1. INTRODUCTION

The role and meaning of the social spaces are inseparably connected with the progress of the urbanisation. The results of the research conducted in about 40 cities of Podkarpackie Voivodeship have confirmed this thesis in a measurable manner [1]. The importance of these spaces increases with the growth of the need for intimacy and peace. Modern man also searches for the sense of security and contact with the natural environment.

Social spaces are also connected with the lighting of the urban interiors. This phenomenon is not only understood as the direct sunlight effect on the living organisms, including humans, but also the illumination of the houses and the heating of external walls, which reduces the energy demand necessary for the heating during the winter.

EVALUATION OF THE BUILDINGS’ SHADOWING IN THE COMPACT HOUSING DEVELOPMENT – SELECTED EXAMPLES

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Abstract
The paper presents results of the buildings’ shadowing analysis performed in the selected areas located near the market square in Leżajsk – a small town in Podkarpacie. The author provided her own formulas for the degree of the shadowing, including the height of the development, distances between the buildings, their location in relation to the directions of the world and the time of the day. The buildings’ shadowing is connected with the limited access of the natural light, and thus it influences the quality of the housing environment. The results of the analysis may be implemented in the shaping of the urban interior, including housing, important due to the constant presence of the man.

Lighting of the interiors and adjacent areas allows to create healthy housing environment and reduces the energy demand, necessary for the heating during the winter.

Streszczenie
W artykule zaprezentowano wyniki analizy zacinienia ścian budynków w wybranych obszarach zlokalizowanych w otoczeniu rynku w Leżajsku – niewielkim mieście województwa podkarpackiego. Podano własne wzory na obliczanie stopnia zacienienia z uwzględnieniem wysokości zabudowy, odległości między budynkami, ich usytuowania względem stron świata i porę dnia. Zacienienie budynków wiąże się z ograniczonym dostępem światła naturalnego, a tym samym wpływa na jakość środowiska mieszkaniowego. Wyniki analizy mogą być wykorzystane w praktyce, w zakresie kształtowania wnętrzurbanistycznych, w tym także mieszkaniowych, ważnych z uwagi na stały pobyt człowieka. Doświetlenie wnętrz obiektów jak i strefy zewnętrznej pozwala kształtować zdrowotne środowisko mieszkaniowe oraz zmniejszać zapotrzebowanie na energię niezbędną na ocieplenie mieszkań w okresie mrozów i chłodów.

Keywords: The lighting of the urban interiors; The length of the shadow; Compact housing development, The height position of the sun.
The proper arrangement of urban interiors serves man, fulfilling, at least partially, the criteria for a healthy and comfortable living environment. One of its elements is the proximity of nature and the possibility of its use for relaxation purposes, facilitated by the appropriate distances between the buildings creating the interior [2]. Due to the price of the land, especially in the city centres, the distances between the buildings are small, and thus the building development is compact. It is characteristic for both old town and modern buildings in the city centres.

Too high intensity of the development is accompanied by the small social spaces – the neighbourhoods. Moreover, unfavourable shading of the interiors and buildings also becomes problematic. Limited light access lowers the standard of the space and reduces its activity [3].

It is difficult to maintain the elements of greenery in the shady places and to provide friendly and convenient living conditions for the modern man. A man who is increasingly anxious to pursue a healthy lifestyle and likes to be in an environment that allows rational management of the natural resources. It applies especially to the cities that have become – as the UN statistics show – the primary and leading places of residence presently and in the future.

The interaction between the natural and man-made environment plays an important role in the undertaken actions as well as the conditions arising from the characteristics of the built area. They include the volume and the height of the objects, they determine the shape of construction, the distances between the buildings, as well as their location to the directions of the world [4].

This paper presents its own formulas for calculating the degree of the shading of the buildings and the spaces between them, created by the neighboring objects. The importance of this factor stems from the fact that solar radiation affects practically all of the physical and biological processes on Earth and is essential to human life. In addition, the sunlight energy is obtained without the input connected to the source [5].

2. SHADING OF THE URBAN INTERIORS

One of the factors related to local climate conditions is the degree of shading of the buildings and the spaces between them. When considering the shading of the urban interiors, the \( h_a \) angle of the sun should be taken into account (Fig. 1). It depends on the latitude of the analysed point and the \( \delta \) declination angle, 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]:

\[
\delta = 23,45 \sin \left( \frac{360 \left( 284 + d \right)}{365} \right)
\]

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. The values of the \( \delta \) declination angle are independent of the geographic position of the analysed point on the globe.

The solar altitude represents the general case, valid for every point on the globe and any location of the building relative to the world. The solar altitude \( (h_a) \) 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 23rd March and 23rd September, the declination angle is \( \delta = 0^\circ \). On 22nd
June the declination angle is \( \delta = 23^\circ 27' \) and on 22nd December \( \delta = -23^\circ 27' \) [7]. Annual changes in the \( h_a \) solar altitude are characteristic for the given latitude, represented by the \( \phi \) parameter, but do not depend on the longitude [7].

The shading of the space between the adjacent development is schematically illustrated in Figure 2. If we adopt the designations presented in the figure, we receive:

\[
h_1/c = \tan(h_a)
\]  

(3)

and so:

\[
c = h_1/\tan(h_a)
\]  

(4)

where:

\( h_1 \) – height of the building causing the shadowing,

\( c \) – length of the shadow,

\( h_a \) – solar altitude.

\[
\frac{h_a}{\omega} = h_a \cos \left( \frac{90t}{t_p} \right)
\]  

(5)

\[
\frac{c}{\omega} = h_1/\left[ \tan(h_a) \cos \left( \frac{90t}{t_p} \right) \right]
\]  

(6)

If the \( c \) (or \( c_\omega \)) shadow length is greater than the distance between the buildings than the elevation of the adjacent building is shaded partially or entirely. The \( h_c \) height of the shading is:

\[
h_c = (c - s) \tan(h_a) = h_1 - s \tan(h_a)
\]  

(7)

After assuming:

\[
\frac{h_c}{s} = \kappa_c
\]  

(8)

we receive:

\[
\kappa_c = \kappa_1 - \tan(h_a)
\]  

(9)

And if we additionally take into account the change in the solar altitude during the day:

\[
\frac{h_c}{s} = \kappa_c
\]  

(10)

Provided formulas are valid for the azimuth \( \gamma = 0^\circ \). The azimuth is the angle between the surface normal to the one in question and the local meridian. It acquires 0 at noon (S). From the sunrise to the noon (E) this angle is assumed to be positive, while after the noon (W) it is negative. In the case when \( \gamma \neq 0^\circ \):

\[
h_c = h_1 - s \tan(h_a)/\cos \gamma
\]  

(11)

or

\[
\kappa_c = \kappa_1 - \tan(h_a)/\cos \gamma
\]  

(12)

After taking into account the change in the solar altitude during the day:

\[
h_c = h_1 - s \tan(h_a) \cos \left( \frac{90t}{t_p} \right)/\cos \gamma
\]  

(13)

or

\[
\kappa_c = \kappa_1 - \tan(h_a) \cos \left( \frac{90t}{t_p} \right)/\cos \gamma
\]  

(14)

The shading occurs when \( h_c \) or \( \kappa_c \) are greater than zero. When \( h_c \) or \( \kappa_c \) are less than zero, it means that the shading does not occur. The whole building is shaded when:
or

\[
\kappa_2 \leq \kappa_c
\]  

(16)

where:

\[
\kappa_2 = \frac{h_c}{h_2}
\]  

(17)

\(h_1\) – the height of the shading building,
\(h_2\) – the height of the shaded building.

Where \(\kappa_c\) and \(\kappa_2\) introduce dimensionless, more universal values, which are more useful in general cases. \(\kappa_c\) – an auxiliary, dimensionless value is defined by the formula 8 as the ratio of the shading height \(h_c\) to the distance between the buildings (s). \(\kappa_2\) is defined by the formula 17 as the ratio of the shading height \(h_c\) to the height of the shaded building \(h_2\).

3. CHARACTERISTICS OF THE SELECTED EXAMPLES

The analysis included nearby locations of the Market Square in Leżajsk – a district city situated in Podkarpacie. Its geographical coordinates are 50,259°N and 22,420°E (the longitude does not affect the results of the analysis). The location of the analysed area is presented in Figure 3.

The area selected for the analysis is characterised by medium-height development (dominated by the buildings of 11 m), mostly properly arranged in terms of urbanisation. The layout of the streets and their geometrical parameters are typical for the old-town building development, created before the traffic expansion. Therefore, in the majority of the cases, the width of the streets determine the distance between the buildings.

Figure 3 presents analysed sections and buildings. 12 sections were selected: A-B and W-Z. The buildings for which the shading analysis was performed contain a dot, symbolising a vertical section of the building. Usually, the shading was situated in the middle of the width.

The \(\gamma\) azimuth was determined for this place, as well as daily hour range of the shading (\(\omega\) hour angle). Selected examples included units of the buildings marked with Latin numbers I to III. Analysed sections were grouped into fours. And so area I included sections A-B, C-D, E-F i W-Z, and area II sections G-H, I-J, K-L i Ł-M. Area III included sections N-O, P-R, S-T i U-V.

4. ANALYSIS RESULTS OF THE SELECTED EXAMPLES

The results of the analysis are shown in Figures 4÷7. Figures 4, 5, and 6 concern succeeding areas I, II and III, while Figure 7 is a summary drawing for all areas and sections.

Even a general look at these drawings indicates a large variety of the shading degree and the time of its occurrence.

The shading degree of the A-B and E-F sections in the I region (Figure 4) is the same, only the shading time during the day in the second one is longer. It is a result of the location of the buildings in question in the street and to the shading development. A shorter period of the shading of the building in the W-Z cross section results from the open space between the buildings. Different degree and shading time of the building in C-D section is justified by the fact that the building in question is located at a perpendicular street to the street where buildings A-B, E-F and W-Z are located.

Figure 3.
Location of the buildings and analysed sections
Bigger shading variations occur in II area (Figure 5). It is caused by the greater diversity of the location of the buildings in relation to each other and to the world. Practically, the degree of shading and the duration of the shade vary considerably between all the sections and buildings concerned. Although the analysis concerns buildings that are also located at two orthogonal (approximately) streets, the distances between them are different than in the case of the buildings located in area I.

The degree of the shading of buildings in area III (Figure 6) is an intermediary between shading in areas I and II. The characteristics of the buildings’ shading in S-T and U-V sections are similar to those in sections A-B and E-F (Area I), while the shade of N-O and P-R are similar to those obtained for I-J and L-M (Area II).

A comprehensive summary of the analysis results of the shading of selected buildings in the area around the Market Square in Leżajsk is illustrated in Figure 7. It shows a large variation in the degree and duration of shading of the buildings, although the buildings appear to be in a small area. However, even small differences in the distance between the buildings and their location in relation to each other cause significant differences in the shadowing. It is an important indication for the designers and an incentive for a detailed analysis of the shading issues in urban planning and architectural design.

5. REMARKS AND FINAL CONCLUSIONS

The paper analyses the height of the $h_c (k_c)$ wall shading caused by the neighbouring buildings on 21st March and 23rd September. These issues are related to the impact of the solar radiation on buildings (natural warming of the exterior walls of the buildings) and ecological urban design. It should be emphasised that the sun’s rays have an impact on the biological and physical processes on Earth and are essential to human life.
The author provided her own final formulas for the $h_c$ height of the wall shading from the adjacent building. These formulas have taken into account the influence of the seasons, the time of day ($\omega$ hour angle), the location of the object in relation to the directions of the world ($\gamma$ azimuth) and the distances between the buildings ($s$). Presented formulas enable proper analysis for every location. They have been used to calculate specific cases. Our own simulation program was used, during the preparation of the graph. The calculations were made for all cases included in the work. The trigonometric functions which were used are continuous so that continuous curves could be drawn.

The results of the analysis prepared for three building units in the vicinity of the Market Square in Leżajsk show that the spatial layout of the urban structures significantly influences the light exposure of architectural interiors. This fact is also significant in shaping the assessment of the quality of the housing environment. In this case, the morphology of the residential areas, including the height of the objects and the distance between them is of fundamental importance.

The shading of the urban interiors always occurs, but its degree depends on the height of the building development and the distance between the objects, as well as the location of the objects in relation to the directions of the world. It changes in annual and daily cycles. At sufficiently large distances between the buildings in relation to their height, the shade can cover only a part of the space between them, but it will not reach the buildings themselves. In the old town development, which is compact, such cases are usually non-existing.

On the basis of the comparison of the analysis results for different areas and sections, it can be stated that the location of the buildings in relation to each other and to the directions of the world has a significant effect on the degree of shading and its duration. Even slight differences in this range greatly affect the degree of shading. It is an important encouragement for a detailed analysis of the shading state in urban planning and architectural design, but also a guideline for the designers of communication systems. In many cases, the distances between the buildings are determined by the width of the streets and the sidewalks.

REFERENCES