Energy and Buildings 141 (2017) 175–185

Contents lists available at ScienceDirect

Energy and Buildings

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

Daylight performance and users' visual appraisal for green building offices in Malaysia

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ARTICLE INFO

Article history:
Received 13 August 2016
Received in revised form 23 January 2017
Accepted 11 February 2017
Available online 20 February 2017

Keyword:
Daylight factor
Daylighting
Discomfort glare
Green building
Visual appraisal

ABSTRACT

Lighting energy savings, as well as visual and non-visual user benefits have been widely attributed to daylighting. This paper explores daylight design strategy, visual appraisal, Daylight Factor (DF), lighting energy usage and discomfort glare using two green building offices in Malaysia, which have incorporated daylighting into both façade and interior design. Visual appraisal surveys were collected from 39 and 145 subjects in the open plan working space of the Energy Commission Building (ECB) and Public Works Department Block G (PWD), respectively. The survey focused on task brightness, colour appearance, uniformity and lighting preference. Discomfort glare assessed via occupant point-of-view luminance maps was juxtaposed here from a glare study involving the same buildings. Illuminance loggers were used to monitor artificial lighting usage as well as the DF on a selected floor of each building. There were no significant differences in occupant responses to the visual appraisal survey for both office spaces. Using MS1525:2014 and Green Building Index (GBI NRNC) tool as baselines, the DF performance of both offices differs significantly: PWD had a 45.5% daylit area, with ECB a 14.8% daylit area for DF >1%. However, lighting energy usage results show substantial savings of 53% and 41% occurred from daylighting. These findings of visual appraisal, DF, lighting energy savings and discomfort glare show a discrepancy in using only the DF to justify the daylight performance of an office space in a tropical climate such as Malaysia. The findings suggest that equivalent consideration should be given to interior design to facilitate daylighting, which is often beyond the control of designer, but in the hands of office end users.

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1. Introduction

In the wake of energy efficiency practices to mitigate the effects of climate change, various sustainable building assessment tools have been established since the late 20th century [1]. The building sector has the highest potential to reduce its carbon output given the same mitigation costs across various other sectors such as transportation and agriculture [2]. In response, the Malaysian government intends to reduce its greenhouse gas emissions intensity by 45% (scaled by GDP) by the year 2030 from its 2005 intensity by introducing various environmental related policies and programs [3–5]. One such program was the establishment of Malaysia's Green Building Index (GBI) in 2009, which signified the start of the green building movement in Malaysia [1].

To date, there are multiple green building certifications in use in Malaysia, such as LEED, Green Mark, GBI and MyCREST, which similarly evaluate the sustainability of a building, taking into account various aspects of design and construction; such as energy efficiency, water efficiency, indoor environmental quality (IEQ), sustainable site management and materials & resources [1,3].

Daylighting is an important aspect of green building design. The benefits of good daylighting to both energy efficiency and visual comfort are well known, as are the consequences [6–9]. Presently, the justification for what constitutes "good" versus "bad" daylight design in green buildings is measured via the Daylight Factor (DF). This paper evaluates the success of the Daylight Factor in producing a well day-lit space in the tropics using two GBI platinum rated government office buildings in Malaysia.

1.1. Daylighting and visual appraisal

The human preference for daylight over artificial light for office spaces is well established [7,10–12]. Daylight both stimulates and regulates our circadian system, which subsequently affects our alertness and mood [13,14]. It also provides variation of luminance and colour that influence the attractiveness and desirability

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http://dx.doi.org/10.1016/j.enbuild.2017.02.028
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of spaces [15]. Provision of windows satisfies the occupants desire for a connection to the outside, consequently improving their mood [12,16]. Carter & Marwaee [17] found that people were more satisfied with the lighting when they had windows, even if windows were not appreciably affecting the lighting at their task location. Galasiu & Veitch [12] also found that glare may be better tolerated from daylight than from artificial light if there was a good view available. A survey of readers' satisfaction at Raja Tun Uda Public Library in Malaysia found 74% of the respondents agreed that their seating preference is affected by daylight [18]. There are also claims that daylight improves work productivity, however as pointed out by Sullivan, Donn, & Baird [19], the findings from laboratory research are not very reliable as people usually take days to adjust to a different luminous environment. This intangible connection between productivity and daylight has constrained the economic feasibility aspect of daylighting to only consider energy savings, which does not take occupants' well-being into account [20].

1.2. Daylighting and energy efficiency

Daylighting can reduce the reliance on artificial lighting, which has been shown to help reduce the cooling load and building energy demand [21]. This is possible as diffuse daylight has a higher luminous efficacy, 110–130 lm/watt, than most artificial lighting, 70–100 lm/watt [22]. Yu & Su [8] reviewed 20 papers and found daylight harvesting can lead to energy savings in lighting of 20–87%. However, these calculations were assessed from non-field measurement methods such as simulation and algorithm calculations.

In the context of tropical skies, Kamaruzzaman et al. [23] evaluated the Klang District Office in Malaysia and found an average lighting consumption saving of 37% due to daylighting. However, it is important to note that occupancy and usage trends will impact energy savings. A study of 4 offices in Korea revealed that despite a 43% reduction in lighting energy use due to automatic dimming, the change in occupancy patterns lead to an increase in lighting energy use by up to 50% [24].

1.3. Current recommendations for daylighting office spaces in Malaysia

The local Malaysia standards required for new green office buildings are the Green Building Index Non-Residential New Construction (GBI NRNC) tool and MS1525:2014 Code of Practice for Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings. Under the daylighting credit EQ8 (for GBI NRNC) points are awarded based on the percentage of coverage of the Net Lettable Area (NLA) that achieves a Daylight Factor (DF) of 1.0–3.5% measured at the work plane [25]. A separate credit on the Post Occupancy Comfort Survey, EQ15, requires that if 20% of occupants are dissatisfied with the overall comfort, including lighting level and glare problems, then corrective action must be taken [25]. There is no specific credit awarded for reducing lighting energy from daylight harvesting; however, there is a collective credit that looks into the reduction of total building energy consumption (Credit EE5 Advanced EE Performance). This means that in design it is possible to score credits in daylighting through DF performance alone. This requires a simulation model without any interior fittings during the Design Assessment stage, which is not representative of the actual interior office condition [26].

MS1525:2014 briefly mentions a recommended DF of 1.0–3.5%, the same as GBI NRNC EQ8. It also recommends an average illuminance of 200 lx for infrequent reading and 300–400 lx for general office spaces [27]. However, these illumination ranges are for artificial lighting only and not optimized for skylight or daylight design in Malaysia [7,28,29].

1.4. Daylighting in Malaysia

A survey of 41 rooms in 5 office buildings across Malaysia showed that none of these office spaces achieved more than 0.5% DF due to the deployment of internal shading devices [28]. Despite the offices having deep overhangs to block direct sun, glare from the high luminance ratio of the window to internal surfaces caused occupants to engage their internal shading. Lim et al. [30] identified 18 government offices in Malaysia with identical façade design, and placement of individual occupant rooms at the perimeter. A simulation study showed that a light shelf could have reduced excessive daylight illuminance and improved uniformity in these offices.

A recent (2016) survey of discomfort glare in six office buildings in Malaysia, including three GBI certified green office buildings, found the most common source of glare in green buildings came from windows [31]. With glare from windows in green buildings experienced by 35% of occupants compared to just 7% in non-green office buildings [31]. In tropical climates, a view of the bright sky is a major glare concern. These findings highlight that façade design principles adopted from temperate climates may not adequately utilize daylight in the tropics [32].

2. Methodology

2.1. Buildings

This daylight performance study took place in two government offices, the Energy Commission Building (ECB) and Public Works Department Block G (PWD) located in Putrajaya and Kuala Lumpur respectively (Figs. 1 and 2). The ECB, completed in 2010, is a multi-award winning green building which obtained GBI Platinum and Green Mark Platinum awards in the Non-Residential category. It was recognised as the ASEAN Energy Award Winner (2012) and ASHRAE Technology Award Runner-Up (2013) [33]. Completed in 2013, PWD was the first high rise building to be certified GBI Platinum [34].

Nikpour et al. [35] explicitly studied the daylight quality of ECB. Despite having an office depth of 18 m, the daylighting strategy of ECB focuses on using a light shelf and atrium to reflect only diffuse daylight into the space. In addition to the removal of ceiling panels and using white finishes for internal surfaces, the cubicle was designed to facilitate daylight across the office space by using translucent partitions (Fig. 1). Roller blinds were provided for occupant's visual comfort at the vision glazing below the light shelf, while louvers between the light shelf and ceiling prevented low angle direct sun from entering the space from above the light shelf. Also of note is the usage of an automatic blind system at the atrium opening which allows only diffuse light from the sky. This was designed to block direct afternoon insolation, which would bring excessive heat gain into the building.

PWD is a 37 storey office tower that allows daylight penetration by taking advantage of perforated horizontal louvers along the vision window (Fig. 2). The closing angle of the horizontal louver is limited to ensure there is a minimum opening for diffuse daylight to enter. Fundamentally, both buildings have daylighting strategies that allow occupants to manually adjust blinds in response to brightness at the window whilst not jeopardizing the abundance of diffuse daylight. Both buildings emphasize daylighting strategies, though different in approach, in an attempt to achieve benefits in energy efficiency and visual comfort [26]. Both office spaces use efficient luminaires (Philips Essential 2 × 28W T5 Fluorescent) controlled by on/off daylight sensors with a set point of 250 lx. The

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