance of sleep and circadian rhythm (Pechacek et al., 2008); reduction of pain and appetite; and improvement of feelings and emotions (Joarder et al., 2009c). Therefore, the amount of daylight incident on patient retina is an important factor to evaluate the therapeutic potentiality of indoor daylighting of in-patient rooms. As patients are assumed to be largely stationary in a hospital room, it allows the consideration and evaluation of daylight intensity in one location (Pechacek et al., 2008). To understand the contribution of indoor daylight level on therapeutic gain to the patient, it will be sensible to present a comparison between the current illumination with the future illumination at patient retina that has been considered as test point for simulation analysis in this paper. This paper consists of three major parts. The first part briefly describes the research methodology for simulation analysis. The second part presents the findings of simulation study. The third part highlights few strategies to incorporate the changing level of daylight in future and how this change could be used to enhance the therapeutic benefit of daylit in-patient rooms.

## METHODOLOGY

The structure of the research methodology is consists of six steps (Figure 1). The first three steps are concerned about the selection of the climate database, geographical location and 3- dimensional space to be used for simulation study. Next, three steps are concerned about evaluation measurement criteria, tools and parameters of simulation study to conceptualise the impact of climate change on the indoor illumination levels at patient retina (i.e. test point) under the future climate change scenarios. The simulation method followed in this paper was adapted from the simulation methodology to identify the impact of climate change on the average indoor illumination published elsewhere (Joarder and Price 2012c). A brief summary of the adopted methodology has been illustrated in Figure 1, described below.



\*L: Low; ML: Medium-Low; MH: Medium-High; and H: High.

Figure 1 Flow diagram of prospective simulation study under future climate change scenarios.

## 2.1 Future climate database, geographical location and case space

For building simulation analysis, time series or time-scales data are required in hourly or more precise levels. Climate change database, modelled by CIBSE (2008), which supports the projections of climate change described by United Kingdom Climate Impacts Programme 2002 (UKCIP02) is used for this research. The UKCIP02 scenarios are based on one of the world most comprehensively validated climate models: Hadley Centre models (Hulme et al., 2002). CIBSE (2008) data were produced at a spatial resolution of 50km and available for 14 UK sites. The current and future CIBSE hourly weather data sets for London are based on the geographical location of Heathrow (latitude = 51.48N, longitude = 0.45W, and altitude = 25m) that is located at 12 nautical miles (22 km/14 mile) west of Central London. For this paper, Heathrow has been selected as the geographical location of hospital building for simulation study.

The 3D in-patient single-bed room, used in the simulation exercise as case space was developed according to the guideline described in Health Building Note 04-01 (2008) published by the Department of Health, UK (Figure 2). The case room has two windows on the south facade with a total 22.3% window-to-floor ratio (Figure 3). Two windows were installed in the same facade (south) of the case room. The first one is a standard viewing window with  $2.43\text{m}^2$  opening area (1350mm x 1800mm) with sill height at 450mm (HTM 55, 1998). The second one is a  $45^\circ$  angled window with  $1.8\text{m}^2$  opening area (1000mm x 1800mm) placed at a height of 1850mm from finished floor level above the viewing window (Figure 2). The  $45^\circ$  angled window was specially developed for hospital in-patient rooms by Joarder (2011; 2012a) which performed better to achieve therapeutic daylight (daylight for health) for patients compared to traditional typical high window configurations. As both daylight and outdoor views are significantly important to accelerate patients' recovery (Joarder et al., 2013; 2010), the widths of both the windows were kept as large as possible (1800mm) after placing the external in-suite (2285mm x 2100mm), to maximise the outdoor views of the patients. The design of the shading for the windows was as it was recommended by Joarder and Price (2012a) for south orientations: 825mm external sunshade; 200mm external 45° angled overhang and 775mm internal light shelf, published elsewhere (Figure 3).

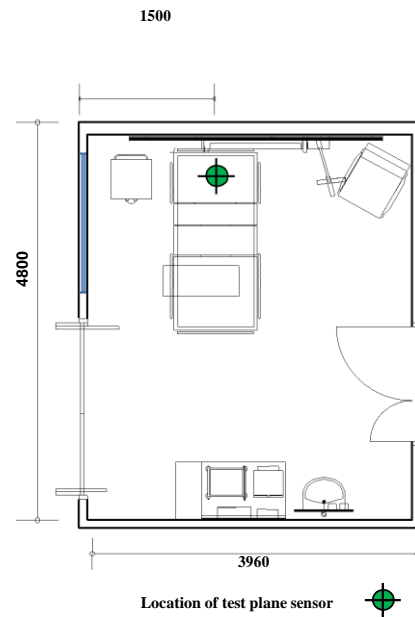


Figure 2 Location of test plane sensor in case space.

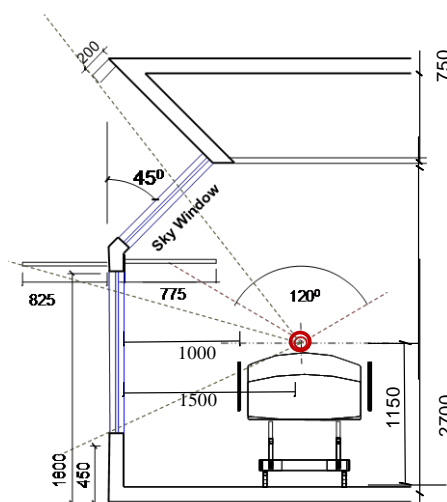


Figure 3 Section shows distance of patient bed and test point sensor from window with recommended shading devices.

At the beginning, the windows were considered without any blinds during simulation analysis to isolate the impact of the change of outdoor daylight level on indoor daylight level due to the climate change, and to avoid the effect of the operations of the internal venetian blinds in daylighting the space (Joarder et al., 2009a; 2009b). Later to evaluate the therapeutic potentiality of the space an internal blind, controlled by an active user, was considered. The height of the test plane was fixed to 1150mm above floor level which represent the patients' average eye level when lying on a bed in different ergonomics positions (Figure 4). The test point sensor was placed 1500mm away from the window surface and the direction of the sensor was considered upward (Joarder & Price 2012a; 2012b; 2012c).

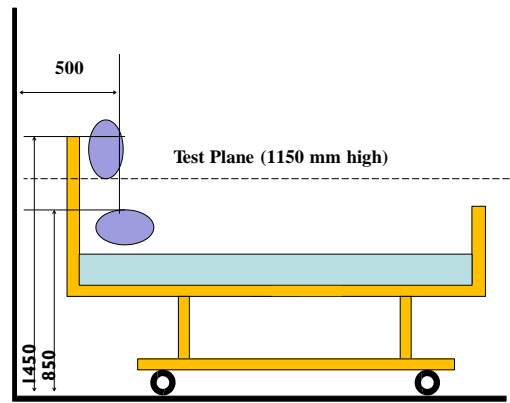


Figure 4: The height of the test plane at 1150mm above floor level (after SLL, 2008).

### 2.2 Daylighting simulation

To understand the magnitude of the changes in indoor daylight levels at test point, simulation was done under current climate data and was compared with the performance under future climate change time slices (i.e. 2020s, 2050s & 2080s) under different levels of anthropogenic carbon-dioxide emissions scenarios (for example low, medium-low, medium-high and high), keeping the rest of the features of the case space unchanged. The daylight levels were simulated with one hour interval at the location of the test point sensor. For each scenario, the test point has 8,760 illumination data considering 24 hours of the day, and 4,380 data considering 12 hours of daylight from 6 AM to 6 PM. The hourly illuminations at test point were averaged for the whole year and considered as the average illumination level at test point for one specific time slice under particular emission scenario. Later, the overall change in annual pattern of daylight level at test point were considered in terms of dynamic daylight metrics (i.e.  $DA^1$  and  $UDI^2$ ) to consider the change in therapeutic potentiality of the space.

The 3D computer-aided design (CAD) drawings generated in ADB (2009) software for single-bed in-patient unit with furniture layouts (based on HBN 04-01 (2008) and DH (2005) was imported to ECOTECT (Figure 1). ECOTECT was used as the modelling interface to launch DAYSIM program that is based on dynamic climate based daylight modelling (CBDMM) method (Mardaljevic, 2006). 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). Changes to material properties (Table 1) and simulation parameters (e.g. timing and duration) were assigned in DAYSIM. Typical Meteorological Year, version 2 (TMY2) weather data provided with ECOTECT 2010 software was replaced with future climate projection data (i.e. CIBSE, 2008) based on current and future Test Reference Years (TRYs) and Design Summer Years (DSYs) hourly weather data sets before calculating annual illumination profiles at test point (Figure 1).

Table 1 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 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 specula reflection

Source: Joarder and Price, 2012a;2012c.

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

source: Reinhart, 2006.

The design illumination level at test point for dynamic daylight metrics (DA and UDI>2000) for this paper was to provide minimum 190 lx daylight (Pechacek et al., 2008) within a maximum discomfort limit of 2000 lx (Nabil et al., 2006) for south orientation, for a duration of 12 hours in a day from 06:00 AM to 06:00 PM (Joarder and Price, 2012c), for an imaginary patient laying on the spine on the bed in a hospital in-patient room located at Heathrow, West London.

## RESULTS

### 3.1. Change of daylight level on test point

Figure 5 summarises the increase of the average indoor illumination level from the present (1983-2004) to the extreme future (2080s under high emissions scenarios) considering the average of 24 hours and the selected 12 hours of daylighting for test point sensor. Increases of illuminations were higher for DSYs cases for test point sensor. Based on DSYs, the average illumination level at test point increased by 2% from 1989 to 2020s and increased further by 3% per 30 years till 2080s under low emissions scenarios. While under high emissions scenarios the increases of the average illuminations at test points were by 3% per 30 years from 2020s to 2080s. As a result the average indoor illumination could raise a maximum of 8% (average 62.56 lx considering 24 hours and 126.46 lx considering 12 hours) in the future (2080s) compared to the present (1989). Based on TRYs, the average indoor illumination can also raise by a maximum of 7% (average 51.90 lx considering 24 hours, and 104.82 lx considering 12 hours) in the future (2080s) compared to the present (1983-2004).

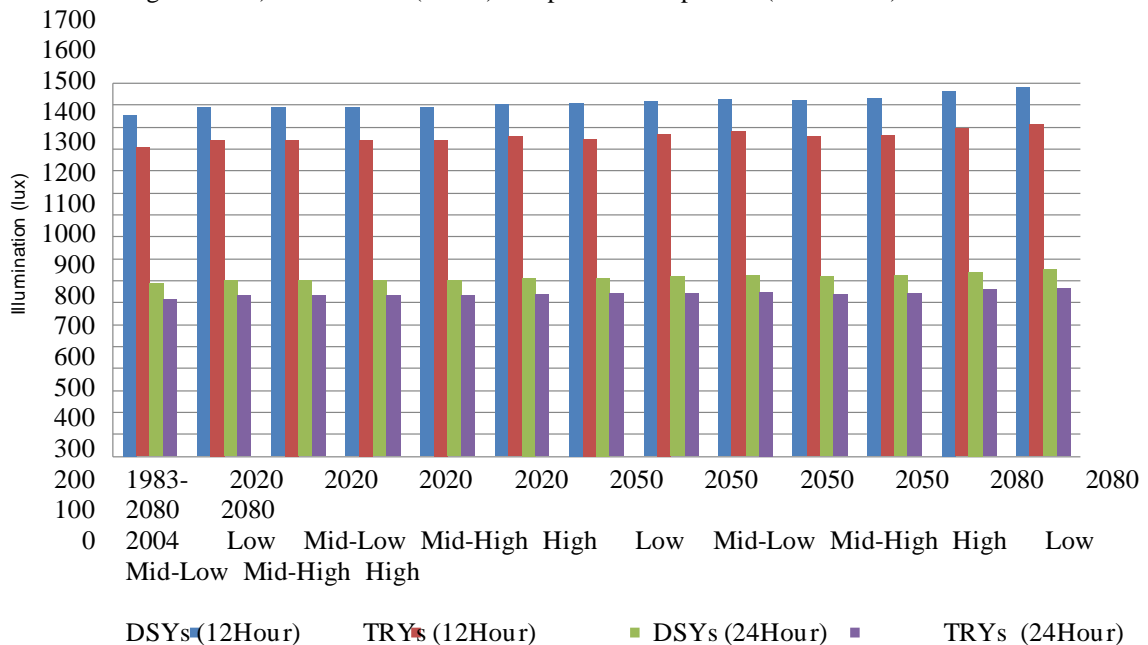


Figure 5: Increase of average indoor illumination levels at core test plane sensors due to climate change.

Figure 6 shows the illumination profile comparison between the present and the extreme future under DSYs at test point. Comparison of annual (Figure 6) and monthly (Figure 7) illumination profiles shows that the variations between the present and the future illuminations are not constant. A closer observation of 24 hours daily illumination profiles (Figure 8) reveal that the differences between the future to the present could vary from - 995 lx (27 January at 12:00 PM) to 3706 lx (24 August at 12:00 PM) on a particular time of the years.

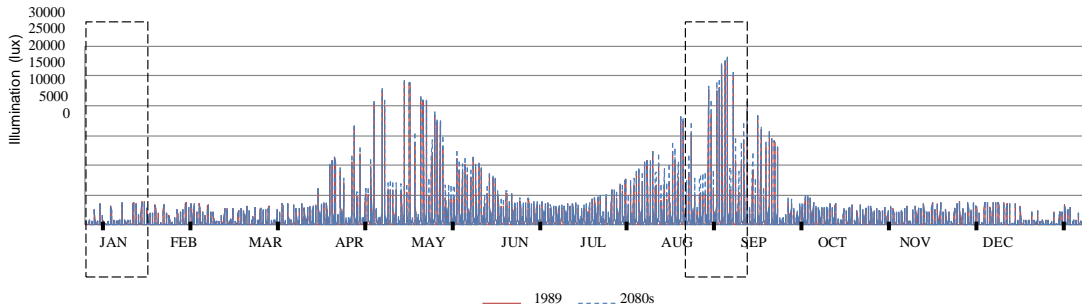


Figure 6: Comparison of yearly illumination profiles between 1989 and 2080s (DSYs) at core test plane sensor.

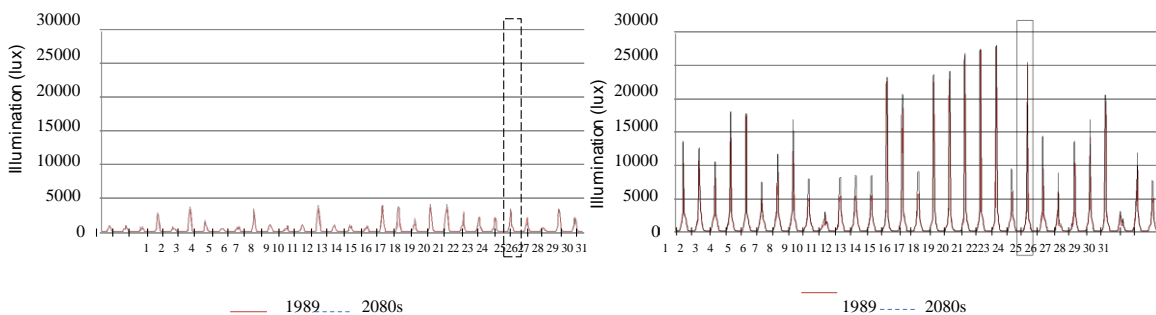


Figure 7: Comparison of monthly illumination profiles between 1989 and 2080s for the months of January (left) and August (right) (DSYs) at core test plane sensor.

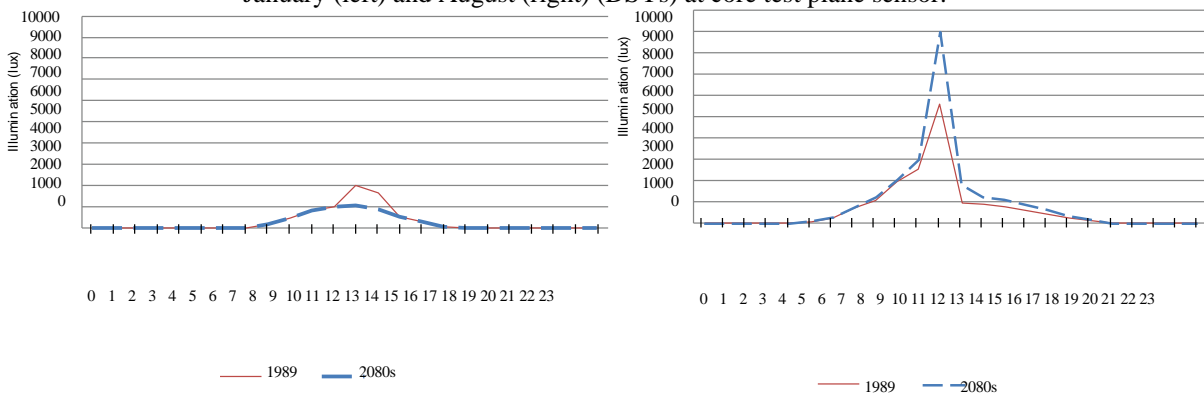


Figure 8: Comparison of 24 hours illumination profile between 1989 and 2080s on 27 January (left) and 24 August (right) (DSYs) at core test plane sensor.

### 3.2. Consideration of the therapeutic effect of changing daylight levels

Comparison of illumination profiles between the present and the extreme future reveal that in most of the future time, the illuminations will be higher compared to the present illuminations, which results an overall 8% increase in the average daylight level at test point. There are both advantage and disadvantage of this increase of illumination in future. The present illumination, which is lower than 190 lx at a particular time, might be increased to a therapeutic level to support patient’s circadian rhythm. At the same time, the present therapeutic illumination at a particular time can cross the limit of comfort (2000 lx) and, therefore, can create glare. As a result, the changing amount of daylight received by patients on their retinas might affect the expected therapeutic gain from daylight on patients’ psychological and physiological improvement during their hospital stay.



It is apparent from detail observation of the single day illumination profiles (Figure 9), that illumination levels varied maximum around noontimes (12:00 – 1:00 PM) when both present and future daylight levels are much higher (exceeds the comfort levels) then the benchmark used in this paper (190- 2000 lx). In other times of considered daylight hours (between 06:00-11:00 AM, and between 02:00- 06:00 PM) the light levels increased gradually. These 24 hours daily illumination profiles suggest that a shift change/adjustment in blind control/operations might be a suitable option to keep the duration and amount of illumination levels nearly constant. In this case the opening and closing of venetian blinds should be earlier in the morning, and re-opening of the blinds in the evening should delay from the present schedule of blind operation. The overall pattern of yearly daylight change on patient retina can be compared by presenting the change in the dynamic daylight metrics (DA and UDI>2000) on the test point.

To understand the contribution of internal blinds on increased daylight level, an internal blind is installed for south orientations with the recommended fixed shading devices mentioned earlier. The design of installed venetian blinds ensures 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  $50\text{W/m}^2$  will hit the test point and will be re-opened as soon as the sunlight will reduce below  $50\text{W/m}^2$ . Figure 9 shows the locations of internal blinds for south orientations with recommended fixed shading devices.

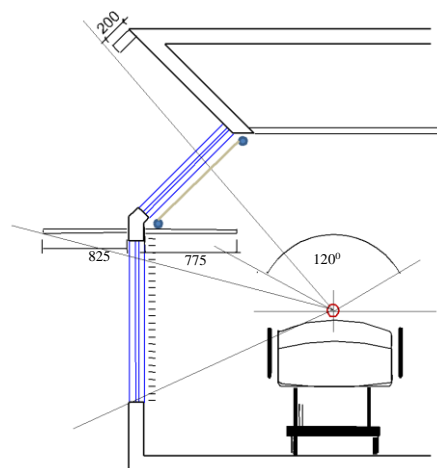


Figure 9 :Section shows the locations of internal blinds for south orientations with recommended fixed shading devices.

Figure 10 shows the impact of blind operations on indoor daylight metrics when the blinds are operated by an active user who opens the blinds in the morning, and partly closes them during the day to avoid direct sunlight (Reinhart, 2002). Under active blind control it will be possible to keep the present DA level constant for both DSYs (76%) and TRYs (75%). The glare level on test point (UDI>2000) remained constant under TRYs (18%), while under DSYs varied 1% (19% - 20%). The overall glare level considering the 63 intersecting points on a 500 x 500mm grid on test plane sensors (DAm<sub>max</sub> above 5%) varied up to 2% (between 35% -37%) for both DSYs and TRYs. It was evident from the analysis of daylight metrics that the integrated shading system with active blind control is capable to protect the increased level of indoor daylight illumination due to climate change.

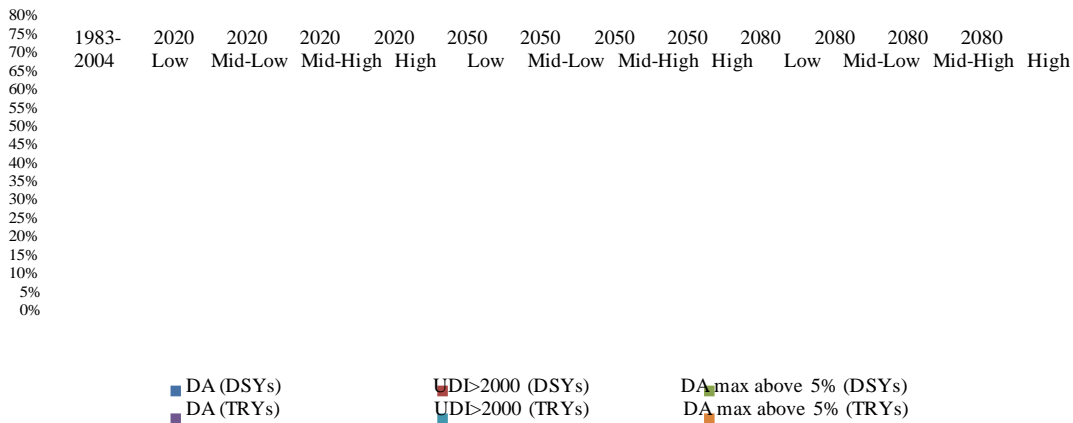


Figure 10: Under active blind controll the DA will remain constant; UDI > 2000 and DAmx above 5% changes slightly (1-2%).

Figure 11 shows a summary of the yearly blind operation schedule to keep the DA levels constant under DSYS and TRYs simulated for this study. To keep the DA level constant under extreme future compared to present, it needs to keep the blinds downward 28% more in a year for DSYS, and 40% more for TRYs.

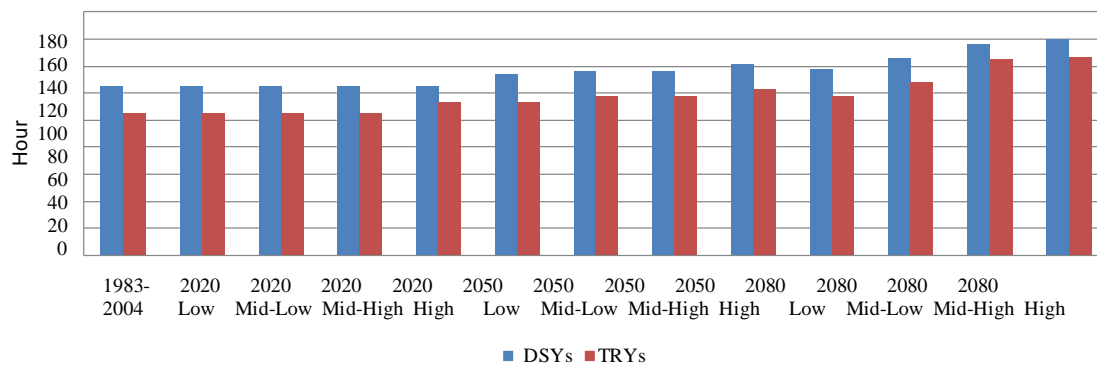


Figure 11: Total number of hours that the blinds need to be kept downward to keep the DA level constant under DSYS and TRYs.

### DISCUSSIONS

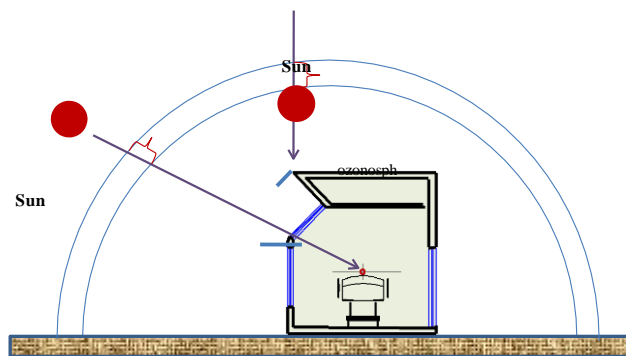
The analysis of the therapeutic daylighting performance of the case window configurations under different future emissions scenarios revealed that, the average indoor illumination at test point can raise by a maximum of 8% (average 62.56 lx) in the future (2080s) compared to the present (1983-2004) based on the CIBSE (2008) database and the differences can vary -995 lx to 3706 lx. Comparing the average illumination increase in test point to the average increase of the room illumination (average of 63 intersecting points at test plane) identified previously by Joarder and price (2012c) as 5%; it seems that average increase in illumination at test point is 3% higher than the average room illumination due to the close location of patient beds near windows. It was also evident that, the difference in indoor daylight levels between the present and the extreme future is due to increase of higher illumination during noontimes (Figure 9) and, therefore, extra protections are needed during this time periods.

The simulation analysis showed that the case window configurations, with integrated shading system with active blind controls are capable to protect the increased level of indoor daylight illumination due to climate change. But, to protect the indoor from increased daylight levels, internal blinds were needed to shut down more often/time during day hours, which might create negative impact on patient clinical improvement due to lack of outdoor views. An outdoor natural view are found positive to patients' recovery process psychologically (Kaplan, 2001; Kaplan et al., 1995; Ulrich, 1979), physiologically (Chang et al., 2005; Lohr et al., 1996; Coleman et al., 1995; Ulrich et al., 1991; Doxon et al., 1987; Verderber et al., 1987; Ulrich, 1984;), emotionally (Adachi et al., 2000; Ulrich et al., 1991; Ulrich, 1981), and in cognitive changes (Tennesen et al., 1995; Cimprich, 1993; Hartig et al., 1991). Both daylight and outdoor view have a significant impact on patient clinical recovery, which was found by previous studies, based on the analysis of real world field data (Joarder et al. 2010; 2013).

The design of simulated venetian blinds presented in this paper, did not allow the direct sunlight into the space and transmitted 25% of diffuse daylight compared to the case when the blinds were removed. It is also possible to enjoy the maximum use of increased daylight level by using specially designed blinds which will not generic in nature but interactive/change continuously (not fixed to  $50\text{W/m}^2$ ) and allow 0%-100% of outdoor daylight throughout the daylight hours to increase DA levels without increasing glare. It is also important to consider that with higher daylight illumination, high heat gain and UVR can enter through the windows into the space and could be harmful to patients (Joarder et al., 2009d).

### LIMITATIONS

In this paper, the impact of the increase of indoor daylight levels was observed by evaluating the performance of south window configurations with fixed and movable shading devices. The design of the case window configurations, with inclined window at the top and tilted ceiling above, has certain advantages in this regard. The pitched service space (or upper floor) above the inclined window provides better protection from direct sun during noontimes; a horizontal skylight without any shade might allow excessive amount of illumination inside patient room during noontime when the sun is near zenith and outdoor ambient daylight level is highest in the environment, as well. Therefore, the 8% increase in average indoor illumination at test point is specific to the particular design of the case window configurations. The simulation analysis showed that the case window configurations, with integrated shading systems and active blind controls are capable to keep the DA and  $\text{UDI} > 2000$  nearly constant in case of the increased level of indoor daylight illumination in the future due to climate change. The result should vary with the change of different window configurations with various types of shading devices.



The specific limitations of the future climate database used in this paper is that, UKCIP02 scenarios are not designed to formally or quantitatively reflect all of the uncertainties of the future climate (Hulme et al., 2002) and the future global and diffuse irradiance data of UKCIP02 have been generated from synoptic data (mainly sunshine duration and cloud cover) using computer models, due to the difficulty of obtaining consistent irradiation data (CIBSE, 2008). Therefore, the assumptions, based on the climate change simulation study of this paper, will only satisfy the projections described by UKCIP02, and will not support other climate change models, for example UKCP09.

In absence of a suitable standard for indoor daylighting to meet therapeutic needs of patients, in this paper, the upper limit of comfortable daylight level proposed by Nabil et al. (2005) to 2000 lux, and the minimum daylight intensity to support human circadian rhythm recommended by Pechacek et al. (2008) to 190 lux, which were later verified for hospital in-patient rooms from real world field data by Joarder and Price (2012b), were selected as the design illumination at the location of patient retina. The direction of the test point sensor was considered upward in this paper. When patients are on bed, the direction of their looking are changed according to the bodies' ergonomic gesture and posture e.g. lying with their spine, inclined and upright on back. For example, if the patients lay with their spine, the directions of the eyes are upward towards the ceiling, and if the patients are in upright position resting on their back, the directions of the eyes are towards the wall. The direction of eyes may vary up-to 90 degrees in angle (parallel to the floor to perpendicular to the ceiling) based on different inclined position of the patient body, resting on tilting back of the hospital beds. The authors found that the measurement of illumination on a horizontal plane, with sensor points upward to the ceiling, which is widely practiced in daylighting simulations, is more sensible compared to the measurement on a vertical plane or inclined plane. Many researchers emphasised that bedridden patients are forced to look at a monotonous white ceiling of hospital rooms and suggested decorative ceiling for hospital rooms (Dutro, 2007; Horsburgh et al., 2001). The impact of decorative hospital ceiling design on patients' choice and performance was found as a positive distraction from many studies (Dutro, 2007; Eriksen, 2001; Ulrich 1991; Cintra 2001). Therefore, the direction of the test point sensor was considered upward; however, with different eye directions the amount of light on retina will be affected, which has not been analysed in this paper.

## CONCLUSION

To conceptualise the impact of climate change on indoor daylight levels and its therapeutic impact on hospital in-patients, in this paper, prospective simulation study is done to identify the change in daylight level on test point (patient retina while lying on the spine), under different future emissions scenarios under UKCIP02. The result shows that the average indoor illumination at patient retina can raise by a maximum of 8% in the future (2080s) compared to the present (1989-2004). The window with fixed shading and active blind operation can protect patient retina from increased daylight levels. However, to protect the indoors from increased daylight levels, internal blinds will be needed to shut down more often/time during day hours compared to the present, which might create a negative impact on patients' clinical improvement due to lack of outdoor views. As the ambient outdoor daylight levels are expected to be increased due to climate change, it was evident from the climate change simulation analysis of this paper that the future climate will probably offer a greater potential for the use of daylight for both visual and therapeutic purposes; however, protection from increased glare and UVB radiation need careful consideration. To get the benefits of higher daylight intensity, due to the climate change, one of the options might be to incorporate flexibility in the design of window shading system by specially designed interactive blinds or movable shades that will allow 0%-100% of outdoor daylight through windows without discomfort. This paper presents a case of the difficulties/uncertainties of using computer based daylighting simulation programs to achieve the design goal based on historical data and, also highlights the necessity for the consideration of future climate data while do daylighting simulation analysis.

### Notes

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).

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