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Sunlight and insolation of building interiors.

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Abstract

Quality of indoor environment can be determined by physical and psychological parameters. Sun radiation access and its vital visual and warm influences are generally required by habitants in interiors. Daylight design of buildings is designed according to minimum illuminance requirements to achieve acceptable visual conditions usually under overcast skies. However, circadian rhythm studies have noticed the importance of higher illuminance levels to stimulate human activities and the proper functions of body organs. Sunlight during a day can offer higher levels of illuminance either directly or by reflection from outdoor and indoor surfaces. There are a lot of indoor spaces permanently occupied by people in various climatic zones in which access to sunlight benefits should be allowed or shaded. Mainly in summer there are workplaces when protection against excessive sunlight causing glare and overheating has to be controlled by sun devices. The survey of criteria for evaluation sunlight provision in buildings across the Europe and basic rules for design of effective insolation of buildings are discussed.

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Keywords: Sunlight; insolation; evaluation of sunlight duration; sunlight provision

1. Introduction

Architectural design of habitable indoor and outdoor spaces is determined by the composition of buildings and interiors within them, orientation and physical properties of building constructions and their components like walls, roofs, façades, windows etc. The quality of indoor environment is influenced by acoustic, thermal, visual phenomena

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and various air pollutants. Sun and sky are main sources of insolation and daylight limiting natural radiation and visual quality of building interiors. Sufficient daylight in interiors is one of the most important factors of health and comfort in buildings [1 - 3]. Daylight influences welfare, human health [4, 5], primarily stimulates and controls circadian rhythms, improves the immune systems, activities of inner and visual organs. As was found by [6] the sunlight is considered by occupants as an important factor of well-being in indoor environment of habitable rooms either residential buildings, offices or in bedrooms of hospitals, schools except classrooms.

Sunlight due to its spectrum and high intensity is utilized in therapeutic applications and in dermatology supporting the production vitamin D and its UV-C component has bactericidal effects [5, 6] while suppressing development of bacteria purifying environment. Exposing skin to sunlight may help to reduce blood pressure, cut the risk of heart attack and stroke. Production of this pressure-reducing compound - called nitric oxide - is separate from the body’s manufacture of vitamin D, which rises after exposure to sunshine UVA irradiation of human skin vasodilates arterial vasculature and lowers blood pressure independently of nitric oxide synthase [7]. This suggests that the cardio-protective effects of sunlight might be due to the nitric oxide released by UVA photolysis of nitrite rather than the UVB induced vitamin D synthesis [8]. This hypothesis was strengthen by the Oplander study [9] investigating blood pressure change post UVA irradiation. Furthermore, population blood pressure correlates directly with latitude and is lower in summer than winter. The findings suggest that exposure to sunlight improves health overall, because the benefits of reducing blood pressure far outweigh the risk of developing skin cancer.

Occurrence of sunny situations varies during a day and can be expressed by the duration time S in hours or by simple dimensionless parameter of relative sunshine duration defined as the ratio of sunny periods to the astronomical day-length or month. The daily relative sunshine duration s_d can be expressed as:

$$s_d = s_i / s_a, \quad [-] \qquad \text{or} \qquad s_d = 100\,(s_i / s_a) \quad [\%] \tag{1}$$

and by the summation of all days in the month the monthly relative sunshine duration s_m will be:

$$s_m = (\Sigma s_i / \Sigma s_a) / MJ \quad [-] \qquad \text{or} \qquad s_m = 100\,(\Sigma s_i / \Sigma s_a) / MJ \quad [\%] \tag{2}$$

where s_i sunshine periods during a day in hours,
s_a astronomical day-length from sunrise to sunset in hours,
MJ number of day in a month.

Sunny situations can be identified from regular measurements of irradiances after recommendation [10] when direct normal irradiance $E_{v,s}$ is at least 120 $W.m^{-2}$.

Contrary to skylight, which illuminates all interior spaces permanently during day time, sunlight can be occasionally blocked by shading clouds or building obstructions. Thus interior effects are influenced by momentary position of the sun and clouds within the window solid angle.

In past two approaches for evaluation of sunlight provision in buildings were proposed and published. The first is based on the measurements resulting in probable sunshine duration expressing possibility of sunshine occurrence in a determined reference day or period [4, 10 - 12]. In this case obtained data of sunlight duration strongly reflect climatic conditions of a specific locality. The second approach assumes a theoretical stable cloudless day/days for sunlight duration assessments, i.e. sky situations with excluded cloud cover [1, 2, 13, 14] and with available sunlight duration from astronomical sunrise to sunset.

2. Sunlight evaluation criteria

Probably, due to climate, social and economic conditions in a specific country the sunlight is respected in the architectural design differently. Traditionally in U.K., Germany and in several EU Eastern countries the standards or codes with criteria and rules for evaluation of sunlight duration were elaborated and are applied. Simple criteria for insolation evaluations were formulated in [13]. In kitchens and bedrooms sunlight should penetrate at least during 1 hour sometime in a day during not less than 10 months within a year from February to November. Sun rays with elevation below 5° were not considered because of obstructions on ground like trees or opposite buildings. In plan, any rays entering under angles higher than 67,5° from the façade normal were ignored because of sunlight penetration block due to facade thickness. The first Czechoslovak standard [15] prescribed isolation 40 minutes every day in the period March 1st to 15th October and allowed the orientation from North of habitable rooms in the azimuth range 60° - 300° in plan.

Nowadays, a similar concept based on the duration of interior insolation in a critical day or period within the year is adopted either in daylight standards or similar codes in several EU countries. In Table 1 is presented the survey of standard criteria for sunlight provision applied in architectural design. There are several EU countries without requirements for insolation in buildings, e.g. Greece or Norway. Generally, in southern EU countries are applied criteria for reduction or elimination of high sun radiation intensities causing glare or overheating. It is important to notice, that there are also buildings occupied by immobile people, children or people which have restricted access to sun radiation. Therefore, in all countries the minimum insolation should be standardised and required in architectural design.

People expect more sunlight in the interiors during dull winter days. Thus, ideal would be to set sunlight criteria for this season but in the urban area this can lead to problems in building orientation and urbanization of cities due to low sun height which could restrict the height of buildings or prolongs distances between them. A compromise solution of this problem is to set sunlight provision criteria to spring or autumn sun paths as is adopted in several national standards or documents to allow development of urban areas and better utilization of sun energy.

Table 1 List of recommended sunlight duration and list of documents in which is required

Country	Sunlight duration requirements/Legislation
Czech Republic	- At least 1,5 hour on March 1st or balance of sunlight duration in the period from February 10th to March 21st is at least 1,5 hour ; - solar altitude is at least 5°.
	Regulation No. 268/2009 about technical requirements for buildings; Standard: ČSN 73 4301:2004.
Estonia	- 3 hours of sunlight during the summer months, i.e. April 22nd to August 22nd.
	RT I: 2002 - Ehitusseadus (Building Code); Standard: EVS 894:2008+A1:2010 (Lighting for residential and office premises).
Germany	- At least 4 hours on March 21st; - 1 hour possible insolation on January 17th (additional winter criterion).
	Bebaungsplan 2007 (Urban planning) - assessing the impact of the planned construction on daylighting of adjacent rooms; Standard: DIN 5034-1: 2010-7.
Italy	- At least 2 hours of sun per day in the period February 19th to October 21st.
	Protocol for evaluation of environmental sustainability for adoption by the Regions in their building regulations; - Regional and Communal codes.
Netherlands	- At least 2 hours of sunlight per day in the period February 19th to October 21st, at least 3 hours of sunlight per day within the period January 21st to November 22nd.
	Some big cities use the so-called 'TNO standard'.
Poland	- At least 3 hours on March 21st and September 21st between 8:00 - 16:00 in schools and buildings for child care while 7:00 - 17:00 in residential buildings on the equinox, - at least 1,5 hour if department has only living room, - at least 4 hours for children play areas in outdoor or at least 2 hours in centre of towns on March 21st and September 21st between 8:00 - 16:00.
	Regulation No. 620/2002 of the Ministry of Infrastructure on the technical requirements to be met by buildings and their placement.
Slovakia	- At least 1,5 hour in low densely area and at least 1 hour in high densely area in the period March 1st to October 13th, (3 hours is recommended), - insolation between 10:00 - 15:00 in the play rooms in building for child care, - solar altitude is at least 5°.
	Regulation No. 259/2008 of the Ministry of Health of the Slovak Republic; Regulation No. 532/2002 of the Ministry of Environment of the Slovak Republic; Standard: STN 73 4301:2005 (Dwellings buildings).

Table 1 Continue

Slovenia	- At least 2 hours on December 21st, 4 hours on March 21st /September 23st and 6 hours on July 21st (TSG-1-004:2010), - insolation of 1 hour on December 21st ; 3 hours on March 21st and September 23st (Municipalities rules).
	Rules on minimum technical requirements for the construction of residential buildings- 2005; TSG-1-004:2010 Technical guideline. Efficient use of energy; Municipalities rules.
Sweden	- At least one room or separable part of a room shall have access to direct sunlight, - at least 5 hours sunlight between 9 am and 5 pm at spring and autumn equinox.
	Boverkets författningssamling - publication Solklart, 1991; Boverkets författningssamling - building regulation BFS 2014:3; H255 - The handbook "To see, hear and breathe in school", 1996.
U. K.	- 25% of probable sunlight hours, at least 5% of probable sunlight hours from 23rd September to 21st March.
	Standard: BS 8206-2:2008; Site planning for daylighting and sunlight, a good practice guide, 2011.

3. Rules for sunlight evaluation

Sunlight penetrates into interiors through windows or skylights. To use all benefits of sun radiation, windows should be openable because of filtering UV radiation by glazing. Insolation depends also on the window width, thickness of façade and window slope and its orientation. As it is shown in Figure 1, it is important to identify transmitted sun rays which cannot reach the indoor space, e.g. due to reflection from glazing or blocking by aperture lining of window. Minimum required sunlight duration is tested by sun beams Θ_1 penetrating into interior within the range of the acceptable angle, in which sun rays can penetrate interior. The dead angle can be determined from width of the opening and thickness of the façade as 90° - Θ_2. Its value 25° is proposed in several national standards.

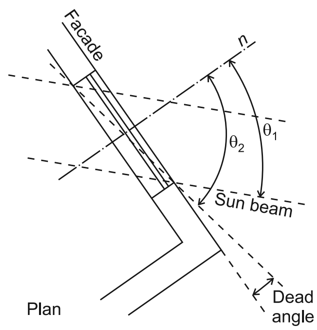
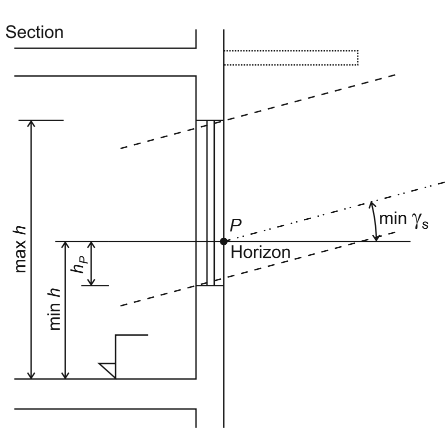


Figure 1 Dead angle and angle of the sun beam incidence Θ_1

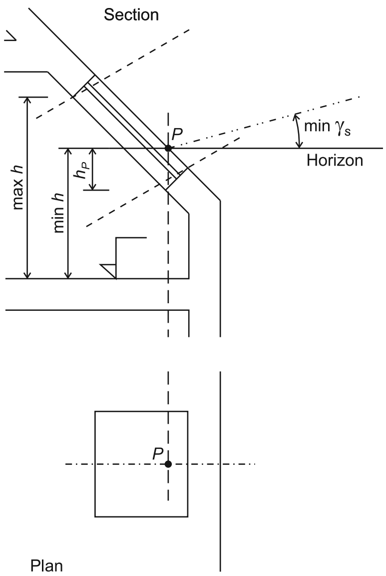
Surrounding buildings in the urban area can screen sun paths and block sun radiation transmission. To evaluate the sunlight it is important to determine location of the reference point *P* on the window plane such that sunrays can penetrate into interior through the glazing area under the overhangs, Figure 2A, and above surrounding obstructions. If γ_s is sun height, α_s is solar azimuth and γ is height of obstructions then rule for calculation of sunlight duration *s* is based on the integration of sunny elemental period s_i (2) after conditions $\gamma < \gamma_s$ if reference point is shaded by obstructions from the ground (e.g. buildings) and $\gamma_s < \gamma$ if reference point is shaded by obstructions from the zenith (e.g. overhangs, balcony, terraces). Testing of the sun rays shading can be processed in the sequence of the solar azimuths α_s, then will be

$$s = \int_{t_{s,i}}^{t_{e,i}} s_i \, dt \qquad \text{[hours]} \tag{2}$$

were $t_{s,i}$ starting time of the sunny period,
$t_{e,i}$ end time of the sunny period,
i number of the sunny period.



A.



B.

Figure 2 Rule for location of the reference point.
A. On a vertical window plane. B. On the plane of a slope window

When reference point *P* is placed on the sill it might occur that sun rays will not penetrate into the interior in the case of a long overhang and block of window frames. If distance h_p will consider thickness of the façade and opaque area of the window frame, than the longer overhangs can be design because of sun rays penetration under overhang. The reference point is taken in the center of the window in several standards which does not respect any longer overhangs, e.g. balcony, Figure 2A. Similar rule for determination of the reference point on the sloped window can be used, as is shown in Figure 2B. Because position of point *P* is eccentric to the main building façade its distance between opposite buildings and main façade is different as well as is true for the point *P*.

In the urban areas surrounding buildings can shade reference point for various times during investigated period. General rule for determination of sunlight duration is based on the determination of period when reference point is exposed to direct sunlight, i.e. starting t_s and finishing t_e time. An example of calculation of the insolation in case of shaded reference point by two buildings is presented in Figure 3. The sun is shining above the one building since 9:45 hour to 11:15, i.e. 1:30 hour. Sun path is totally shaded by the second building, therefore insolation is not recorded since 11:15 to 13:00. Because end of insolation is limited by the dead angle the duration of second insolation period will be 53 minutes. Finally, the daily insolation of reference point is calculated by the summation of both periods, e.g. s = 1:30 + 0:53 = 2:23 hours.

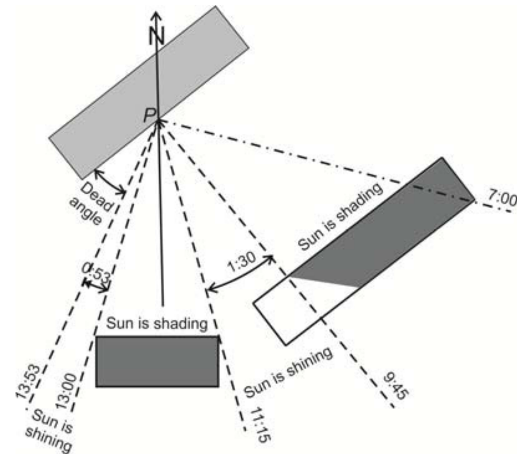


Figure 3. Example of evaluation of the insolation at the reference point *P*

4. Conclusion

Sun, light and air are substances which are considered as main factors of life on the Earth and which are important also in design of health building environment. While Middle Ages were characteristic by dense urbanization closed by fortifications, the last two centuries opened town environments to nature and to sun. The access to sun in the residential building became one of the priorities of the apartment quality. To design good insolated interiors the criteria and rules have to be determined thus to allow urbanization of cities with sufficient interior insolation. As recent practice have showed the minimum insolation of 1,5 hour at equinox seems to be adequate for people in buildings. Reference point, in which insolation is calculated, should be located at the façade surface in the area of the window respecting orientation of the window façade, dead angle and the minimum admissible solar altitude. Insolation of interiors should be required in residential buildings, building for health care, seniors, children and for people with restricted access to sun.

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