Influence of date of computation of insolation duration on acceptable height and position of buildings

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Abstract. The influence of the date of computation of insolation duration on the acceptable mutual position of buildings and their height was studied. The relevance of the research is explained by changing of the date of normative insolation computation from March 22 to April 22, which had been adopted in Russia. The study was performed using computer 3D modeling of buildings and building of the fields displaying the duration of insolation on the building walls and surrounding territories. It is demonstrated that when calculating the insolation with the new date of April 22, it is acceptable to increase the height of buildings and reduce the distance between buildings by 30%, as well as to reduce the angle between a northern building wall and the parallel from 48° to 24°. The specifics of insolation for L-shape buildings was revealed. It is shown that with transition of the calculation date from March to April, the insolation on inner walls decreases. The study of this special case was performed. The examples are given, which show negative manifestations of the revealed effect. The studies were performed in AutoCAD package using the system of automatic computing and building of insolation fields.

1. Introduction
Insolation is lighting of facilities with direct sunlight. In Russia, when designing buildings, the computation of insolation duration is mandatory. The computation is performed in compliance with the current standards [1,2], stipulating the calculation date and other parameters, which the insolation should conform with.

Before 2017, the computation for the central part of Russia was performed for March 22 or September 22 – the equinox day. In 2017, a new computation date was set – April 22 or August 22. With this new date the solar elevation angle increases, as does the duration of day time. This allows to increase the acceptable height of buildings and reduce the acceptable distance between buildings [3-8].

The objective of this work is to study the influence of the switching to a different date of computation of insolation duration on the acceptable height of buildings and building density.

2. Method of Research
The research was performed in AutoCAD [9,10] package based on computer-aided design system for calculation of insolation [11,12] by means of building and studying of insolation fields [8].

To calculate the duration of insolation in point A, we build 3D models of buildings at an undefined scale, see Figure 1(a). We build a cone of rays, with the vertex placed in point A. The cone axis i is determined by the value of angle φ, which is equal to the geographical latitude. For Moscow and
Chelyabinsk, $\varphi = 55$ degrees. Angle $\delta$ is calculated using the Cooper formula [8,13,14]. For March 22, $\delta = 0$, that is, the cone degenerates into plane $\gamma$. For April 22, $\delta = 11.93$ degrees. The cone is cut off at the level of the horizon plane $\text{horizon} \supset A$, meanwhile the rays of the sunrise $AB$ and sunset $AC$ are determined.

We build crossings of buildings with the cone, and the rays from point $A$, covering these crossings, see Figure 1(b). We find points 1…5 where rays cross the circumference of the cone base. In the cone base plane, see Figure 1(c), we measure angles $\alpha$, $\alpha'$, $\alpha''$, which define the duration of insolation sectors, then we calculate their sum $\alpha_E$. The value of $\alpha_E$ is converted into time interval $\text{insol}$ as per ratio $15^\circ = 1$ hour.

![Figure 1. Algorithm of measuring the duration of insolation: a – parameters of the cone of rays; b – the cone crossing the buildings; c, d – measuring the angles of insolation.](image)

According to the standards [1-3], angles $\varepsilon = 15^\circ$ are subtracted from $\alpha_E$ at sunrise and sunset. If point A is located on a building’s wall, a 3D model of a window, balcony or recessed balcony is created in this point. In simplified calculations, instead of these models, the preliminarily determined angles $\eta$ [1] are subtracted from $\alpha$ sum, see Figure 1(d). In our work, a model of smooth walls with $\eta = 8^\circ$ was adopted. The computation algorithm takes into consideration a whole number of other requirements, the detailed description of which is given in work [8].

The obtained final value is compared to the acceptable value. If the point has a sole sector of insolation (continuous insolation), then the acceptable value equals 2 hours; in case of several sectors (discontinuous insolation) it equals 2.5 hours.

The insolation fields given below are formed by the insolation computation inside the contour of a wall or space. The calculations are made in the knots of a rectangular grid. The number of cells along each direction of the grid is set depending on the required accuracy within the interval of 50 to 150. In the points markers are placed, the color of which is determined by the value of insolation $\text{insol}$, see Figure 4(c). The zones of acceptable insolation are colored yellow or green. The unacceptable insolation is marked red and blue.

The red zone appearing on building walls is taken as the criterion of the maximum permissible position or height of buildings.

3. Distance between Buildings

Let us consider the changes in the insolation fields in case of shortening the distance between two buildings parallel to each other and oriented along the meridian. The buildings’ dimensions should be deemed identical: 120 in length, 15 in width, and 60 in height.

With the distance $\text{del} > 105$, the insolation of all the walls and ground is $> 3$ hours. The exception is the northern walls where insolation is absent. When $\text{del} = 100$, a small green-colored zone $2<\text{insol}<3$ forms, see Figure 2(a). As the distance between the buildings gets shorter further on, this zone increases, see Figure 2(b). When $\text{del}=80$, red-colored zone in the form of a thin strip in the bottom wall appears on the inner building walls, see Figure 2(c). This is a sign of the case of unacceptably low insolation $\text{insol} < 2$ on the buildings’ lower storey. When $\text{del} = 60$, red-colored zone on the wall increases significantly, see Figure 2(d). When $\text{del} = 55$, blue-colored zone appears on the wall.
signaling that insol < 1 hour, and vast red zone forms on the ground, see Figure 2(e). The maximum permissible distance between buildings at which red zone appears on building walls equals del = 80, see Figure 2(c).

![Figure 2](image)

**Figure 2.** Fields of insolation depending on the distance del between the buildings. March 22: a – del = 100; b – del = 90; c – del = 80; d – del = 60; e – del = 55; f – color of markers. April 22: g – del = 60; h – del = 55; i – del = 40.

In April the picture of the insolation fields repeats itself qualitatively. However, acceptable distance between buildings decreases. Green zone appears at del=80. The picture, see Figure 2(g), forms at del=60. Red zone appears at del=55, see Figure 2(h). Blue zone appears on the walls at del=40, see Figures 3(i).

Therefore, as per the criterion of forming of red zone, the changing of the computation date from March 22 to April 22 allows to put buildings by ≈30% closer to each other.

4. Height of Buildings
Let us assess the influence of the computation date on the maximum height of buildings. Let us take the same model of two parallel placed buildings of identical height, oriented along the meridian. Let us consider the results of two experiments. The first experiment aimed at determining the maximum height for March and April at del=80, and the second one – at del = 100. Let us adopt the previous criterion of unacceptable insolation – appearance of red zone in the lower storeys on the inner building walls.

In March for del=80 the maximum height equaled h=60, see Figure 2(c). Let us change the computation date to April. With the same value of del=80, we will gradually increase the height of both buildings until red zone appears, see Figure 3 (a). The maximum height in April equaled 85, i.e. it increased by ≈30% as compared to March.

Let us compare the maximum height of the same buildings at del=100. For March, the maximum height was reached at 75, see Figure 3(b). For April, at h=105, see Figure 3(c). That is, like in the previous experiment, the acceptable building height for April 22 grew by ≈30%.
5. Building Position Relative of the Parallel

On March 22 the daylight period equals 12 hours. On April 22 this period equals ≈14 hours 21 minutes, that is, longer by ≈2 hours 21 minutes. Let us assess the influence of the daylight period duration on the possible position of buildings. We will perform the assessment experimentally, by decreasing the value of angle \( \lambda \) and determining the duration of insolation on the wall, see Figure 4(a).

On March 22, at \( \lambda \geq 65 \), the insolation of the whole wall exceeds 3 hours (yellow zone on the whole wall). Green zone appeared at \( 64 \geq \lambda > 48 \), see Figure 4(a). Red zone, which shows the maximum value of angle \( \alpha_f \), covered the whole wall at \( \alpha_f = 47 \) and remained till \( \lambda \geq 45 \), see Figure 4(b).

At \( \lambda < 45 \), the insolation of the wall is less than 1 hour (blue zone), see Figure 4(c).

When performing computation for April 22, the picture of the fields is qualitatively as it was before. However, green zone appears at \( \lambda = 40 \). Red zone covers the whole wall at \( 24 \leq \lambda \leq 18 \), see Figure 4(d). Blue zone forms at \( \lambda < 18 \).

The cause for that is explained by the fact that the beginning of the sector of light for a random point of the wall in March matches with the East-West parallel, see Figure 5(e). In April the sector of light begins \( \omega = 17.6^\circ \) earlier, see Figure 4(f). Views are built in the direction of the rays cone axis \( i \), see Figure 1(a).

Therefore, when performing computation for April 22, as compared to March 22, the angle between the direction of the northern wall and the parallel can be decreased from 48 to 24 degrees, i.e. twice.
6. Specifics of Insolation of L-shape Buildings

The previous experiments demonstrate that insolation in April increases, as compared to March. However, it was determined that for L-shape buildings the duration on insolation on the inner walls decreases in April, as compared to March. To reveal the causes, a model given in Figure 5 (a) was studied. The length of a high-rise building was set as equal to 1460, what guaranteed that the light cone was crossing the upper edge of the building from February through October. In points 0-20, which corresponded to the lower storey windows, the duration of insolation was measured, and light sectors were controlled.

Figure 5(b) and (c) shows that for window points 0-11 insolation decreases from December till June, and including from March to April. For instance, in point 2, see Figure 5(b), curves 4 and 5, when performing computation for March 22, the duration equaled 5 hours 6 minutes, or 76.5°. When computing for April 22, the duration decreased to 4 hours 34 minutes, or 68.5°, that is by 32 minutes.

The effect of insolation decrease is revealed from point 0 to point 11.5. In point 11.5, starting from February through October, insolation does not depend on the date of computation. After point 11.5 the usual effect of the insolation increase resumes, as June 22 nears.

![Figure 5](image1)

Figure 5. Changing in the duration of insolation on the walls of an L-shape building: a – building model; b – insulation in the points as per different months of the year (day 22); c – insolation depending on the month; d – model of insolation.

The effect of insolation decrease is revealed from point 0 to point 11.5. In point 11.5, starting from February through October, insolation does not depend on the date of computation. After point 11.5 the usual effect of the insolation increase resumes, as June 22 nears.

Figure 5(d) depicts the model explaining the revealed effect of the insolation decrease. The change in the angle of the sector of light is shown, which is located between the walls of the L-shape building. The cone angles φ and δ are assigned values, which enhance the clarity of the result. The cone corresponds to summer season. It is obvious that angle α°, measured as per the ray cone, is smaller than α°, measured in March as per equinox plane λ. Using the same model it is possible to trace other specifics of the effect under consideration. As the distance between the cone and the angle edge increases, the ratio between angles α° and α changes. There exists a cone position, at which α° = α, and with further increase of the distance α° > α.

Figure 7 (a) shows the manifestations of the insolation decrease effect under consideration. Models of two buildings for March 22 are given. The models were determined using the method [15–17]. The computation as per March 22 demonstrated that the construction of these buildings would not result in the unacceptable insolation of the existing buildings – this is obvious form the absence of red zones on...
the walls of these buildings. However, the computation as per April 22 for the same buildings revealed the appearance of red zones, meaning that insolation in certain parts of the walls became lower than the standard value. Therefore, the conclusions made on insolation as per March 22 became invalid for April 22.

7. Conclusion

The method was proposed for assessing geometrical shape and mutual position of buildings based on building fields of insolation. The acceptable shape of buildings and their position are determined as per appearance, in the reference parts of the walls, of the red-colored signal zones standing for low level of insolation.

The suggested method is fulfilled via the system of automatic computation of insolation [8,11], as well as [18-20]. The method’s efficiency increases with the increase of the building density and of the complexity of geometrical shapes of buildings.

In most cases of dense building, the changing of the computation date from March 22 to April 22 allows to increase the height of buildings by 30%, decrease the distance between buildings also by 30%, and decrease the maximum angle between the northern wall of a building and the parallel from 48° to 24°.

It was determined that for L-shape buildings the changing of the computation date from March 22 to April 22 may cause the decrease in insolation on the inner walls. This will lead to inaccurate results based on measuring insolation as per March 22 while switching to a different date of computation, to April 22 in particular.

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Figure 6. Changing in the duration of insolation in case a new building is constructed: a – examples of two buildings; b,d – insolation as per March 22; c,e – April 22.
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