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Optimisation of daylight admission based on modifications of light shelf design parameters

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ABSTRACT

This study was conducted to optimise daylight admission as ambient lighting in an open-plan examination room of a dental hospital in Bandung, Indonesia. Parametric design was conducted for new light shelves, to be placed on the east and west façades of the building. Optimisation was performed using genetic algorithm, taking into account the external and internal widths, external tilt angles, and specularity of the light shelves, for two scenarios: keeping and removing the existing overhangs on both façades. The optimisation objectives were to maximise the spatial daylight autonomy at the perimeter area ($sDA_{300/50\%(p)}$) and minimise the annual sunlight exposure ($ASE_{1000,250}$) on the occupied floor area of the examination room. Different optimised values were obtained for the east and west façades. In the first scenario, the resulting objective function yields an increase of 4.9% compared to existing condition, whereas the increase is 16.7% in the second scenario. Both metrics in the second scenario have satisfied the criterion.

Uncertainty in the first scenario is found smaller than that in the second scenario, due to the removal of overhangs that bring more daylight in the latter.

1. Introduction

In the context of building design, daylighting is an important component that needs to be considered seriously in the approach to achieve energy efficiency and sustainability (e.g. [1–3]). Particularly in healthcare facilities, admission of daylight in spaces where patients are present is expected to create a positive healing environment, by enhancing health condition of the patients and reducing the recovery time (e.g. [4–6]). In workplaces, it has been long known that access to daylight and view are beneficial in creating healthy, comfort, and productive working environment. It has been shown that human generally perceive daylight and view as highly valuable features in buildings (e.g. [7,8]).

However, there are many situations in which daylight cannot penetrate effectively in buildings, particularly in the deepest part [9,10]. In an open-plan building site, for instance, the central space normally has got the least amount of daylight, while increasing the window area would not be possible due the risk of increasing the heating/cooling load. In such situations, daylight transporting system is a plausible and promising solution. Various types of daylighting systems exist, but many are mostly applicable for relatively large spaces in which there is sufficient space for placing the system. One of the systems that require only relatively small space is light shelf, which is a device specifically designed to direct daylight to the deeper part of the room, while also functioning as a shading device in blocking (direct) sunlight. A light shelf generally comes in the shape of a horizontal or inclined baffle, typically lies below a clerestory window, and above the 'normal' or view window [11].

Light shelves design and performance assessments have been reported and discussed by many researchers (e.g. [12–18]). One of the most important parts in designing light shelves is determining the optimum parameter, to ensure a maximum performance. Nonetheless, most of the previous studies evaluated the relevant values using factorial design or one at a time, in optimising the parameter. Alternatively, the use of reference curve has been promoted by Kurtay and Esen [19], for various locations based on selected latitudes, hence also with some degrees of uncertainty. Meanwhile, the use of parametric modelling and optimisation through evolutionary computing has

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become more popular nowadays to determine the optimum solutions in building design.

In particular, the technique of genetic algorithm (GA) has become one of the most popular options. It is inspired by the process of natural selection to find a high quality solution that satisfies the need or objective of the optimisation. The concept of GA was originally developed in the 1950's [20–22] and has expanded ever since in various branches of science and engineering. In principal, GA employs similar operators as in biological evolution process, including among others crossover, mutation, and selection, in order to obtain offspring that are supposed to be better (i.e. closer to the defined objective or fitness function) than their parents. After several iterations or re-generations, the obtained fitness value shall become sufficiently high and stable. At that point, the final generation is taken as the optimal solution to the defined optimisation problem.

In the daylighting context, GA has been applied in optimising the shape of daylight openings, either windows or skylights, in a given space (e.g. [23–25]). The GA optimisation process is expected to run in a relatively short time, with results that satisfy the objective and are obtained in a systematic, yet effective manner. Nonetheless, few studies have been done in applying the GA method in optimising various parameters of light shelves. Also, most studies in daylight transporting systems focused on office or residential buildings, and not so much on healthcare facilities in which medical staff and patients are involved.

1.1. Daylighting in dental hospitals

As far as medical doctors are concerned, among many specialisations of them, dentists are one of the groups whose daily task mainly concerns with recognising position, shape, and colour of small target objects (i.e. teeth). In this case, lighting is an important environmental factor in ensuring good working performance of the dentists.

To create good practice of lighting in (dental) hospitals, a number of national and regional standards are available for indoor lighting in working environments (e.g. [26]). Specific requirements in dentistry operating lights have been prescribed [27]. A number of references in literature on lighting for visual shade matching are available (e.g. [28–32]), and several experiments on lighting conditions in dental hospitals had been conducted by various researchers (e.g. [33–36]).

However, most of the aforementioned studies generally did not consider the ambient lighting, or assumed a constant one from artificial lighting. Meanwhile, daylighting in buildings is associated with many positive effects and benefits for the occupants. This was taken as the main motivation of the presented study, in which ambient lighting from daylight was optimised by mean of daylight transporting system (in this case, light shelves) to improve the lighting quality in a dental hospital. The quantity of daylight itself is not formally prescribed in standards nor medical regulations; however, the USGBC recommendations [37,38] may be taken as reference, in which a certain value of $sDA_{300/50\%}$ is suggested for the perimeter area, which is unique to healthcare premises. Therefore, this article focuses on design optimisation of light shelves using GA method, taking a dental hospital with open-plan examination room as the case study.

1.2. Aims and objectives

This study aims to optimise the design parameters of light shelves in a healthcare facility, in this case a dental hospital in Indonesia, to maximise daylight performance in the space, using GA optimisation technique. The objectives are as follows:

(1) to determine the optimum parameters for the designed light shelves, and
(2) to obtained the optimised daylight performance indicators upon the most optimum design parameters and their uncertainty.

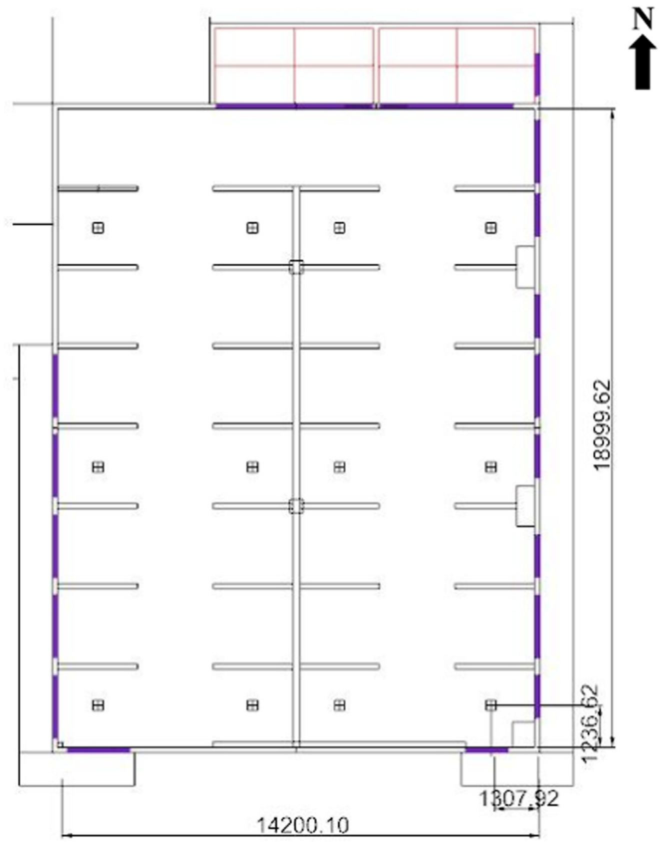

Fig. 1. Floor plan of the observed space.

To achieve the objectives, computational building performance simulation was applied, after verifying the geometric model of the existing condition. Section 2 provides the methods in modelling, simulation, and verification test. Section 3 provides the results and discussion, whereas Section 4 concludes the article.

2. Methods

2.1. Observed space

The observed space is located in the Dental Hospital of Padjadjaran University in Bandung, Indonesia (6.93°S, 107.61°E). The building is located in a relatively dense neighbourhood, with mostly dwellings and offices in the surrounding. The hospital serves mainly as educational hospital, particularly for final year dentistry students. The examination room in the hospital is a 14.2 m × 19.0 m open-plan space on the second floor, in which 29 dental units are placed in cubicles. The floor plan of the space is shown in Fig. 1. All patients and dentists in duty are therefore located in the same space.

Most of the view windows are present on the east and west (both are long) façades, and there are two on the south façade. The thick lines in Fig. 1 denote the position of the windows. The north wall is adjacent to another room in the building, while the south side is connected to another room that extends further south. The northwest wall (7.1 m long) is also adjacent to another room, hence comprising no windows. The elevation views of all walls and façades, as seen from inside, are displayed in Fig. 2. Most of the windows are at height of 0.7 ∼ 2.6 m above the floor.

All dental units on the east side of the space are located next to a group of windows (Fig. 2c), while only 5 out of 8 dental units on the west side are located in that way (Fig. 2d), since the remaining are situated next to a wall adjacent to another room. Working hours in the hospital is between 08.00 and 17.00 h on Monday to Friday. The