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Analysis of daylight factors and energy saving allowed by windows under overcast sky conditions

Ignacio Acosta*, Carmen Munoz, Miguel Angel Campano, Jaime Navarro

Instituto Universitario de Arquitectura y Ciencias de la Construcción, Universidad de Sevilla, Spain

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ABSTRACT

The aim of this research is to quantify the daylight factors produced inside a room for different models of windows, and to conduct an analysis of the results obtained. All trials were performed under overcast sky conditions, as these represent the worst case scenario for calculation. The shape, size and position of the window are variable, as is the reflectance of the inner surfaces of the room. A total of 28 simulations are provided by the lighting simulation program Daylight Visualizer 2.6, validated by the CIE test cases. After trials it was concluded that square windows produce daylight factors slightly higher than those obtained with horizontal windows and noticeably higher than those measured with vertical windows, considering the same surface of openings. It is confirmed that the daylight factors are directly proportional to the glass surface, except in the area near the window. It is also concluded that the windows in the upper position allow higher luminance at the back of the room than those in centered locations. Finally, the energy savings produced by the different models of windows is calculated.

1. Introduction and objectives

1.1. State of the art

Windows are a key element in architecture, as they represent the most basic resource for allowing natural light inside buildings [1]. The proper design of windows also improves thermal comfort and brings about a notable energy saving in artificial lighting [2].

Daylight factor is the simplest and most common measure to quantify the daylight allowed by a window, as they express the potential illuminance inside a room in the worst possible scenario, under overcast sky conditions when there is less exterior daylight. At present, the daylight factors represent the most widely used metric in the evaluation of daylighting. Moreover, this definition is recognized by the CIE as one of the key metrics in lighting [3]. Since daylight factors are assessed under overcast conditions, the sun's position is not relevant, so the calculation is independent of the location of the room. Therefore, the measurement of daylight factors does not depend on time, window orientation or location of the room, they are only affected by the geometry of the model. According to the definition of daylight factor, the calculation of the illuminance at an interior point is immediate as long as the external illuminance is known.

Nevertheless, it is important to mention other methods for daylight evaluation, such as daylight autonomy [4], developed by Reinhart et al., which is one of many currently existing metrics that consider the dynamic aspects of daylight and is usually applied for annual calculations.

Daylight factors produced by windows have been studied since the early modern treatises on daylight [5]. In order to simplify its calculation this metric is seen as the sum of three components [3]: the sky component, the internally reflected component and the externally reflected component. The methods of calculation provided more than half a century ago are still valid nowadays. Currently, most treatises [6,7] solve the sky component using analytical formulas and the reflected components using empirical methods.

Empirical methods do not give reliable results, as can be observed from the daylight factor method [8], based on very limited calculation conditions and defined as a low accuracy method [9]. Other empirical calculation methods obtain results with similar accuracy [10,11].

However, at present, lighting simulation programs allow the calculation of daylight factors with greater accuracy than empirical methods [12,13], making them extremely useful tools in the field of natural lighting.

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* Corresponding author. Permanent address: Instituto Universitario de Arquitectura y Ciencias de la Construcción, Universidad de Sevilla, 41012 Seville, Spain. Tel.: +34 647550654.

E-mail address: iacosta@us.es (I. Acosta).

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Furthermore, lighting simulation programs have allowed the development of new methods for calculating daylight factors, whose accuracy has been supported by computer simulations. An example of this is the study by Ghisi et al. [14], who developed a calculation method, contrasted with VisualDOE, which determines the ideal window area for maximum efficiency considering the use of natural and artificial lighting. The authors conclude that smaller or wide rooms result in greater energy savings in lighting and the ideal window area tends to be higher in low thermal load orientations. Another notable example can be found in the research of Li et al. [15], who developed a calculation procedure relying on the daylight coefficient concept and confirming the results using the Radiance program. In this study, the authors create a method based on multiple tables and charts for establishing illuminance.

In addition, lighting simulation programs have been used to establish the design conditions of windows and rooms. A noteworthy example is that of the research by Munoz et al. [16], where the authors analyze different metrics in an office illuminated through windows. This study allows the authors to quantify the loss of performance of windows depending on external obstructions.

Currently, most research supported by computer simulations studies daylight factors produced by windows with blinds or shading devices. One of the most interesting articles in this field is that by Alzoubi et al. [17], who analyze the performance of windows with vertical and horizontal shading devices. The authors conclude that there is an optimal orientation for shading devices that keeps the internal illuminance level within the acceptable range with minimum amount of solar heat gain. In this research, the authors also determine the energy saving produced by different shading devices.

The research by Sanati et al. [18] is also worth noting; it concludes that window blinds are not properly used by the occupants and that the use of slat systems allows higher energy savings in artificial lighting. Some interesting research can be observed in the study by Villalba et al. [19] on the permeability of urban trees in daylighting of windows using models based on blinds.

The study on window design is not only based on daylighting conditions. Another approach focuses on thermal comfort, as shown in some research [20,21]. In any case, it is a fact that the study of windows is an endless source of research results.

1.2. Aim and objectives

The aim of this research is to quantify the daylight factors inside a room for different models of windows, conducting an analysis of the results obtained. All trials were performed under overcast sky conditions, as these represent the worst case scenario for calculation. The shape, size and position of the window are variable, as is the reflectance of the inner surfaces of the room.

Accordingly, this research is based on three main objectives:

1. To represent the quantification of daylight factors in more conventional calculation models, so that it serves as a reference for window design in architecture.
2. To conduct an analysis of the resulting daylight factors and obtain criteria for shape, size and position of windows.
3. To determine the energy saving produced by different models of windows.

2. Description of methodology for calculation

2.1. Choosing the calculation model

The calculation model for the analysis of daylight factors is defined as a room 3.00 m wide by 6.00 m deep by 3.00 m high. The ceiling, walls and floor of the room have a thickness of 0.25 m. A window of variable shape, size and position is located in the 3.00 m wide façade. The double-leaf window has 0.05 m thick joinery and double glazing which produces a solar factor of 0.7. The reflectance of the inner surfaces of the calculation model is variable, accordingly two basic room models —with light or dark surfaces— are defined. The inner surfaces of the room are diffuse reflectors and the Lambertian reflection of daylight is therefore directly proportional to the cosine of the angle between the observer's line of sight and the surface normal. All variables of the calculation model are shown in Fig. 1:

The measurement of daylight factors is performed on the axis of symmetry of the calculation model and on two equidistant axes at 1.00 m. Therefore, the study points are located on these axes with a spacing of 0.50 m and a height above ground of 0.60 m. The study points are represented in Fig. 1. A total of 36 study points are used in each model.

The calculation model is defined according to the following variables:

Window shape:

S: Square shape, length/height ratio of 1·1.
H: Horizontal shape, length/height ratio of 2·1.
V: Vertical shape, length/height ratio 1·2.

Window size:

10: Window surface/Façade surface ratio equal to 10%, equivalent to 0.90 m^2.
20: Window surface/Façade surface ratio equal to 20%, equivalent to 1.80 m^2.
30: Window surface/Façade surface ratio equal to 30%, equivalent to 2.70 m^2.
40: Window surface/Façade surface ratio equal to 40%, equivalent to 3.60 m^2.
60: Window surface/Façade surface ratio equal to 60%, equivalent to 5.40 m^2.
80: Window surface/Façade surface ratio equal to 80%, equivalent to 7.20 m^2.

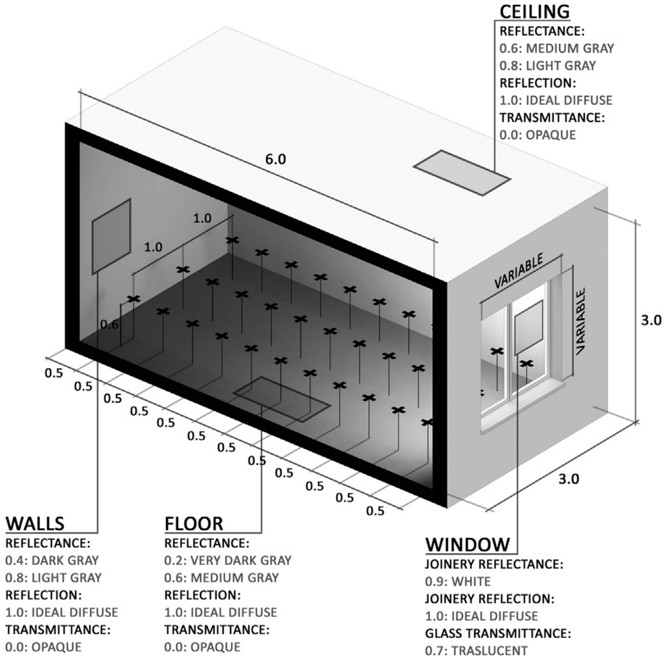

Fig. 1. Calculation model.