Journal of Building Engineering 20 (2018) 510–519

Contents lists available at ScienceDirect

Journal of Building Engineering

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

The selection of brise soleil shading optical properties for energy conservation and glare removal: A case study in Qatar

Albert Al Touma, Djamel Ouahrani*

Department of Architecture and Urban Planning, College of Engineering, Qatar University, P.O. Box 2713, Doha, Qatar

ARTICLE INFO

Keywords:
Brise soleil
Energy demand
Light dimming control
Visual comfort

ABSTRACT

Energy efficiency in buildings is crucial for the design of sustainable cities, especially in hot climates where demands are high. This study investigates the impact of the shading optical properties on the space energy demands when brise soleil is installed in offices with one fully-glazed façade in four different orientations. The criteria for the selection of best shading property are an office with minimal possible total energy demand and maximum outdoor view without any occupant sensation of visual discomfort caused by glare at any time of the year. In addition, this study examines the feasibility of integrating light dimming control to these offices.

A simulation model of an office space with external shading on a fully-glazed façade in one pre-selected orientation was developed and validated. Parametric studies on the shading reflectance and transmittance properties were conducted and their effects on spaces energy demands were observed for Qatar's climate, mimicking a developing country with harshly hot weather conditions. In south-oriented offices, savings caused by the addition of brise soleil reach 36.3%; unreflective or barely transmissive slats are recommended and light dimming control is unjustified. Moreover, unreflective opaque shading without light dimming control is found to be optimal in east and west-oriented offices as it saves 37.2% of the space overall energy demand. In contrary, installing highly-transmissive shadings with light dimming control is justified in north-oriented offices as it keeps full outdoor visual sight and still saves energy of up to 11.6%.

1. Introduction

In developing countries, the shift into sustainable cities requires improvements in the built environments to achieve energy-efficiency and low-carbon buildings. In existing buildings, glazed surfaces are the weakest component of the space thermal envelope and the most vulnerable to outdoor conditions; they transmit a significant amount of solar radiation and absorb and re-emit considerable share of heat into the indoor space [1]. In fact, they are the largest contributor towards the space energy demands in hot climates [2]. This problem has even magnified by the progressive demand for fully-glazed façades in office spaces. The office occupants nowadays expect fully-glazed façades in their workplace as they increase their visual sight to outdoor, improve daylighting and enhance their productivity [3]. However, this raises several complications caused by the augmented space energy demands and amplified visual discomfort originated by glare.

Extensive research has been conducted to reduce the contribution of glazed surfaces to the space thermal loads. The proposed novel methods include the installation of multiple pane glazing systems [4], the addition of phase-change materials to the glazing gaps [5], the integration of glazing systems with a solar chimney and passive evaporative cooler [6,7], and the use of single and dual airflow windows [8–10] as well as double-skin facades [11–13]. Although all of these methods have managed to diminish the space loads variably, they are not considered as robust engineering practices as their applications in hot climates limit their effective performances. More importantly, none of them is capable of mitigating the occupants' visual discomfort since these proposed systems have only targeted the reduction of solar transmission and absorption of the glazed surfaces with no regards to their effects on glare.

To overcome the problem of glare visual discomfort and produce simultaneous reduction in radiation transmission and absorption by glazing surfaces, research has switched back to the conventional addition of shading devices [14]. These devices, which consist of blinds, shutters, screens and brise soleil, have been extensively studied in literature to assess and quantify their benefits [2,14–16]. More recently, these devices were integrated with shading control strategies that adjust the shading slat inclination angle to achieve a desired objective (i.e. obstructs beam solar radiation, enhance daylighting, ameliorate thermal and/or visual comforts…) [14,17,18], as well as lighting

* Corresponding author.
E-mail address: djamel@qu.edu.qa (D. Ouahrani).

https://doi.org/10.1016/j.jobe.2018.08.020
Received 24 June 2018; Received in revised form 3 August 2018; Accepted 30 August 2018
Available online 01 September 2018

control strategies that dim indoor electric lighting whenever daylighting is sufficient [14,19,20]. A major drawback of these studies is that their outcomes are only valid for the weather locations where they were applied. For instance, cooling demands are minor in moderate climates; consequently, lighting loads were comparable and dimming control turned out to be justified. Similarly, shading control may require frequent maintenance costs in dusty countries, therefore troubling its practicality. Under different climates, the incorporation of shading control is still controversial considering their expensive maintenance costs when weighed against their benefits on thermal and visual comforts, and the integration of lighting control may be unjustified considering the original share of lighting load in the space total energy demand, eventually re-shedding the lights back on fixed shadings.

Out of all types of fixed shading devices, literature proves the underestimation of brise soleil. These devices consist of large, fixed and inclined slats positioned at a pre-determined distance away from the façade external surface [21]. Their large physical dimensions as well as their distance from the façade give them unique characteristics; they prevent the shading over-obstruction of the outdoor sight and eliminate any glare visual discomfort through the cautious selection of its slat-to-slat separation distance [21]. Furthermore, they may be completely opaque or selectively transparent. They are preferable in high-rise buildings as they cover a significant portion of the façade surface while still keeping the view to outside, and do not require maintenance and operation costs in comparison with the automated blinds.

Despite the fact that the addition of all types of shading devices, including brise soleil, have served their purposes in removing glare visual discomfort and mitigating the space lighting and cooling loads, all the aforementioned studies suffered from at least one of the following drawbacks. Firstly, many studies used simplified shading models that poorly represent the real impact of shading optical properties on the space thermal performance, eventually underestimating the space cooling power and energy demand considerably [22]. Secondly, many studies found in literature considered the addition of shadings irrespective of the optimal selection of the slat physical dimensions. Thirdly, many researches considered the addition of shading on one façade orientation, hence ignoring the effect of solar radiation intensity hitting different vertical surfaces. Lastly, very few studies have investigated the impact of shading optical properties on glare and energy saving outcomes, with none ever covering brise soleil in hot climates. Despite the significant advances achieved in the modeling of shading optical properties when combined with glazing systems [23–25], most case studies pertinent to energy savings and visual comfort, which are based on either experimental observations or simulation modeling, often considered only one set of shading solar and visible properties (i.e. transmittance, reflectance and absorptance), while very few have ever considered the sensitivity of outcomes due to changes in these properties [18].

In a previous study conducted by the authors, the careful selection of brise soleil physical dimensions (i.e. slat width and slat-to-slat separation) was analyzed in different façade orientations in Qatar to provide a glare-free indoor environment while ensuring maximum possible daylighting penetration. Accordingly, savings in space thermal energy demands and CO_2 emissions were quantified [21]. The experimentally-validated simulation model also overcame several modeling drawbacks discussed in literature [21,22]. In this study, the impact of the brise soleil optical properties on the space thermal energy demand in hot climates is parametrically investigated in different orientations to select the most favorable design that optimizes energy savings considering only the shading physical dimensions that are able to remove all visual discomfort caused by glare. The selection of the ideal shading slat reflectance and transmittance in such climates cautiously considers the possible incorporation of light dimming control to justify its usage in specific façade orientations and disprove it in others. Consequently, this study would assist the research society in highlighting the importance of proper selection of shading optical properties on any building space design and the corresponding sensitivities of its energy performance, the occupants' visual comfort and the feasibility of light dimming control to changes in these properties.

2. Methodology

2.1. Model development

In order to achieve the objectives of this study, a software that performs energy simulations and analyses as desired by the user was deemed necessary. EnergyPlus Version 8.5.0 [26] was selected for this purpose due to its accuracy in predicting buildings' thermal performances [27], its capability of integrating shading devices [18], and its ability of estimating glare visual discomfort represented by the Daylight Glare Index (DGI) [28]. Although many studies have proposed the use of alternative glare-representative indexes such as the Daylight Glare Probability (DGP) [29,30], EnergyPlus still adopts the DGI model as a proper and validated index for the quantification of glare visual discomfort.

A simulation model of an office space with one fully-glazed façade oriented in one pre-determined direction with or without shading installed on its external surface was developed. The model was designed to run for sizing periods (i.e. one summer and/or winter day) or annual simulations. It considers brise soleil shading only whenever this option is desired and selected by the user. The software uses the heat balance method, which accounts for the detailed heat transfer and air movement between the façade and shading [31]. In addition, the built-in model of the shadings in EnergyPlus considers the inter-reflections of radiation rays that prevent the underestimation of the solar energy transmitted into the space [22]. Moreover, the daylighting calculation considers the lights reflections of the space inner surfaces using a radiosity method [18,31].

The simulation model takes the following inputs: space dimensions and envelope properties, shading dimensions and thermo-physical properties, internal occupancy, equipment, lighting and infiltration loads and schedules, surfaces' outer thermal boundary conditions and the desired weather file. The model was also made capable of incorporating light dimming control whenever this option was desired. On the other hand, the model outputs each surface inner and outer temperatures, occupant's DGI at a pre-selected position, and the space cooling, heating, lighting, occupancy, equipment and infiltration loads at each time-step.

The simulation parameters related to the heat transfer calculation algorithms, solar radiation quantification and distribution on the space different surfaces, daylighting calculation method and the load and temperature tolerances were all selected appropriately to ensure accurate and robust simulations [18,28]. Detailed explanations of these parameters are found in [14,21]. Most importantly, the *ZoneHVAC: IdealLoadAirSystem* cooling system option was used; it calculates the space thermal energy demands without having to design a full HVAC system.

2.2. Model validation

2.2.1. Experimental setup

Since the developed model inputs were selectively chosen to mimic actual office spaces, it was necessary to validate it experimentally in order to assess its capability in estimating the changes in the desired parameters. The parameters relevant to this study are the space total thermal load and the Daylight Glare Index (DGI).

A series of experiments were carried out at the Energy Efficiency and Building Design Laboratory at Qatar University; the laboratory is composed of four experimental spaces in two different chambers, where each space has one fully-glazed façade oriented towards the south. Each space has a floor area of 7.56 m^2 and a height of 2.32 m. One office space from each chamber was used for the experiment; the first had no