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PROVIDING AN INTERIOR DAYLIGHT ENVIRONMENT THROUGH THE USE OF LIGHT PIPES

KSZTAŁTOWANIE WEWNĘTRZNEGO ŚRODOWISKA OŚWIETLENIOWEGO ZA POMOCĄ ŚWIETLIKÓW RUROWYCH

A b s t r a c t

The paper presents the effect of using additional daylight illumination of building interiors using tubular skylight systems. Interior illuminance distribution was analysed using a combination of two daylight sources – window and skylight pipes. The results were obtained for cloudy weather conditions. Final remarks concern the effectiveness of supplementary daylighting of interiors using different configurations of light pipes.

Keywords: *daylight, tubular skylights, interior illuminance, simulation*

S t r e s z c z e n i e

W artykule omówiono możliwość wykorzystania doświetlenia wnętrz światłem dziennym za pomocą systemów świetlików rurowych. Przeanalizowano rozkłady natężenia oświetlenia wnętrza przy zastosowaniu kombinacji okna ze świetlikami rurowymi. Wyniki otrzymano dla warunków nieboskłonu zachmurzonego. Określono skuteczność doświetlania w przypadku zastosowania różnych rozwiązań i konfiguracji świetlików.

Słowa kluczowe: *światło dzienne, świetliki rurowe, oświetlenie wewnętrzne, symulacja*

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1. Introduction

Daylight utilization in the design of a healthy building environment is a crucial point, not only with regard to the indoor environment quality but also from an energy efficiency point of view. People spend a majority of time during the day in selected types of the non-residential buildings e.g. offices. Therefore, it is necessary to provide high indoor comfort parameters including the lighting quality. Daylight distribution and directionality of light determine the main parameters of visual comfort and comfort indexes. The main visual comfort indexes are based on two parameters: luminance and illuminance. Daylight illuminance inside the building is changeable and depends on external parameters like weather, time, season and urban development. Similarly, the amount of light inside the building strongly depends on architecture design, geometry, size of windows and surface properties (transmission and reflection characteristics). Nowadays, the starting point for daylight design is some simple guidelines which are giving inaccurate results. This approximation is based on the percentage of glazing, the ratio of glazing area to floor area or the maximum depth of the room which should not be exceeded. It is a relatively easy but a too imprecise approximation. In some cases, creating an appropriate lighting environment does not simply need horizontal windows, but also untypical solutions like a light shelf [1], light breakers [2], light pipes or optical fibers [3]. These solutions are used due to limitations of architecture, spatial condition and the unique character of natural light.

The aim of this study is the analysis of interior illuminance distribution in the room illuminated by a combination of window and light pipes. The paper presents the results of simulations of the different optical properties of windows and various positions of light pipes. Subsequently, an analysis was carried out for the selected combination of windows and light pipes.

2. Visual comfort

Use of daylight for lighting building interiors is a prerequisite to ensure a comfortable and healthy working environment [4]. Daylight is the healthiest kind of light for the human eye because of its colour and continuous spectrum. Lighting condition has an impact on speed, accuracy and effort associated with activity. It has also a great influence on health, well-being and life quality. Therefore, it is important to create a visually comfortable interior of the room by providing lighting of a suitable quality and quantity. It should be emphasized that comfort depends on many parameters, but it is also very subjective.

An appropriate light environment which ensure the visual comfort, visual effectiveness as well as security, is mainly associated with following values [5]: lighting intensity, luminance distribution and glare. In the following paper, only one of these parameters – illuminance was considered. Ensuring an adequate level of illuminance and its spatial distribution affects how quickly and easily visual tasks may be carried out. Insufficient lighting causes tiredness, sleepiness, worsening mood of the observer and additionally, it may be the cause of accidents. The required average illuminance in the field of work and on the immediate surroundings of the workspace are given in standard EN 12464-1 Light and lighting. Lighting jobs. Part I. Indoor work places. For most scenarios, the illuminance on the work area should be in the range of 20 lux (noticeable human traits) to 2000 lux. In the immediate surroundings of the workspace, the illuminance value might be slightly lower. Another important parameter is the uniformity of illuminance (ratio of the smallest measured illuminance on a given surface to the average illuminance on the plane), which should be at least 0.7 on the work plane and 0.5 on the immediate surroundings for continuous operations. Lack of uniformity of illumination causes ocular muscle fatigue, which is related to the need to adapt to changing light intensity.

3. Light pipes vs. windows

There have been some research works on the performance of light pipes over past decades [6, 7]. The main task of light pipes is to supply natural light into areas of the building with limited or zero access to daylight. They can be also situated in the rooms with shape, dimensions or optical properties of existing windows causing insufficient light distribution. Light pipes consist of three parts: outside collector installed on the roof, tube to transport daylight and diffuser. The transport tube can be rigid or flexible. The main goal of the light pipes is to collect the solar radiation through the cupola, its transporting by tube and dissipating in the room. The type of the lower glazing, matt or transparent, determines the interior daylight distribution. Matt glazing causes a more regular distribution of light while for transparent, it is more diverse. Light pipes provide less light than traditional windows due to losses in the transport tube. However, in dimly lit rooms, especially with north oriented windows, light pipes can be used to increase the illumination. Besides, the application of light pipes allows for a decreased surface area of windows which consequently reduces the threat of a glare effect or overheating problems in the summer period. Previous analyses of combination system of windows and light pipes are available in the literature [8].

4. Case study

The test cell analysed here was 3 m high, 3 m wide and 9 m deep. The external surface was 9 m^2. For the purpose of analysis, the representative types of glazing have been selected. The visible transmittance for ten types of glazing components rises gradually by 10% from 10% to 100%. In this case, the whole external surface was treated as a transparent area which is 1/3 of the total floor area. In the second case, only the size of the window has been changed gradually by 10% from 100% (totally glazed surface) to 10%. For each transmittance and size of window, six variations of light pipes' geometry with a diameter of 0.35 m and 0.85 m were assessed. In the paper, two types of the emitter were analysed – matt (mat) and transparent (tran). Transmittance for collector and both types of emitters was assumed as 0.9. The analysed tube was 1.0 m long and has internal reflectance at a level of 0.95. Analysis was performed for six cases due to the number and position of the light pipes (Fig. 1). In the first three cases, one light pipe located on the 1.5 m (1.1), 4.5 m (1.2) or 7.5 m (1.3) depth was analysed. Next two cases were performed for two light pipes situated on the 1.5 m

Fig. 1. Position of the light pipes according to the window

and 4.5 m (2.1) or 4.5 m and 7.5 m (2.2) depth. In the last case (3.1) three light pipes were located on the 1.5 m, 4.5 m and 7.5 m depth.

The analysed part of the building was located at a point with central Europe climatic conditions (longitude, latitude and meridian respectively 52.25N, 21.0E, –15.0) and south oriented. The luminance of the sky was assumed according to the Standard Overcast Sky Distribution developed by the *Commision Internationale de l'Eclairage* (CIE) [9]. Results were saved and analysed for 21st of March at 12:00.

The numerical calculation for vertical windows has been done using RADIANCE- which is based on Ray-tracing methodology [10]. Analysis of the daylight distribution supplied by light pipes was performed using the calculation program, HOLIGILM (**HO**llow **LI**ght **G**uide **I**nterior i**L**lumination **M**ethod). The calculation method of this program is based on the analytical solution and the Ray-tracing method [11].

5. Results analysis

The analysis was divided into two parts. In the former part, the interior daylight distribution was performed due to the different optical properties of the glazing partition as well as the position and diffusivity of the light pipes (Fig. 2). It can be noticed that for most of the analysed cases of the façade optical properties, interior illuminance is sufficiently high across the whole surface of the room (> 500 lux). Additional light from light pipes is required in only four cases. The first two were characterized by visible transmittance equal to 100% and a small area of the window with a size of 10% and 20% of the glazing. The next cases for the fully glazed façade with visible transmittance at a level of 10% and 20% were chosen. According to the analysis of the light pipes, the maximum values of the illuminance for matt and transparent light pipes (Fig. 2. c, d) are comparable and reach almost 600 lux. The significant difference between them is visible due to the distribution. The matt diffuser caused more event light than the transparent one. For further research, three cases (1.3, 2.2, 3.1) were adopted both for the matt and the transparent diffuser. Illuminance resulting from window light is the highest near the window and low in the opposite side of the room. Therefore, additional lighting was chosen for light pipes located deep in the room (1.3, 2.2). Furthermore, case 3.1 was analysed with three light pipes uniformly illuminating the whole analysed surface. Additionally, in the second part of the analysis, a study of the illuminance for a light pipe with a 0.35 m diameter was included. Graphs in Fig. 3 present illuminance distribution in the room illuminated by a combined system of window and 0.35 m diameter light pipes. It can be noticed that additional illuminance from light pipes is slight at a maximum of 100 lux. Therefore, light distribution for analysed cases is insufficient (< 500 lux), except for the combination system of 20% glazed surface of the façade and three light pipes with matt diffusers.

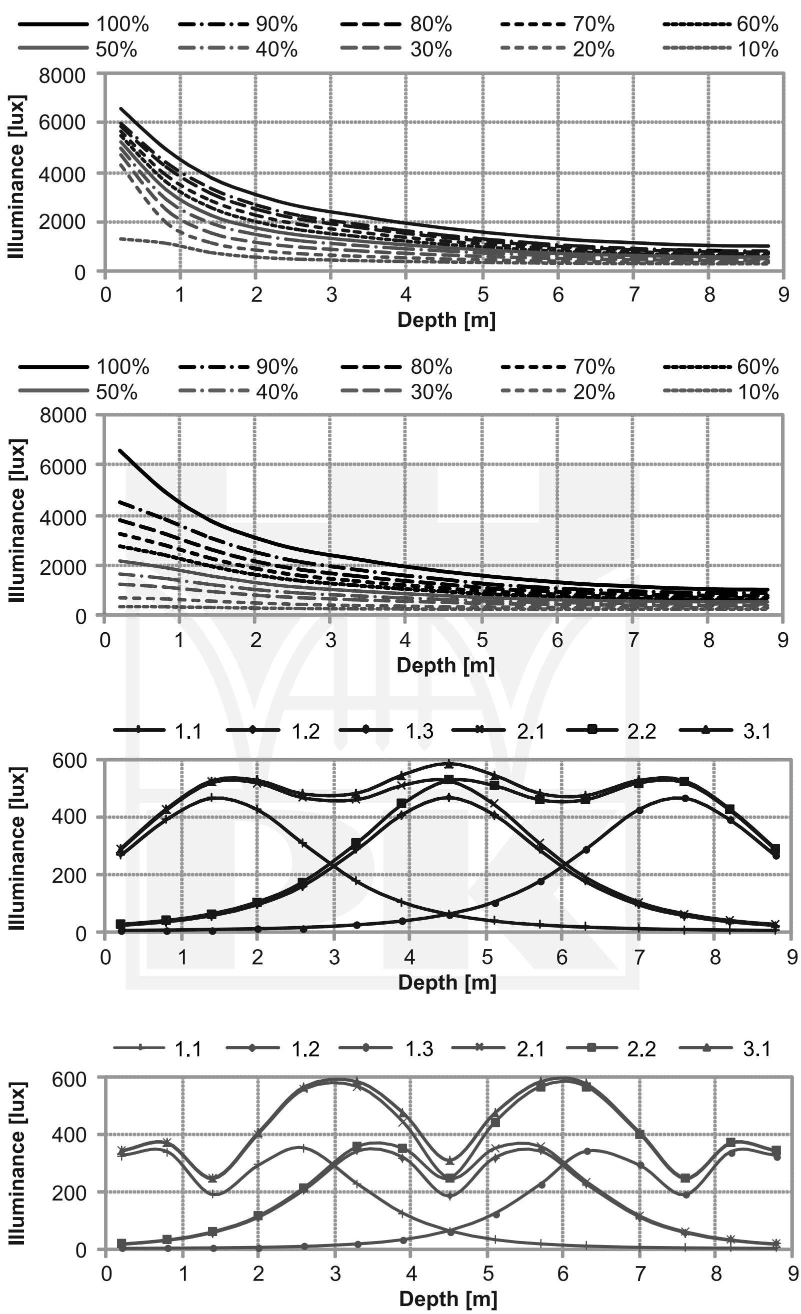

Fig. 2. Interior illuminance for different: a) size of the window, b) visible transmittance of the window, c) position of 0.85 m diameter light pipes with transparent diffuser, d) position of 0.85 m diameter light pipes with matt diffuser

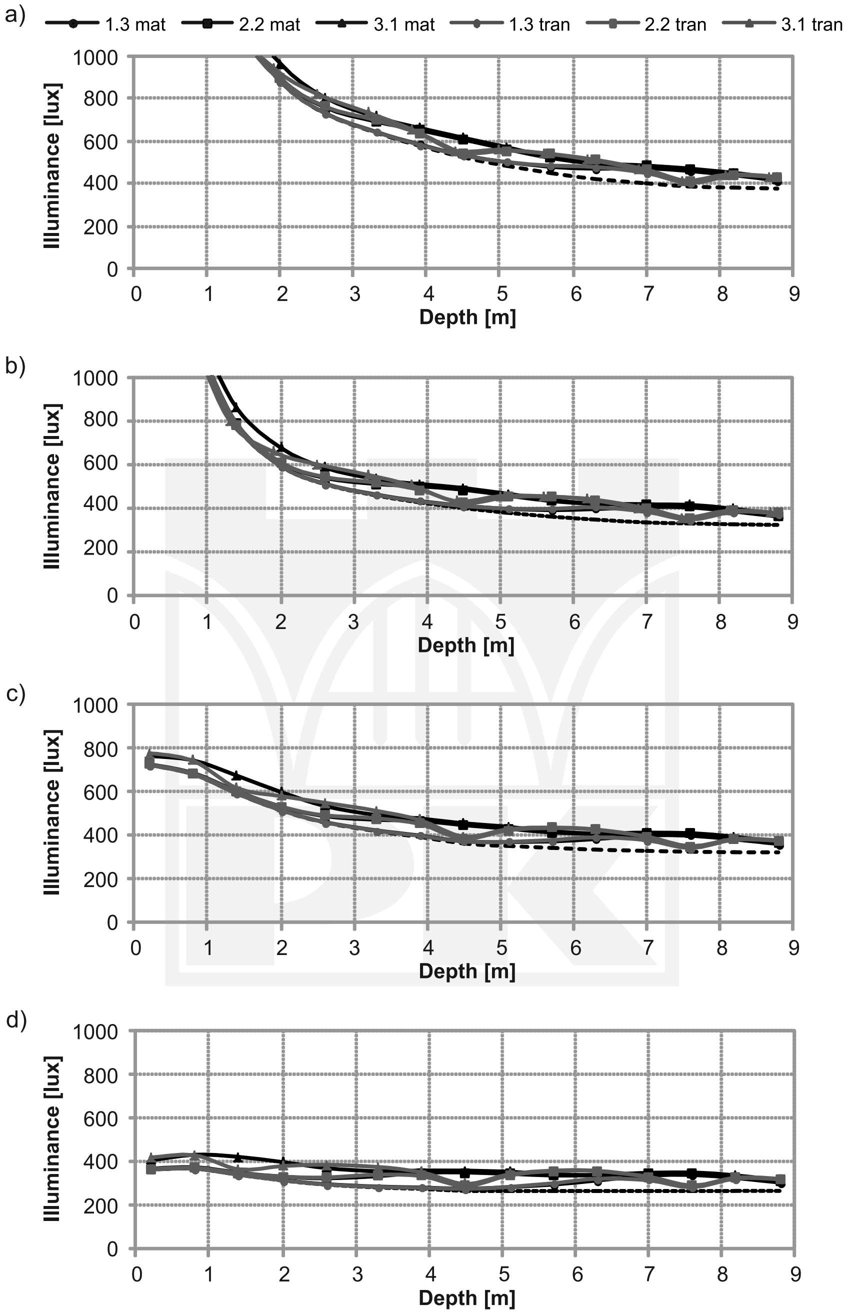

Fig. 3. Interior illuminance for light system combined from the 0.35 m diameter light pipes and window of: a) 20% glazing surface of the facade, b) 10% glazing surface of the facade, c) 20% visible transmittance, d) 10% visible transmittance

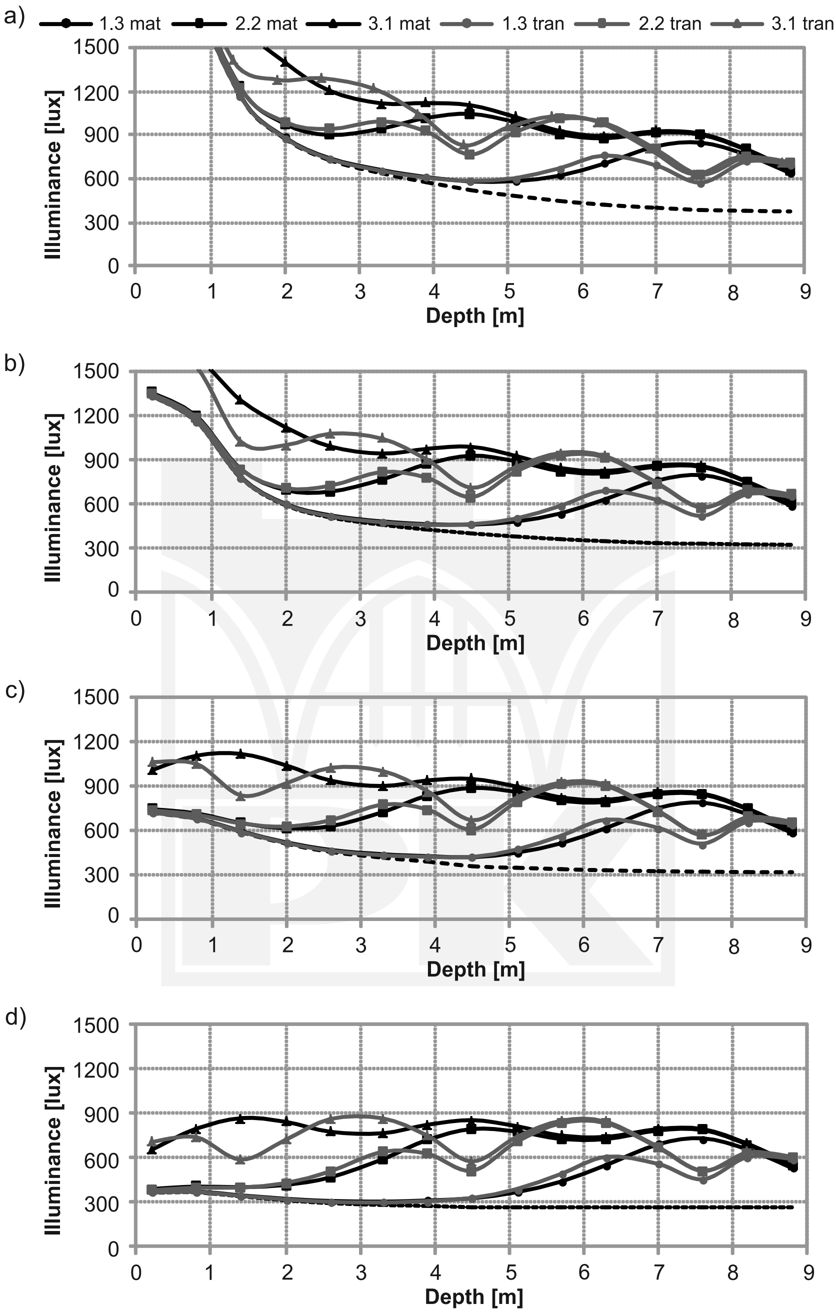

Fig. 4. Interior illuminance for light system combined from the 0.85 m diameter light pipes and window of: a) 20% glazing surface of the facade, b) 10% glazing surface of the facade, c) 20% visible transmittance, d) 10% visible transmittance

Figure 4 presents results due to the application of bigger light pipes with a diameter of 0.85 m. All combined systems with a 20% glazing surface provide minimum illuminance in the whole room. In other cases, the use of two or three light pipes is required to ensure 500 lux.

6. Conclusions

In the paper, analyses of the interior illuminance for individual and combined systems of window and light pipes in the longitudinal room were performed. Windows with high visible transmittance or a large surface area ensure sufficient illumnance distribution in the whole room. Additional lighting from the light pipes is reasonable only for windows with a low visible transmittance (< 30%) or small surface (< 30%). Light passing through these kinds of windows does not provide required illuminance distribution in the opposite side of the room. Consequently, application of light pipes as a source of additional illuminance in the deep parts of the room can solve the problem. Furthermore, high levels of illuminance from light pipes with matt and transparent diffuser are comparable for overcast sky distribution. However, the matt diffuser causes more uniform light distribution. Therefore, it is recommended to use light pipes with a matt diffuser to ensure high visual comfort. Additionally, on preliminary examination, light pipes with a diameter of less than 0.35 m result in low additional light and application of them in combined systems with windows is inefficient.

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