doi: 10.18720/MCE.84.18

Luminance distributions in the tropical sky conditions

Распределение яркости в условиях тропического неба

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Key words: daylight climate; firmament types; sky luminance distributions; cloudiness coefficient; daylighting calculations

Ключевые слова: световой климат; типа небосвода; распределение яркости неба; коэффициент облачности; расчет естественного освещения

Abstract. Lighting engineering in construction is a complex scientific field, which requires the amalgamation of knowledge in the field of daylighting, construction and architecture, as well as other areas, including the humanities. Many studies have proven the benefits of natural light on health, activity, visual well-being and human productivity. Global environmental issues and the sustainable development movement require architectural design to achieve maximum energy efficiency. For all intents, daylighting calculations depend on the luminance distributions of the sky types. Currently, standard documents are used for the luminance distribution and daylighting calculations under overcast sky conditions in Vietnam, where the overcast sky and clear sky are not typically considered. For these reasons, an update of theoretical studies in the daylighting calculations and design the daylighting systems must be completed. Accordingly, this study offers the modern methods of analyzing the firmament luminance distributions when calculating Daylight Factor on the more realistic sky conditions. For this, the sky type have to be defined according to the location. Fifteen international standard types of the firmament with their descriptors are provided by Kittler et al. and a technique using a relation of diffuse and total solar illuminance levels named the cloudiness coefficient K_o are considered to define the sky condition in Hanoi and Ho Chi Minh City. As the results, the typical sky type for Hanoi is the partly cloudy sky no gradation towards zenith, slight brightening towards the Sun; when the sky type for Ho Chi Minh City is the partly cloudy, with brighter circumsolar region. From these results, the sky luminance distributions for daylighting calculations were proposed. A comparison shows the difference between these calculations can be allowed at the altitude angles γ of a point in the sky above 50° with the relative errors below 10 %. The method offered and verified in this study showed that, it has potential to be used for difference climate areas.

Аннотация. Светотехника в строительстве представляет собой сложную научную область, которая требует обобщения знаний в области естественного освещения, строительства и архитектуры, а также других областей, в том числе гуманитарных. Многие исследования доказали преимущества естественного освещения здоровья, активности, визуального благополучия и производительности человека. Глобальные экологические проблемы и движение за устойчивое развитие требуют архитектурного проектирования для достижения максимальной эффективности использования энергии. По этим причинам обновление теоретических исследований в расчетах естественного освещения и проектирования систем естественного освещения должно быть завершено. В настоящее время стандартные документы используются для расчетов естественного освещения в зависимости распределения яркости неба в условиях пасмурного неба во Вьетнаме, где особенность неба является не типично ясным и не типично пасмурным. Соответственно, это исследование предлагает современные методы анализа распределения яркости небосвода при расчете коэффициента естественного освещения на реальном небе местности. Для этого тип неба местности должен определяться. Пятнадцать международных стандартных типов небосвода с их дескрипторами, которые предоставляются Киттлером и др. и метод расчета по коэффициентам облачности K_o используются при определении реального неба в Ханое и Хошимин. Результаты показывают типичный тип неба для Ханоя - это облачное небо без градации к зениту, слабое осветление к Солнцу, когда тип неба для Хошимина является облачным, с более яркой окружной областью. Из этих результатов, значения распределения яркости неба предложены. Приведение сравнения показывает, что разница между этими методами расчета может быть разрешена при углах высоты расчетной точки в небе выше 50° с относительными погрешностями ниже 10 %. Метод

Фыонг Н.Т.Х. Распределение яркости в условиях тропического неба // Инженерно-строительный журнал. 2018. № 8(84). С. 192–204.

предложенный и подтвержденный в этом исследовании может использоваться для разных климатических зон.

1. Introduction

1.1 State of the art approach

Daylight is the sustainable source of lighting for buildings. Research has proven that it could provide energy saving, good color rendering, high work productivity, good visual comfort as well as human physiological and psychological needs. That natural light has always played a dominant role in human life [1–7]. To correctly calculate daylighting and accomplish energy simulations it is necessary to study daylight conditions during the whole year. There are several methods for defining daylight conditions in different climates and locations. The illuminance availability approach provides a direct view on illuminance changes, their leves and difference, because illuminance is calculated by the intergration of luminance in the window solid angle, it is important to define luminance distribution on the sky under different situations [5, 8]. In most simulation programs, the models of the CIE overcast and CIE clear sky are applied. By now, in some simulation programs such as RADIANCE, Design-Builder…, intermediate skies are considered.

The luminance distributions of the sky is represented as a superposition of four standard CIE skies using the approach described in (Perez et al. 1990) [9]:

The general characteristics of the clear-sky luminance distributions are a large peak near the Sun: a minimum at a point on the other side of the zenith from the Sun, in the vertical plane containing the Sun, and an increase in luminance as the horizon is approached.

The Clear Skies luminance distributions has the form (Kittler, 1965, CIE, 1973) [10]

$$\beta_{cs}=\frac{L_{(\alpha,\gamma)}}{L_z}=\frac{(1-e^{\frac{-0.32}{\sin\gamma}})(0.91+10.e^{-3X}+0.45.\cos^2 X)}{0.274.(0.91+10.e^{-3Z_s}+0.45.\cos^2 Z_s)} \quad (1)$$

$$X=\arccos(\cos Z_s.\cos Z+\sin Z_s.\sin Z.\cos A_z) \quad (2)$$

Description of the Clear Turbid Skies luminance distributions (Matsuura, 1987) [11] by the expression:

$$\beta_{ts}=\frac{L_{(\alpha,\gamma)}}{L_z}=\frac{(1-e^{\frac{-0.32}{\sin\gamma}})(0.856+16.e^{-3X}+0.3.\cos^2 X)}{0.274.(0.856+10.e^{-3Z_s}+0.3.\cos^2 Z_s)} \quad (3)$$

For the Intermediate Skies, formula describes the luminance distributions is [10]:

$$\beta_{is}=\frac{L_{(\alpha,\gamma)}}{L_z}=\frac{Z_1Z_2}{Z_3Z_4} \quad (4)$$

where:

$$Z_1=\frac{\left[1.35(\sin 3.59\gamma-0.009)+2.31)\sin(2.6\gamma_s+0.316)+\gamma+4.799\right]}{2.326} \quad (5)$$

$$Z_2=\exp\left[-0.563\gamma(\gamma_s-0.008)(\gamma+1.059)+0.812\right] \quad (6)$$

$$Z_3=0.99224.\sin(2.6\gamma_s+0.316)+2.73852 \quad (7)$$

$$Z_4=\exp\left[-0.563(\frac{\pi}{2}-\gamma_s)(2.6298(\gamma_s-0.008)+0.812)\right] \quad (8)$$

The Overcast Sky luminance distribution has the form (Moon & Spencer, 1942) [12]:

$$\beta_{os}=\frac{L_\gamma}{L_z}=\frac{1+2\sin\gamma}{3} \quad (9)$$

Unlike the clear sky case, the overcast sky distribution does not depend on the solar azimuth or the sky azimuth. Note that at fixed solar altitude the zenith ($\gamma=\pi/2$) is three times brighter than the horizon ($\gamma=0$).

where β_{cs} : Clear sky luminance distributions (cd.m^{-2}).

β_{ts} : Clear turbid sky luminance distributions (cd.m^{-2}).

β_{is} : Intermediate sky luminance distributions (cd.m^{-2}).

β_{os} : Overcast sky luminance distributions (cd.m^{-2}).

α, γ : Azimuth and altitude angles of a point in the sky (radians).

L_z: Sky zenith luminance (cd.m^{-2}).

γ_S: Altitude angle of the Sun (radians).

L_z: The zenith luminance (cd.m^{-2}).

Z: The angular distance between a sky element and the zenith, Z = 90^0 - γ.

$L_{\gamma\alpha}$: Luminance in any arbitrary sky element (cd.m^{-2}).

X: The angular distance of the sky element from the Sun, defined by equation (2) (radians).

Z_s: The zenith distance of the Sun (radians).

A_z: The azimuth difference between the element and the solar meridian (radians) with $A_z = |\alpha - \alpha_s|$.

α and α_s are azimuthal angel of the vertical plane of the sky element and Sun position respectively (radians).

The definition sky type based on the concepts justifies the task to develop the new set of sky standards of Kittler et al., [13], which uses the ratio of diffuse sky illuminance to extraterrestrial horizontal illuminance D_v/E_v and the luminous turbidity factor T_v as the descriptors of sky types. A comparison with method assessment the luminance distribution for a particular location based on the cloudiness calculation proposed by A.K. Solovyov was conducted.

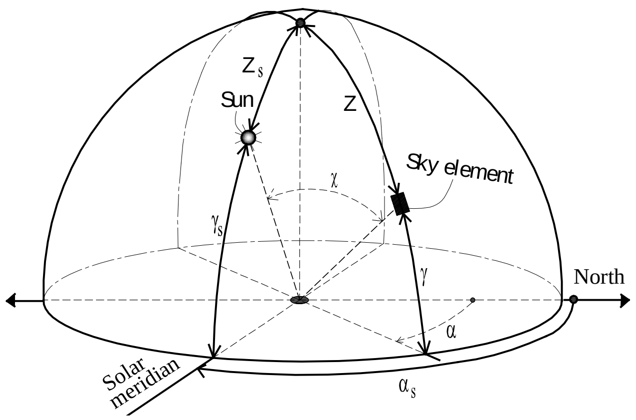

Figure 1. Angles defining the position of the Sun and sky element [4].

1.2. Aim and objectives

The aim of this research is to estimate the luminance distributions in real sky condition tropical Vietnam. Accordingly, this research is based on two main objectives:

– Define the sky types with two methods calculation: the first one using parameters of diffuse horizontal illuminance D_v to extraterrestrial horizontal illuminance E_v and the luminous turbidity factor T_v as descriptors of the sky types; the second one using the cloudiness coefficient K_0 to define real sky condition by statistic of cloudiness.

– Obtain the value illuminance distributions β from the real sky condition.

2. Methods

2.1. The research process flow

Figure 2 shows the flowchart of the research process, which was developed to determine the values of luminance distributions under a tropical climate in Vietnam with the representatives of Hanoi and Ho Chi Minh City.

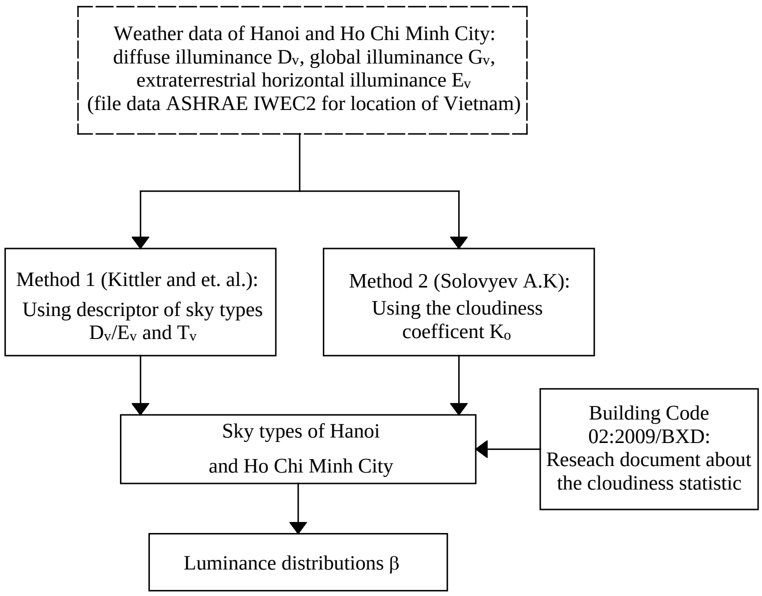

Figure 2. The research process.

2.2. A set of standard skies characterizing daylight conditions by Kittler et al.

To make a measurement ruler of relative luminance distributions in different sky types, a set of standard skies characterizing daylight conditions identified with three main purpose-conscious concepts [13]:

– The discrepancies and absence of standards to characterize unsteady-state daylight climates.

– The need of linking the whole spectrum of skies between the already standardized CIE Overcast and CIE Clear Skies covering the real conditions.

– The trend to evaluate and accept also cloudy and partly cloudy sky models which were seldom specified due to the complete absence of parameterization and measured sky luminance distributions.

Considering these concepts, fifteen sky types of relative luminance distributions by Kittler et al (1998) based on scan measured luminance data at Tokyo, Berkeley and Sydney were proposed at the same time. Five overcast, five clear and five transitional skies are modelled by the combination of graduation and indicatrix functions and the solution is proposed as a CIE code draft CIE (2001) [13, 14]. This determination of daylighting conditions is more detail and covers the whole occurrence spectrum considering different diffuse scattering by the atmosphere and effects of direct Sunlight [13, 15].

To identify the sky type at least two of the descriptors have to obtain: the relative of diffuse horizontal illuminance Dv to extraterrestrial horizontal illuminance E_v and the luminous turbidity factor T_v which approximates the number of ideally clean atmospheres representing an actual case [4, 16,17].

$$T_v = \frac{-\ln(\frac{P_v}{E_v})}{av.m} \tag{10}$$

$$\frac{P_v}{E_v} = \frac{G_v}{E_v} - \frac{D_v}{E_v} \tag{11}$$

$$E_v = 133.8 \sin \gamma_s \text{, lux} \tag{12}$$

$$m = \frac{1}{\sin\gamma_s + 0.50572(\gamma_s + 6.07995^0)^{-1.6364}} \quad (13)$$

$$A_v = \frac{1}{9.9 + 0.043.m} \quad (14)$$

where: T_v is the luminous turbidity factor.

P_v is direct solar horizontal exterior illuminance (Klux).

E_v is extraterrestrial horizontal illuminance (Klux).

D_v is diffuse sky illuminance (Klux).

G_v is global illuminance (Klux).

m is the air mass penetrated and A_v its ideal luminous extinction, dependent on solar altitude γ_s (degree) [18].

Calculation of the relative luminance distributions after the CIE general sky concept was provided with a functional formula. The position of the Sun and of the arbitrary sky element as well as parameters a, b, c, d and e which describe atmospheric conditions have to be taken as input calculation quantities.

$$\beta = \frac{L_{\gamma\alpha}}{L_z} = \frac{f(X)\phi(Z)}{f(Z_s)\phi(0^0)} \quad (15)$$

The luminance gradation function φ relates the luminance of a sky element to its zenith angle:

$$\phi(Z) = 1 + a.\exp(\frac{b}{\cos Z}) \quad (16)$$

$$\phi(0^0) = 1 + a.\exp b \quad (17)$$

$$f(X) = 1 + c\left[\exp(dX) - \exp(\frac{d\pi}{2})\right] + e.\cos^2 X \quad (18)$$

$$f(Z_s) = 1 + c\left[\exp(dZ_s) - \exp(\frac{d\pi}{2})\right] + e.\cos^2 Z_s \quad (19)$$

When $0 \le Z \le \pi/2$ and at the horizon is $\varphi(\pi/2) = 1$.

Standard parameters a, b, c, d and e can be estimated after the definition of the sky type from Table 1.

Table 1. Standard parameters with various sky types.

Type	Gradation	indicatrix	a	b	c	d	e	Description of luminance distributions
1	I	1	4.0	-0.7	0	-1.0	0.00	**CIE Standard Overcast Sky, alternative form** steep luminance gradation towards zenith, azimuthal uniformity
2	I	2	4.0	-0.7	2	-1.5	0.15	Overcast, with steep luminance gradation and slight brightening towards the Sun
3	II	1	1.1	-0.8	0	-1.0	0.00	Overcast, moderately graded with azimuthal uniformity
4	II	2	1.1	-0.8	2	-1.5	0.15	Overcast, moderately graded and slight brightening towards the Sun
5	III	1	0.0	-1.0	0	-1.0	0.00	**Sky of uniform luminance**
6	III	2	0.0	-1.0	2	-1.5	0.15	Partly cloudy sky, no gradation towards zenith, slight brightening towards the Sun
7	III	3	0.0	-1.0	5	-2.5	0.30	Partly cloudy sky, no gradation towards zenith, brighter circumsolar region
8	III	4	0.0	-1.0	10	-3.0	0.45	Partly cloudy sky, no gradation towards zenith, distinct solar corona
9	IV	2	-1.0	-0.55	2	-1.5	0.15	Partly cloudy, with the obscured Sun
10	IV	3	-1.0	-0.55	5	-2.5	0.30	Partly cloudy, with brighter circumsolar region
11	IV	4	-1.0	-0.55	10	-3.0	0.45	White-blue sky with distinct solar corona
12	V	4	-1.0	-0.32	10	-3.0	0.45	**CIE Standard Clear Sky, low illuminance turbidity**
13	V	5	-1.0	-0.32	16	-3.0	0.30	**CIE Standard Clear Sky, polluted atmosphere**
14	VI	5	-1.0	-0.15	16	-3.0	0.30	Cloudless turbid sky with broad solar corona
15	VI	6	-1.0	-0.15	24	-2.8	0.15	White-blue turbid sky with broad solar corona

Table 2. Typical value of descriptor linked with various sky types.

Sky type	Sky code	T_v	Ratio D_v/E_v
1	I.1	Over 45	0.10
2	I.2	Over 20	0.18
3	II.1	Over 45	0.15
4	II.2	Over 20	0.22
5	III.1	Over 45	0.20
6	III.2	Over 20	0.38
7	III.3	12.0	0.42
8	III.4	10.0	0.41
9	IV.2	12.0	0.40
10	IV.3	10.0	0.36
11	IV.4	4.0	0.23
12	V.4	2.5	0.10
13	V.5	4.5	0.28
14	VI.5	5.0	0.28
15	VI.6	4.0	0.30

In Table 1 gave fifteen standard relative luminance distributions which are based on six groups of a and b values for the gradation function and six groups of c, d and e values for the indicatrix function. The resulting curves are illustrated in Figures 3 and 4 [4].

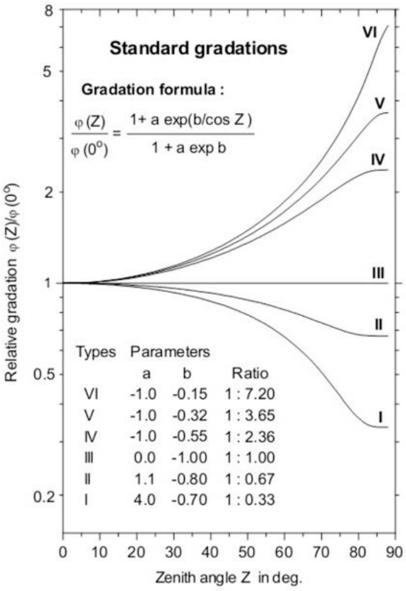

Figure 3. Standard gradations.

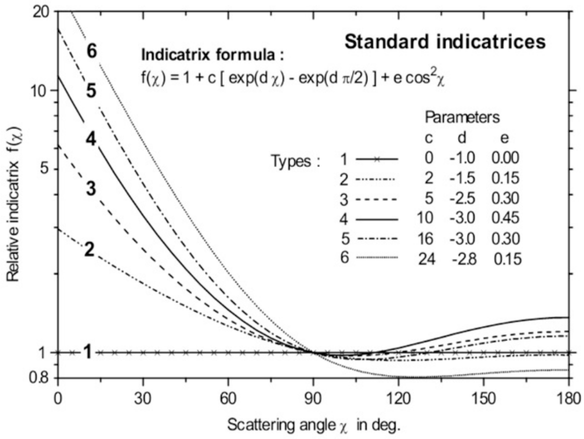

Figure 4. Standard indicatrices.

According to formulas from (10) to (19) after the sky type of the location has been defined, using standard parameters a, b, c, d and e for target sky types, the values luminance distributions of the real sky are obtained.

2.3. Assessment the light climate for a particular location based on the cloudiness calculation K_0

This is based on calculation the relative sky luminance distributions gap between two extreme CIE standard skies by using the cloudiness calculation and proposed by A.K. Solovyov. The method of determining the estimated positions of the Sun in the sky is described in document [19, 20]. In short:

The values of the elementary illumination of the sky sectors with angular dimensions in latitude 15^0 and on the meridian 70^0 (from 10^0 to 80^0) were calculated. These values are the sum of the elementary illuminance by the sectors of the sky. In regions with the clear sky, luminance distributions depends on the Sun's position relative to the light opening. A position of the Sun is taken into account, where for a given orientation of the light opening, the value of Daylight Factor will be minimal, and the value of outdoor illumination will approach the critical E_{cr}. Then we have:

The condition of minimal Daylight Factor: From the articles [19, 20], the results show that the value of the angular distance of the sky element from the Sun X equals 105^0 and 225^0 are the most unfavorable orientation area of a light opening in relation to the solar meridian. In the calculations to definition sky luminance distributions, the position of the Sun has to be fixed as stated above as these formulas (1) and (2) can be suitable for practical calculations if X and Z_s values are used. It should be noted that in case of sky types 1, 3 and 5 (Table 1), when luminance azimuth uniformity takes place, sky luminance does not depend on the orientation of the light opening and in these cases, therefore, the Daylight Factor does not depend on the Sun's position.

The condition of critical illuminance E_{cr}: Method calculation for room natural illumination in the clear sky condition with proposing the adverse Sun's latitude at a given light opening orientation and external illuminance tends to critical (E_{cr}). The E_{cr} values were selected according to the follow expression for determining the Sun's latitude:

$$E_{cr} = 100\frac{E_{art}^{norm}}{e^{norm}} \quad (20)$$

Where E_{art}^{norm} is normalized artificial illuminance and e^{norm} is normalized Daylight Factor values.

In the study [21], the analysis daylight assessment for Vietnam was taken with the represent of diffusue horizontal illuminances for Hanoi. It shows relative of Daylight Factor e (%), critical external illuminance E_{cr} (lux) and normalized artificial illuminance E_{art}^{norm} (target illuminance, lux) based on the analysis period of time from the working time using daylighting in a space (Table 3). For instance, Mardaljevic J. et al. [22] were evaluated some most probable daily activity hours e.g. 7:00 – 20:00, 8:00 – 17:00, 8:00 – 19:00 or 9:00 – 16:00. For Vietnam this period from 08h00 to 17h00 is represented as 100 % working time.

Table 3. Recommended average DF and E_{cr} for Vietnam

E_{art}^{norm} (lux)	50% of the analysis period		80% of the analysis period		100% of the analysis period	
	e (%)	E_{cr} (lux)	e (%)	E_{cr} (lux)	e (%)	E_{cr} (lux)
500	1.5	33333	2.25	22222	3.5	14286
400	1.2	33333	1.8	22222	2.8	14286
300	0.9	33333	1.35	22222	2.1	14286
200	0.6	33333	0.9	22222	1.4	14286
100	-	-	< 0.5	-	0.7	14286

Thus minimum critical external illuminance amounted approximately to 15000 lux, from which covers practically all E_{cr} value interval of the analysis period. From numerous studies, which carried out in the field study of outdoor illumination, the most reliable are measurements of Khrochitsky, Zeker and Littlefair, as well as P. Tregenza [20, 23], that confirm each other. As a result P. Tregenza suggests the following empirical formulas for horizontal diffuse illumination:

$$E_D = 10.5(\gamma_s + 5)^{2.5}, \text{ (with } -5^0 < \gamma_s \le 5^0) \quad (21)$$

$$E_D = 48800.\sin^{1.105}\gamma_s, \text{ (with } 5^0 < \gamma_s \le 60^0) \quad (22)$$

Using expressions (21) and (22) the angular heights of the Sun are obtained for various values of the critical illuminance.

Table 4. Calculation height distance of the Sun γs depend on critical illuminance E_{cr}.

E_{cr} (lux)	γ_s (grad.)	E_{cr} (lux)	γ_s (grad.)
15 000	20.1	25 000	33
17 500	23.3	27 500	36.5
20 000	26.5	30 000	40.1
22 500	29.8	32 500	44.4

If we assume that statistically, cloudiness ranges from overcast to clear sky conditions, a simple technique, which was proposed by G Gillette and S. Trido to account for local cloudiness can be used. The ratio of the diffuse to the global horizontal irradiances as well as the ratio of the diffuse to global illuminances, which named the cloudiness coefficient $K_0 = E_D/E_Q$ provides a better information on cloudiness. This coefficient decreases from 1.0 under completely overcast skies to values around 0.2 under cloudless skies [19, 20, 24, 25]. Hence, the luminance of any point of the sky determined can be presented at a time as the weighted average of its two extreme value:

$$L(z,\alpha) = \xi.L(z,\alpha)_{clear} + (1-\xi).L(z)_{overcast} \tag{23}$$

Where: $L(z,\alpha)_{clear}$ is luminance of clear sky by R. Kittler's formula; $L(z)_{overcast}$ is luminance of overcast sky by Moon and Spencer's law; ξ is a phase function corresponding to the normal distribution law confirmed in work [25].

$$\xi = \frac{1+\cos(K_0.\pi)}{2} \tag{24}$$

3. Results and Discussion

The weather data of diffuse horizontal illuminances, global horizontal illuminances and extraterrestrial horizontal illuminances are collected for Hanoi, Ho Chi Minh City cities from file ASHRAE IWEC2 – "White Box Technologies, weather data for energy calculations". This file was developed for ASHRAE by White Box Technologies, Inc. and based on the integrated hourly basis over the ISD surface for 3012 locations outside the US and Canada that have a minimum of 12 years of recording up to 25 years [26].

3.1. Define sky type with relative D_v/E_v and the luminous turbidity factor T_v based on a set of standard skies proposed by Kittler et al.

To obtain the relative of D_v/E_v, the data of diffuse horizontal illuminance and extraterrestrial horizontal illuminance were used in formulas (10) – (14). The result of calculations shown on Table 5.

Table 5. Descriptor D_v/E_v of Sky types.

Month	January	Febuary	March	April	May	June	July	August	September	October	November	December	Annual average
T_v	17.8	17.3	13.4	22.6	30.2	23.5	26.1	17.1	18.6	6.5	6.5	12.5	**17.7**
D_v/E_v	0.36	0.31	0.38	0.35	0.37	0.37	0.35	0.36	0.36	0.33	0.33	0.34	**0.35**
Sky type of Hanoi	VI	VI	VI	VI	VI	VI	VI	VI	VI	X	X	IX	**VI**
Sky type of Ho Chi Minh City	XIV	X	XIV	XIV	IX	X	X	X	X	X	X	X	**X**

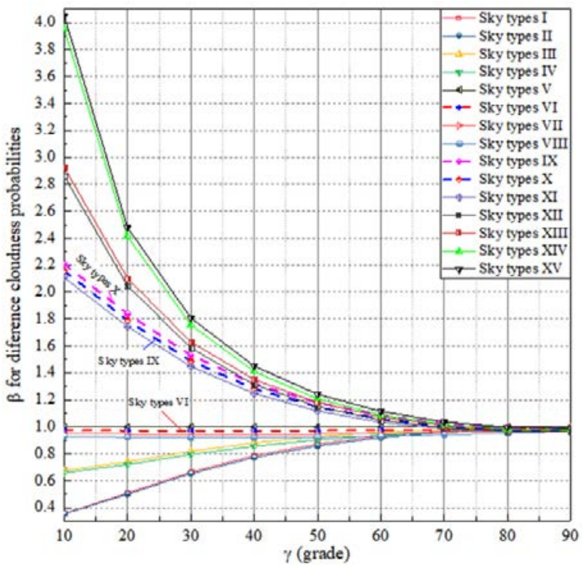

Figure 5. Distribution of relative luminance β in depending on sky types (sky type VI for Hanoi and X for Ho Chi Minh City).

In Hanoi, the sky types from October to December are partly cloudy with the obscured Sun and partly cloudy with the brighter circumsolar region, which describes sky types 9 and 10. From January to September, the typical sky type identifies partly cloudy sky, no gradation towards zenith, slight brightening towards the Sun with sky type 6. When the sky type 10 – partly cloudy, with brighter circumsolar region was represented for Ho Chi Minh City.

Figure 5 shows the graphic of relative luminance distributions β in depending on sky types, which was computed from the formulas from (15) to (19). For the calculations, standard parameters of sky types were used. The position of angular distance of the sky element from the Sun X estimated equals 105^0 (or 225^0) is the most unfavorable orientation area. The angular distances between a sky element and the zenith, $Z = 90^0 - \gamma$ were determined when γ changes from 10^0 to 90^0.

3.2. Define sky type based on the cloudiness coefficient K_0

To estimate sky types for these cities with the cloudiness coefficient K_0, the values of diffuse and global illuminances were obtained. The results have shown the values of K_0 average are 0.81 for Hanoi and 0.57 for Ho Chi Minh City (Table 6A and 6B).

Table 6A. Calculation cloudiness coefficient K_0 for Hanoi (21.03^0 N).

Hours / Month	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	Average K_0
1	-	1.09	0.90	0.79	0.93	0.40	0.72	0.73	0.65	0.69	0.86	0.84	0.72	-	0.78
2	-	0.91	0.80	0.90	0.88	0.49	0.79	0.87	0.83	0.89	0.92	0.84	0.94	-	0.84
3	-	1.02	0.98	0.93	0.93	0.56	0.89	0.90	0.90	0.89	0.93	0.95	0.96	-	0.90
4	1.08	1.27	0.97	0.87	1.02	0.52	0.79	0.88	0.82	0.78	0.86	0.72	0.89	0.80	0.88
5	0.78	0.91	0.78	0.74	0.74	0.50	0.73	0.70	0.70	0.71	0.72	0.77	0.92	0.93	0.76
6	0.91	0.92	0.89	0.82	0.81	0.53	0.82	0.84	0.86	0.87	0.89	0.94	0.92	0.87	0.85
7	0.92	0.96	0.92	0.88	0.82	0.56	0.81	0.82	0.83	0.85	0.81	0.87	0.90	0.95	0.85
8	1.15	1.05	0.89	0.83	0.85	0.57	0.79	0.85	0.80	0.78	0.91	0.96	1.02	1.15	0.90
9	0.85	0.95	0.80	0.74	0.71	0.44	0.64	0.64	0.67	0.69	0.71	0.83	0.96	-	0.74
10	-	1.26	0.77	0.71	0.69	0.45	0.64	0.69	0.65	0.71	0.84	0.91	0.95	-	0.77
11	-	0.95	0.81	0.72	0.71	0.39	0.60	0.62	0.60	0.63	0.75	0.88	0.83	-	0.71
12	-	0.82	0.86	0.68	0.71	0.38	0.66	0.65	0.64	0.68	0.77	0.90	0.90	-	0.72
															0.81

Table 6B. Calculation cloudiness coefficient K_0 for Ho Chi Minh City (10.82^0 N).

Hours / Month	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	Average K_0
1		0.71	0.58	0.53	0.50	0.48	0.47	0.48	0.48	0.50	0.53	0.58	0.55		0.53
2		0.51	0.55	0.54	0.40	0.36	0.34	0.34	0.35	0.39	0.44	0.52	0.69		0.45
3		0.75	0.58	0.49	0.44	0.40	0.38	0.39	0.40	0.44	0.49	0.56	0.74		0.51
4	0.72	0.68	0.53	0.46	0.42	0.39	0.38	0.39	0.41	0.44	0.50	0.58	0.74		0.51
5	0.82	0.69	0.58	0.53	0.49	0.46	0.45	0.46	0.47	0.48	0.51	0.56	0.69		0.55
6	0.82	0.68	0.58	0.55	0.52	0.48	0.47	0.47	0.47	0.49	0.53	0.57	0.66	0.60	0.56
7	0.77	0.72	0.63	0.60	0.58	0.54	0.53	0.53	0.53	0.57	0.60	0.64	0.70	0.69	0.62
8	0.68	0.73	0.62	0.58	0.56	0.53	0.51	0.52	0.53	0.55	0.59	0.61	0.69	0.57	0.59
9	0.74	0.74	0.65	0.60	0.58	0.57	0.54	0.55	0.56	0.60	0.62	0.67	0.70		0.63
10	0.68	0.74	0.69	0.63	0.60	0.58	0.58	0.56	0.58	0.61	0.63	0.69	0.83		0.64
11	0.62	0.75	0.64	0.58	0.57	0.54	0.54	0.56	0.57	0.60	0.62	0.66	0.81		0.62
12		0.71	0.62	0.57	0.55	0.54	0.53	0.52	0.54	0.56	0.59	0.65	0.82		0.60
															0.57

Using formulas from (23) to (24), the luminance distributions β according to different cloudiness coefficient K_0 is determined by summing the values of illumination from the sky sectors. The results are obtained in Figure 6.

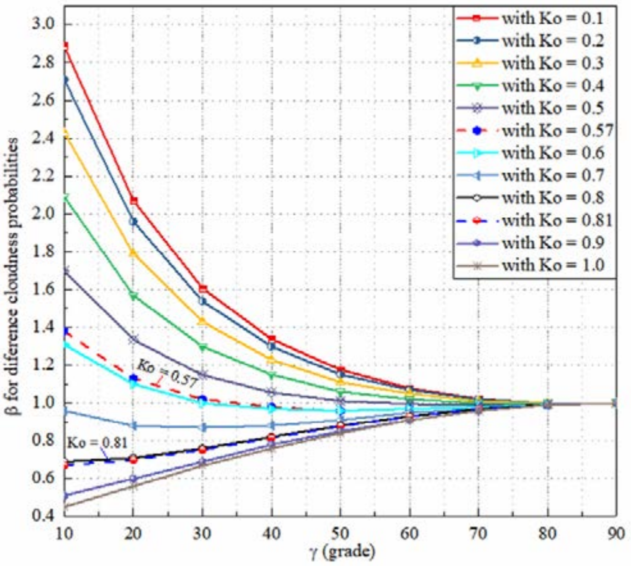

Figure 6. Distribution of relative luminance β with different cloudiness probabilities (for average cloudiness coefficient K_0 = 0.81 in Hanoi and K_0 = 0.57 in Ho Chi Minh City).

The study of Pham Ngoc Dang et al. about daylight climate in Vietnam [27–29], respectively with the document Building code [30] show that the cloudiness statistic has a great influence on daylight climate. The tropical sky of Vietnam is typically with high cloud covered of Cirrus (Ci) and Stratus (St), Cumulus (Cu) clouds. Statistic cloudiness Cirrus (Ci) and Stratus (St) is form at high altitude between 4 ÷ 12 km characterizes for the Sunny days. In this status, the sky characterizes of the high level of diffuse radiation and diffuse horizontal illuminance. Type of clouds Cumulus (Cu) and Cumulonimbus cloud (Cb) is form at low altitude (below 2 km and 0.6 ÷ 1 km) characterizes for the nasty days. The Cumulonimbus cloud is a dense, towering vertical cloud, forming from water vapour carried by powerful upward air currents. If observed during a storm, these clouds may be referred to as thunderheads. Besides, there are different types of cloud as Cirrostratus (Cs), Stratocumulus (Sc), which are formed at middle altitude.

For more specific sky conditions of Hanoi, the sky type VI - Partly cloudy sky, no gradation towards zenith, slight brightening towards the Sun. This sky type nearly approached to the Standard CIE Sky of uniform luminance. In consideration of the cloudiness coefficient K_0 = 0.81 was obtained for Hanoi; this is logical with the cloud covered of 7.8/10 from Code of Standard 02:2009/BXD. In the winter, the sky more clearly with sky type IX and X; or with K_0 value of 0.71 ÷ 0.74. In this period, statistic cloudiness from Code Standard show 6.4/10 ÷ 6.7/10 [30].

For Ho Chi Minh City, the sky is more clearly with statistics cloudiness average of value 6.3 [30], K_0 is 0.57 and sky type X was defined. Generally, the sky types in Hanoi and Ho Chi Minh City characterize by statistic cloud covered and Sunlight exposure as shown in Table 5-7.

Table 7. Statistic cloud covered and hours of Sunlight exposure for Hanoi and Ho Chi Minh City [30].

		January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Hanoi	(1)	8.2	9.1	9.2	8.7	7.7	8.2	8.0	7.9	6.8	6.4	6.5	6.7	7.8
	(2)	74	47	47	90	183	172	195	174	176	167	137	124	1585
Ho Chi Minh	(1)	4.6	4.4	4.4	5.6	6.9	7.5	7.3	7.4	7.7	7.3	6.6	5.7	6.3
	(2)	245	246	272	239	195	171	180	172	162	182	200	223	2489
	(1): Statistic cloudiness. (2): Hours of Sunlight exposure.													

For an overview, a comparison results defining luminance distributions for Hanoi and HCM by difference methods has shown on Table 8. As the results, it is seen that with altitude angles of a point in the sky γ above 50^0, relative errors of the values luminance distributions β values less than 10 %. This means that under city building conditions, when the lower part of the horizon is blocked by an adjacent building, the results obtained by these two methods give a little difference.

Table 8. Comparison results defining luminance distributions for Hanoi and Ho Chi Minh City.

γ (grade)	CIE overcast sky	Distribution luminance β					
		Hanoi			Ho Chi Minh City		
		K_0	D_v/E_v, T_v	Relative error (%)	K_0	D_v/E_v, T_v	Relative error (%)
10	0.45	0.67	0.98	- 31.33	1.38	2.16	- 36.1
20	0.56	0.70	0.97	- 28.04	1.13	1.79	- 36.9
30	0.67	0.75	0.97	- 22.78	1.02	1.49	- 31.5
40	0.76	0.82	0.97	- 15.75	0.98	1.28	- 23.4
50	0.84	0.88	0.97	- 9.53	0.96	1.15	- 16.5
60	0.91	0.93	0.98	- 4.67	0.97	1.06	- 8.5
70	0.96	0.97	0.98	- 0.96	0.98	1.01	- 3.0
80	0.99	0.99	0.98	0.67	0.99	0.98	1.0
90	1.00	1.00	0.99	1.14	1.00	0.99	1.0

4. Conclusion

1. To obtain the luminance distributions of real sky using in daylighting calculations, the sky types of tropical Hanoi and Ho Chi Minh City were defined based on the two extreme CIE Standard Skies: Overcast Sky (Moon & Spencer) and Standard Clear Sky (R. Kittler). In this research, the two methods of calculation were presented: method define luminance distributions based on a set of fifteen skies proposed by R. Kittler and et al.; the method using the cloudiness calculation K_0 to define the real sky luminance distributions gap between two extreme CIE Standard skies. This first method must begin with the definition the sky type with the parameter of descriptors D_v/E_v and T_v. As the results, sky types VI and X respectively were defined for Hanoi and Ho Chi Minh City.

2. Previous studies and standard documents confirm the result of calculation with the conclusion in the sky type of tropical Vietnam is neither overcast sky nor clear sky. The typical sky type is the partly cloudy sky with high cloud cover at high altitude Cirrus (Ci) and Stratus (St) in Sunny days, type of clouds Cumulus (Cu) and Cumulonimbus cloud (Cb) is form at low altitude characterizes for the nasty day.

3. The values of relative luminance distributions were presented. A comparison shows differences between results from the two methods respectively maximum equals 31.33 % ÷ 36.9 % for Hanoi and Ho Chi Minh City at the altitude angles γ of a point in the sky 10^0. Minimum differences below 10 % at the altitude angles γ above 50^0. This implies that under city building conditions when the lower part of the horizon is blocked by an adjacent building, the difference between these methods can be allowed.

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