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# REVIEW OF SUNLIGHT EXPOSURE OF BUILDINGS IN CENTRAL EUROPE CLIMATIC CONDITIONS

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Abstract. The sunlight exposure represents one of key parameters of indoor climate comfort. The evaluation of sunlight access into buildings is based on a methodology of European standard EN 17037. The methodology is focused on specification of an insolation time which would comply with requirements for the sunlight expo sure of permanently occupied spaces like houses and residential buildings as well as schools or hospitals. The sunlight exposure evaluation is recommended to be between 1st February and 21st March. The specific date from the interval can be selected for individual evaluations. This is a relatively long period of days in which the insolation could vary meaningfully.

The aim of this study is to evaluate how the sunlight exposure might be changed in the recommended standard period in dependence on the geographic locality and climatic conditions in the Central Europe region. It depends on the sunlight time and specific design situations as well as shading obstructions. The review of the sunlight exposure is determined. The review results can perform information about design possibilities for the sunlight exposure in real buildings in the given climatic locality.

Keywords: Solar radiation, sunlight exposure, solar altitude, building insolation.

## 1. Introduction

Sunlight positively influences on indoor climate in buildings. Access of sunlight into rooms is one of key parameters of the building design [1, 2]. Sunlight time for building insolation performs importance of the insolation for occupied rooms [3, 4]. Criteria for evaluation sunlight provision in buildings and basic rules for design of effective insolation of buildings were specified in standard requirements [5]. They are useful for comparable evaluation of sunlight exposure in different European localities. These requirements represent ways of urban development regulation with respect of solar radiation access for sustainable and comfortable built environment.

Requirement are specified for residential buildings as well as schools and kindergartens and hospital rooms. For the insolation assessment all aspects need to be considered as a window size and its position in the facade and orientation to cardinal points, distance and geometry of shading obstructions. Geographic locality and date and time of the evaluation also play key role for the insolation prediction.

The insolation is evaluated for the control point positioned on the internal surface of the window glass pane. It is position where the point and the window jamb limit the horizontal angle of the solar radiation access. Apart the horizontal angle also a vertical angle is taken into the consideration.

This elevation angle represents of minimum solar altitude which can be accepted for the sunlight access into a room. This angle is a parameter for specification of minimum solar exposure changes in different European countries as determined in the standard metric of EN 17037 [5]. This minimum angle is lower for northern countries compared to southern localities. This is in a response of sun position. Values of minimum solar altitude are for capital of EU countries specified for day of 21st March [5].

The sunlight exposure can be evaluated for any days between 1st February and 21st March. This is a relatively long interval in which insolation can be changed significantly [6]. This paper is focused on a study of the daytime for determination of minimum solar altitude for a specified locality in the EU region.

## 2. Method

Sunlight access into a building was studied localities of the Central Europe region with latitudes from 46° to 52.5° which comprises countries Slovenia, Switzerland, Hungary, Austria, Slovakia, Czechia, Poland and Germany. Capitals of the mentioned countries are specified for geographical localities and minimum required solar altitude. The minimum solar altitude was calculated for 1st and 21st February as well as 1st and 21st March for sunlight exposure time minimum 1.5 hour of sunlight exposure for sunny and cloudless conditions.

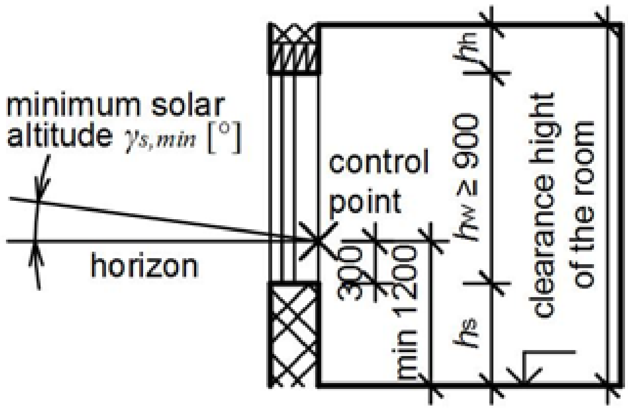


Figure 1. Minimum solar altitude in accordance with EN 17037 [5] ($h_s$ is height of the window sill, $h_w$ is height of the window, $h_h$ is height of the window head).

Solar altitude is determined as:

$$\gamma_s = \arcsin(\cos\omega_\eta \times \cos\varphi \times \cos\delta + \sin\varphi \times \sin\delta), \tag{1}$$

where

$\omega_\eta$ [°] is hour angle determined by:

$$\omega_\eta = 15° \times (TST - 12), \tag{2}$$

$TST$ is true solar time in hours,

$\varphi$ [°] is the geographical latitude of the site,

$\delta$ [°] is the declination of the sun determined by:

$$\delta = 0.3948 - 23.2559 \times \cos(J' + 9.1°) - 0.3915 \times \cos(2 \times J' + 5.4°) - 0.1764 \times \cos(3 \times J' + 26.0°). \tag{3}$$

The parameter $J'$ [°] indicates the day number converted to an angular measure and is determined by equation:

$$J' = 360° \times \frac{J}{365}, \tag{4}$$

where $J$ is the day number of the year (e.g. for 1st January, $J = 1$ and for 31st December, $J = 365$, February is taken to have 28 days).

## 3. The solar altitude in the considered localities

The solar altitude was calculated in all localities according Equation (1). The necessary input parameters are listed in the Table 1.

| **Country** | **Capital** | **Geographical latitude $\varphi$ [°] by EN 17037 [5]** | **Geographical longitude $\lambda$ [°] of the capital** |
|---|---|---|---|
| Austria | Wien | 48.12 N | 16.22 E |
| Czechia | Prague | 50.10 N | 14.22 E |
| Germany | Berlin | 52.47 N | 13.25 E |
| Hungary | Budapest | 47.48 N | 19.05 E |
| Poland | Warsaw | 52.17 N | 21.00 E |
| Slovakia | Bratislava | 48.20 N | 17.07 E |
| Slovenia | Ljubljana | 46.22 N | 14.33 E |
| Switzerland | Bern | 46.25 N | 7.28 E |

Table 1. Considered localities and their characteristics.

It was considered with true solar time. The large variable of the geographical longitude in the considered localities was the reason. The declination of the sun determined by Equation (3) is:

- $\delta = -17.30°$ for 1st February, the day number of the year is $J = 32$;

- $\delta = -10,80°$ for 21st February, the day number of the year is $J = 52$;
- $\delta = -7,83°$ for 1st March, the day number of the year is $J = 60$;
- $\delta = -0,02°$ for 21st March, the day number of the year is $J = 80$.

The Figure 2 shows the dependence of the sun altitude on time during the day.

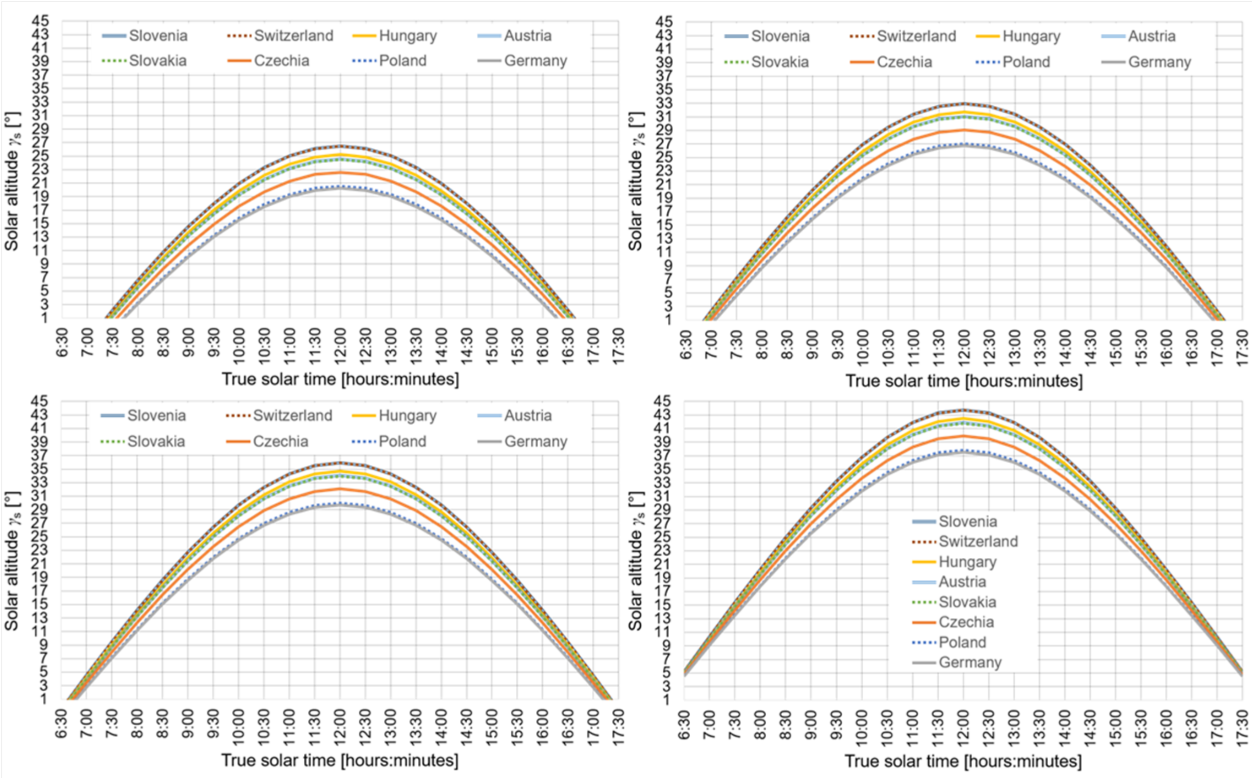


Figure 2. Dependence of the sun altitude on the time (top left for 1st February, top right for 21st February, bottom left for 1st March, bottom right for 21st March).

## 4. Extreme limit for the position of the sun

The standard EN 17037 [5] specifies the maximum diversion of the normal line of a window from the south 120°, as shown in Figure 3 on the left. This means the maximum position of the window lining from 30° to 210°.

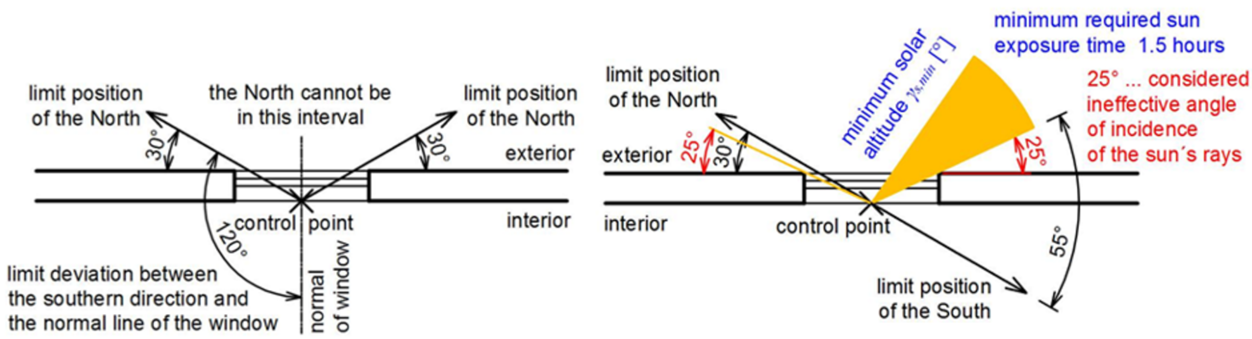


Figure 3. Recommended window orientation to cardinal points (on the left) and marginal condition of calculating the minimum solar altitude (on the right).

It can be seen from Figure 3 on the right that the effective angle of incidence of the sun's rays is in the range from 55° to 185° at the limit of the window orientation. It is necessary to know the azimuth of the sun to express the minimum required height of the sun. The topographic azimuth $\alpha_s$ [°] given in EN 17037 [5] is determined according to the equation:

$$\alpha_s = 180° \pm \arccos \frac{\sin \gamma_s \times \sin \varphi - \sin \delta}{\cos \gamma_s \times \cos \varphi}. \tag{5}$$

The use of the astronomical azimuth $\alpha_{ast}$ [°], which represents the divergence of the sun's rays from the south, is more advantageous for the subsequent calculation (with the use of [7] and [8]):

$$\operatorname{tg}\alpha_{ast} = \frac{\sin\varpi_\eta}{\sin\varphi \times \cos\varpi_\eta - \cos\varphi \times \operatorname{tg}\delta}. \tag{6}$$

All partial quantities mentioned in Equations (5) and (6) have already been described above. The Equation (6) is advantageous in expressing the required sun exposure time by means of an hour angle $\omega_\eta$ [°]. Subsequent expression of the height of the sun depending on the hour angle is our effort namely, as the following mathematical adjustments show:

$$\operatorname{tg}\alpha_{ast} \times \sin\varphi \times \cos\varpi_\eta - \operatorname{tg}\alpha_{ast} \times \cos\varphi \operatorname{tg}\delta = \sin\varpi_\eta \tag{7}$$

$$(\operatorname{tg}\alpha_{ast} \times \sin\varphi \times \cos\varpi_\eta - \operatorname{tg}\alpha_{ast} \times \cos\varphi \operatorname{tg}\delta)^2 = 1 - \cos^2\varpi_\eta \tag{8}$$

$$\begin{aligned}\operatorname{tg}^2\alpha_{ast} \times \sin^2\varphi \times \cos^2\varpi_\eta - 2 \times \operatorname{tg}^2\alpha_{ast} \times \sin\varphi \times \cos\varphi \times \cos\varpi_\eta \times \operatorname{tg}\delta \\ + \operatorname{tg}^2\alpha_{ast} \times \cos^2\varphi \times \operatorname{tg}^2\delta + \cos^2\varpi_\eta - 1 = 0\end{aligned} \tag{9}$$

$$\begin{aligned}(\operatorname{tg}^2\alpha_{ast} \times \sin^2\varphi + 1) \times \cos^2\varpi_\eta - (2 \times \operatorname{tg}^2\alpha_{ast} \times \sin\varphi \times \cos\varphi \times \operatorname{tg}\delta) \times \cos\varpi_\eta \\ + tg^2\alpha_{ast} \times \cos^2\varphi \times \operatorname{tg}^2\delta + \cos^2\varpi_\eta - 1 = 0.\end{aligned} \tag{10}$$

The solution of the general quadratic equation written in the form $ax^2 + bx + c = 0$ has two roots, which are determined according to the equation:

$$x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}. \tag{11}$$

The solution for the value of the hour angle at the boundary of the ineffective angle of incidence of the sun's rays is obtained substituting Equation (10) to Equation (11). The 1st root of the equation (the + sign) is important:

$$\begin{aligned}\cos\varpi_\eta = &\frac{2 \times \operatorname{tg}^2\alpha_{ast} \times \sin\varphi \times \cos\varphi \times \operatorname{tg}\delta}{2 \times (\operatorname{tg}^2\alpha_{ast} \times \sin^2\varphi + 1)} \\ &+ \frac{\sqrt{4 \times (\operatorname{tg}^2\alpha_{ast} \times \sin\varphi \times \cos\varphi \times \operatorname{tg}\delta)^2 - 4 \times (\operatorname{tg}^2\alpha_{ast} \times \sin^2\varphi + 1) \times (tg^2\alpha_{ast} \times \cos^2\varphi \times \operatorname{tg}^2\delta + \cos^2\varpi_\eta - 1)}}{2 \times (\operatorname{tg}^2\alpha_{ast} \times \sin^2\varphi + 1)}.\end{aligned} \tag{12}$$

The solution of Equation (12) is given in Table 2 for the considered localities. Latitudes were considered according to Table 1. The azimuth value was $\alpha_{ast} = 55°$ in accordance with the above text. The declination values are given in Section 3.

The required sun exposure time of 90 minutes, i.e. 1.5 hours, corresponds to an hour angle. After substituting into the modified Equation (2): $\omega_{\eta,1.5\mathrm{h}} = 15 \times 1.5 = 22.5°$. The limit value of the hour angle is therefore:

$$\omega_{\eta,req} = \omega_\eta + \omega_{\eta,1.5\mathrm{h}} = \omega_\eta + 22.5. \tag{13}$$

| **Country** | **Hour angle Min. solar altitude** | **Date** | | | |
|---|---|---|---|---|---|
| | | **1st February** | **21st February** | **1st March** | **21st March** |
| Austria | $\omega_\eta$ [°] | 58.495 | 53.915 | 51.913 | 46.769 |
| | $\gamma_{s,min}$ [°] | -6.99 | 0.83 ⟶ **0.7** | 4.37 ⟶ **4.3** | 13.65 ⟶ **13.5** |
| Czechia | $\omega_\eta$ [°] | 58.703 | 54.378 | 52.486 | 47.624 |
| | $\gamma_{s,min}$ [°] | -7.73 | -0.04 | 3.44 ⟶ **3.3** | 12.58 ⟶ **12.4** |
| Germany | $\omega_\eta$ [°] | 58.889 | 54.863 | 53.101 | 48.568 |
| | $\gamma_{s,min}$ [°] | -8.55 | -1.01 | 2.41 ⟶ **2.3** | 11.38 ⟶ **11.2** |
| Hungary | $\omega_\eta$ [°] | 58.418 | 53.753 | 51.715 | 46.480 |
| | $\gamma_{s,min}$ [°] | -6.737 | 1.13 ⟶ **1.0** | 4.69 ⟶ **4.5** | 14.02 ⟶ **13.9** |
| Poland | $\omega_\eta$ [°] | 58.869 | 54.806 | 53.027 | 48.453 |
| | $\gamma_{s,min}$ [°] | -8.45 | -0.89 | 2.53 ⟶ **2.4** | 11.53 ⟶ **11.4** |
| Slovakia | $\omega_\eta$ [°] | 58.505 | 53.935 | 51.937 | 46.805 |
| | $\gamma_{s,min}$ [°] | -7.02 | 0.80 ⟶ **0.6** | 4.33 ⟶ **4.2** | 13.61 ⟶ **13.4** |
| Slovenia | $\omega_\eta$ [°] | 58.250 | 53.418 | 51.308 | 45.890 |
| | $\gamma_{s,min}$ [°] | -6.23 | 1.72 ⟶ **1.5** | 5.32 ⟶ **5.2** | 14.75 ⟶ **14.6** |
| Switzerland | $\omega_\eta$ [°] | 58.254 | 53.426 | 51.318 | 45.905 |
| | $\gamma_{s,min}$ [°] | -6.24 | 1.71 ⟶ **1.6** | 5.31 ⟶ **5.2** | 14.73 ⟶ **14.6** |

Table 2. Minimum solar altitude $\gamma_{s,min}$ [°].

The minimum solar altitude is obtained by substituting the required hour angle $\omega_{\eta,req}$ [°] together with other known data to Equation (1).

The values of the equation of time are by Equation (15) following: $-0.226$ h for 1st February; $-0.232$ h for 21st February; $-0.212$ h for 1st March and $-0.122$ h for 21st March.

The negative values $\gamma_{s,min}$ [°] mean that the sun position is too low and it is not possible to ensure sun exposure therefore. The positive values $\gamma_{s,min}$ [°] apply during simplification that local time is the same as true solar time. The values behind the arrow, which are reduced by 0.1° to 0.2°, are considered more appropriate. They take into the account the tolerance of the results and also apply to the calculation of true solar time according to Equation (14).

Determining the date of sun exposure will be necessary to verify the validity of the calculation. The true solar time required to accurately calculation of Equation (2) is determined in dependence on the location and local time:

$$TST = LT + \frac{\lambda - 15}{15} + ET, \tag{14}$$

where

$TST$ is true solar time in hours,

$LT$ is true solar time in hours,

$\lambda$ is true solar time in hours,

$ET$ is equation of time in minutes (need to convert to hours for further use):

$$ET = 0.0066 + 7.3525 \times \cos(J' + 85.9°) + 9.9359 \times \cos(2 \times J' + 108.9°) + 0.3387 \times \cos(3 \times J' + 105.2°), \tag{15}$$

in where $J'$ [°] is determined by Equation (4).

| Country | Time* | Quantities | 21st February | 1st March | 21st March |
|---|---|---|---|---|---|
| Austria | s | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | 0.7 / 0.78 | 4.3 / 4.32 | 13.5 / 13.51 |
| | | Sunlight exposure [from : to] | 6:54 to 8:24 | 7:02 to 8:32 | 7:22 to 8:52 |
| | d | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | 0.7 / 0.77 | 4.3 / 4.35 | 13.5 / 13.59 |
| | | Sunlight exposure [from : to] | 7:03 to 8:33 | 7:10 to 8:40 | 7:25 to 8:55 |
| Czechia | s | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | — | 3.3 / 3.44 | 12.4 / 12.50 |
| | | Sunlight exposure [from : to] | | 7:00 to 8:30 | 7:22 to 8:49 |
| | d | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | — | 3.3 / 3.31 | 12.4 / 12.43 |
| | | Sunlight exposure [from : to] | | 7:15 to 8:45 | 7:29 to 8:59 |
| Germany | s | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | — | 2.3 / 2.32 | 11.2 / 11.28 |
| | | Sunlight exposure [from : to] | | 6:57 to 8:27 | 7:15 to 8:45 |
| | d | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | — | 2.3 / 2.36 | 11.2 / 11.23 |
| | | Sunlight exposure [from : to] | | 7:17 to 8:47 | 7:29 to 9:00 |
| Hungary | s | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | 1.0 / 1.13 | 4.5 / 4.66 | 13.9 / 14.00 |
| | | Sunlight exposure [from : to] | 6:55 to 8:25 | 7:03 to 8:33 | 7:24 to 8:54 |
| | d | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | 1.0 / 1.01 | 4.5 / 4.58 | 13.9 / 13.98 |
| | | Sunlight exposure [from : to] | 6:52 to 8:22 | 6:59 to 8:29 | 7:15 to 8:45 |
| Poland | s | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | — | 2.4 / 2.40 | 11.4 / 11.50 |
| | | Sunlight exposure [from : to] | | 6:57 to 8:27 | 7:16 to 8:46 |
| | d | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | — | 2.4 / 2.45 | 11.4 / 11.45 |
| | | Sunlight exposure [from : to] | | 6:46 to 8:16 | 6:59 to 8:29 |
| Slovakia | s | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | 0.6 / 0,75 | 4.2 / 4.29 | 13.4 / 13.48 |
| | | Sunlight exposure [from : to] | 6:54 to 8:24 | 7:02 to 8:32 | 7:22 to 8:52 |
| | d | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | 0.6 / 0,65 | 4.2 / 4.23 | 13.4 / 13.48 |
| | | Sunlight exposure [from : to] | 6:59 to 8:29 | 7:06 to 8:36 | 7:21 to 8:51 |
| Slovenia | s | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | 1.5 / 1.67 | 5.2 / 5.36 | 14.6 / 14.68 |
| | | Sunlight exposure [from : to] | 6:56 to 8:26 | 7:05 to 8:35 | 7:26 to 8:56 |
| | d | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | 1.5 / 1.57 | 5.2 / 5.30 | 14.6 / 14.67 |
| | | Sunlight exposure [from : to] | 7:12 to 8:42 | 7:20 to 8:50 | 7:36 to 9:06 |
| Switzerland | s | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | 1.6 / 1.66 | 5.2 / 5.20 | 14.6 / 14.67 |
| | | Sunlight exposure [from : to] | 6:56 to 8:26 | 7:04 to 8:34 | 7:26 to 8:56 |
| | d | Requirement / Real min. solar altitude $\gamma_{s,min}$ [°] | 1.6 / 1.69 | 5.2 / 5.26 | 14.6 / 14.63 |
| | | Sunlight exposure [from : to] | 7:41 to 9:11 | 7:48 to 9:18 | 8:04 to 9:34 |

* The letter s indicates simplification that $LT$ (local clock time) = $TST$ (true solar time).
The letter d indicates the determination of $TST$ according to Equation (14).

Table 3. Sunlight exposure (total sunlight exposure is min. 1.5 hours in all cases).

## 5. Results

Minimum solar altitude is a key parameter for building insolation assessment. Results of the minimum solar altitude $\gamma_{s,min}$ [°] for sunlight exposure 1.5 hour are for all localities summarized in Table 3. It is obvious that for geographical localities of Central Europe the minimal solar altitude is applicable from about 21$^{st}$ February and from 1$^{st}$ March for localities with latitude bigger than 50°.

However, it must not be forgotten that the sun's rays at an elevation of up to 5° (see [8]) above the horizon cover a relatively large distance through the atmosphere. Namely, the effectiveness of the positive effects of sunlight is reduced.

## 6. Conclusion

The paper shows results of sunlight exposure of the Central Europe localities based on the EN 17037 methodology. Results show that the method of the building insolation assessment has a potential impact of the building design and its indoor environment in different climatic localities. Climate-based evaluation of the solar provision in buildings has utmost importance especially in highly occupied indoor spaces.

Sunlight exposure has importance for indoor climate in buildings [9]. Window position and orientation play key roles for access solar radiation into interiors. It is influencing factor for urban planning and building design [10–12]. Minimal solar altitude was calculated for several European localities. Results calculated according to the standard EN 17037 show relatively bigger differences in minimal solar altitude influenced by the geographic latitude, day and time of the assessment. The minimal solar altitude is applicable parameter from 21$^{st}$ February in the Central European region. This region is mostly characterized by partly cloudy and overcast skies. It means that the exposure to sunlight should be considered carefully to ensure insolation in interiors. This is mostly important for places with permanent occupancy like residential buildings, schools and hospitals.

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