Solar Energy 149 (2017) 164–175

Contents lists available at ScienceDirect

Solar Energy

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

Daylighting simulation for the configuration of external sun-breakers on south oriented windows of hospital patient rooms under a clear desert sky

Ayman Wagdy, Ahmed Sherif *, Hanan Sabry, Rasha Arafa, Islam Mashaly

The American University in Cairo, AUC Avenue, P.O. Box 74, New Cairo 11835, Egypt

ARTICLE INFO

Article history:
Received 4 July 2016
Received in revised form 31 March 2017
Accepted 5 April 2017
Available online 12 April 2017

Keywords:
Spatial Daylight Autonomy (sDA)
Annual Sunlight Exposure (ASE)
Shading devices
Tilt angle
Clear sky

ABSTRACT

Provision of a healing environment could help arrive at better healthcare outcomes. Healing environments that enjoy natural daylight have a positive impact on the health and well-being of patients and medical staff. They contribute to the achievement of shorter lengths of stay, reduction of stress and increase of patients and staff satisfaction. Several studies have emphasized the positive role of daylighting as one of the most influential factors for creating successful healing environments in healthcare facilities. This is especially important in patient rooms, which represent the largest component of hospital buildings.

Provision of adequate daylighting is quiet a challenging task in desert locations which are typically characterized by year-long clear skies. External sun-breakers are typically used in these locations to control solar penetration, thus improving illuminance distribution and decreasing visual discomfort.

This study aims at defining the main characteristics of the sun-breakers that could be used to control solar access into hospital patient rooms under clear-sky conditions. The study addressed two common patient room designs: inboard bathroom design and outboard bathroom design. The tested rooms had three equidistant sun-breakers that are externally fixed in front of a window facing south in Cairo, Egypt. The focus was on the impact of the sun-breakers' cut off angle and the corresponding tilt angle on year-round illuminance distribution and visual discomfort. The main goal was to ensure adequate daylighting performance without discomfort glare inside these rooms.

Parametric simulation runs were performed using Grasshopper, Diva-for-Rhino, and SpeedSim-for-DIVA, plug-ins for Rhinoceros modeling software to interface with the simulation engines Radiance and Daysim software.

The outcomes of this study identified the range of sun-breaker cut off angles and their corresponding tilt angles which produced adequate daylighting performance for the two patient room types at different window to wall ratios. In general, the number of accepted sun-breaker cases increased with higher window to wall ratios for both patient room designs. It was noted that a wider range of accepted tilt angles was identified for the patient rooms having inboard bathrooms. Both the inboard and outboard bathroom designs had the same range of accepted cut off angles. It was observed that efficient daylighting performance was achieved in all tested WWRs for the two patient room layouts with cut off angles between 50° and 54° with the wall. Moreover, horizontal sun-breakers achieved successful results in all tested WWRs for the two patient room layouts. It was also noted that the cut off angles were more influential in providing adequate daylighting performance in comparison with tilt angles.

1. Introduction

Configuring the windows of hospital patient rooms should be carefully considered. They should provide adequate daylighting levels while minimizing glare occurrence. The objective is to improve the quality of healthcare and to at the same time reduce the energy consumption of artificial lighting. This is quite challeng-

* Corresponding author.
E-mail addresses: aymanwagdy@aucegypt.edu (A. Wagdy), asherif@aucegypt.edu (A. Sherif), drhanansabry@gmail.com (H. Sabry), rashamahmoud@aucegypt.edu (R. Arafa), islammashaly@aucegypt.edu (I. Mashaly).

http://dx.doi.org/10.1016/j.solener.2017.04.009
0038-092X/

ing under the clear skies of desert locations, where solar penetration is very intense all year round. Sun shading devices were typically used as solar control means in these environments. The effectiveness of external window configuration and shading device formation in delivering adequate daylighting is strongly related to patient room layout design. Daylighting performance in an outboard patient room layout is clearly different from that of an inboard patient room design (Sherif et al., 2015a). A systematic investigation on the shaping of window openings and their associated shading devices in relation to the different room layout designs is necessary for arriving at environmentally friendly hospitals that support patient care.

Numerous publications addressed the positive effect of providing daylight in hospital patient rooms. In a review article, Joseph (2006) highlighted the importance of incorporating daylighting in hospital design. Daylight provision was found to be useful in the treatment of several diseases, including neonatal hyperbilirubinemia and depression. In addition, daylight helps increasing vitamin D metabolism and enhancing sleep and circadian rhythms, as well as the reduction of pain. Daylight was also found essential in the adjustment for night-shift work by nurses and staff. In another study, a questionnaire survey was used to review the impact of daylighting on hospital staff needs and satisfaction (Alzubaidi et al., 2013). The study examined the effect of daylighting on patient diagnosis, treatment, recovery period, and comfort level. Survey results showed that the majority of doctors and nurses asserted the importance of daylight provision in patient rooms. It helped make work easier and facilitated review of patient recovery through recognition and interpretation of changes in patient skin color. Survey respondents considered daylight as having many health benefits including fast recovery, reduction of patients length of stay, and enhancement of staff comfort levels.

Another group of publications tried to relate environmental aspects, such as daylighting, with healthcare outcomes. In an attempt to develop patient room designs that create healing environments, the effect of natural daylight on the patients' average length of stay was investigated (Choi et al., 2012). Studied factors were patient's average length of stay as an index of health outcome, and the differences in the environment during daylight hours, such as illuminance, luminance ratio, and illuminance variation in the hospital's patient rooms. Another attempt aimed at correlating daylighting with photobiology data as means for improving patients' health (Pechacek et al., 2008). Radiance-based Daysim simulation program was used to simulate Daylight Autonomy in a hospital patient room. Results of photobiology research were utilized to determine threshold values for lighting. These values were used as goals in daylighting simulations, where they included the spectrum, intensity, and timing of the light at the human eye. The study emphasized the impact of hospital patient room configuration which comprises the room orientation, window to wall ratio (WWR), and glazing material in enhancing the circadian efficacy of the patient's room.

Other publications, which were more directly related to this paper, addressed the configuration of the external façade and window openings of hospital patient rooms for the provision of daylight. In a research that aimed at providing daylighting and external view while minimizing energy consumption, Shikder et al. (2010) investigated the optimization of window openings. An optimization methodology was demonstrated through parametric computer simulation to determine the optimum window design in the form of window width, sill and lintel heights and shading device depth. In another paper, provision of daylight and external view in three common patient room layouts was investigated (Sherif et al., 2014c). The aim was to arrive at the influence of room shape and the associated Window-to-Wall Ratio in providing sufficient and comfortable daylighting. Simulation techniques were utilized for identifying the most effective patient room configuration and its associated Window-to-Wall Ratios (WWRs). The research addressed these factors for three commonly used patient room layouts oriented towards the south orientation in the desert climate of Cairo, Egypt. Results demonstrated the influence of room shape on daylighting performance in hospital patient rooms. Patient room layouts having nested or inboard bathrooms proved to be most successful in providing daylighting in the south orientation. An outboard bathroom patient room layout provided a limited range of acceptable window configurations. Conclusions were drawn recommending the acceptable range of WWRs for each room configuration. Another paper was concerned with the impact of the three common patient room designs on daylighting and energy performance (Sherif et al., 2014b). The performance resulting from using a range of window sizes under the clear-sky desert sun of Cairo, Egypt was examined. Results demonstrated that solar penetration is a critical concern affecting patient room design and window configuration in regards to daylighting in desert locations. The study assessed the need for a careful consideration of the size of windows that were protected by an overhang in relation to different patient room designs. Window configurations that satisfy both energy and daylighting requirements were identified. The recommended WWRs were 70–90% for patient rooms of the outboard bathroom and 30–40% WWR for patient rooms of nested and inboard bathroom. A similar study tested the window shading effect on daylighting of hospital patient rooms by use of simulation software such as Daysim, but in the city of London (Joarder and Price, 2012). Factors such as solar control criteria, line of vision, aesthetics were accounted for in the study. The use of one type of shading device for the whole building was recommended while integrating more shading devices to satisfy the shading requirements of each orientation. As for glare, its possibility was found to be most at South followed by west then east and north respectively. Consequently, adding internal venetian blinds, external sunshades, external overhangs and internal light shelves to the south were proposed, while internal venetian blinds, external sunshades, and external overhangs to the west were proposed.

In another attempt, a parametric workflow and optimization for generating and evaluating alternative façade configurations of patient rooms were introduced (Sherif et al., 2015b). The approach manipulated the external wall façade at efficient inclination angles and changed window distribution for the optimization of daylighting of a south oriented patient room under the desert clear-sky of Cairo, Egypt. A genetic algorithm was used. Results demonstrated that parametric workflows and optimization could be effectively used to generate patient room façade designs that provide superior daylighting performance, where a wide range of unconventional façade designs with 100% daylit area on both the bad area and the room area, with 0% of partially-daylit and over lit areas were achieved. On the other hand, internal venetian blinds and external sunshades could be efficient in the east, and only internal venetian blinds could be used in the north. In a more detailed research, Sherif et al. (2016) investigated the shapes of horizontal blind slats that best suit the outboard hospital patient room layout in Cairo, Egypt. The paper utilized parametric tools and simulation software to systematically test possible slat shapes to fulfill year-round daylighting adequacy on the bed surface and the room area and to maximize patient's access to external view. The sDA on the room surface plane was found to be the limiting factor in determining acceptable slat shapes. Flat shaped blind slats or gently-curved ones achieved better results in both daylighting and exposure to external view. In another study, the enhancement of daylighting and external view of hospital patient rooms as means for achieving a "Salutogenic" hospital was investigated. Salutogenic design, which was coined by Dilani (2008), is related to the generation of a health-promoting design of healthcare facilities. It adopts day-