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The study of effective factors in daylight performance of light-wells with dynamic daylight metrics in residential buildings ☆

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ABSTRACT

Increasing housing demand and the precious value of city land have caused to the construction of multi-storey, deep-plan and compact buildings. Architectural design needs to provide the appropriate penetration of daylight and ventilation into the deep-plan buildings. Therefore further researches are necessary in the field of natural lighting and ventilation systems. Light-well is an architectural daylight system to deep-plan building which is widely used in the residential buildings of the case study of this research (Tehran, Iran). In this study, effective factors in daylight performance of light-wells are investigated with dynamic daylight metrics. In this research, the continuous daylight autonomy (DA_{con}) is utilized for evaluating of annual illuminance for attached rooms to light-well.

The main goal of this research is to estimate the effect of some affecting variables on the daylighting performance of light-wells (the area and horizontal section form, the optimal height of the light-well, orientation variation and the slope of light-well surrounding wall) to provide suggestions for better utilization of light-wells in residential building. 352 computer simulations using Daysim software have been conducted to assess the expressed variables. Also, Autodesk Ecotect software has been used as graphical user interfaces for Daysim. The findings of this study show the better daylighting performance of cylindrical light-wells compared with the common square light-well in Tehran. Also, the optimal height of different types of light-wells in residential buildings has been suggested with regards to the adequate daylight autonomy (DA) in connected rooms to light-well. The results of this study show that the increasing of the suggested optimal height for different types of light-wells is possible with increasing the slop of walls of light-wells and the window size in the lower floors.

1. Introduction

Population growth in big cities and the precious value of city land, have led to the construction of high-rise, deep-plan and compact buildings. Consequently, maintaining the high skin to volume ratio that allows daylight to reach most building spaces is inapplicable. Deep plan building is a building in which the horizontal distance from the external wall is many times greater than the floor to floor height. Useful daylight penetrates about 5–7.5 m (2–2.5 times the floor-to-ceiling height) inside a building from the windows (RIBA, 2007).

Three new strategies have been developed to bring daylight deeper into the new building forms and to control and distribute direct sunlight. One of them is improving the conventional techniques (this strategy seeks to improve the conventional daylighting technique capabilities to deliver daylight by using new optical materials, elements and devices, such as overhangs, light shelves, blinds, screens, and light filters), the other is developing new glazing systems (the glazing technologies are mainly concerned with enhancing the thermal insulation properties, and thus allow more glazing area to be applied in order to admit as much daylight as possible while preventing transmission of as much solar heat as possible). And the third strategy is inventing of innovative daylighting systems which is more concerned about delivering daylight into remote and windowless spaces in buildings and aims

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to maximize the utilization of the available daylight (Mayhoub, 2014).

In any strategy, newly developed devices and optical materials are used. The produced daylighting systems additionally contribute in conserving energy, protecting the environment, and enhancing building users, productivity and well-being.

Daylighting systems without shading (such as light pipes and light wells) are designed to redirect daylight to areas away from a window or skylight opening. They may or may not block direct sunlight (IEA, 2010). Increased housing demand and land prices have caused to the construction of multi-storey residential buildings in the case study of this research (Tehran, Iran) and widely application of light-wells in these buildings. In this study, effective factors in daylight performance of light-wells are investigated with dynamic daylight metrics and the design principles to optimize the daylight performance of light-wells are suggested.

2. Literature review

The related statistics to energy consumption in different countries show that artificial lighting is one of the highest consumers of electrical energy. The global residential lighting electricity consumption in 2005 was estimated by the IEA to be 811 TW h which is 18.3% of residential electricity consumption (IEA, 2006). The energy consumption for lighting varies greatly among different countries. For example, in the US, Energy Information Administration (EIA) estimates that in 2016, about 279 billion kW h of electricity were used for lighting by the residential sector and the commercial sector in the United States. This was about 10% of the total electricity consumed by both of these sectors and about 7% of total U.S. electricity consumption. Residential lighting consumption was about 129 billion and the commercial sector, which includes commercial and institutional buildings, and street and highway lighting, consumed about 150 billion kW h for lighting (EIA, 2017). In Iran (The location of case study of this research), 30% of the total residential electricity consumption (in the year 2012), is linked to artificial lighting which is almost 12% higher than the global average (Iran Electric Power Industry Statistics, 2014). Therefore, electric lighting is one area where significant savings energy consumption is possible.

The studies have shown that 40% energy savings (In relation to electric lighting energy) could be obtained by using appropriate daylight (Dubois and Blomsterberg, 2011). In another study, a table of lighting energy savings has been reported by space type (private office, open office and classroom) and controls type (multilevel switching, manual dimming, daylight harvesting and occupancy sensors). Their findings say that the lighting energy savings ranges from 6% to 70% across eleven categories of space types and controls types. It has been reported that integration of artificial lighting with the use of energy efficient luminaires and architectural daylight systems can help reduce the electrical energy demand and improve vision efficiency of the occupants (Kumar Soori and Moheet, 2013). Also, several studies have shown the positive effects of daylight on improving human perception and mood and also comfortable feeling (Kellert et al., 2008; Wasserman, 2011).

Fig. 1. The examples of light-wells in Tehran.