Automation of computation of insolation duration in architectural design

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Abstract. The system of automated computation of the insolation duration is considered as applied to the tasks of architectural design. The model and algorithm of computation and plotting are given. The system allows to perform computation in a point, inside a contour, plotted on a territory or a building’s wall. By way of illustration, shadow movement animation is performed, as well as building of the sectors of light indicating at the reasons of limited insolation. The influence of the computation date on the insolation duration is considered. It is demonstrated that changing the date of the normative computation from March 22 to April 22 reduces the region of unacceptable insolation by 50…70%. The examples of computation are given. The system interface is considered. A brief description of the system’s software implementation is provided. The models are designed in the AutoCAD package. The programs are written in the AutoLisp programming language.

1. Introduction

Insolation is lighting of facilities with direct sunlight. Insolation positively influences the human biology. One of the insolation criteria is its duration. In architectural design ensuring insolation in rooms, apartments, spaces is mandatory. In Russia certain standards apply to the insolation duration [1].

Observation of the insolation standards is the factor limiting the building accommodation of buildings. New buildings must not disturb the insolation of those constructed earlier. In the context of the increasing density of building in Russia, the date of normative calculation was corrected from March 22 to April 22 [2,3].

Russian architectural companies mostly perform the computation of the insolation duration at the design stage using insolation diagrams [4,5], building shadows [6], shadow movement animation [7]. These methods require much time, and are characterized with low accuracy, especially in case of complex shapes of buildings.

Systems of automated computation of the insolation duration are being created [8,9]. One of those is the system considered below, which was created by this paper’s author. It operates in AutoCAD package medium [10,11], which is used as a base by many architecture and construction companies in Russia. The system was successfully tested in performing computations as ordered by a number of companies. In the process of using the system there appeared suggestions on improving its algorithm, software implementation and interface, which have been fulfilled in the new variant of the system.
The objective of this work is to describe the algorithm of computation of the insolation duration fulfilled in the improved automated system [10], its interface and software implementation, as well as to assess the influence of switching to a different computation date on the insolation duration.

The given plotting are performed in the automatic mode using the system under consideration.

2. Geometric model of determining the insolation duration

Computing the insolation duration is a geometrical task. A known model [12] of the sun’s movement across the sky is accepted. The radiant flux streaming from the sun and into calculated point A is generally a surface of a circular cone, see Figure 1(a). The cone vertex is located in point A. Arrow \( \text{N} \) indicates to the North. Angle \( \varphi \) is equal to the geographical latitude of the location, see Figure 1(b). For Moscow and Chelyabinsk \( \varphi \approx 55^\circ \). Angle \( \delta \) is calculated using the Cooper formula [13,14]:

\[
\delta = 23.45 \sin \left( \frac{2 \pi \text{data}}{365} \right)
\]

where \( \delta \) is an angle in degrees, \( \text{data} \) – number of the calendar day. For January 1, \( \text{data} = 1 \); for March 22, \( \text{data} = 81, \delta = 0 \) (equinox); for April 22, \( \text{data} = 112, \delta = 11.93^\circ \), for June 22, \( \text{data} = 173, \delta = 23.5^\circ \), for December, 22 \( \text{data} = 354, \delta = -23.5^\circ \).

Sections AB and AC determine the rays of the sunrise and sunset respectively. They are found on the intersection point of the cone of rays and the horizon plane horison, passing through point A. Part of the cone, located above the plane horizon, determines the duration of daytime. Cone1 corresponds to the period between March 22 and September 22; cone2 – to the period from September 22 till March 22. On March 22 and September 22, \( \delta = 0 \), and the cone transforms into plane \( \gamma \) (equinox plane).

When models of buildings cross the cone of rays, shadow sectors \( \beta', \beta'' \), and insolation sectors \( \alpha', \alpha'' \) are formed, see Figure 1(a).

![Figure 1. Model of the sun’s movement across the sky: a – cone of rays; b – cone parameters.](image)

![Figure 2. Algorithm of computing the insolation duration: a – models of buildings; b – light cone; c – cross-sections of buildings by the cone; d – measurements of the insolation sectors (calculation example for June 22).](image)
3. Algorithm of computing the insolation duration

The algorithm is explained within a case study of a group of buildings, see Figure 2(a). 3D models of buildings are built in an arbitrary scale. Calculated point A may be located on a building’s wall or “on the ground”. The values of \( \varphi \) are used to determine the position of the equinox plane \( \gamma \). The values of data (see the formula) are used to determine angle \( \delta \). A model the circular cone is built with angle \( \delta \), vertex in point A, and axis \( i \perp \gamma \), see Figure 1(b), 2(b). Part of the cone located below horizon plane \( \text{horizon} \supset A \) is cut off. Lines \( m, n \) of the intersection between the cone and the models of buildings are determined, see Figure 2(c).

All the computations are performed in plane \( \gamma \) or \( \gamma' \parallel \gamma \). Lines \( m, n \) and the cone are projected onto this plane, see Figure 2(c,d). Using projections \( m', n', \text{cone}' \), the values of angles \( \beta_1, \beta_2, \epsilon, \eta \) are measured. After angles \( \beta_1, \beta_2, \epsilon, \eta \) are subtracted from sector \( \alpha \), and the conditions given below are taken into consideration, insolation sectors \( \alpha_1, \alpha_2 \) are left. The value of \( \alpha \Sigma = \alpha_1 + \alpha_2 + \ldots \) is converted into time interval insol as per ratio \( 15^\circ = 1 \) hour.

![Figure 3. Insolation depending on the date: a – April 22; b – March 22; c – December 22.](image)

The algorithm implies the following computation conditions.

- Insolation during one hour after sunrise and one hour before sunset is not taken into account [1]. If the insolation sector adjoins the borders of \( A'B' \) or \( A'C' \), angles \( \epsilon = 15^\circ \) are subtracted, see Figure 2(d).

- If point A is located on a building’s wall, angle \( \eta \) adjoining the wall is subtracted (Figure 2…).

- If the insolation comprises several sectors of light, then the duration of the biggest sector should be no less than 1 hour, otherwise the insolation in point A is considered to be absent [1].
• If in case of several insolation sectors the duration of one of the sectors is no less than two hours, then the insulation is considered to be continuous with the permissible value of 2 hours.
• Duration of shadow sector \( \beta \) must be no less than 10 min. Otherwise the duration of the insolation surrounding the sector \( \beta \) is considered to be continuous.

4. Insolation depending on the computation date
Let us consider the change of insolation in point A depending on the date of computation. The shape of the buildings, the position of point A, and geographical latitude \( \varphi \) are constant, see Figure 2(a). Only the light cone angle \( \delta \) changes.

July 22, see Figure 2, is the longest day. Cone angle \( \delta = 23.45^\circ \). Building 1 does not impede insolation. Building 2 stops insolation. Two sectors of light are formed: \( \alpha_1 = 23.4^\circ \) and \( \alpha_2 = 50.4^\circ \). Sector \( \alpha_1 \) from the sunrise side is limited by \( \varepsilon \). Sector \( \alpha_2 \) is limited by \( \eta=8^\circ \) from the building’s wall. The insolation duration amounts to 73.8°, that is insol = 4.92 hours, or 4 hours 55 minutes.

April 22, see Figure 3(a), both buildings stop insolation and form two sectors of light: 21.1° and 19.1°. The insolation at sunrise is not taken into consideration since its duration does not exceed the values of \( \varepsilon \). The value of insol = 2.68 hours.

March 22, see Figure 3(b), is the equinox day. The insolation also comprises two sectors, insol = 2.27 hours.

January 22, see Figure 3(c), is the shortest day of the year. The insolation is determined only by building 2. The sector at sunrise is not taken into consideration as it does not exceed \( \varepsilon=15^\circ \). The insolation is determined by the sector of light in 15.9°. The value of insol = 1.06 hours.

Insolation may comprise one or several sectors of light. In case of a single sector the insolation in the point is considered acceptable [1] if its duration insol \( \geq 2 \) hours. If several sectors of light are formed (discontinuous insolation), it is required that insol \( \geq 2.5 \) hours.

The conclusion of the acceptable duration of insolation is made during computation on a certain date. Before 2017, for the central part of Russia this was the date of March 22 or September 22 [1]. According to new standards this date is set for April 22 or August 22 [2]. In the example above, a discontinuous insolation was detected on the indicated days. Therefore, when computing as per March 22, the insolation is below the acceptable value (insol < 2.5 hours). For April 22, the insolation value is acceptable.

5. Insolation of Territory and Walls of Buildings
Computation for a territory with arbitrary contour is provided for. This may be a land plot or a building’s wall. Inside the contour points are set in the knots of a uniform grid of the required density. In each point the insolation computation is performed following the algorithm considered above. In the points markers are placed, the colour of which is determined by the value of insolation insol, see Figure 4(c). The zones of acceptable insolation are coloured yellow and green. The unacceptable insolation is marked red and blue. Dark gradations show the zones of continuous insolation (one light sector), light coloured ones are the zones of discontinuous insolation (several sectors of light).

When computing for April 22, see Figure 4(a), as compared to March 22, see Figure 4(b), the zones of unacceptable insolation are significantly reduced. For instance, on March 22 point A was located in the red zone, and on April 22 point A is located in the green zone.

A “control” mode is provided for, see Figure 4(d), which displays only the zones of unacceptable insolation, uniting red and blue zones, for instance s1, s2. The changes in the areas of these zones also show that the unacceptable insolation is reduced at switching from the computation date of March 22 to April 22. The area of zone s1 reduced by 68%, for zone s2 the value decreased by 58%. For wall s3 of building 2 the decrease in the value equaled 57%. The whole wall s4 had acceptable insolation in April.
Figure 4. Insolation of territory and walls of Buildings: a – April 22; b – March 22; c – color of the insolation markers; d – "control" mode.

6. Additional possibilities of the system

To assess the authenticity of the computation results, visualization of the sectors of light is performed, see Figure 5(a). Points \(M, L, K\) allow to determine the reasons of insolation limitation and perform correction of the shape and location of buildings impeding insolation.

Shadow movement animation, see Figure 5(b – d), is performed in the automatic mode using the tools of AutoCAD package. A set of rendering frames is formed. The frames are combined into one file. The camera is moved along the trajectory of the sun with the set location latitude, date and survey direction: plan or axonometry. The number of frames per second is set. Also a single frame mode is provided for, as well as a mode displaying the sun’s trajectory.

Figure 5. Visualization and control of the results of the insolation computation: a – control of the insolation sectors (March 22, point A); b – animation frames (April 22, left to right 9-00, c – 12-00, d – 15-00).

Setting of angles \(\eta\), see Figure 2(d), many not be enough to take into account the influence of a window, a recessed balcony or a balcony. To ensure a more accurate determining of insolation with consideration to the specifics of the shape of these facilities, an automatic building of their 3D models is provided for. The models are placed in the preset points on the wall of buildings.

The system is controlled by buttons on a special panel. After indication of each button, a corresponding dialog window opens for input of the parameters’ values. Also, text information with comments to the computation results is displayed.
7. Brief Information on the System’s Software Implementation
The system’s software support is written in AutoLisp, being part of AutoCAD package [15-18]. At the preliminary stage models of buildings as solids-objects are created, see Figure 1, Figure 2(a). The models may be shape of any degree of complexity. An automatic variant of building simple models is provided for by means of extrude plan. To compute insolation of a territory, its contour is delineated, and for a point’s insolation a marker is placed.

The parameters which define the computation mode (ϕ, data, normative values of insolation, etc.) are set by default for Moscow, and may be corrected in the dialog windows.

The program runs the algorithm given above, see Figure 1, 2, by using commands of a graphic editor, and forming lists and sets with functions list and ssget with their further processing through relevant functions of AutoLisp.

![Figure 6. Calculation example: a – building models, b – insolation sectors at points A, B; c – insolation before the construction of a new building; d – after construction.](image)

Once angle δ is computed (see the formula), command revolve creates a cone as revolvedsurface. Part of the cone located below the horizon plane is cut off using slice command. The lines of intersection of the cone and the buildings’ models are determined by interfere command. They are spline. Command pedit converts spline into polylines 3dpoly. Peaks of these lines are extracted from the database by function entget. Command ucs sets plane γ. By converting coordinates using function trans the peaks are projected onto plane γ. Using the peaks projections function angle computes the values of angles β and lists them. By processing these lists angles α are calculated.

When computing the territory insolation, the buildings’ models and the cone are converted into polyline networks with a triangular case frame. The lines of intersections of the buildings and the cone are determined at multiple intersection of triangles. This algorithm is more complex but allows to significantly reduce the computation time.

The dialog windows, animation and rendering of plottings are also made using AutoLisp tools together with AutoCAD commands.

8. Conclusion
The described results obtained through the automated system of insolation computation demonstrate that changing the normative date from March 22 to April 22 reduces the region of the unacceptable insolation of territories by 20-30%, and of walls and buildings by 50…70%, what allows to increase the density of building and the height of buildings. However, cases were revealed when specifics of the shapes of buildings did not allow to achieve the same results. These cases will be considered additionally. The insolation zones, see Figure 4, revealed by the developed system have complex geometry. Studying them is undoubtedly interesting from the scientific point of view.

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Figure 6 shows an example of using the system in a real project, see Figure 6(a). It required to determine how new building 1 (97 Kaslinskaya St., Chelyabinsk) affected the existing buildings 2,3. The insolation was determined for options before the new building’s construction, see Figure 6(c), and after it, see Figure 6(d). The first variant of the project revealed the decrease in the zone of acceptable insolation of building 2. In special points checks were performed by plotting the sectors of light, see Figure 6(b). The computation results were taken into account in the final variant of the project by means of correcting the shape and position of building 1.

The developed system is a modern software tool for performing complex computation of the insolation duration. The system allows to significantly improve the accuracy, visualization and authenticity of calculations in architectural design, and is recommended for wide implementation, especially in the context of increased density of urban building and complexity of buildings' geometry [19,20].

References
[1] Hygienic requirements for insolation and solar control premises of inhabited and public buildings and grounds 2.2.1/2.1.1.1076-01 http://best-stroy.ru/gost/r38/311
[2] Amending 1 in the sanitary rules and norms Sanpin http://docs.cntd.ru/document/420398169
[3] The stroke of a pen we have been deprived of the Sun in the apartments: "the city is ugly" http://www.mk.ru/social/2018/03/01/rosherkom-pera-nas-lishili-solnca-v-kvartirakh-gorod-budet-bezobraznyy.html
[4] Shmarov I A, Zemcov V A and Korkina E V 2016 Insolation: the practice of rationing and calculation Housing construction (Moscow: Strojmateral) 7 pp 48–54
[5] Shmarov I A, Zemcov V A, Zemcov V V and Kozlov V A 2018 Updated methods of calculating the duration of insolation of premises and territories on the insoljacionnym charts Housing construction (Moscow: Strojmateral) 6 pp 24–31
[6] Pritykin F N and Shkuro E Yu 2017 Analytical Method of Defining Shadow Areas of Buildings and Structures to Determine the Optimal Place of Location on the Specified Area Bulletin of the South Ural State University. Ser. Constr Engineering and Architecture 17 (2) pp 59–64
[7] Insolation in Revit Architecture https://lyafell.blogspot.com/2013/08/revit-architecture.html
[8] CITIES: Solaris-Architect 7.00 http://sitis.ru/1z531
[9] Chronolux (duration of insolation) https://dwg.ru/dnl/5226
[10] Kheyfets A L 2010 The program of the automatic calculation of the insolation Certificate about State registration of computer programs №2010613828
[11] Kheyfets A L 2007 Computer-aided calculation of duration of insolation Bulletin of the SUSU. Ser. Constr Engineering and Architecture (Cheljabinsk: SUSU) 4 14(86) pp 51–54
[12] Koroev YU 2014 Descriptive geometry (Moscow: Knorus) p 422
[13] Cooper's Formula http://pvedrom.pveducation.org/ru/sunlight/declin.htm
[14] Cooper P I 1969 The absorption of radiation in solar stills Solar Energy 12 pp 333–346
[15] Kheifets A, Loginovskiy A, Butorina I and Vasileva V 2015 Engineering 3D computer graphics: tutorial and workshop for academic undergraduate (Moscow: Yurayt) p 602
[16] Kheifets A 2002 Engineering computer graphics AutoCAD. Teaching experience and a width of views (Moscow: Dialogue MEPI) p 432
[17] Poleshuk N N 2015 Programming for AutoCAD 2013-2015 (Moscow: DMK Press) p 262
[18] AutoLisp is the language of graphic programming in the AutoCAD system http://kappasoft.narod.ru/info/acad/lisp/a_lisp.htm#L
[19] Kheifets A L 2012 The Calculation of Insolation Length in the Conditions of Compacting Development Privolzhsky scientific journal (N Novgorod: NNGASU) 3 pp 9–10
[20] Kheyfets A L and Samorukov A V 2014 Method for determining the permissible volume of construction, taking into account the duration of insolation in architectural design Patent for invention No 2505853