Lighting of the Urban Interior in the Residential Environment

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Abstract. Sustainable development is an inclusive concept, which has, among other things, significance for the shaping of architecture and urban planning assumptions related to the principles of sustainable design. They include the need to respect the land, care for present and future generations, rational management of the natural resources, energy efficiency and the use of alternative energy sources. The indicated attitude in the field of project activity is vital for its effect, which directly influences the comfort of living and social satisfaction, so important for the success of the investment. Sustainable design requires expressing the concern the natural environment, which is an inseparable part of the human habitat. It affects the comfort of living, the shape of pro-health conditions, and also has a positive effect on the psychological well-being of a person. The study aims to assess the impact of the climatic conditions on the quality of residential areas. Rational use of the characteristic features of climatic zones and the conditions that are associated with them determine the improvement of the quality of the built environment shaped by the man. Climatic factors such as solar radiation, temperature, air circulation and air humidity are essential for low-energy building, whose indicators depend on the use of appropriate technologies and materials as well as on natural factors such as climatic features. The object - in its full life cycle, taking into account its parameters or the energy demand, is controlled by the BIM standard, which gains an ever-growing number of supporters. It is also a technology obligatory in many countries, applied in the field of design practice, which is of particular importance for facilities with large cubic capacity. Control over bigger structures allows to minimise errors in the functioning of the facilities or plan the costs associated with their maintenance, including scheduled repairs and modernisation. BIM is particularly useful for controlling energy indicators of the facilities, whose sizes depend on the relationship between the natural environment and the constructed one. The analysis of the indicated compounds allows to formulate guidelines useful at particular stages of shaping housing development, and thus forming buildings and urban spaces. Variable meteorological factors are possible to be defined by conditions allowing the determination of climatic zones with their characteristic features. The degree of solar radiation depends on: the state of the atmosphere, the properties of the ground and other surfaces, the geometric layout of the considered urban interior including biologically active areas, population density, the size of the city, and the extent of its industrialisation. The temperature is also influenced by the size of the urban centre and the developed areas, population, the morphology of the place and accompanying meteorological factors (cloudiness, windfall). The article presents the influence of the insolation on the architectural object and housing conditions. It should be emphasised that solar radiation is necessary for the physical and biological processes on Earth, essential for human life. In addition, the energy of radiation is obtained without inputs associated with the source of the origin. Therefore it is crucial for spatial planning, conditioning proper lighting of urban interiors and promoting thermal comfort in places of residence, using a natural source of heat.

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1. Introduction
Urban space is becoming increasingly important in the creation of the modern housing environment. One of the conditions to ensure its high quality is the limitation of the human interference into the natural environment. It is particularly significant in the small town, where the natural landscape is an important part of its image [1]. Despite this common tendency, we are often forced to live in the new housing complexes with high architectural standards but without proper urban values. There is a less choice for the residents to select a housing unit that would be alluring not only due to its attractive name but also due to the correctness of the spatial solutions. Our choice is reduced not because of our limited self-determination in the decision-making, but because we live in a housing environment that does not create favourable conditions for the proper management of the area, or provides the sufficient size of the open space. Not many such places exist on the market, except single-family, free-standing developments. In fact, one of the few good examples of the proper urban conditions include the housing complexes of the 70s/80s, which despite the low standard of the architectural qualities, provide attractive spatial solutions. Open spaces and thus the favourable distances between the buildings offer an adequate amount of the light, which in consequence, have a positive influence on the psycho-physical condition of the man, his sense of intimacy and peace, as well as the ability to spend time actively. These conditions create the possibility of proper ventilation, creating the appropriate mesoclimate, where lighting is a great asset, [2].

Somewhat different living conditions exist in the small towns where single-family housing predominates, although more and more multi-family housing complexes appear. They are often intensively built, with no common places, or spaces free from the development. The issue of the urban spaces and the conditions they offer is important today, given the fact that the city - regardless of its size - has become the primary and leading living environment of the modern man (as reflected in the UN statistics).

Proper relations between the man and nature are regarded as the main purpose of the city functioning. It is an important element in the process of shaping a high-quality housing environment, and thus promoting environmentally friendly solutions. A society increasingly aware of the negative changes in the functioning of the urban centres sees the need for the principles of sustainable development and ecological architecture. It results from the increasing public awareness concerning the condition of the environment and its resources, [3, 4].

The undertaken efforts must include the model of the assessment of the impact of the buildings on the environment and the human, with regard to the whole life cycle (life cycle assessment). It results of the observation of the long-term effects of architecture on the environment. Although it’s a long process, it gives an opportunity to obtain an objective judgment about the effects of the interaction between the environment and the built elements. It also enables to create of the favourable spatial conditions and architectural forms that use advanced elements based on the previous simulation studies, that also take into account climatic factors influencing the planning of the buildings of appropriate scale and form. The size and height of the building, including the line of the development, its shape, and the distance between the objects, are also of great importance.

The pro-ecological conceptual design gives priority to the inclusion of the climatic factors which result from the local micro-climate, dependent on the natural and anthropogenic conditions. These conditions take into account urban planning process, local heat sources and the topography of the terrain. On a micro-urban scale, these dependencies can be considered with respect to the spatial arrangement of the building surroundings, its location (including the type and the shape of the terrain), its orientation and the shape or geometry of the roofing, as well as the spatial form of the building.

2. The scope and characteristics of the assessment of the residential environment.
The scope of research on the housing environment, taking into account climatic conditions, includes an assessment of the relationship between the spatial planning of the urban development and the natural elements in three problem groups. The first group concerns the assessment of the natural climatic factors such as interior sunlight, thermal conditions, humidity and the ventilation [5-7].

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The second group involves the spatial structure of the urban development in macro, meso, and microscale. The conditions analysed at the macroscale refer to the region and the city. Mesoscale conditions refer to the district and the housing settlement, while the microscale to the city block and its nearest surrounding. The third group deals with the spatial relationships of the objects and the environment, taking into account spatial arrangement of the environment and the form of the objects.

The assessment of the impact of the climatic conditions on the living environment allows formulating guidelines. They are valuable on various stages of the formation of the living environment, using the most favourable natural conditions for the arrangement of the buildings and urban spaces. Variable meteorological factors such as temperature and humidity, sunshine, wind or rain, are defined by the conditions that determine the climatic zones and their characteristic features.

The amount of the sunlight depends on the state of the atmosphere, the properties of the terrain and other surfaces, the geometrical system of the urban interior, including the biologically active areas, the size of the city, the population density and the degree of the city’s industrialisation, [5]. The temperature is also influenced by the size of the city, the size of the built-up area, the population, the morphology of the urban centre and the accompanying meteorological factors (cloudiness, rain, the wind).

This article analyses one of the important results related to the climatic conditions – the sunlight. The significance of this factor results from the fact that the sunlight affects all of the physical and biological processes and is essential to the human life. In addition, the sunlight energy is obtained without the input connected to the source.

3. Light exposure of the urban interiors.

The analysis of the light exposure of the interiors includes three factors: direct exposure to the sky, the shading of the walls caused by the hood (and balconies) and the shading of the walls caused by the neighbouring buildings. All of these cases should include the angular height of the sun- $h_\alpha$ (Figure 1)

![Figure 1](image_url). Determination of the height of the sun in relation to the building in question - determination of the angular parameters.
The angular height of the sun \( (h_a) \) depends on the latitude of the analysed point and the declination angle \( \delta \), which in turn relies on the angular position of the sun in regard to the surface of the equator. The declination angle can be calculated from the approximate formula [6]:

\[
\delta = 23.45 \sin \left( \frac{360 \times 284 + d}{365} \right)
\]  

where \( d \) determines the number of the days from the beginning of the year. The declination angle varies through the year. This variation is presented in Figure 2.

![Figure 2. Variations of the declination angle (\( \delta \)) through the year](image)

Angular height of the sun \( (h_a) \) is:

\[
h_a = 90^\circ - \phi \pm \delta
\]  

where \( \phi \) is the latitude of the point in question (place). This latitude acquires a plus (+) sign for the northern hemisphere and a minus (-) sign for the southern hemisphere. On 23\textsuperscript{rd} March and 23\textsuperscript{rd} September, the declination angle is \( \delta = 0^\circ \). On 22\textsuperscript{nd} June, the declination angle is \( \delta = 23^\circ 27' \) and on 22\textsuperscript{nd} December, \( \delta = -23^\circ 27' \). The variations of the angular height of the sun \( h_a \) are presented in Figure 3.
Figure 3. Variations of the angular height of the sun through the year.

The angle of the sky exposure $\lambda$ is the degree of the interior lighting. Its physical essence is presented in Figure 4.

Figure 4. Parameters for the analysis of the sky exposure angle

Angle $\lambda$, and more accurately $\tan \lambda$ may be calculated from the formula:

$$\tan \lambda = \frac{s_1 h_2 + s_2 h_1}{h_1 h_2 - s_1 s_2}$$  (3)

Assuming:
\[ \kappa_1 = \frac{h_1}{s}, \kappa_2 = \frac{h_2}{s}, \epsilon_1 = \frac{s_1}{s}, \epsilon_2 = \frac{s_2}{s} \quad (4) \]

We receive:

\[ \tan \lambda = \frac{\epsilon_1 \kappa_2 + \epsilon_2 \kappa_1}{\kappa_1 \kappa_2 - \epsilon_1 \epsilon_2} \quad (5) \]

Additionally for:

\[ h_1 = h_2 = h = \kappa s \quad (6) \]

We receive:

\[ \tan \lambda = \frac{4\kappa}{4\kappa^2 - 1} \quad (7) \]

The wall shadowing caused by the protruding hood \((h_{cw})\) with the outreach of \(ao\) equals to:

\[ h_{cw} = a_o \frac{\tan(h_o)}{\sin(90^\circ + \gamma)\sin \beta - \cos \beta \tan(h_o)} \quad (8) \]

where:
- \(a_o\) – the outreach of the hood in regard to the elevation,
- \(\gamma\) - azimuth being the angle between the normal surface (in respect to the one in question) and the local meridian; Zero is at noon (S); From sunrise to the noon (E) this angle is assumed to be positive, in the afternoon (W) – negative,
- \(\omega\) - Hour angle; at noon it is equal to 0, it increases hourly by 15° longitude; Before the noon this angle is assumed to be positive and the afternoon -negative.

In practice, it is better to calculate the \(h_{cw}\) for the sun dominance from the following formula:

\[ h_{cw} = a_o \frac{\tan(h_o)}{\sin(90^\circ + \gamma)} \quad (9) \]

And changes in the day can be adjusted by the \(\rho_t\) factor calculated from the formula:

\[ \rho_t = \cos(90t/t_p) \quad (10) \]

where:
- \(t\) - considered time for which we determine the angular height of the sun, always calculated from the moment of the daily sun dominance (before the noon, we assume it to be positive and after the noon - negative),
- \(t_p\) – the number of the hours from the sunrise to its dominance - the noon- or from the noon to the sunset.

For the purpose of the analysis, it is better to operate on the relative values, not only the absolute values of the \(h_{cw}\). Then, it is possible to introduce the dimensionless factor \(\kappa_{cw}\), which is the relative height of the shading of the wall from the protruding hood \((h_{cw})\) in relation to the outreach of the hood \((a_o)\). The value of the \(\kappa_{cw}\) factor is calculated from the formula:

\[ \kappa_{cw} = \frac{h_{cw}}{a_o} \quad (11) \]
The shading of the walls from the adjacent buildings is depicted in Figure 5.

![Figure 5](image)

**Figure 5.** Parameters for the analysis of the wall shading from the adjacent buildings

While assuming parameters presented on the figure we receive:

\[ \frac{h_1}{c} = \tan(h_a); \quad c = \frac{h_1}{\tan(h_a)} \]  \hspace{1cm} (12)

\[ h_c = (c - s) \tan(h_a) = h_1 - \tan(h_a) \]  \hspace{1cm} (13)

After assuming:

\[ \frac{h_c}{s} = \kappa_c \kappa_1 - h_1/s \]  \hspace{1cm} (14)

we receive:

\[ \kappa_c = \kappa_1 - \tan(h_a) \]  \hspace{1cm} (15)

And if we additionally take into account the change in the angular height of the sun during the day:

\[ \kappa_c = \kappa_1 - \tan(h_a) \cos(90t/t_p) \]  \hspace{1cm} (16)

Provided formulas are valid for \( \gamma = 0^\circ \)

4. Results and discussions

The results of the analysis are shown in Figures 6 to 8. Figure 6 refers to the angle of the sky exposure (\( \lambda \)). The analysis also includes the variable location of the observation point on the street (\( \varepsilon 1 \)). The
charts were prepared for the different heights of the buildings located on both sides of the street and the ratio of the height of the buildings to the distance between them ($\kappa$).

All of these parameters have a significant impact on the value of the sky exposure, but the ratio of the height of the building to the distance between the objects is especially important. The impact of the location of the observation point is also obvious. In the case of the classic pedestrian crossings, this angle is smaller than for the observer located in the middle of the street. The sun exposure of the street canyon is determined by its whole width.
The results of the analysis considering the wall shading caused by the protruding hood are shown in Figure 7. The analysis included the location of the building in relation to the directions of the world (\(\gamma\) angle - azimuth being the angle between the surface normal to the one in question and the local meridian assumed as zero for the sun dominance at midday and the sun angular height).

Based on the results of the analysis it can be stated that the shading of the wall from the protruding hood is greatly affected by both the \(\gamma\) azimuth angle and the \(h_a\) angular height of the sun. The greater the height of the shadow, the greater the value of the \(h_a\) angle. It is worth noting that the formulas and graphs given are valid only when the sun illuminates the wall.

**Figure 6.** The results of the analysis of the sky exposure angle for: a – \(\kappa_1 = \kappa_2\), b – \(\kappa_1 = 1.0\), c – \(\kappa_1 = 2.0\)

**Figure 7.** The results of the analysis of the \(h_{cw}\) wall shading from the protruding hood: a - depending on the position of the building in relation to the directions of the world (angle \(\gamma\)) for different values of the \(h_a\) angular height of the sun, b - depending on the \(h_a\) angular height of the sun for different building locations in relation to the directions of the world (\(\gamma\)).

Figure 8 shows the influence of the adjacent building on the shading of the building wall. It includes the ratio of the height of the shaded building (\(h_1\)) to the distance between the objects (s) represented by the \(\kappa_1 = h_1/s\) factor and the time of day represented by the \(\omega\) hour angle. It is assumed that the change of time by one-hour results in a change in \(\omega\) angle by 15°. Zero is obtained at noon, in the hour of the daily sun dominance. This angle acquires positive values before the noon and negative later on. The results of the analysis show that the discussed shading is highly dependent on the value of the \(\kappa_1\) factor. The time of day (hour angle \(\omega\)) depends on the angular height of the sun (\(h_a\)). The
highest shading occurs during the winter months when the angular height of the sun is the lowest. Of course, the height of the shading cannot be greater than the height of the shaded building.

Figure 8. The results of the analysis of the $h_c$ wall shading according to the $h_1$ height of the adjacent building and the $s$ distance between the buildings, for the $h_a$ angular height of the sun: a – 20°, b – 40°, c – 60°
5. Conclusions
The article presents the analysis of some climatic factors that influence the conditions of the residence. The $\lambda$ angle of the sky exposure and the height of the wall shadowing, caused by the hc ($\kappa_1$) adjacent buildings and the hcw ($\kappa_{cw}$) hoods were analysed. This issue is related to the importance of the direct impact of the solar radiation on the buildings and the pro-ecological urban planning.

The author provided her own final formulas for the $\lambda$ sky exposure, the hc height of the shading of the wall from the adjacent building, and hcw from the hood. These formulas have taken into account the influence of the seasons, the time of day, the location of the object in relation to the directions of the world, as well as the $\phi$ latitude, which influences the ha angular height of the sun. Presented formulas enable proper analysis for every location.

The graph presenting the value of the declination angle ($\delta$) is shown in Figure 2. It is valid for each latitude and longitude. It depends only on the setting of the equator with respect to the sun. In the case of the angular height of the sun (ha) the latitude described by the $\phi$ parameter is important. Thus, it must be determined individually for each place (point) considered.

The results of the analysis make it possible to conclude that, the value of the $\lambda$ sky exposure angle depends on the location of the observation point, on the width of the street ($\varepsilon_1$), and above all, on the mutual height of the buildings situated on both sides of the street and the ratio of the height of the building to the distance between them ($\kappa$).

The height of the wall shading depends on the season, the day, the length of the hood, as well as the relation of the height of the shading building to the distance between the objects. During the moment of the sun dominance, the height of the shading created by the outreach of the hood is much higher than the shading caused by the adjacent buildings. The opposite situation occurs in the morning and the evening. From dawn to noon, the shading provided by the neighbouring buildings is decreasing, while shadow provided by the hood is increasing. It is the other way round in the afternoon.

The intensity of the urban interiors lighting is an important factor affecting the quality of the living environment and the ecological, architectural design. It results from the role of the sunlight in the course of the biological and physical processes on Earth. In addition, it influences the thermal comfort of the place of the residence and the use of the natural heat.

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