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THE CALCULATION METHOD FOR LIGHT CLIMATE PARAMETERS BASED ON SUN-LIGHTING EFFICIENCY AND THE COMPARATIVE ANALYSIS OF LIGHT CLIMATE IN HANOI AND MOSCOW

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ABSTRACT

The main source of daylight is the Sun. The Earth's atmosphere scatters its light due to the air, water vapour, ice particles (at high altitudes), dust, various gases, and other contaminants that appear in the air as a result of human activities. This forms a daylight diffuse (scattered) component, which is a data basis for calculation of daylight in buildings. This basis has its own features for a given region.

This article shows a calculation of sun-lighting efficiency in Vietnam. We obtained a variation of horizontal daylight illuminance in Hanoi (21.03°N). Comparing it with the variation of horizontal daylight illuminance in Moscow (55.70°N), we can see a high level and a distribution uniformity of outdoor illuminance in Vietnam. The maximum levels of diffuse illuminance and total illuminance in Hanoi are 45.2 and 58.52 klx; the maximum levels of diffuse illuminance and total illuminance in Moscow are 28.3 and 53.1 klx. Besides, illuminance levels in winter months are much higher for Hanoi than for Moscow. This can be explained by different latitudes of these cities and by the Sun motion.

Keywords: local light climate, tropical climate, diffuse horizontal illuminance, total horizontal illuminance, sun-lighting efficiency, cloud cover statistics

1. INTRODUCTION

Horizontal illuminance is an important factor of light climate resources in each region. At the present day, Vietnam offers no complete standards of computational methods for design of daylight in buildings. This paper contributes to the development of such standards and energy-efficient daylighting systems. This work also allows us to extend the available data on day-time changes in illuminance levels for all months in those Russian cities that are not included in the Daylighting Set of Rules and other reference materials.

The daylight factor *D* is used for rate setting of daylight/combined lighting indoors and for design of buildings and constructions. *D* is the ratio of daylight illuminance that is created by skylight, direct or reflected, at some point of a given plane indoors to a simultaneous value of outside horizontal illuminance that is created by light of a fully open firmament. We should mention that the notion *D* makes sense only under an overcast sky with a luminance distribution specified by the International Commission on Illumination (CIE). In this case, *D* does not depend on an orientation of the window with regard to the Sun, and this is a constant value for a given point of the room.

The overcast sky is not common for the tropics. Total sunlight and direct sunlight strongly affect the choice of a daylighting system indoors. Depending on the architectural solution of the enclosing structures using solar protection devices, direct sunlight gives more or less reflected light indoors. To assess the energy efficiency of daylighting systems for buildings in the tropics, the research of the light climate is required with regard to data on total horizontal illuminance and diffuse horizontal illuminance.

We do not have any data from field measurements of daylight illuminance in Vietnam at this time. The data on the light climate are calculated as per lighting efficiency of solar radiation with solar radiation satellite data. Lighting efficiency of solar radiation strongly depends on the current altitude of the Sun. Specifically, direct solar illuminance and lighting efficiency of direct solar radiation depend on the altitude of the Sun. The total (global) illuminance and the diffuse illuminance do not directly depend on the altitude of the Sun. The lighting efficiency of solar radiation is higher with diffuse lighting than with total lighting [1, 2].

Articles [3, 4] present 3 methods for calculation of lighting efficiency of solar radiation (including direct lighting efficiency, total lighting efficiency, and diffuse lighting efficiency of solar radiation) based on the corresponding mathematical models. To define lighting efficiency of solar radiation, we have chosen a model that was developed in Vietnam as part of this study [5]. This model was used to calculate daily variations in diffuse illuminance and total illuminance.

2. RESEARCH AND CALCULATION METHODS

ASHRAE IWEC2[1] weather data were selected to calculate the lighting efficiency of diffusive solar radiation (K_D) and the lighting efficiency of total solar radiation (K_Q) (lm/W). The software fills or reduces the data to hourly time steps and calculates the lighting efficiency level when converting the raw Integrated Surface Hourly Database to the local time. The data on the light climate of Hanoi accumulated for 12 years, from 2005 to the end of 2017, are typical. Meanwhile, the choice of typical months is based not only on average distributions but also on statistical distributions of different climatic parameters over months as per the records of long-term observations. The typical months selection method that is widely used to create first files of a typical meteorological year (*TMY*) was developed by the *NREL*[2] in the early 1980s (*NCDC*[3], 1981). The Finkelstein-Schafer (*FS*) statistics technique is used to select a *TMY*. Its main indicator is the *FS* value (statistics), which is determined by a total difference between a distribution of the candidate month and a long-term distribution in the same calendar months for the recording period. The *FS* statistics is evaluated with different climate parameters, which are later assigned with weighting coefficients and then summed. The month with the lowest *FS* value is considered the most representative typical month [6].

Wherein:

- The solar position is calculated by the formulas:

$$h_o = \arcsin\left\{\begin{matrix} \sin\delta\cdot\sin\varphi+\cos\delta\cdot\cos\varphi\times \\ \times\ \cos[15^0\cdot(12-T)] \end{matrix}\right\}, \text{deg},$$

$$\delta = 23.45\cdot\sin[\frac{360}{365}(d-81)] \text{ or}$$

$$\delta = 23.45\cdot\sin[\frac{360}{365}(284+d)], \text{deg},$$

where: d is sequential number of day of year, counting from January 1; h_o is Sun altitude, deg; δ is solar declination on any day of year, deg; T is time, h (e.g. 16h 15m = 16.25h); φ is latitude (south latitude with minus sign), deg;

- K_D and K_Q are calculated as follows:

$K_D = 0.1\cdot h_o + 67$, klx/(cal·cm^{-2}·min^{-1}),

$K_Q = 0.1\cdot h_o + 62$, klx/(cal·cm^{-2}·min^{-1});

- Diffuse illuminance and total illuminance are obtained by multiplying diffuse solar radiation data (cal·cm^{-2}·min^{-1}) by K_D and by multiplying total solar radiation data (cal·cm^{-2}·min^{-1}) by K_Q;
- K_D and K_Q are 70 and 65 klx/(cal·cm^{-2}·min^{-1}) or 101 and 93 lm/W in Hanoi according to this model.

3. RESULT ARGUMENTATION

It is obvious from the variation calculation results of diffuse daily illuminance and total daily illuminance in Hanoi and Moscow (compared by *the light climate* [7]) (Figs. 1, 2) that:

[1] *ASHRAE IWEC2* temporary files were developed for the American Society of Heating, Refrigerating and Air-Conditioning Engineers (*ASHRAE*) by *White Box Technologies, Inc.* These files are based on the integrated surface hourly database for 3,012 locations outside the US and Canada with ≥ 12-year (and ≤ 25-year) records. URL: http://weather.whiteboxtechnologies.com/IWEC2.

[2] *National Renewable Energy Laboratory*

[3] *National Climatic Data Centre*

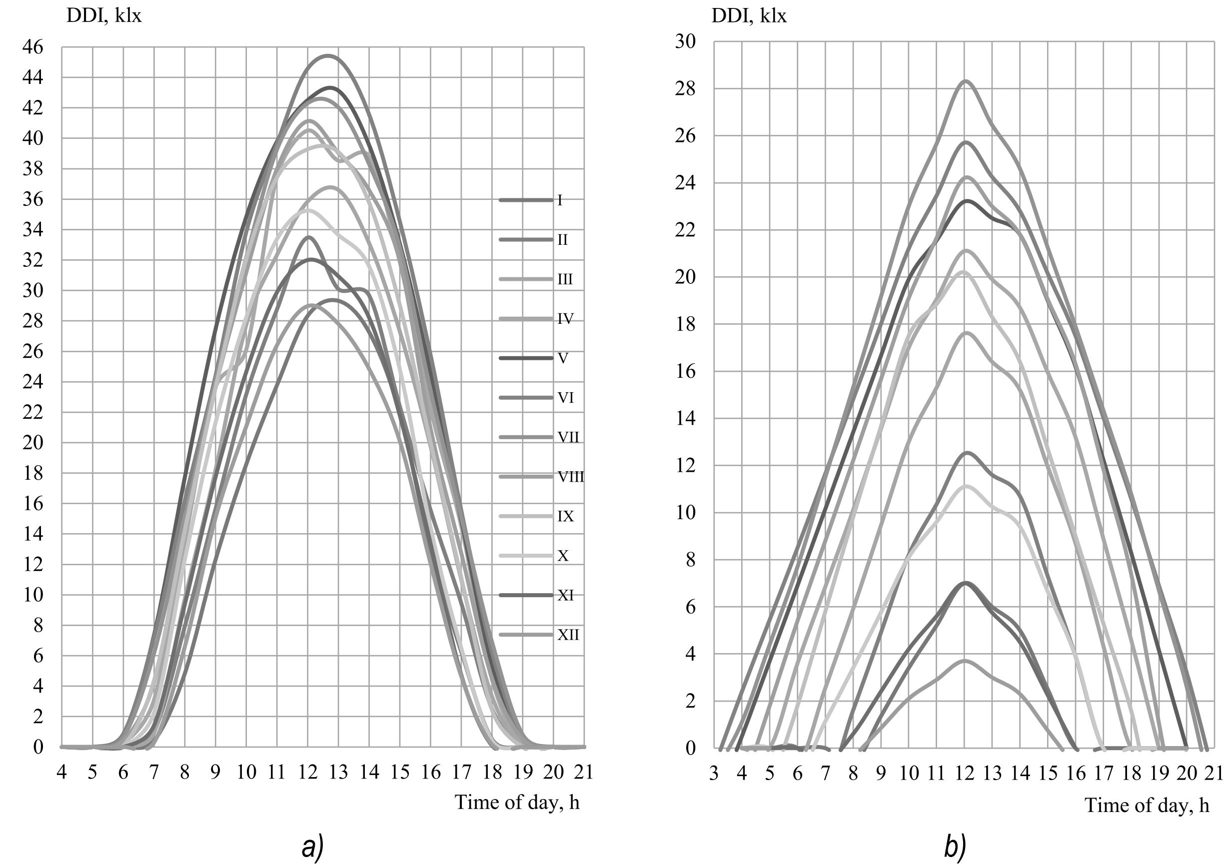

Fig. 1. Diagrams of variation in diffuse daylight illuminance (DDI) in Hanoi 21.3°N (*a*) and Moscow 55.7°N (*b*)

- Outer diffuse illuminance in Hanoi slightly varies between summer and winter months. The maximum diffuse illuminance level is 29 klx in winter periods (December) and 45 klx in summer periods (June). The high level of daylight horizontal illuminance in Hanoi is equally distributed within almost every month. Sunrise time is 05:15 (for June) and 06:35 (January). Sunset time is 18:39 (June) and 17:08 (December).
- The diagrams of diffuse daily illuminance variation in Moscow show a large difference in illuminance levels for winter and summer and a small duration of daylight for winter (from 08:23 to 15:27 for December) with the maximum level of diffuse illuminance of 3.7 klx. The longest duration of daylight for summer is 17h 30m (from 3:15 to 2:04 for June) with the maximum level of diffuse light of 28.3 klx.

The definition of daylight resources is very important for a design strategy of buildings in order to improve the energy efficiency of daylighting systems. The high level of daylight in Hanoi, with its equal distribution over months, allows daylight to use in this city all year round. The tropical climate, with large solar radiation, puts a large thermal load on building enclosures [8]. Therefore, daylighting systems featuring solar protection shall be widely used to reduce room heating during the summer period. Besides, solar protection devices weaken daylight illuminance in rooms by reducing direct lighting from the sky.

However, solar protection devices play a role of reflective panels at some point, which increase the level of reflected light indoors (with direct sunlight on these reflective panels). The research [9] carried out by the Moscow State University of Civil Engineering obtained *D* field results in a particular room of a building after installation of visor solar protection devices that show that the average *D* in a room with side light openings is 3.87 % under a clear sky with a total cloud cover of up to 2 points, which is higher than the average *D* under a cloudy sky that is 2.89 %. This means that solar-protected daylighting systems are more efficient in direct sunlight for tropical latitudes. To assess the energy efficiency of such systems, it is necessary to conduct a research of direct facade solar illuminance at different orientations and an impact

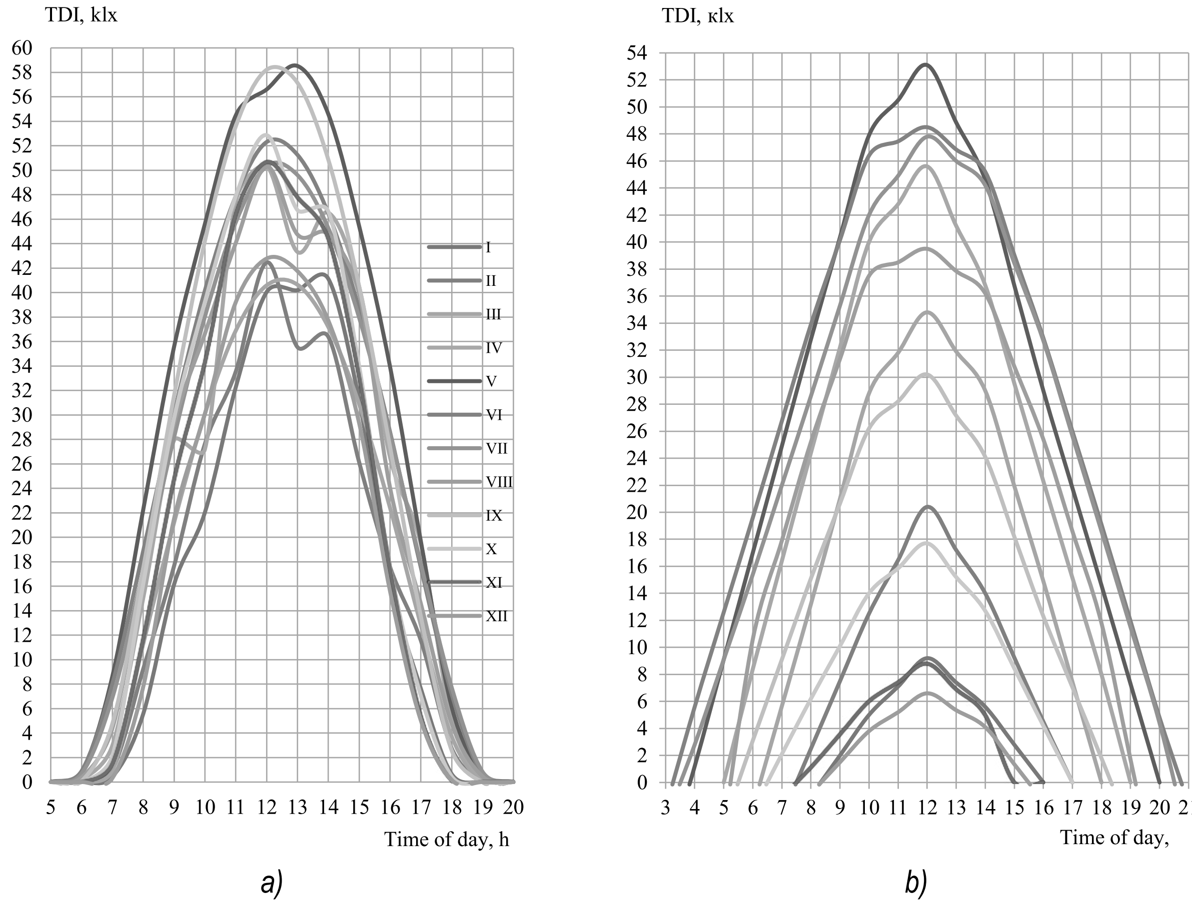

Fig. 2. Diagrams of variation in total daylight illuminance (TDI) in Hanoi 21.3°N (*a*) and Moscow 55.7°N (*b*)

analysis of various solar protection devices in daylighting systems of buildings.

Figs. 1, 2 show that consideration of total daylight for rooms featuring solar protection devices and other devices that exclude direct solar radiation could significantly improve the energy efficiency of daylighting systems in buildings without affecting the internal environment comfort of buildings not only in Hanoi, but also in Moscow.

CONCLUSION

The research of recent-years weather data and the analysis allow us to assess the light climate of the area and to obtain the materials for further studies of daylight in construction. The light climate resource data were obtained during the analysis of the survey results of daylight illuminance in Hanoi and Moscow. They show the illuminance distribution uniformity in Hanoi by months and the distribution nonuniformity in Moscow. At the same time, consideration of the total daylight illuminance with solar protection devices allows to reasonably assess the energy efficiency of daylighting systems even in the light climate of Moscow, which is actually much higher than the calculated efficiency with the assumption of a cloudy sky, according to the CIE. This allows us to consider the daylight in buildings to be a promising direction for improving the energy efficiency of buildings, especially in the tropical conditions of Vietnam, where various solar protection devices should be widely used. This allows not only to reduce the energy consumption associated with lighting, but to significantly reduce the thermal load indoors and the energy consumption associated with air conditioning.

The introduced technique allows us to calculate variation diagrams of diffuse illuminance and total illuminance in all cities of Vietnam and Russia, to clarify lighting and climatic factors, and to accept the regional daylighting standards at the modern level. Special field measurements of daylight horizontal illuminance will be carried out to determine the uncertainty of the calculation results.

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