The impact of shading by vegetation on the level of daylight in buildings: A case study

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Abstract. An optimal supply of daylight has a positive effect on the physical and psychological health of building users. In the working environment, daylight is a decisive aspect that significantly determines the overall work efficiency of employees. Several factors influence the internal comfort of the environment, but one of the main factors is visual comfort. Nevertheless, excessive sunlight, especially in summer, can cause discomfort. Nowadays, there is a broad spectrum of elimination options for excessive solar gain. This contribution is devoted to a less discussed elimination option, specifically the shading of buildings by surrounding vegetation and its importance in an urbanized environment. The study evaluates the administrative premises of the building for education. The illuminance measurement was performed in two offices with the same orientation. Based on the measured values, the effectiveness of the shading by vegetation element in the current environment and time is detected. The paper aims to investigate the impact of shading by vegetation on the internal visual comfort of employees, based on the concept of daylighting, and recommend appropriate measures to achieve an optimal daylight level.

1 Introduction

In today's world, where people spend more than 90% of their time indoors, it is essential to understand the impact of lighting on their health, comfort, and productivity. In addition to optimal lighting conditions, sunlight offers effective energy harvesting options. The presence of natural light reduces the need for artificial lighting, which accounts for up to 28% of total energy consumption in buildings [1]. Daylighting refers to the presence and use of natural sunlight in the interior of a building to illuminate the space and create visual comfort. When designing for daylighting, several factors must be considered, such as the location and orientation of the building, as well as the number and size of the openings that allow light to enter the interior. Daylighting is not just about providing sufficient light, but also about its distribution and minimizing the adverse effects caused by excessive radiation [2]. The lighting quality depends mainly on the distribution of light flux, brightness, the predominant direction of lighting, and the occurrence of unwanted phenomena. Visual interior comfort can be disrupted by unpleasant glare, which can increase the internal air temperature [3]. The

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intensity of solar radiation in the interior can currently be regulated by several commonly used options, such as shading elements, the type of glazing of windows and glazed structures, or coating glazing systems. Shading by the surrounding environment and vegetation also has a significant impact on lighting in buildings [4].

2 Buildings shading by vegetation

Daylight in buildings has significant action besides the aesthetic and comfortable perception of the environment also on the sustainability and efficiency of buildings. One aspect that can significantly affect daylighting in buildings is shading by surrounding vegetation. This phenomenon has a significant impact on the energy consumption of buildings in addition to the indoor comfort of the environment [5]. Strategically placed trees, depending on their type, shape, and distance from the building, can achieve the desired shading and thus affect the energy demand for heating and cooling. Another advantage of vegetation is evapotranspiration, which can reduce the air temperature in the vicinity of the building by up to 5°C [6]. In one study, the authors focused on the impact of tree shading on energy savings in warm climates. The research was conducted on a two-story house in Mexico. According to the study, the annual energy savings for air conditioning due to tree shade reached 76.6%. The result indicates a significant impact of vegetation shading in warm climates [7]. Another study examines the impact of shading on the environment of residential buildings in a humid tropical climate. The researchers compared two nearly identical houses in Malaysia. One of them was surrounded by vegetation, and the other was not. Temperature and humidity were measured simultaneously in both houses for ten days. The results showed that the indoor air temperature in the shaded house was 3.4 °C lower than in the unshaded one. It suggests energy savings for air conditioning in tropical areas [8]. The impact of tree shading on reducing energy costs has been studied by researchers since the last century. A study was conducted on residential buildings in Sacramento, California. The result showed a total savings of 9% on heating and cooling costs [9].

Based on the studies, tree shading has a significant impact on the energy efficiency of buildings, but it depends mainly on the climatic conditions. In addition to energy savings, shading also affects the indoor lighting climate of buildings. Shanghai researchers studied the placement of trees in urban areas and between individual buildings. The study focused on optimizing the shape of trees between buildings to meet the daylighting requirements of buildings. The result was a formula for determining the type of trees suitable for planting around a building. The formula can predict the future growth of the trees and its impact on daylighting in the building [10]. From a simulation perspective, trees are very complex to model due to their shape. For 3D modelling of vegetation, many factors need to be considered, such as leaf shape, leaf aging, density, colour, leaf gap fraction, and many others. Due to these diverse morphological characteristics, tree modelling is challenging. Researchers in Canada addressed these characteristics in their study, which described a detailed scheme for creating dynamic tree models. The tree models are intended to improve the accuracy of building simulations [11]. In their next study, they proposed a method for modelling a perforated tree crown based on a photograph. The technique is based on the percentage of gaps captured in the photograph, from which a 3D model is created. The result is a 3D model of the tree crown that casts a shadow like a real tree [12]. The impact of vegetation on daylight availability in buildings is the subject of another study. The authors focused on tree parameters such as leaf size, density, and reflectivity. The study confirmed that vegetation shading significantly affects indoor lighting conditions. Distance from the building is also a significant factor. A disadvantage is trees that are placed close to the building, which can create large shadows that can lead to the need for artificial lighting [13].

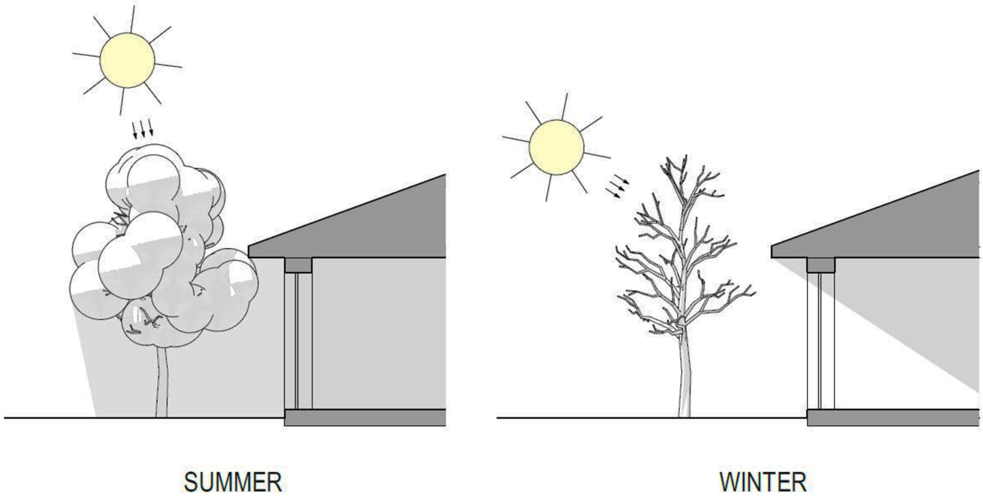

Fig. 1. Shading by vegetation in summer and winter (according to [14]).

3 Description and methodology

The subject of the contribution is the administrative space of a building in Kosice, Slovakia. The offices are facing southeast and are located on the third floor. Measurements were realized in two selected offices in July and December of 2023. The dimensions of the offices and their lighting openings are identical. The room internal dimensions are 3.67 x 5.65 m, and the room height is 2.75 m. The size of the standard double-glazed window is 1.2 x 1.8 m with a parapet height of 0.85 m. The first office (Room A) is shaded by a tree, and the second office (Room B) is without any shading. The illuminance (lx) was measured in nine points in the rooms at a height of 0.75 m above the floor (Figure 2.).

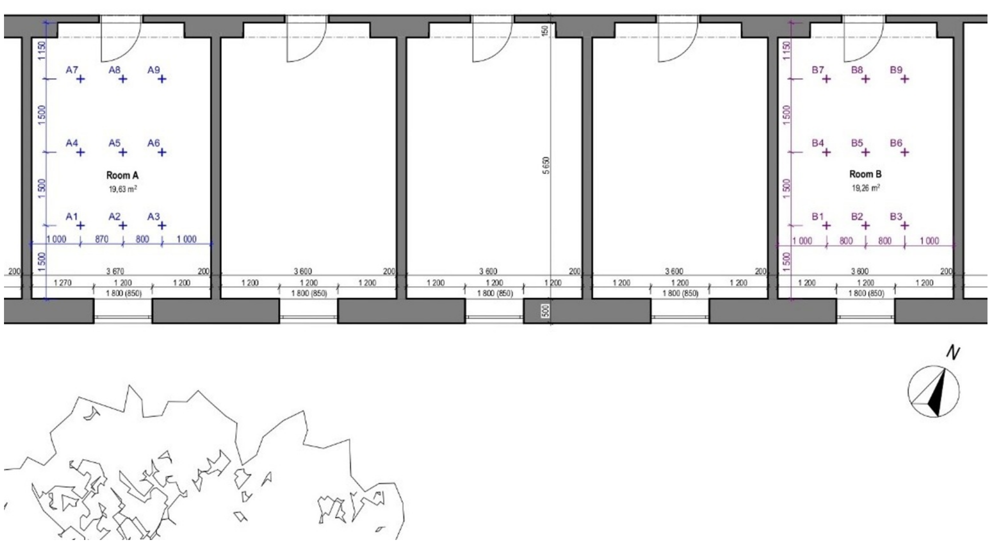

Fig. 2. Floor plan of the tested office rooms.

The measurements were carried out on one summer and one winter day. The illuminance measurements in nine points were repeated three times. The daylight factor was calculated from the measured data and the averaged DF values were considered in the results. The indoor and outdoor illuminance was measured using a luxmeter (PRC Krochmann – RadioLux 111) (Figure 3.).

Fig. 3. Used lux meter RadioLux 111, advanced version class A.

3.1 Internal daylight requirements

The basic quantitative characteristic of daylighting is illuminance. The daylighting of the interior from the perspective of quantity is evaluated by the daylight factor. The daylight factor characterizes the photometric properties of the interior of a building depending on the construction of the lighting system. It is expressed as the ratio of the value of daylighting that penetrates through the window structures to the evaluated workplace (E_i) to the maximum external illuminance of an unshaded horizontal plane (E_o), under conditions of a gradual distribution of brightness on a completely overcast sky [15].

$$DF = (E_i/E_o)*100\ (\%) \tag{1}$$

In Slovakia, the requirements for daylighting are specified by the standard STN EN 17037 Daylight in buildings [16]. The requirements are determined based on the classification of the work activity of the selected room in the relevant class of visual activity. The rooms under consideration are used for medium precision to precision production, it includes activities such as writing, reading, or drawing. Therefore, the rooms belong to the third and fourth light–technical classes, which characterize precise and medium-precise visual activity. The requirements are determined based on the classification of the work activity of the selected room in the relevant class of visual activity. Standard values of the daylight factor are defined according to the vision class. The minimum standard value is DF = 1.5 - 2% and the average standard value is DF = 5 - 6% [17]. For spaces where productive work is performed, an average illuminance of 500 lx is recommended, and for other areas in the room, a minimum of 300 lx [18].

4 Results

The paper presents the results of measurements for a room with and without vegetation shading in July and December under the overcast sky. In summer, the illuminance values in room A ranged from 14.4 – 130.2 lx and in room B from 37.3 to 355.2 lx with an outdoor illuminance from 10 500 to 12 000 lx. In winter, the illuminance in room A ranged from 59.17 to 470.8 lx and in room B from 178.6 – 1 027.0 lx with an outdoor illuminance from 6 000 to 9 500 lx. The resulting calculated daylight factor values are shown below (Figure 4.-5.).

Fig. 4. Daylight factor average values during summer measurement.

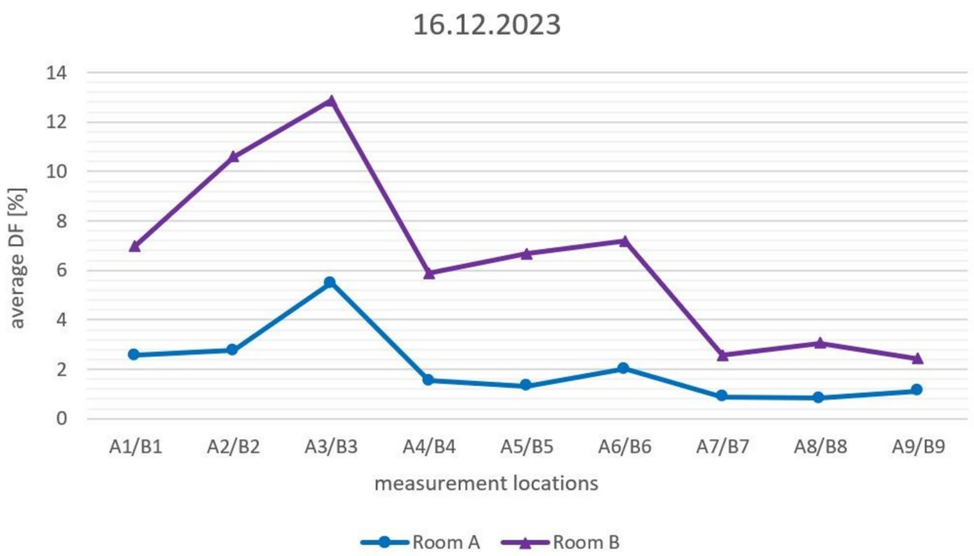

Fig. 5. Daylight factor average values during winter measurement.

5 Conclusion

Daylight is one of the most important factors affecting the perception and functionality of an interior. Its deficiency or excess can disrupt internal visual comfort and negatively impact the health and productivity of occupants. Daylight in buildings can be affected by various factors, including the surrounding environment and vegetation. Based on the studies mentioned, the impact of vegetation shading on building lighting and energy efficiency is undeniable [19].

The results of the presented study confirmed this effect by comparing the same offices where one is shaded by a tree (Room A). Shading by vegetation during summer reduced the average daylight factor in the most illuminated point of the room by up to 64.87%. The average daylight factor in a shaded room was reduced by 57.3% in winter. However, the shading was so intense that room A did not reach the average DF value required by the standard. The highest illuminance values in room A did not reach 150 lx, which is insufficient for a working environment. Lack of light in the work environment can lead to higher energy consumption for artificial lighting. In this case, excessive shading is caused by insufficient distance between the tree and the building. Nevertheless, many other factors also come into, such as the shape and density of the leaves or the size and perforation of the tree crown. In the unshaded room B, the lighting in the workspace was above 300 lx in summer, which is not exactly ideal. In winter the illumination in the workspace exceeds 500 lx, which can uncomfortably disturb visual comfort. The study shows that shaded room A is not sufficiently naturally lit in summer or winter. Conversely, not shaded room B was lit in summer, but in winter there can be unpleasant glare. External or internal shading elements would be suitable to regulate solar radiation. Another continuation of the study could be a look at the energy efficiency of the building.

Based on the study, the proper selection and placement of vegetation around a building can regulate daylighting in the interior and simultaneously reduce energy consumption for artificial lighting. In this way, surrounding vegetation can play an important role in the energy balance of buildings. Therefore, it is crucial to pay adequate attention to vegetation elements and their placement during the design and renovation of urban areas and buildings, to achieve optimal conditions. Even in this way, we can create an environment that supports the health, comfort, and efficiency of residents.

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