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REVIEW OF THE CURRENT STATE AND FUTURE DEVELOPMENT IN STANDARDIZING NATURAL LIGHTING IN INTERIORS

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ABSTRACT

Three elements mainly wind, water and sun seemed to determine in ancient ages the basic phenomena of life on Earth. Architectural history documented the importance of sun influence on urban and building construction already in layouts of Mesopotamian and Greek houses. Not only sun radiation but especially daylight played a significant role in the creation of indoor environment. Later, in the 20^{th} century, a search of interaction between human life in buildings and natural conditions were studied considering well-being and energy conscious design recently using computer tools in complex research and more detail interdisciplinary solutions. At the same time the restricted daytime availability of natural light was supplemented by more efficient and continually cheaper artificial lighting of interiors.

There are two main approaches to standardize the design and evaluation of indoor visual environment. The first is based on the determination of the minimum requirements respecting human health and visibility needs in all activities while the second emphasizes the behaviour and comfort of occupants in buildings considering year-around natural changes of physical quantities like light, temperature, noise and energy consumption.

The new current standardization basis for daylight evaluation and window design criteria stimulate the study of methodology principles that historically were based on the overcast type of sky luminance pattern avoiding yearly availability of sky illuminance levels. New trends to base the daylight standardization on yearly or long-term availability of daylight are using the averages or median sky illuminance levels to characterise local climatological conditions.

This paper offers the review and discussion about the principles of the natural light standardization with a short introduction to the history and current state, with a trial to focus on the possible development of lighting engineering and its standards in future.

Keywords: daylight standardization, daylight criteria, evaluation of daylight in buildings, daylight sources

1. INTRODUCTION

There is a recent call to unify illumination criteria used for daylight and artificial lighting of interiors on common bases of good health and visibility conditions as well as interior environmental well-being. The main aspects of healthy and good visual environment can be classified in categories [1–5]:

– Physiological: human health, exposure to daylight and sunlight, appropriate illuminance, non-visual effects, luminance distribution, avoidance of glare, contrast between background and observed details/objects, visual acuity and possibility to recognize small details in required time;

– Psychological: view out, wellbeing, orientation in a space, saturation of a space by natural light and the principle of creating a mood;

– Aesthetical: colour harmony and enhancing the attractiveness of an indoor space;

– Social: cultural heritage and national/local specification of tradition;

– Environmental: reduction of CO_2 production due to reduction of electricity consumption;

– Economical: maximum utilisation of natural light and costs optimisation, energy savings;

– Technological: function and task oriented devices, performance costs, assembly and maintenance requirements and systems for daylight harvesting.

Daylight design is a complex process requiring respect to all these aspects to contribute the valuable and human scale in building interiors. To this, the standards, codes and guidelines for practice are and have to be elaborated [3, 6]. In the lighting engineering preferable are objective physical units, e.g. illuminance in lux instead of relative Daylight Factors still used in daylighting standards and daylight practice.

2. A SHORT HISTORY OF UTILIZATION OF NATURAL LIGHT IN BUILDINGS

Ever since primitive humans realised the restrictions of daylight and the need of an artificial light source at night-time they learnt to set fire, the fireplace became not only the source of warmth and light but also a social gathering and communication meeting centre.

The first civilisation is dated since 3000 BC when Mesopotamian established towns Ur, Uruk or Kish. Houses had a simple construction with atrium and built with unglazed apertures [7]. Greek houses were constructed more compact with peristyle where colonnades were on three sides. From peristyle, the open space, entrances there were to rooms [8]. Living spaces were illuminated through doors or windows also by old stone lamps causing discomfort of smoke and ash. Later candles with cotton wicks were used in Roman houses instead.

Vitruvius introduced a simple rule for daylight evaluation in a room. If from the place with daylight requirement is seen a substantial part of sky hemisphere, this place is sufficiently illuminated by natural light, Fig. 1, [8]. This rule was applied by architects in the Roman period. It can be noticed that this rule was the first criterion for evaluation of daylight in buildings acceptable by authorities.

When Pierre Bouguer started with his photometric measurements his reference source was a candle in the first subjective luminance meter by Marie [9] with many glass filters to reduce the sky luminance. Anyhow, that meant the start of experimental photometry by Bouguer [10]. Few years later Johann Lambert [11] started his studies theoretically determining interior illuminance as geometrical influence of window solid angle seen from the actual illuminated planar element relative to outdoor illuminance. Lambert´s assumption proved to be a very useful, simple and practical choice for the sky luminance standard for calculating interior daylighting in relative terms:

$$\frac{E_{v,i}}{E_{v,d}} = \frac{L_a\ \omega_p}{\pi\ L_{vZ}} = \frac{\omega_p}{\pi} = R.S.F, \qquad (1)$$

where $E_{v,\,i}$ is the indoor illuminance of the illuminated element [lx],

$E_{v,\,d}$ is the outdoor illuminance from the whole unobstructed sky hemisphere [lx],

$L_a = L_{vZ}$ is the luminance of an unity arbitrary or zenith sky element [cd/m^2],

ω_p is the aperture solid angle projected onto the illuminated plane,

π is the solid angle of the sky hemisphere projected onto the horizontal illuminated plane,

R.S.F. is the relative Reference Sky Factor serving as a skylight criterion [11].

Due to the lack of sky luminance data he assumed that a perfect overcast sky was absolutely uniform and even in all azimuth directions which could be equal to constant or unity.

Access to daylight and sunlight was an important aspect in building design some centuries ago. At that time, rules of thumb were used, like window head height to room depth or limit of room depth [12]. Importance of natural light was recognised for first time in UK in Prescription Act, 1832 known as Act Right of Light [13, 14], after which any owner of property can have his previous access to daylight

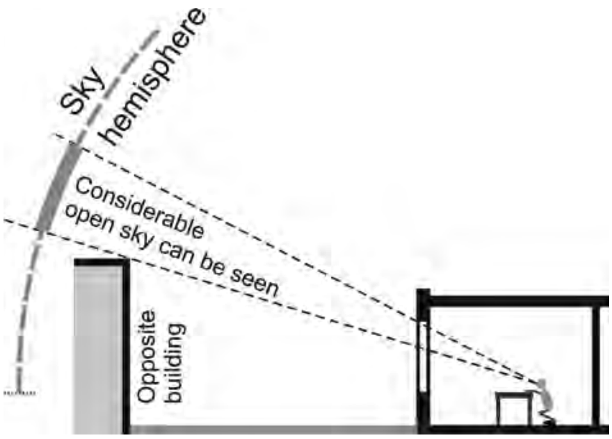


Fig. 1. Ancient rule for daylight evaluation Marie, after [8]

for 20 years. These single rules are based on the geometrical configuration of windows in the room and surrounding buildings.

Industrialization in European countries, e.g. England and Germany in 19th century, led to establishing factories consuming solid fuels and producing in the atmosphere large quantities of pollution. This had negative consequences on the human health and local environment. Logically, the solutions for improvement in health conditions of people were looked for. Elimination of the sunlight absence and increase of daylight in dully building interiors was one, but any important way to improve environment in buildings.

Measurements of sky luminance distribution on the overcast sky, as the worst daylight source, by Schramm [15], Kähler [16], Kimball and Hand [17], Krat [18] showed that real overcast sky has not a uniform luminance distribution but it is characterized by the gradation of sky luminance 1:2–1:3 from horizon to zenith. Moon and Spencer [19] published formula (2), which was recommended for standardization by CIE – International Commission for Illumination [20].

$$L_\gamma = \frac{L_z(1+2\sin\gamma)}{3}, \qquad (2)$$

where $L\gamma$ is the luminance in direction of angle γ above the horizon [cd/m^2],

L_z is the zenith luminance [cd/m^2].

Only now after long term regular sky luminance measurements and e.g. with 1-minute interval, measurements can be more precise for sky situations and daylight conditions in the exterior and building interiors during a day, season or the whole year characterizations [7–27].

Discussions about the importance and sense of standardization in technical branches are often provided by engineers. This process contributes to the developments of new technologies when standard requirements are beneficial or also can be ineffective or result from worse conditions in the case of differences between intention and application conditions [6]. History shows that this process is complicated, depends on current knowledge, climate and national specifications as well as society advancement and prosperity.

The 20th century is characterized by expansion of various architectural styles opened to nature, sun and human needs. Le Corbusier opened interiors of residential buildings to sun exposure when in his principles of Functionalism were formulated 5 points [29]. One of those recommendations is to construct buildings "with horizontal windows preferably running along the whole length of the facade". Glazed façades of office buildings constructed during the second period of last century uncover serious problems with glare, overheating inside and energy performance of buildings.

There are localities with high population and high price of ground, like New York or Hong Kong. The main aspects for consideration in New York City planning was air and daylight on the streets [30–31]. The vertical illuminance on the façade and unobstructed area were criteria for construction of high rise residential buildings in Hong Kong [32–35]. Gifford in [36] caused social problems in densely urban areas i.e. higher crime, children wrong behaviour, a fear from fire or insufficient daylight. These negative experiences lead to re-evaluate the concept of urban density to more human environment. Generally, it provoked new thesis about creation of indoor environment in the human scale.

3. DAYLIGHT METRICS

Daylight in interiors is permanently changing during a day in intensity and spatial distribution while sun and sky are the main sources for indoor illumination and determination of their characteristics, parameters and metrics, still searched [2, 7, 37–39]. Daylight metrics can be applied in three static, dynamic and rating categories comprising daylight evaluation in building.

3.1. Minimum Requirements

Daylight Factor (D)

After the definition [http://eilv.cie.co.at/term/279], the Daylight Factor D is the ratio of indoor illuminance E_i in the point of interest to illuminance $E_{v,d}$ received from the unobstructed hemisphere of an overcast sky where the contribution of direct sunlight to both illuminances is excluded.

Application of D brings several advantages, like simple evaluation of window size design and verification of daylight evaluations and also disadvantages, like any possibility to evaluate time and intensity of illuminance variability, orientation of the room and design daylighting in physical unit lx with independence on the daylight variability.

Illuminance on a working plane

However, respect can be also performance of visual tasks with requirements for to precise recognitions of observed details. In this case the threshold of illuminance in lx on a working plane should be determined.

3.2. Daylight Simulations

Daylight simulation covers computer based calculations of the daylight availability outside or inside of a building during year or other period with one or several sky conditions. Outputs of the simulation are levels of illuminance, luminance or their indoor distributions in the form of a scene or visualization [27]. Several simulation methods can be used for evaluation of daylight.

Daylight Autonomy (DA)

The static and dynamic of daylight autonomy are distinguished. The static daylight autonomy is based on the evaluation of the Daylight Factor at the point of interest when the overcast sky conditions are considered. The dynamic daylight autonomy is based on the prediction of the sufficient illuminance at the point of interest at determined time step (on hourly or less) over the year. DA results in the percentage of the year when a minimum illuminance threshold is met by daylight, [40–42].

Diffuse Daylighting Autonomy

Diffuse Daylighting Autonomy is based on hourly meteorological data, which are processed using the model [23] in order to calculate the hourly value of outdoor horizontal diffuse illuminance or the hourly value of inclined diffuse illuminance. To consider room orientation the parameter diffuse daylight autonomy is weighed [43].

Daylight reference year (DRY)

The daylight reference year is respected by synthetic annual series of probable exterior direct, diffuse and global illuminace generated using statistical methods from precise real photometric and radiometric measurements. The DRY for Bratislava and Athens contains real daily illuminance courses in representative months [44]. The first DRY based on the photometric variables was generated by Petrakis [45]

Useful daylight illuminance (UDI)

Principle of UDI concept is based on the evaluation of illuminances occurring during a year that fall in the range of minimum and the maximum. The minimum illuminance represents threshold for visual task performance and maximum level is the highest illuminance acceptable by occupants [42–43, 46].

Climate based daylight modelling (CBDM)

Climate-based daylight modelling is a method for prediction of annual radiant or luminous quantities, the illuminance and luminance in absolute values are derived from standard meteorological datasets containing data from all sunny and sunless conditions. CBDM offers climatic data from a specific locality for evaluating daylight availability, building orientation and application of shading devices, etc. [38, 47].

Annual daylight exposure

Annual daylight exposure is an indicator defined as the cumulative amount of visible light incident on a investigated point over the year expressed in lx per year [48].

3.3. Certification of Building Sustainability

Parallel to standardization the activities of certification of building environment or building sustainability are present proposed, e.g. LEED, BREEM, DNGB [38, 41]. Daylight plays only a partial role in the scoring evaluation of these systems [49] which does not fully respect principles of photometry. Contrary to standardization, the certification systems can significantly reduce the importance of visual environment within interest for other aspects.

4. A SHORT HISTORY OF ARTIFICIAL LIGHTING

During medieval years were candles standardized and manufactured from animal suet or beewax and later in the 18th century a candle was considered as a light unit. Of course, no artificial light source could compete with the enormous luminance of the sun or the sky that penetrate into rooms.

Besides the utilization of fire as an artificial light source whether in the form of torches, oil lamps or candles, the original and true artificial light source started with the inventions in 1799. Two new sources of energy were discovered in the form of an electric battery by A. Volta and W. Murdoch illuminated his house using lighting gas [50]. The latter gas lighting was applied in U.K. and Europe for more than 200 years especially in street lamps and partly avoided in closed interiors. Electric lighting of interiors needed almost hundred years for many developments in electricity production, transfer of electric current and safe interior sources in form of incandescent glass bulbs.

The first were invented by J. Swan [51] and exhibited in 1879 later followed with more practical alternatives by T.A. Edison [51] including also proposed artificial lighting systems for buildings realized in New York in 1882 while the Yablochkov candle [52] was installed in Paris as a first demonstration for street and theatre illumination during the Paris Exhibition in 1878.

Nevertheless, incandescent electric bulbs wasted a lot of energy due to their back-body temperature radiation. In the further search gas filled neon tubes and fluorescent tubes suitable for interiors enabled further energy savings and cheaper consumption costs and were surpassed in the 21st Century by newer light emitting diodes (LEDs) with possible spectral choice, longer life time, lower energy consumption and price.

Technology progress for the economically prosperous countries became favourable for illumination of interiors in all cases when daylight is low or dark outdoors often in regions with many overcast days. Under these circumstances it seems that previously worst December overcast skies, so critical during 18th to 20th Centuries, are not so important now and in case of necessity the needed illuminance levels can be easily coped with the cheap electric lighting.

To ensure minimum lighting conditions for reading and writing as well as for visual tasks in schools, offices and industry, the horizontal illuminance was standardized in lx levels [53]. Thus, design calculations in photometric units are comparable and can be easily checked.

In the spaces of rooms with insufficient daylighting levels for visual tasks can be applied artificial lighting to supplement daylight in accordance with concept PSALI [37].

5. METHODOLOGY FOR DAYLIGHT STANDARDIZATION

There are two ways of daylight standardization. The first concept is based on the determination of requirements reflecting minimum or maximum acceptable values describing interior daylight conditions. The second way is pointed on the relation between occupant behaviour and year-around changes of natural light quantities. In both, the sky conditions play significant role in daylight standardization.

Standardization of daylight in accordance with the first approach works with simple static criteria and procedures applying assumption: when the limit is complied in practice then visual conditions will be satisfactory during building performance. This philosophy is valid generally until daylight quantities will dominantly exceed limits (e.g. luminance will not arise to glare, or large size of windows will produce overheating etc.). In such cases, the additional measures should be applied (e.g. assembly of shading devices, daylight level control etc.). Generally current standards, regulations and codes are based on the formulation of illuminance, luminance, view out, or glare limits.

The second way of daylight standardization is based on year-round measured data and formulation of human behaviour in annual interior occupation, i.e. not only under limit situation but also behaviour during a day, month, season or whole year respecting also artificial lighting possibilities.

Due to the multiple changes of natural influences (e.g. daily sun path, geographical latitude, cloudiness etc.) as well as human activities in interiors with various well-being and visibility requirements (e.g. circadian biorhythm, life style, visual needs concerning frequent activities etc.), several complex varieties are to be respected when human aspects with energy conscious optimization have to be considered in building and urban design.

However, only until the last years of the 20th Century few momentary measurements of sky luminance were studied almost exclusively under overcast skies and no long term data in different localities were available. Neither the meteorological services nor satellites gathered any photometric data besides irradiance in broad spectral bands. This deficiency was meant to overcome the International Daylight Measurement Programme (IDMP) started by the CIE in 1991. The complex measured data in many localities enabled to study dynamical randomly occurring states influenced by local climate. According to the long-term measured skylight luminance and illuminance collected in time steps in different locations characterized the overall daylight climate worldwide. The set of instant minute horizontal sky illuminance changes with either zenith luminance or luminance sky scans also prepared the possibility to standardize the daylight de-

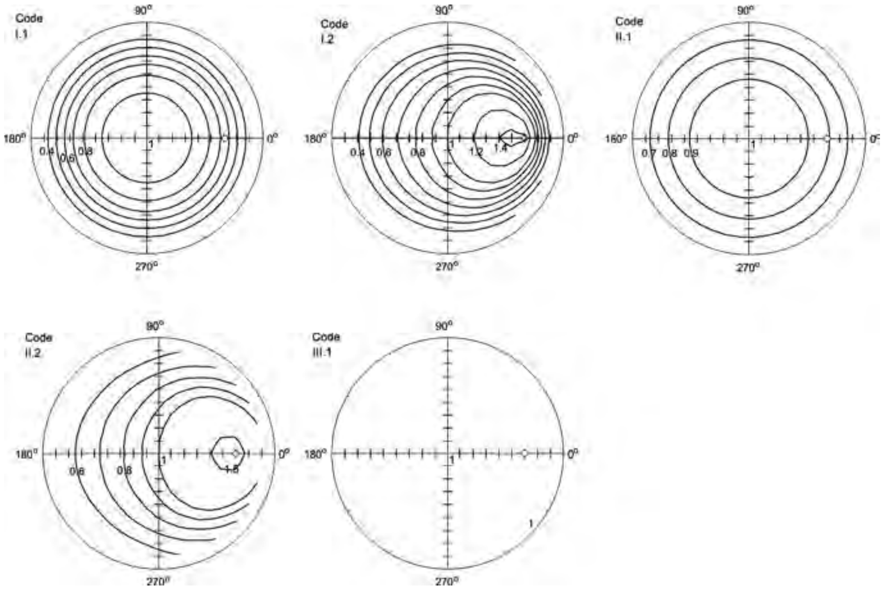


Fig. 2. Examples of sky luminance patterns of ISO/CIE overcast sky types

sign and evaluation after several methodologies, presented below as points A, B, C, D.

A. To derive a set of typical quasi-homogeneous sky types occurring worldwide by selecting such cases from the vast data base within the range from overcast (sunless) to cloudy or polluted clear skies with sunlight.

In fact this method was originally used already by Lambert J.H. [11] assuming the uniform and unity sky luminance on the whole overcast sky which enabled to derive calculation formulae to determine exterior and interior illuminance levels and graphical tools e.g. Danilyuk's charts [54], Waldram diagrams [55, 56] or BRS protractors [57]. Lambert's assumption of a unity sky luminance after measured sky luminance gradation was corrected after the proposal by P. Moon and D.E. Spencer [19] and adopted by CIE as the CIE Overcast Sky [20]. Using this new standard further corrections in the derivation of the Sky Component of Daylight Factor caused by different oblique glass transmittance for single or double glazing or for rough cast wired glass in apertures with different slope [58] enabled to produce a set of more practical protractors [2]. The need to expand the sky range from overcast to clear standards was successfully accomplished applying this methodology when selecting a set of fifteen sky types [59–61], adopted now by CIE and also internationally by ISO [63]. In Figs. 2–4, standard sky luminance patterns are shown of all fifteen types of skies in the relative units presenting overcast, clear skies and quasi cloudy skies expressed as homogeneous models under sun altitude 30°.

All ISO/CIE sky types are identified by number 1–15 or by code characterising the number of the standard gradation function (Roman letter) and standard indicatrix by number [60, 61,63].

Typical overcast skies absolutely block and shade sunlight having only luminance gradation characteristics with a temporary penetration ratio of ground to extraterrestrial horizontal illuminance E_{vd}/E_{voh}. However, clear sky luminance patterns are influenced by sun presence and together with luminance gradation are strongly dependent on sun beam scattering reaching the whole sky vault that can be characterized by the ratio of zenith luminance L_{vZ} to sky horizontal illuminance E_{vd}, i.e. L_{vZ}/E_{vd} [7]. Analysing the sky luminance distribution enables to determine the relative scattering function, which co-acts with gradation forming the relative sky luminance pattern [59, 61]. When absolute L_{vZ} is known or calculated [60] a sky luminance pattern in physical units, e.g. kcd/m^2 is available. When the sky luminance in the window solid angle is given it can serve computer programs input for calculation of indoor illuminance in oriented rooms as well as temporary risk of glare.

B. To represent and study the daily sky and sunlight courses with respect to turbidity and cloudiness influences under clear skies with the aim to determine their mutual interrelation dependent on solar altitude and sky type.

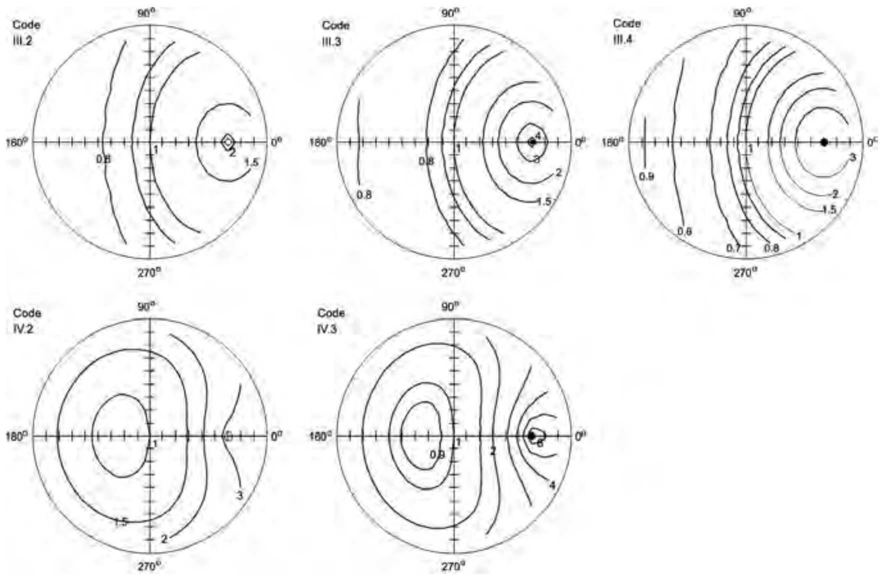


Fig. 3. Examples of sky luminance patterns of ISO/CIE quasi cloudy sky types with sun in position of solar altitude 30°

Although it seems that the typology of sky types is the simplest and evident criterion, but the basic idea is in the definition and determination of luminance distribution on the whole sky vault under sunshine is influenced the mutual participation of skylight and sunlight due to atmospheric turbidity and cloudiness.

The fundamental influence of pollution in atmosphere especially in cities and industrial zones effects considerably relation between sky and sun illuminance level changes [64, 65]. Such transformations also occur in subtropical and tropical climates with lots of sunny days due to humidity rise and dispersed cloud veil gradually covering the whole sky vault [66].

To be able to analyse and categorize the occurrence of individual sky types it is inevitable to have local regular measurement data. The selection has to trace chosen sky types according to parameters like solar altitude, the significant range of L_{vz}/E_{vd} [59, 67].

C. To characterize yearly or long-term skylight conditions and local daylight climate.

In example this method was used to document five year occurrence of CIE/ISO sky types in various seasons after measurements in Bratislava and Athens [68]. Exterior horizontal illuminance levels were selected from 5 min database and sky type occurrences graphically presented in Fig. 5*a*, and Fig. 5*b*. Bratislava represents Central European

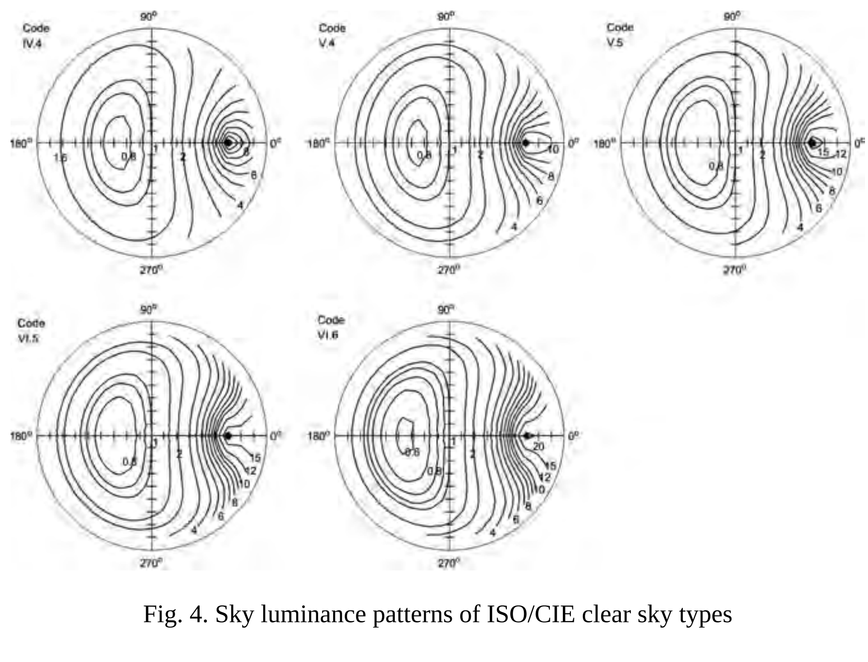


Fig. 4. Sky luminance patterns of ISO/CIE clear sky types

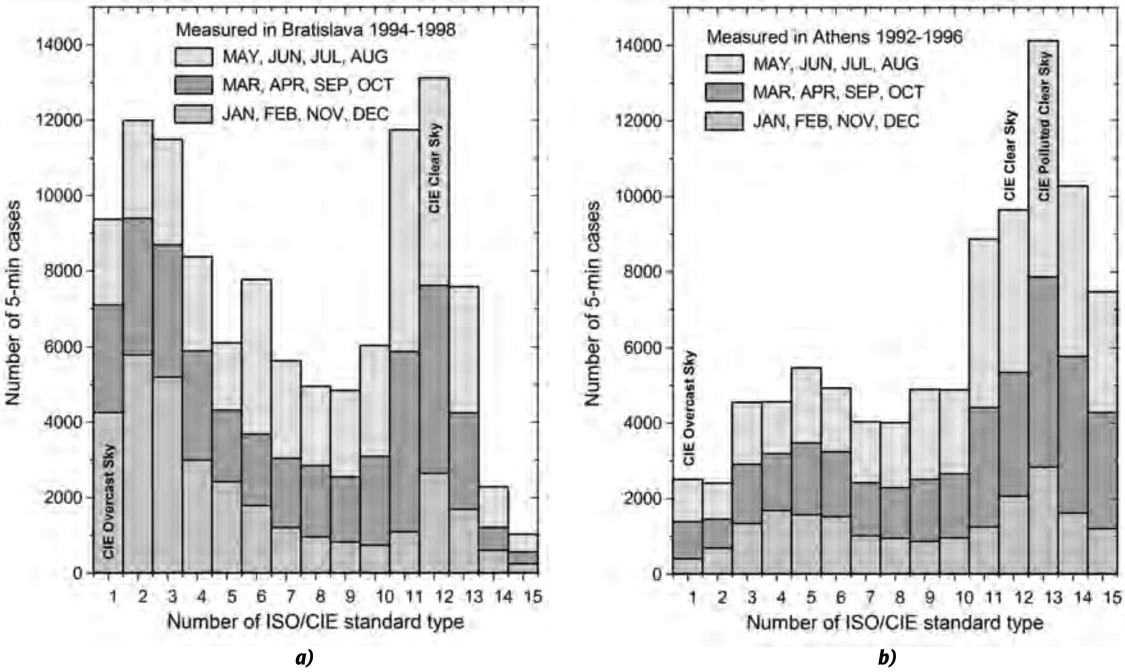


Fig. 5. Sky type occurrence as method for presentation of local daylight climate, [68]
a) Bratislava, Central Europe climate, *b)* Athens, Mediterranean climate

daylight climate with characteristic higher occurrences of overcast/cloudy skies, clear skies mainly in summer while sunny and clear situations are dominant in Athens in Mediterranean location.

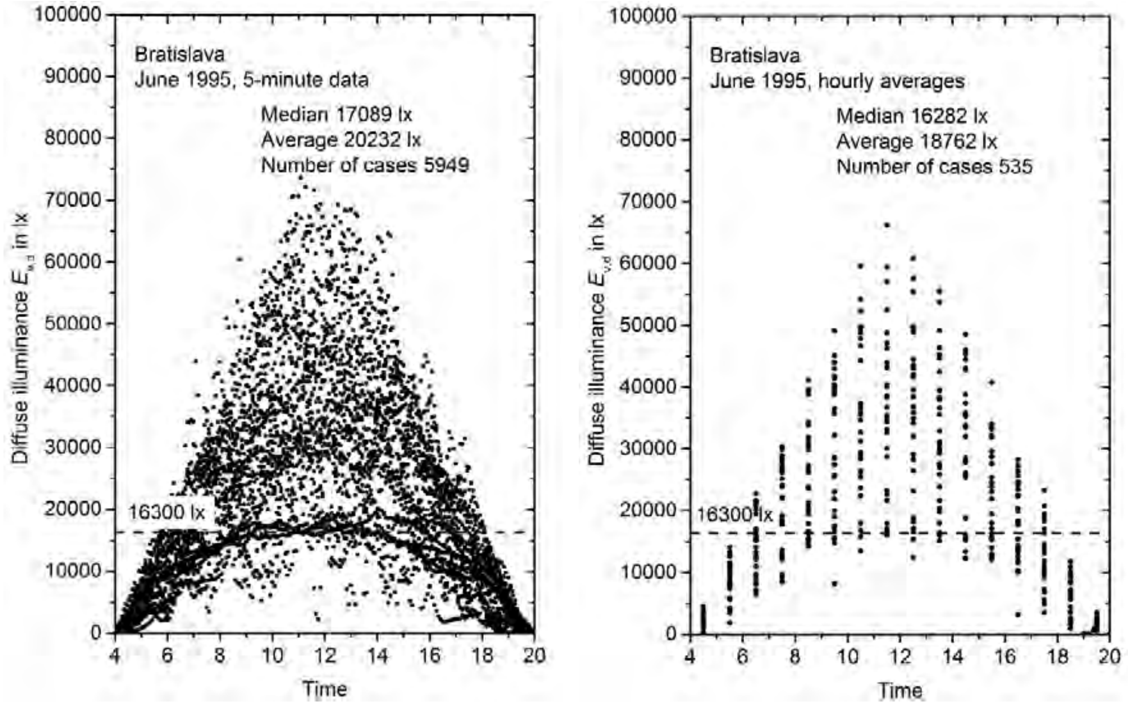
Several assumptions respecting regional lifestyle, activity pattern or target skylight requirements can be taken into account. For instance, in [69] were evaluated some most probable daily activity hours e.g. 7:00–20:00, 8:00–17:00, 8:00–19:00 or 9:00–16:00, but finally for the calculation of the meridian characterization were applied the daily periods from sunrise to sunset. Such yearly meridian skylight illuminance of all CEN capitals was recommended as a standard criterion [70].

D. Determine the yearly statistical characteristics of exterior horizontal skylight illuminance based on the measured data can express local skylight availability.

Having the detail measurement data it is possible to derive few comparisons of skylight illuminance occurrence evaluated from measured precise, short term, data or their hourly averages. However, it is problematic how to use relevant data in formulation of daylight standard criteria. Whether the whole range of measured sky illuminance from sunrise to sunset are to be taken as basic, e.g. for a month with highest illuminance levels in June, Fig. 6, or March representing skylight in equinox, Fig. 7 or referenced specific periods of daily human activities as suggested by [69] or 7:00–16:30 for office buildings and 7:00–14:30 for schools as prescribed in Slovak regulation [71]. Consequences indicated by vertical lines in March are shown in Fig. 7*a* and in Table 1. The prescribed by [70] value 16300 lx of median diffuse illuminance for Bratislava is shown in Table 3. Differences between 5-minute and hourly data are indicated in comparison of *a* and *b* both in Fig. 6 and Fig. 7 and it is evident that hourly averages reduce illuminance levels and offer less information about daylight availabili-

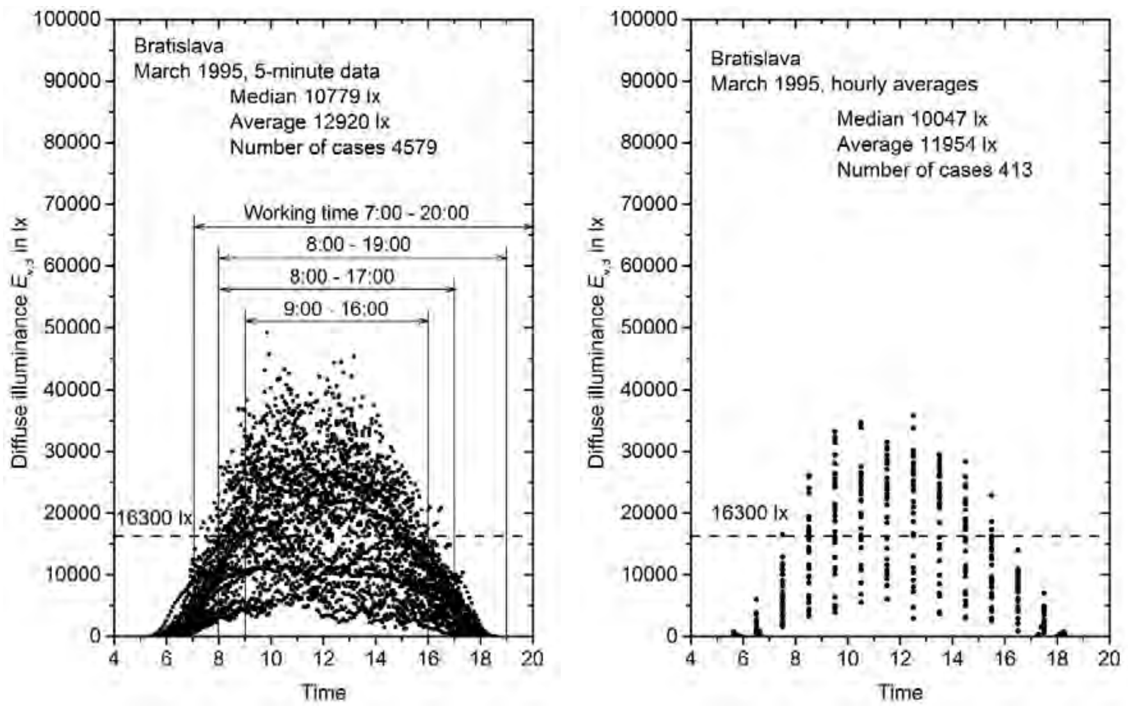
Table 1. Statistical Sky Illuminance of 5-minute E_{vd} in March 1995 in Bratislava for Working Hours

Working time	Sunrise – sunset	8:00–17:00	9:00–16:00	8:00–18:00
Average, lx	12920	16339	17986	15009
Median, lx	10779	15002	17700	13447
Count, number	4579	3379	2635	3732



a) ***b)***

Fig. 6. Daily availability of diffuse horizontal illuminance in June 1995 in Bratislava.
a) Minute averages, *b)* Hour averages



a) ***b)***

Fig. 7. Daily availability of diffuse horizontal illuminance in March 1995 in Bratislava.
a) 5 minute averages, *b)* Hour averages

ty in the locality. When the period of working time will be considered then higher illuminance levels as criterion can be expected.

Daylight is perceived by human eye at the moment of its occurrence, therefore databases applied in daylight standardization should contain the data measured in the shorter intervals.

Table 2. Selected Standards and Documents Containing Requirements and Recommendation for Daylight Evaluation in Buildings

Country	Number	Description
Australia	AS1680.1–2006	Interior lighting – General principles and recommendations
Belgium	NBN L13–002:1972	Dagverlichting van gebouwen – Voorafbepaling van de daglicht-verlichtingssterkte bij overtrokken hemel (benaderende grafische methode)
Brazil	NBR15215–1	Iluminação natural – Parte 1: Conceitos básicos e definições
	NBR15215–2	Iluminação natural – Parte 2: procedimentos de cálculo para a estimativa da disponibilidade de luz natural
	NBR15215–3	Iluminação natural – Parte 3: Procedimento de cálculo para a determinação da iluminação natural em ambientes internos
	NBR15215–4	Iluminação natural – Parte 4: Verificação experimental das condições de iluminação interna de edificações – Método de medição
Canada	PWGSC1989	PWC Daylighting manual, Ottawa
CEN	EN17037	Daylight of building
China	GB50033–2013	建筑采光设计标准
Czech Republic	ČSN73 0580–1	Denní osvětlení budov – Část 1: Základní požadavky
	ČSN73 0580–2	Denní osvětlení budov – Část 2: Denní osvětlení obytných budov
	ČSN73 0580–3	Denní osvětlení budov. Část 3: Denní osvětlení škol
	ČSN73 0580–4	Denní osvětlení budov. Část 4: Denní osvětlení průmyslových budov
Estonia	EVS894: 2008	Loomulik valgustus elu- ja bürooruumides
Germany	DIN5034–1	Tageslicht in Innenräumen – Teil 1: Allgemeine Anforderungen
	DIN5034–2	Tageslicht in Innenräumen; Grundlagen
	DIN5034–3	Tageslicht in Innenräumen – Teil 3: Berechnung
	DIN5034–4	Tageslicht in Innenräumen – Teil 4: Vereinfachte Bestimmung von Mindestfenstergrößen für Wohnräume
	DIN5034–5	Tageslicht in Innenräumen – Teil 5: Messung
	DIN5034–6	Tageslicht in Innenräumen – Teil 6: Vereinfachte Bestimmung zweckmäßiger Abmessungen von Oberlichtöffnungen in Dachflächen
Great Britain	BS8206: Part 2	Lighting for buildings: Code of practice for daylighting
Hong Kong	Regulation APP-130	Lighting and Ventilation Requirements – Performance-based Approach

6. STANDARDIZATION OF NATURAL LIGHT IN INTERIORS

Quality of indoor environment depends mainly on factors affecting human perception of light, warm, noise and air composition. To create good and satisfactory visual conditions for work, rest and various activities in buildings the criteria and rules for illumination system design, building construction and so for evaluation of natural and artificial light utilization should be determined. There are several countries which have adopted regulations, standards and national rules for design and evaluation of daylight and insolation in buildings Table 2, [42, 72–75]**.** In accordance with laws [76] and [77] and regulations [78–80] daylight design and evaluation of sunlight exposure are checked by hygienic authority waving obligation to take official decision in Slovakia.

Country	Number	Description
Japan	JIES-008–1999	Indoor Lighting Standard
Netherlands	NEN2057	Daglichtopeningen van gebouwen
Norway	Regulation No. 77, 14. June 1985	Technical regulations to the Planning and Building. Updated by the regulation No. 1069, 29th August 2001
Poland	Regulation of Ministry for Infrastrukture, (*Dz.U. Poz. 1422*)	W sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie
Russia	СП 23–102–2003	Естественное освещение жилых и общественных зданий
	СП 52.13330.2016	Естественное и искусственное освещение
Serbia	SRPS U.C9.100:1963	Дневно и електрично осветљење просторија у зградама
Slovakia	STN73 0580–1	Denné osvetlenie budov. Časť 1: Základné požiadavky
	STN73 0580–2	Denné osvetlenie budov. Časť 2: Denné osvetlenie budov na bývanie
	STN73 0580–1/Z2	Denné osvetlenie budov. Časť 1: Základné požiadavky
	Regulation No. 541/2007 Z.z.	o podrobnostiach o požiadavkách na osvetlenie pri práci.
Slovenia	Rule UL. RS, No. 43, 3.6.2011	Pravilnik o zahtevah za zagotavljanje varnosti in zdravlja delavcev na delovnih mestih
	Rule UL. RS, No. 61, 2.11.2017	Pravilnik o minimalnih tehničnih zahtevah za graditev stanovanjskih stavb in stanovanj
Sweden	SS91 42 01	Byggnadsutformning – Dagsljus – Förenklad metod för kontroll av erforderlig fönsterglasarea
Ukraine	ДБН В.2.5–28	Природне і штучне освітлення.

Generally daylighting in interiors is evaluated after Daylight Factor criteria e.g. [81–101]. In Sweden simple 1/10 of window area to floor area is applied [102] in other several countries rules for daylight evaluation have been applied e.g. [103–115], as shown in Table 2.

7. NEW STANDARD EN17037 DAYLIGHT OF BUILDING

Progress in the illuminating engineering research increases the role of daylight as an important factor of human health and labour in an indoor environment. In Europe health of people and effective utilization of natural sources are highly respected, therefore a new standard with criteria for evaluation of daylight in buildings is now to be adopted in Europe. The work group CEN/TC169/WG 11 Daylight was established with the mandate to elaborate an EN standard “Daylight of buildings”. The proposed EU daylight standard [70] was approved by experts of CEN countries. This proposal tries to change the current relative Daylight Factor criteria to absolute illuminance units prescribed for certain visual task categories similar as used in artificial lighting in illuminated interiors. Due to the EU geographic territory span from Mediterranean to far Northern countries this standard introduces the new concept of the median exterior diffuse illuminance $E_{v,\,d,\,med}$ representing sufficient daylight availability during the half of the year as a substitution of the unidentified overcast sky and Sky Factor criterion for aperture design. Some interesting capitals from the [70] list are in Table 3.

This standard covers all main subjects associated with design and evaluation of natural visual environment, i.e. daylighting, view out, sunlight and glare, [116–119]. Also specifies minimum recommendations for visual task performance, impression of lightness indoors and for providing an adequate view out as well as recommendations for the duration of sunshine exposure. Standard can be applied to all spaces which are regularly occupied by people for extended periods, except spa-

Table 3. The Median of External Diffuse Illuminance $E_{v,d}$, *med* and D_{TM}, and D_T Requirements for Indoor Illuminace $E_{v,i}$ for Selected CEN Capital Cities, [70].

Country	Capital city	Geographical latitude, deg	$E_{v,d,med}$, lx	$E_{v,i}$, lx			
				100	300	500	750
				D_{TM},%	D_T,%		
Cyprus	Nicosia	34.88 N	18100	0.6	1.7	2.8	4.1
Spain	Madrid	40.45° N	16900	0.6	1.8	3.0	4.4
Croatia	Zagreb	45.48° N	17000	0.6	1.8	2.9	4.4
Slovakia	Bratislava	48.20° N	16300	0.6	1.8	3.1	4.6
Belgium	Brussels	50.90° N	15000	0.7	2.0	3.3	5.0
Germany	Berlin	52.47° N	13900	0.7	2.2	3.6	5.4
Denmark	Copenhagen	55.63° N	14200	0.7	2.1	3.5	5.3
Sweden	Stockholm	59.65° N	12100	0.8	2.5	4.1	6.2
Iceland	Reykjavik	64.13° N	11500	0.9	2.6	4.3	6.5

ces where daylighting is hindering to the work to be performed.

7.1. Daylighting

Evaluation of daylighting is based on the annual availability of the diffuse horizontal illuminance $E_{v,d}$ in the specific locality. As a reference value is proposed as a climatological parameter the median diffuse horizontal skylight illuminance $E_{v,d,med}$, Fig. 8. These medians can be determined from long term regular daylighting measurement or satellite data for any locality.

Application of median illuminance indicates that interiors will be satisfactory illuminated over the summer half year, but during the rest half year, intensities of daylighting are lower and natural light should be supplemented by artificial light. The minimum daylight provision is considered if a minimum target illuminance level is achieved across a percentage of the relevant area of the space for at least 50 % of the daylight hours. Minimum illuminance level 100 lx and adequate level 300 lx represent criteria for just acceptable natural illuminance in interiors. Moreover, it is possible to apply the categories 500 lx and 750 lx of indoor illuminance in the case of requirements for performance of more precise visual tasks over a fraction of the relevant area, e.g. 50 % of the space. If values of indoor illuminance level E_i and median diffuse horizontal skylight illuminance $E_{v,d,med}$ are determined, the Minimum Target Daylight Factor D_{TM} and Target Daylight Factor D_T can be calculated either for indoor illuminance 100 lx as:

$$D_{TM} = \frac{E_i}{E_{v,d,med}} = \frac{100}{E_{v,d,med}} \ [\%], \qquad (3)$$

or for at least indoor illuminance $E_{T,i}$ = 300 lx, 500 lx and 750 lx as:

$$D_T = \frac{E_i}{E_{v,d,med}} = \begin{cases} 100\dfrac{300}{E_{v,d,med}} \\ 100\dfrac{500}{E_{v,d,med}} \\ 100\dfrac{750}{E_{v,d,med}} \end{cases} [\%]. \qquad (4)$$

Inserting a value of $E_{v,d,med}$ into (3) or (4) it is possible to calculate Minimum Target Daylight Factor D_{TM} or Target Daylight Factor D_T for any arbitrary locality, Table 3. It is important to realise that D_{TM} or D_T are not equal to any Daylight or Sky Factor used earlier, because the basic assumption of overcast sky is untrue.

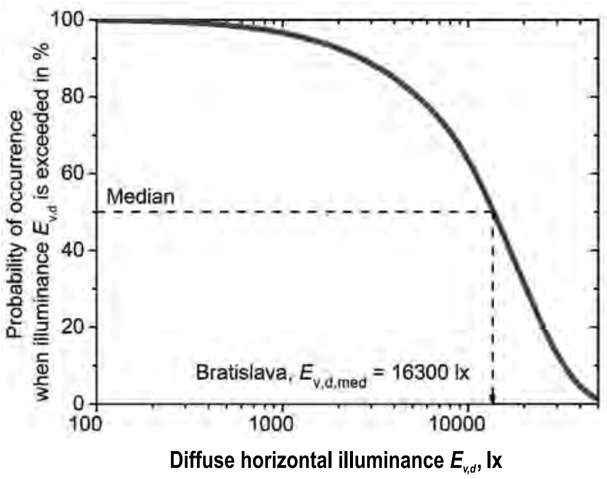


Fig. 8. Median diffuse horizontal skylight illuminance $E_{v,\,d,\,med}$ for Bratislava

Value $E_{\mathrm{v,\,d,\,med}}$ = 16300 lx was determined for Bratislava (geographical latitude ϕ = 48,20° N) [69] and it is included in the EN standard proposal [70]. If $E_{\mathrm{v,\,d,\,med}}$ = 16300 lx will be applied, then criterion for acceptable minimum daylighting D_{TM} = 0.61 % ~ 0.6 % and should be exceeded over 100 % of the space. Criterion for adequate daylight illumination of at least 300 lx on the working plane over 50 % of the space will be $D_{\mathrm{T,300}}$ = 1.84 % ~ 1.8 %.

It is important to notice, that statistical parameter median represents the centre of the available levels of illuminances occurring in the nature, so also in the specific locality. That means, the utilisation of sufficient daylight in interiors is only during half of the year. If interiors are currently illuminated by daylight longer time than 50 % of the year time, there is a risk that in new constructed buildings of the same type will be designed windows of smaller dimensions and consumption of energy for electric lighting will rise. Contrary to this, the energy can be saved in those type of buildings which are illuminated by the artificial lighting more than half of the year.

The methodological derivation of D_{TM} and D_{T} assumes statistical evaluation of yearly diffuse illuminance data resulting from a mixture of various sky situations. It is important to realise that the Target Daylight Factors do not correspond to the Daylight Factor representing overcast sky conditions defined in ILV [62], therefore these two parameters cannot be exchanged.

Daylighting is evaluated in the grid of points on the reference level 0.85 m above the floor with a perimeter of the grid is 0.5 m from side walls.

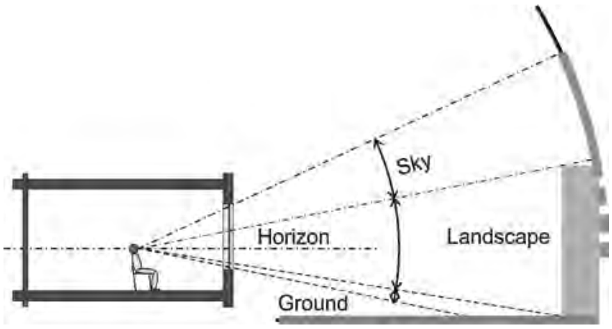


Fig. 9. Composition of the good view

7.2. View

Indoor spaces regularly occupied by people should provide good view to outside to supply information for orientation, weather and changing of the outside scene. View is standardized in three levels with specific functions: a layer of sky, a layer of landscape and a layer of ground, Fig. 9. The most important view layer for human eyes is view to sky because of accommodation of eyes to infinity and sky colour stimulating processes of various organs.

Standard prescribes minimum sight angle, outside distance of the view and position of the reference points (1.2 m for sitting person and 1.7 m for standing person). Minimum distance between room façade and opposite building façade has to be 6 m.

7.3. Sunlight

People in residential buildings or family houses are very sensitive to access of sunlight mainly in Central and Northern Europe. Generally, interiors in Southern European countries are rather protected against excessive overheating from the sun radiation. In these countries there are also people with reduced mobility, with various diseases, or children, which need to have access to sunlight in interiors. The recommended insolation is at least 1.5 hour on a selected date between February 1$^{\mathrm{st}}$ and March 21$^{\mathrm{st}}$ in apartments of residential buildings or family houses, patient rooms in hospitals and play rooms in nurseries. Possible sunlight duration is considered when solar altitude γ_{s} is higher than minimum and sun disk is not shaded by surrounding obstructions. Evaluation reference point P is located minimum 1.2 m above the floor and 0.3 m above the sill in the middle of the window width, Figs. 10, 11.

Value of the minimum solar altitude γ_{s} is determined for all capital cities of CEN member countries after a rule that orientation of the window nor-

Table 4. The Minimum Solar Altitude γ_s on March 21st when Sunlight Duration is 1.5 Hour, [70]

Country	Capital city	Geographical latitude, deg	Minimum solar altitude γ_s, deg
Spain	Madrid	40.45° N	19
Croatia	Zagreb	45.48° N	15
Slovakia	Bratislava	48.20° N	14
Belgium	Brussels	50.90° N	12
Germany	Berlin	52.47° N	11
Denmark	Copenhagen	55.63° N	10
Sweden	Stockholm	59.65° N	8
Iceland	Reykjavik	64.13° N	6

mal *n* can be considered up to 120° from South to East or clockwise to West, Fig. 11. Values of the minimum solar altitudes γ_s for selected capital cities with the reference day March 21st and sunlight duration 1.5 hour are presented in Table 4. The value of minimum solar altitude for other cities, reference day and sunlight duration can be determined considering the position of the window normal 120° from South.

7.4. Glare

Indoor spaces are illuminated through windows or skylights which can be categorised as large light sources. Glare can be caused by direct or reflected sunlight or by very bright clouds seen in windows during sunny situations. The proposed method applying the parameter Daylight Glare Probability *DGP* based on the formula (5) is standardized. The *DGP* defines measurable physical quantities causing glare from daylight sources.

$$DGP = 5.87\times10^{-5}\times E_v + 9.18\times10^{-2}\times \times log\left(1+\sum_i \frac{L_{s,i}^{2}\times\omega_{s,i}}{E_v^{1.87}\times P_i^2}\right)+0.16, \qquad (5)$$

where E_v is the vertical illuminance at the eye level [lx],

P is the position index,

L_s is the luminance of glare source [cd/m²],

ω_s is the solid angle subtended by glare source,

i is the number of glare sources.

The *DGP* method can be applied in side lit indoor spaces where activities comparable to reading and writing are expected. *DGP* cannot be applied in spaces illuminated by horizontal openings and in position located far away from the window, or where the low levels of daylighting are.

It is important to notice that the method UGR applied in glare evaluation from artificial lighting sources cannot be used for evaluation of glare from natural light sources, e.g. from sun.

8. FUTURE DEVELOPMENTS

We have observed a technological and social development paradox, i.e. very precise and detail results are sent from science and research activities but there are low absorption limits of the praxis. Praxis in daylight design and production of daylight technologies expects simple solutions, which are not expensive, are without extra qualification requirements and consume minimum labour time and

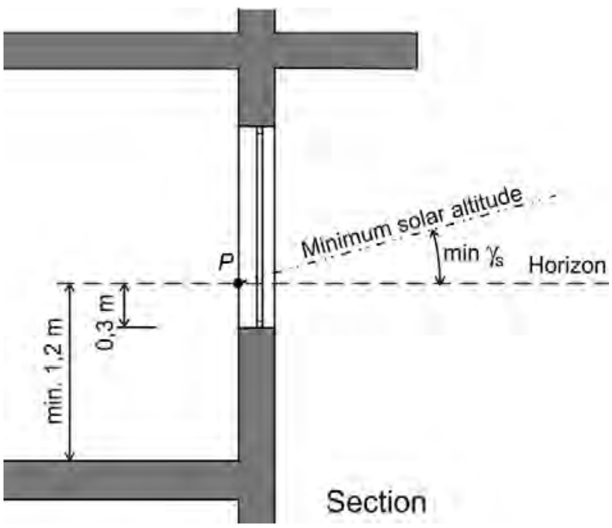


Fig. 10. Placement of reference point for evaluation of sunlight duration

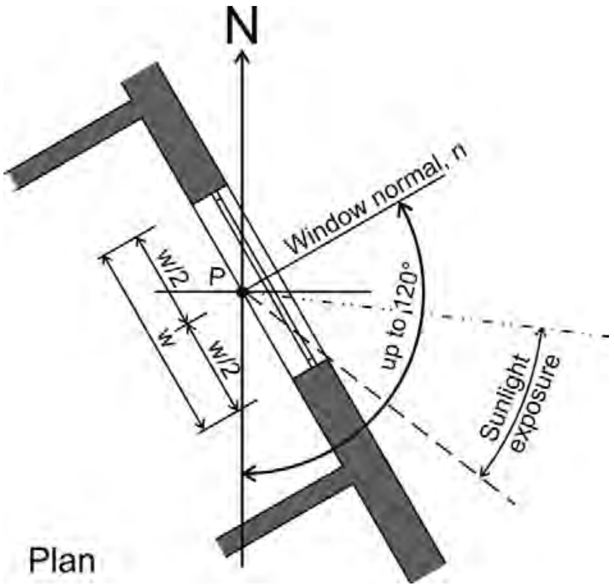


Fig. 11. Scheme of possible window orientation, with the farthest direction from South to East

energy. Quality of outcomes is often taken as a secondary point of interest. Therefore, standards and regulations as engine of activity, rules and development should be applied as basic in lighting engineering. As was mentioned the standardization is specific and an important process in the technical area, which influences the quality of products, visual environment and well-being of occupants in buildings.

For many centuries, human needs are practically the same conditions, but for their accomplishment requirements, assumption, tools and technologies are permanently changing from primitive to more and more sophisticate. New scientific knowledge, technologies and current computerisation leads to study detail relation between natural light conditions and human needs and form a new quality of indoor visual environment. There are several aspects determining trends in future development in the area of interior natural lighting.

8.1. Health

Because all buildings are constructed for people, therefore, imperative for current and future trends is to stimulate health conditions of occupants during their activities and rest by designing indoor illuminance. Daylight as natural source of indoor illumination has to be accessible for all people without any form of discrimination everywhere. Especially spaces designed for children or elderly people must be designed with daylight apertures.

8.2. Science

New research activities are named with a new title but often are periodically solved as the same subjects with new methods and tools. It is very important to formulate problems on the base of photometry, human physiology and psychology in the daylight science. Applying other quantities, e.g. radiant or rating should be avoided because it can incorporate extra errors and substantial deform quality of visual environment and interpretation of achieved results.

Daylight science should be based on the real precise measurements of the sky and sun characteristics as primary daylight sources. There is some information about local daylight availability or daylight climate worldwide. To utilise more effective daylight in interiors its occurrence and dynamic changes should be evaluated in physical units.

The description of spectral properties of daylight sources, colour rendering in the indoors and aspects of the chronobiology matching with artificial sources can be expected in the future research process. New knowledge should be transferred also in to the standardization process with relevant verifiable criteria.

Future research of day and artificial lighting should prove whether less light with daylight than with electric light is sufficient to perform the same visual task [120]. This phenomenon does not allow exchanging quantitative expressions of artificial lighting standard criteria to daylighting and vice versa.

View into near future

The luminous solar constant is one of the basic parameters applied in daylight calculations [121]. To achieve comparable results of daylight solutions the value of the luminous constant should be standardized worldwide.

View into distant future

The standard [70] leaves the classical static approach for daylight evaluation in interiors and brings an opportunity to develop new climatic evaluation methods and tools. Some problem can occur when the statistical parameter as median of daylight availability should be verified. As was mentioned, the sky luminance distribution is crucial in modelling of temporal indoor illuminance. This problem can be studied due to analysis of characteristics of standard sky samples compared with parameters of statistically derived criteria. This approach can be inspiring also for standardization in the simulation of annual daylight availability.

View into horizon close to infinity

Nobody knows what will be in the next century but our civilisation has ambition to conquer the cosmos. As was indicated by Darula in [122], daylight will still be a crucial component of indoor environment. Conditions for life on the Earth and in the Space are totally different. We can expect that new light sources and constructions of luminaires will be developed to supplement natural light source. It is important to respect temporal human physiological needs not to destroy natural body functions. Approach to daylight design can result in the revision of several definitions in lighting engineering.

8.3. Technology

In interior spaces with insufficient daylight the artificial light will be adapted as much as to daylight and will be more and more applied. There is discussion about solutions of artificial sources simulating daylight. Measurements of daily illuminance courses at CIE IDMP stations show, that each exterior daylight situation is original without repetition. Simulation of daylight by artificial sources will require development of such technologies which will produce synthetic lighting situation without repetitions, with intensity changes, relevant colour and dynamic characteristics, and similar influences on human body comparable to daylight courses.

8.4. Economy

Without money, there is no music. Skylight and sunlight are received on the Earth without costs but utilization of daylight and its control in interiors requires investment costs for assembly daylight technologies and costs for their operation. Generally, proper design of natural illumination can save money because electric lighting is switch off when daylight is utilized. New standard [70] is the first bridge for better official application of supplementary lighting and application of artificial lighting in situations with undervalued daylighting.

8.5. Energy

Energy plays an important role in all industrial and tertiary branches in last decades. Energy has become a commodity and its importance will rise also in the future. Tendency is to apply technologies with the lowest energy consumption. This trend is true if respected human needs and will be applied with cheap and effective daylight devices without waste production because nature works without waste.

8.6. Society

Behaviour and expectance of occupants to utilize daylight and sunlight are determined by climatic conditions and activities inside. Generally, people like well lit and sunny rooms in residential buildings. Criteria of standards and system of operation of daylight devices can significantly influence the quality of indoor luminous environment. One can expect redistribution of manual works to more intelligent while people will be more and more replace by robots and computer algorithms in the working process. This can create new conditions for illumination of work places with respect to needs for human, artificial intelligence and coincidence of both.

9. CONCLUSIONS

The gradual progress and development of human civilization and culture were determined by basic needs of mankind and are partly oriented also towards the knowledge of:

– Determination of time and geographical orientation [123, 124] influenced by the sun coordinates or sun path changes with their repetition during years;

– Observation of the sky luminance pattern changes influenced by weather, atmospheric turbidity, cloud type and cover varieties;

– Influences of sunlight and skylight on building fronts with different orientation as well as their penetration through windows inside building interiors.

New knowledge about nature and light are basis for practical design and evaluation of natural and artificial indoor visual environment. Technical standards play a significant role in these activities due to criteria and recommendation. History is showing us, that in the countries with adopted technical standards the economic growth is higher than in other countries. Standards give rules, limits and allow checking effectiveness of lighting systems. Standards are expensive, require a regulatory authority for their administration, and can bring risk when their outcomes are not beneficial, therefore require-

Table 5. The Comparative Geographical Latitude φ and Longitude λ of Russian Cities with Selected CEN Cities

Russian city	φ, deg	λ, deg	CEN city	φ, deg	λ, deg
Makhachkala, Dagestan	42.58° N	47.30° E	Rome	41.90° N	12.50° E
Volgograd	48.71° N	44.51° E	Paris	48.87° N	2.3° E
Komsomolsk-on-Amur	50.57° N	137.00° E	Brussels	50.85° N	4.35° E
Irkutsk	52.28° N	104.28° E	Amsterdam	52.37° N	4.90° E
Moscow	55.75° N	37.62° E	Copenhagen	55.68° N	12.57° E
Saint Petersburg	59.93° N	30.39° E	Oslo	59.91° N	10.75° E
Archangelsk	64.55° N	40.56° E	Reykjavik	64.13° N	21.82° W
Murmansk	68.96° N	33.08° E			

ments must be realistic and testable [6]. Standards should create basis for save minimum requirements, as is presented in this study, and, on the other hand, basis for development of industry, economical and society growth.

Standard criteria and rules in the lighting engineering should be based on the photometric quantities and variables. Conversion irradiance measurements to photometric variables should not be applied because of incorporating extra error depending on the quality of used algorithm.

Development in daylight practice is focused to the formulation of daylight climate conditions and looking for relevant criteria for window design and creation of human acceptable visual environment. The definition of daylight sources applicable in practice seems to be a crucial task for future research. Regular measurements of daylight variables should be carried out in the short intervals collecting instantaneous data. Hourly averages do not represent daylight situations momentary perceived by human eyes.

Standards also can contain useful information and paradigms for other parties. Daylight standardization can bring a rather fair and uniform agreement for a vast territory or states geographically prolonged in the North – South latitudes, e.g. in Russia or the European Union. Applying the same methodology [69] which was used in elaboration of the standard [70], it would seem possible to characterize median sky illuminance also in Russian cities, e.g. the comparable city geographical coordinates are presented in Table 5.

For Archangelsk, as representing the polar regions, is roughly similar to Reykjavik, geographical latitude circa 64.13 N.S. Petersburg is a region close to 60° latitude (approximately that of Helsinki, Stockholm and Oslo) influenced by its close distance to the Baltic Sea. Moscow is representing the continental Russian climate with the same latitude as Copenhagen. Volgograd is a major centre of Southern Russia with the geographical latitude close to Paris, Vienna and Bratislava. Furthermore, it would be wise to take into consideration also the extreme climates of Murmansk (68.96° N) on the far North Russian border or the most Southern border region of Dagestan with the same latitude as Rome. Of course, values of $E_{v,\ d,\ med}$ will slightly differ because of local climate difference.

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