Solar Energy 170 (2018) 358–368

Contents lists available at ScienceDirect

Solar Energy

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

Assessment of skylight design configurations on daylighting performance in shopping malls: A case study

Wessam El-Abd[a,*], Basil Kamel[b], Moemen Afify[a], Medhat Dorra[a]

[a] Architectural Department, Faculty of Engineering, Cairo University, Egypt
[b] Architectural Department, American University in Cairo (AUC), Egypt

ARTICLE INFO

Keywords:
Parametric analysis
Commercial buildings
SRR
Hot climate

ABSTRACT

In Egypt and the Middle East, there is an obvious tendency of establishing new shopping malls and indoor commercial centers that provide collective facilities. However, they are accompanied by multiple design challenges including the provision of natural lighting for the interior spaces, which requires a careful consideration for the environmental design aspects. This research aims to provide a methodology to assess and optimize skylight designs to achieve better daylighting performance. A case study for a shopping mall in Cairo is selected where different skylight design configurations are examined. Skylight parametric variations include different opening ratios and visual transmittance values. Daylighting performance is tested in regards with daylit area coverage, potential for glare and accompanied energy consumption used for artificial lighting. A parametric simulation for 50 different cases are conducted and a multiple-criteria optimization is carried out to optimize material and ratio of size. Other parameters could be investigated in further researches. The optimum solution is further extracted and compared to the current base case. These results shows that early considerations in skylight and interior design could achieve more than 50% reduction in the overlit area, while achieving minor improvements in the daylit area. Yet, retrofitting measures are applicable for post construction and occupation periods.

1. Introduction

Nowadays in the Middle East and Egypt, shopping and commercial malls are increasingly built in the cities and outskirts. The reason behind this increasing number is due to the facilities that those commercial centers provide, such as multiple services in one place, easy parking, security, and air conditioned area especially in hot arid climates (Keng et al., 2007). Thus, huge investments are directed towards building more commercial malls in these countries, which creates a competitive environment between investors and architects. Even though huge shopping mall requires a huge amount of energy, in terms of embodied and operational energy needed to operate specifically mechanical systems and artificial lighting, contemporary designs usually neglects the environmental aspects of the design, which consequently leads to- increasing energy consumption. Given that building sector consumes around (46.2%) of the overall energy (HBRC, 2009). Egypt has faced several blackouts due to an extreme shortage in generating electricity in the last few years, which rises the alarm of the importance to consider our energy consumption rates and design practices. Even though Egypt is gifted by clear sky most of the year, those buildings are poorly designed to achieve a maximum benefit from the natural light. One of the main problem of those shopping malls is due to the arrogance tendency of the designers and architects to only consider the luxurious aesthetic aspects that satisfies the needs of the investors and public rather than integrating the environmental aspects and creating some tradeoffs during the design process.

Given the skylight as one of the most common elements used when designing indoor shopping malls, its main aim is to provide natural lighting for the closed indoor spaces of the court yards and corridors. Daylighting is effective in building design affecting efficiency of spaces. When daylight is taken into consideration, more comfort could be achieved and energy consumption could be reduced. Daylight is considered as the best source of light as it strongly reaches human visual reaction. It gives a sense of brightness that can have a great influence on the people (Li et al., 2006). This research aims to address the design parameters of skylights in the indoor shopping malls, in terms of opening ratio and material that provides an optimum daylighting. The objective of this research is to assess daylighting performance of the skylight of an existing shopping mall in Cairo as a case study, and to investigate an optimized skylight design parameters that enhances the

* Corresponding author.
E-mail address: wessam.el79@Eng1.cu.edu.eg (W. El-Abd).

https://doi.org/10.1016/j.solener.2018.05.052
Received 13 May 2017; Received in revised form 3 April 2018; Accepted 14 May 2018

daylighting performance for the indoor spaces, in addition to investigating the equivalent reduction in the energy consumption used for artificial lighting. Followed by a literature review on daylighting and its measuring methods, a case study is selected for the investigation and analysis. The case study is modeled using Rhinoceros 3D software and DIVA for Rhino in Grasshopper for parametric simulation and optimization. The results are further post processed to generate visual graphics and select optimum skylight parameters. This study addresses architects and investors who are in charge of building shopping malls in the Middle East and Egypt specifically. It provides a guidance and a methodology to assess and optimize skylight designs in shopping malls to reduce energy consumption used for artificial lighting while providing visual comfort.

In the first section of this article, an introduction is provided for this research, followed by the second section that presents a review on the previous literature on the same topic. The third section states the methodology used to analyze, assess and optimize the skylight of the selected case study. The fourth section presents and analyzes the selected case study while stating the boundary conditions of the simulation and optimization. In the fifth section, the results are presented and a correlation between skylight ratio, material and daylighting performance are illustrated. The sixth and last section raises the argument on skylight design in hot climates and the means and opportunities of applying optimized and retrofitting measures on the existing indoor shopping malls in the country and the region.

2. Literature review

2.1. Daylighting in hot climates

Daylighting is an essential component in the holistic environmental design of buildings. When skillfully introduced, daylight creates an ambience of quiet contemplation and visual comfort, in addition to the tendency of minimizing the usage of artificial lighting and environmental adapting devices (American Architectural Manufacturers Association (AAMA), 1987). Thus, the architectural design is the main factor that defines the quality of indoor daylighting availability. Daylight availability varies based on building geometry and orientation; internal walls visual specification; fenestration designs; and urban configurations (Amer et al., 2013; Li et al., 2013). The benefits of daylighting making energy saving, the percentage of energy saving depends on many factors, one of this factor is type and transmittance of glazing, other factors are reflection of the surface of case study, the height and the area of the space (Sudan et al., 2015a, 2015b). courtyards could provide a good amount of daylighting depends on the shape (circular or square) and its size, glazed area, reflective of the surface, the type of sky (Acosta et al., 2013, 2015; Calcagni and Paroncini, 2004).

The sun is considered to be the main source of light, generally providing 32,000–100,000 lux of illumination based on which time of the year, the latitude, and cloud coverage (Hoyle, 2011; Karlen et al., 2012). While, the illuminance from the sky varies according to an hourly and seasonal basis. A typical overall variation might be from 2000 lux at midday on a gloomy day in December to 100,000 lux in full sun in June (Baker and Steemers, 2000). There are many factors that affect the daylight quality in buildings, such as building orientation, shape, space between building, when it is taken into consideration it affects daylighting performance in the building (Abd EL-Montleb and Ali Ahmed, 2012; Amer and Attia, 2014) There are two important design parameters that directly affects daylighting performance in the buildings; windows and skylights. Windows are those vertical transparent elements mostly used in buildings with manageable compartments sizes, such as office, residential, medical zones. On the other hand, skylights are those vertical transparent elements used to cover larger indoor spaces such as commercial buildings and indoor courtyards while providing natural lighting.

2.2. Skylight in hot climates

Several researches investigated the influence of the skylights on daylighting. Treado et al., among other authors (Laouadi and Atif, 2001; Treado et al., 1984) concluded that lighting through skylights is more effective than through windows, thus it has a great effect in illuminate for indoor spaces. However, the usage of skylights is more critical in hot climates, due to the accompanied undesired sunlight radiations that increases indoor temperatures dramatically (Al-Obaidi et al., 2017). An integrated shape of domed pyramid skylight was studies in New Delhi (Chel et al., 2010). The results showed that by the vertical height of the dome is inversely proportional with daylighting acquisition. Another research examined a round shaped skylight. The flux transfer method was used to calculate the efficiency of the proposed skylight based on various height to width ratio. The research studied the diameter of the rounded skylight in relation with its height as well as integrating internal walls reflectivity. It was concluded that height to area ratio is inversely proportional with daylighting availability, while wall reflectivity has a significant influence on enhancing interior daylighting values. When integrating daylighting captive technologies, Acosta and Navarro have studied daylighting design with light scoop skylights under overcast sky conditions (Acosta et al., 2012). The main aim of this study was to determine the most suitable height/width ratio to obtain higher illuminance levels within the space. Subsequently, a study was carried out to define the most suitable distance required between light scoops to ensure homogeneous lighting. Another study identifies the holistic skylight design parameters in terms of first the external environment resembled in sun position, solar radiation, different types of skies. Second, skylight roofing systems and the effect of daylight versus heat gains and the optimum glazing materials in relation with indoor wall reflections (Al-Obaidi et al., 2014).

2.3. Skylight and thermal comfort

When it comes to the relation between skylight and thermal gains, Laouadi and Galasiu studied the effect of skylight on the thermal and energy performance (Laouadi et al., 2002). That research aimed to investigate the optimum design alternatives based on their effect on the thermal and energy performance of atriums. Design alternatives counted on glazing types, surface area, shape, and interaction of the atrium with its adjacent spaces. Another physical properties of the skylight that highly affect the thermal performance are the thermal conductivity (U-value) of the chosen material and Solar Heat Gain Coefficient (SHGC). The result of this study showed that the sky light pyramid shape has greater influence than flat shape that reaches up to 25% of increasing. Previous literature studied the effect of skylight with their different design configurations on daylighting and indoor illuminance quality. It has shown that it is hard to define a generic optimum shape or material for a skylight, as it highly depends on the environmental and boundary conditions of each case study. Moreover, as long as daylighting metrics and measuring methods are being developed it keeps the doors open for more investigations and experiments.

It is worth to mention that many researches that studied skylight were based on cold climate conditions, while rarely were relevant to hot climates. Knowing that it is not preferable in the hot climates to use the skylights, yet is important to investigate possible optimizations for skylight designs in hot climate. In Egypt, studies concerning skylights designs could barely be found. Unfortunately, almost all the commercial buildings based in Cairo uses skylights focusing on the aesthetic aspects only, thus it requires a thorough investigation to study the effect of those current designs and the possibility to optimize those designs considering daylighting and thermal comfort. Even though, in this article, thermal comfort studies have not been thoroughly studies, this paper aims to be a guide references for architects and investors focused on designing indoor shopping malls in hot climate regions. It proposes a working methodology and framework to be used when designing