Therapeutic Daylight for Hospital Patients: A Search for the Benchmarks

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Abstract

To evaluate the therapeutic potential of daylit in-patient rooms, it is important to know the characteristics of daylight objectively (e.g. intensity and duration) which might support patient health effectively and are merely different from lighting requirements for visual purposes, such as viewing objects and doing work or movement. In the absence of a suitable standard, the upper and lower limits of daylight recommended by previous researchers to support patient health and comfort were selected for verification as the benchmarks of therapeutic daylight for hospital patients. Therapeutic daylight was defined as the level of daylight that can support patients to recover quickly. A field survey was conducted to collect real-world patient data from an existing hospital building. Clinical and demographic information were collected from hospital records. The amount of daylight that a particular patient might experience on the head during his/her stay in the bed was estimated by calculating the average ratio between two indoor data loggers: one installed at the back wall of patient bed (head side) and the other kept on vacant beds at the location of patient head. Based on the amount of daylight experienced, the sample patients were grouped under three categories and their post operative length of stay (LoS) inside in-patient rooms were compared using Multiple Linear Regression (MLR) analysis. The coefficient estimates of the developed MLR model (adjusted R square = 0.516, F = 40.931 (Sig. < 0.001)) shows that while holding the other explanatory variables constant (provision of outdoor view, rent of the rooms, mean arterial pressure, heart rate and diabetes mellitus), being in lower daylight group (below 190 lx) adds 42 hours (t=3.096, P value=0.002), and being in higher daylight group (above 2000 lx) adds 29 hours (t=2.094, P value<0.037) in patient post operative LoS in hospital rooms with respect to the group experienced the moderate levels of daylight (between 190 – 2000 lx). It was concluded that the range of 190 – 2000 lx can be regarded as effective daylight intensities within which positive health outcomes are more likely to occur, and architects could use this benchmark for therapeutic daylighting design.

Keywords: therapeutic daylight, hospital patient, length of stay (LoS), multiple linear r egression (MLR), standards.

Introduction

To make an objective assessment of the subjective issues related with therapeutic effect of daylight on hospital patients, some level of simplification is necessary. In the absence of any accepted scale for the measurement of therapeutic effect of daylight, contemporary research (e.g. Gochenour et al., 2009 and Pechacek et al., 2008) consider effective circadian rhythm (biological events that occur at regular intervals) as an indicator of therapeutic effect of daylight. It is also admitted that, in addition to circadian rhythm, multiple mechanism are engaged in improving performance of hospital patients under daylit environment (Lockley et al., 2006), and still researchers are struggling to identify those mechanism (Nelson et al., 2003). The exploration of the complete and accurate biological mechanism as the effect of daylight is somewhat outside of the scope of this paper. As it is very difficult, if not impossible, to isolate the effect of daylight on circadian rhythm from other physiological and psychological mechanism, this research focuses on evidence than the mechanism to identify the therapeutic effect of daylight on hospital patients. This research considers reduction of patient length of stay (LoS) in hospitals as the therapeutic effect of daylight. The objective of this research is to test the range of daylight intensities within which patients LoS are expected to be reduced referred from literature. This paper comprises two main parts: a review of previous literature to identify the benchmarks of daylight intensities within which patient LoS inside in-patient rooms are expected to be reduced; and the field investigation for the verification of the benchmarks identified from the first part.

Identification of the benchmarks from literature

To incorporate therapeutic effect of daylight in the architectural design of hospital in-patient rooms, it is important to know the intensities of daylight that may support to reduce patients LoS in hospitals. A review of the existing lighting standards and recommendations for hospital in-patient rooms was necessary at the beginning of the research. Table 1 presents a comparison of some current recommendations (ADB, 2009; SLL, 2008; CIBSE, 2002 and IESNA 2000) on general internal lighting for hospital wards and single bedrooms.

Most of the lighting and photobiology publications are focused on artificial lighting sources (Pechacek et al., 2008) to meet the visual needs, including the recommendations presented in Table 1. It is recognised that even artificial light and daylight might have the same intensity level; the properties of artificial light and daylight are different with respect to human perspective. Individuals accept less daylight compared to artificial light to do the same visual activities (MIT IAP, 2008). The physiological and psychological effects of lighting are especially different from these two sources of light. Therefore, the standards for daylight and artificial light should differ for both visual and health purposes.

Table 1: Recommendations for lighting for hospital words and single bedrooms.

Lighting Purpose	Maintained Illuminance (lx)			
	ADB (2009)	SLL (2008)	CIBSE (2002)	IESNA (2000)
General lighting	100		100	75-200
Local lighting for reading	150	300-520	300	200-350-500
Lighting for simple examination		300-520	300	
Lighting for examination and treatment		1000	1000	
Night lighting, observation lighting	5	5-10	5	
Lighting for bathroom and toilets for patients			200	

Identification of the lower limit

Threshold values defined by the outcomes of photobiology research, in terms of intensity, timing and spectrum of light for effective circadian rhythm (MITDL, 2011); can be tested to verify the benchmark for therapeutic purpose. Pechacek et al. (2008) first attempted to provide some objective characteristics of daylight for circadian efficacy applicable for healthcare facilities. Pechacek et al. (2008, p.7) developed this system of equivalencies where '*an inferred radiometric spectrum of a known light source is multiplied by the circadian action spectrum [C(λ)] curve to determine a circadian weighting [W-C(λ)]*'. To account for the variability of the changes of daylight in apparent colour temperature with time of day, orientation and weather conditions, D65 (ASTM, 2006) was assumed for south, east, and west orientations, and D75 (ASTM, 2006) for north orientations in their research. Pechacek et al. (2008) validated that the same circadian power will be achieved with 190 lx daylight for south, east, and west orientations, and 180 lx for north orientations with an uncertainty of ±10 to 20 lx, when daylight will be transmitted through a double-pane, clear, low-E window. The timing and duration of daylight exposure are also important for circadian system. The timing was fixed from 06:00 AM to 06:00 PM with duration of 12 hours average daylit period (applicable for most of the locations) on patients' eyes. The details of the system are available in Pechacek et al., (2008). The paper (Pechacek et al., 2008) later received the Taylor Technical Talent Award (TTTA, 2009) from the Illuminating Engineering Society of North America (IESNA). Gochenour et al. (2009) also applied the proposed index to evaluate the circadian potentiality of daylit space in residential buildings.

Although, Pechacek et al., (2008) work is a significant advance on evaluation of the therapeutic effect of daylight, it is not beyond limitation and criticism (Gochenour et al., 2009). Pechachek et al. (2008) derived the action spectrum from the response of fixed doses of monochromatic light based on the studies of night-time melatonin suppression. The response to polychromatic light, for example daylight during the daytime, is still not entirely understood. There is still gap in knowledge to set appropriate values for regulating individual's circadian rhythm, and other physiological and psychological systems from photobiology. Pechacek et al. (2008: p.5) admitted that their method presented used off the shelf technology and the findings should not be taken as an absolute measure of circadian efficacy or health potential because '*the precise definition of the human circadian action spectrum [C(λ)] is still underway*' and the model predictions needs to be tested. The test of Pechacek et al., (2008) recommendation (if minimum 180/190 lx of daylight around patients head can provide circadian stimulation to patients) is beyond the scope of this paper, however, if 180/190 lx daylight can be considered as lower limit of therapeutic daylighting to reduce patient LoS in hospitals is one of the interests of this study.

Identification of the upper limit

Identification of the upper limit of therapeutic daylight is critical, as higher intensity of daylight needs to be incident on the patient retinas to start biological stimulation inside the body which might create visual discomfort. After reviewing the published findings, Nabil et al. (2006: p.905) provided a detailed classification of daylight intensities based on the data from field studies on occupant preferences and behaviour that considers the '*propensity for excessive levels of daylight that are associated with occupant discomfort and unwanted solar gain*', the results being summarised in Table 2. Nabil et al. (2006) concluded that, daylight illuminance in the range 100–2000 lx are potentially useful for the inhabitant of a room.

Table 2: Classification of daylight intensities based on occupants' preferences and behaviour (Nabil et al., 2006).

Daylight illuminances	**Occupants' preferences**
lx < 100	insufficient daylight as sole source and needs significant amount of additional artificial light
100 – 500 lx	effective daylight as sole source and can be used in conjunction with artificial light
500 – 2000 lx	desirable or at least tolerable level of daylight
lx > 2000	likely to produce visual and/or thermal discomfort

Rogers (2006: p.13) proposed that the threshold of potentially glary conditions depend on the design illumination of a space and '*a patch of illuminance at least 10 times greater than the design illuminance typically represents an occurrence of direct daylight that could potentially cause glare and other visual comfort problems in a daylit space*'. ADB (2009), CIBSE (2000) and Nabil et al. (2006) proposed minimum 100 lx; IESNA (2000) recommends 75-200 lx for general lighting and Pechacek et al. (2008) proposed minimum 180/190 (±10 to 20) lx on patient head for circadian support. Based on different sources, according to Roger's (2006) proposal, glary conditions can vary from above 750 lx to 2000 lx. Many researchers suggest that much higher light levels – in excess of 1000 lx – are needed to stimulate biological systems compared to the visual systems (Middleton et al., 2002; Baker, 2000; Zeitzer, 2000; Muneer, 2000). Hence, above 2000 lx, which is the level likely to produce the visual and/or thermal discomfort found by Nabil et al. (2006), is more acceptable as the upper limit of therapeutic daylighting. The discomfort indexes proposed by Nabil et al. (2006) and Rogers (2006) are based on office and classroom environments and the values are needed to be further verified before recommending for hospital environments. In this research, 2000 lx and 190 lx of average daylight level around patients head were selected to be verified from the real world field data as the benchmarks of therapeutic daylight for hospital patients which could reduce their LoS inside in-patient rooms.

Verification of the benchmarks from field

Methodology

A field survey was conducted to collect real-world patient data from an existing hospital building (Square Hospital, Dhaka, Bangladesh; Figure 1). Data collection comprised two phases. In the first phase, 31 indoor data loggers were fixed at the back wall of each patient bed (head side) at the cardiac inpatient unit (Figure 2) for one year. The indoor data loggers were fixed on the wall at 2000mm height from floor level to avoid shadow on sensors due to movement of patients and hospital staff during work (Figure 3).

Figure 1: Case hospital building- Square Hospital Ltd., Dhaka, Bangladesh (courtesy:SHL).

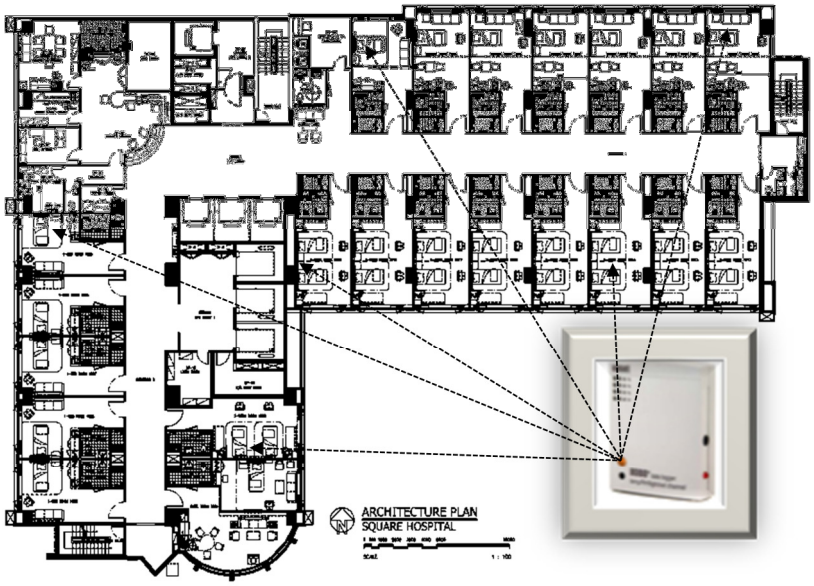

Figure 2: Architectural plan of study space- Cardiac Inpatient Unit located at tenth floor, where indoor data loggers were installed (courtesy:SHL).

Figure 3: Location of indoor data logger(source: Joarder et al., 2010).

During observational studies, the researcher noticed that most of the heart surgery patients were lying with their spine on hospital beds after coming back from Cardio-Thoracic Intensive Care Unit (CTICU) to the cardiac surgery unit. Doctors also advised that patients are instructed to lie on their back without creating any pressure on chest and should not rest on sides, particularly on left sides. To identify the amount of daylight that a patient receives on his/her retina, additional data loggers were kept by rotation (as there were always some patients on the in-patient unit) on vacant beds at the location of patient head for 24 hours (Figure 4). In the absence of the patients, the data loggers on the beds recorded the amount of daylight that a patient might get while lying on the bed. An average ratio between two data loggers (one on the bed and the other on the wall) was estimated for each bed of the cardiac in-patient unit. The estimated ratio for each in-patient bed was multiplied with the reading of the data loggers installed on the wall for one year to calculate the amount of daylight that a particular patient might experienced on head during his/her stay in the hospital bed. Based on this calculated amount of daylight, the sample patients were grouped in three categories. The first group contained the patients who had experienced lower levels of daylight (below 190 lx) in the maximum time of their stay inside in-patient unit. The second group contained the patients who had experienced moderate levels of daylight (between 190 lx to 2000 lx) in the maximum time of their stay inside in-patient unit. The third and last group contained the patients who had experienced higher levels of daylight (above 2000 lx) in the maximum time of their stay inside in-patient unit. The second group was taken as reference and their post operative LoS inside in-patient rooms were compared with other two groups. A Multiple Linear Regression (MLR) model was developed to understand the functional relationships between the patient LoS and daylight level at patient head in presence of other (clinical, demographic and environmental) variables listed in Table 3, to observe what might be causing the variation in the patient LoS.

Figure 4: Placement of additional data loggers on a vacant bed.

Table 3: List of variables primarily considered.

Clinical variables (unit)	**Demographic variables (unit)**	**Environmental variables (unit)**
Patient LoS (hour)	Gender	Room type
Systolic blood pressure (mm Hg)	Age (year)	Provision of outdoor view
Diastolic blood pressure (mm Hg)	Weight (Kg)	Rent of the room (Tk/day)
Mean arterial pressure (mm Hg)	Height (cm)	Room temperature (^{o}C)
Heart rate (beats/ min)	Body mass index	Relative humidity (%)
Respiratory rate (resp/min)		Dayight (lx)
Body temperature (^{o}F)		
Saturation of peripheral oxygen (%)		
Fasting blood sugar (mmol/l)		
Fluid balance (ml)		
Ejection fraction value (%)		
Smoker		
Hypertension		
Dyslipidaemia		
Diabetes mellitus		
Myocardial infarction		
Transient ischaemic attack		
Bronchial asthma		
Stroke		
Cerebral vascular diseases		
Chronic renal failure		

Data collection and analysis

A total number of 263 post-operative patients, who underwent a Coronary Artery Bypass Graft (CABG) surgery and experienced varying lighting conditions at their stay in hospital rooms, were selected as sample

for the study. At the beginning of field investigation, sources of clinical data which will be used as variables in statistical model were identified. Clinical data (e.g. LoS, blood pressure, body temperature, heart rate and respiratory rate) and demographic information (e.g. age, gender and BMI) were collected from case hospital patient record. This research ensures compliance with the Data Protection Act 1998, and was checked by an Ethical Advisory Committee. The objectives of the research were informed to the hospital authority, and researchers took approval prior to start survey.

The first phase of the study started on 21 July 2009 at 00:00 and ended on 31 July 2010 at 23.00 while illumination values above patient beds were obtained by the readings of indoor data loggers (Figure 3) as described in Section 3.1. After completing the first phase, the second phase took place during 9 September 2010 to 18 September 2010. The amount of daylight that a particular patient might experience on the head during his/her stay in the bed was calculated following the method described in Section 3.1. The collected data were used to determine the effects of upper (2000 lx) and lower (190 lx) limits of therapeutic daylight, identified from literature review in Section 2, on patient LoS. The hypothesis of this particular study was that, patients LoS will be higher if they spent most of their hospital stay time under lower and higher level of daylight environment compared to moderate level of daylighting (190-2000 lx).

Development of MLR model

The dependent variable of the model was the patient LoS in hours. For each observation, a total of 31 possible explanatory variables were considered at the beginning listed in Table 3. To determine the multicollinearity between explanatory variables, that may bias the standard error, generate wrong sign and implausible magnitudes in the coefficients (Chin et al., 2003), Pearson Correlation among the primary selected explanatory variables were analysed. The most significant variable from the correlated variables was separated to develop a suitable statistical model. For example, mean arterial pressure (MAP) was significantly correlated with weight, height, body mass index (BMI), age, gender, systolic blood pressure, diastolic blood pressure, respiratory rate, fluid balance, smoking habits and hypertension, and the correlated variables were dropped from the model. In the next stage, a stepwise regression analysis was conducted among the short listed non-correlated variables to select the “best” set of explanatory variables, and insignificant variables were eliminated from the model, such as myocardial infarction (MI), ejection fraction (EF) value and dyslipidaemia. Table 4 presents a sample summary statistics of the variables considered in the final MLR model. The information of lighting was incorporated in the model by two-categorical variables represented by lower (lx<190 lx) and higher (lx>2000 lx) daylight group of patients with respect to moderate (190 – 2000 lx) group, mentioned earlier. Finally, four environmental variables and three clinical variables were selected for the MLR model. The final set of variables, their coefficients (B), standardized coefficients (Beta), t-statistics together with the *p-values* are shown in Table 5.

Table 4: A sample summary statistics of variables included in the MLR model.

Variables	Min/ NO.	Max/ NO.	Mean	Std. Deviation
Patient LoS in hour (dependent variable)	48.00	666.00	109.63	61.67
Lower levels of daylight (lx<190 lx)	Yes (11)	No (252)	-	-
Moderate levels of daylight (190 – 2000 lx)	Yes (241)	N0 (22)		
Higher levels of daylight (lx>2000 lx)	Yes (11)	No (252)	-	-
Provision of outdoor view (POV)	Yes (210)	No (53)	-	-
Rent of the room	3500	17500	4655.89	1658.44
Mean arterial pressure (MAP)	60.00	110.57	85.85	6.34
Heart rate (HR)	72.00	120.00	91.03	7.79
Diabetes mellitus (DM)	Yes (107)	No (156)	-	-

Model interpretation

The analysis of the MLR model (Table 5) shows that four variables increased patient stay time inside in-patient unit, and three variables were responsible for decreasing the stay time (POV, MAP and HR). Six variables (lx<190, POV, Rent, MAP, HR and DM) were highly significant (less than 1%) and one variable (lx<2000) was significant at a level of four percent in the MLR model. The column of un-standardised coefficients (B) provides the values for explanatory variable for the MLR equation. Expressed in terms of the variables used, the estimated MLR equation can be written as Equation 1 (adjusted R square = 0.516, F = 40.931 (Sig. < 0.001)).

It is evident from the developed MLR model (Equation 1) that the stay time of the patients for two daylight categories used as explanatory variables, were significantly higher compared to the reference group who experienced moderate levels of daylight in the maximum time of their stay inside in-patient unit, therefore, confirmed the recommendations of previous research (e.g. Pechacek et al., 2008; Rogers, 2006; Nabil et al., 2006; 2005). The coefficient estimates show that while holding the other explanatory variables constant, being in lower daylight group adds 42 hours (t=3.096, p value=0.002) and being in higher daylight group (lx>2000) adds 29 hours (t=2.094, p value=0.037) to patient LoS in hospitals compared to the group experienced moderate levels of daylight.

Table 5: MLR Model to confirm the range of daylight for therapeutic purpose.

Explanatory variable	Un-standardized coefficients (B)	Standardized coefficients (Beta)	t-statistics	*p-values*
Constant	242.596		4.959	<0.001
lx <190 lx	42.337	0.138	3.096	0.002
lx >2000 lx	28.592	0.093	2.094	0.037
Provision of outdoor view (POV)	-24.079	-0.157	-3.340	0.001
Rent of the rooms	0.013	0.353	7.363	<0.001
Mean arterial pressure (MAP)	-1.392	-0.143	-3.238	0.001
Heart rate (HR)	-0.965	-0.122	-2.795	0.006
Diabetes mellitus (DM)	71.310	0.571	13.120	<0.001

** Dependent Variable: Patient LoS in hour; R Square =0.529; adjusted R Square =0.516; F = 40.931 (Sig. < 0.001).*

$$LoS = 242.596 + 42.337\,(lx<190) + 28.592\,(lx>2000) - 24.079\,(POV) + 0.013\,(Rent) - 1.392\,(MAP) - 0.965\,(HR) + 71.310\,(DM) \quad (1)$$

Therapeutic and intuitive judgement confirmed the validity and practicality of mathematical signs in the model (Equation 1). A view to the outdoor may help to reduce the LoS of patients (t=-3.340, p value=0.001) agreed with the finding of past researchers Ulrich (1984) and Joarder et al. (2010). It is logical that in a modern and expensive private hospital such as Square Hospital, Dhaka, patients with better economic conditions are more intend to stay in luxury rooms with higher rent till their complete satisfaction to recovery compared to the patients with less affording capabilities who prefer to stay in economy rooms (i.e. shared rooms) and tend to leave the hospital earlier with a reasonable recovery status of their health with doctor's consent. The impact of the rent of the room which reflects patients' economic capabilities, thus, have a strong influence on LoS in hospital (t=7.363, p value < 0.001).

Medical judgements also confirmed the validity and practicality of the mathematical signs of the clinical variables. Due to the influence of anaesthesia during open heart surgery, the blood pressure and heart rate are usually reduced compared to patients' normal state (Neto et al., 2004) when they come back to the cardiac surgery unit. The patient recovery process accelerates with the increase of blood pressure (t=-3.238, p value=0.001) and heart rate (t=-2.795, p value=0.006) to normal stage, as a result, stay time in hospital is reduced. It is logical that patients with diabetes will take more time (Morricone et al., 1999) compared to non-diabetes patients to recover (t=13.120, p value <0.001).

Conclusion

In work paper, the experiments were conducted to collect data from field to develop MLR model to confirm the daylight intensities within which patients LoS inside in-patient rooms are expected to be reduced (defined as therapeutic daylight), identified from literature at the beginning of the paper. The analysis of photobiology and daylight literature reveals that a minimum of 190 lx might needed to be incident on patient retinas to stimulate circadian rhythm and illumination higher than 2000 lx might create visual and thermal discomfort. The estimation of MLR model (Equation 1) emphasised that the CABG patients who experienced higher (above 2000 lx) and lower (below 190 lx) levels of illumination in the maximum time inside in-patient rooms, stayed significantly higher (extra 29- 42 hours) times than the patients who experienced moderate levels of daylight (190-2000 lx) in the maximum time of their stay in hospital rooms. It was concluded that the range of 190-2000 lx can be considered as the benchmark for therapeutic daylight intensities within which reduction of patients LoS are more likely to be happened. Architects and designers could use this benchmark to design daylit in-patient room, supportive to patient clinical recovery in hospitals.

The specific limitation of the methodology applied in this research was that, the ratio between two data loggers was calculated for one day data but considered for the whole year. As the ratio was calculated in absence of patients, hence the effect of patients' behaviour on blind adjustment and artificial light control was not possible to include. As, the estimated values of daylight were not directly used in the MLR model and only used to group the sample patients under three categories, the deviation from exact value have little impact on grouping patients (for example, the patients experienced average 500 lx or 1500 lx will fall in the same moderate daylight group). The research might be replicated by taking samples from different types of patients other than CABG to confirm the presented results.

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