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THE CRITERION OF ACCESS TO THE SKY VIEW IN RESIDENTIAL ENVIRONMENT ARCHITECTURAL DESIGNING

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Abstract

Standards specifying the requirements for daylight in shaping the interiors of residential buildings do not cover issues related to visual perception and the role of light as a carrier of images of the outside world. The general recommendations in this regard, given in the 2018 European Lighting Standard can hardly be considered an unambiguous, precise normative regulation. According to the author, the inalienable element of the view through the window is the image of the sky, which is the basic reference in human perception of the space of the external environment. The aim of the research is to identify the main determinants for ensuring access to the sky view from apartments in housing estates with high intensity of development. The analyzes are based on the author's simple graphical research methods capable of simulating the visual perception of images of the external environment space through a window. The key parameter in the analyzes is the vertical viewing angle, called the sky view entry angle. Its minimum value set at 7.5°C is of fundamental importance in shaping the geometric relations between neighbouring buildings. The research results oblige, in the context of the paradigm of sustainable housing development, to recognize the criterion of access to the sky view from residential interiors as a mandatory design guideline.

Keywords: **Graphical methods of analysis; *Relative retinal image*; Sight line; Sky view entry angle; View through the window; Viewing angle; Visual perception; Residential environment architectural designing.**

1. INTRODUCTION

1.1. Foreword

From the dawn of time, a feature of urban structures is the increasing density of their buildings. For thousands of years, this was due to the spatial limitations of defensive cities. Today, however, it is the result of many new factors mostly of an economic nature. One of the basic problems of urban living space development is and has been to satisfy the age-old need for sensual and physical relations between man protected by utility interiors and the surrounding external environment. These vital connections are and have been realized through the window, which explains why the history of architecture is largely the history of the window.

Man functions alternately both in the natural conditions of the external environment and in architectural interiors separated from it. Both of these environments create one existential living space necessary for his health and well-being. The primary sense of perception of this space is the sight, which provides its visual representation in the human mind [1, 2].

The need for eye contact with the external space through the window is primarily psychological but window also has basic role in ensuring the flow of physical factors of the external environment into living interiors. The inviolability of the window functions may be protected by the law. An example of this was English Property Law known as Ancient Lights (1663). These regulations ensured the owner of a building or house the right to light received from and through windows – and thus also to an unobstructed view through the window. Windows used for light by an owner for 20 years or more could not be obstructed by the erection of an edifice or by any other act by an adjacent landowner [3].

1.2. Multidisciplinary aspect of the issue

The research undertaken is part of the interest in the issue of view through windows, represented by many scientific fields and in the broader context of the relationship between the internal and external environment. Studies of a wide spectrum of issues represented by numerous items of scientific literature in this field confirm the high rank of these problems in the modern world. Particular emphasis should be placed on their multidisciplinary nature and unquestionable relations to the impact of the doctrine of sustainable development. Due to the limited scope of this article, the author does not discuss these works in detail, limiting himself to listing them in the list of references. The purpose of referring to them is to show the general scientific background, and thus to show the importance of the research topic undertaken. Parallel to Town Planning, Architecture and Construction, this issue is of interest to researchers from other fields, such as: Environmental Psychology [4–6]. Environment and Behaviour [7–9]. Construction and Environment [10–13], Lighting Research and Technology [14–19] as well as the Human Factors, Ergonomics and Medicine [20–22].

One of the key undertakings in this research area was an interdisciplinary project initiated by the National Research Council of Canada under the name "The Physiological and Psychological Effects of Windows, Daylight and View at Home: Review and Research Agenda" [23]. This program allowed to identify over 270 items of scientific papers prepared by 2012, which indicates the importance scale of these issues. The research program was aimed at supporting architectural and lighting solutions that are beneficial to the health and well-being of the inhabitants. The summary of the report contains conclusions that should be emphasized as important for the research undertaken. The first is that separation from the view of sky and the outside world should be avoided. The second indicates that the view outside also contributes to well-being, especially if it's nature.

The effects of these strictly scientific activities constitute the theoretical basis of a real strategy for the implementation of the concept of sustainable urban development. An example of this could be the statutory requirements to provide city residents with access to the sky and sunlight. A good example of the effective application of such a strategy in practice is the activity of the city of Toronto. In their building design guidelines, they established an obligation to protect access to sunlight and the view of the sky, defined as the measurable amount of sky seen above and between urban building blocks [24]. The importance of these essential regulations is expressed in a clear, simple statement: Losing the view of the sky restricts access to light, affecting comfort, quality and enjoyment of the public sphere [25].

The high rank of the window view criterion in the assessment of the apartment value is well reflected in the real estate market. Research of scientific publications in the field of real estate economics confirms the dependence of the value of apartments and houses on the quality of the view from their windows – the more sky and open space to the horizon, the higher the price [26]. It is well known that houses on the shoreline have twice the market value of houses located a mile inland. The quality of the view from the windows translates directly into the price of a flat or house. According to estimates by one of New York's largest real estate appraisals and consultancy firms, an apartment on a higher floor with nearly unobstructed views can cost 25 percent more than an apartment without views on the lower levels [27].

1.3. Brief historical background

Literature studies on the topic have shown two cases of a method that directly uses the optics of the human visual apparatus to obtain a view of the sky from the window of living quarters. One of them comes from the work of Marcus Vitruvius Pollio: de Architectura, Book VI, Chapter 6, dated to the 1st century BC [28]. A Roman architect wrote: (...) *in the city, the height of the party walls or the tightness of the situation may obscure the light. In that case, we should proceed as follows. In the direction from which the light is to be received, a line should be drawn from the top of the obscuring wall to that part where the light is to be introduced, and if looking up along this line, a large area of open space can see the sky, light can be obtained from that quarter without fear that it will be covered; (...), which was summed up a few lines later: (...) In short, one can assume as a general rule that where the sky is visible, openings for windows should be left in such a part so that the building is bright.* (…).

The second case is about 200 years old and comes

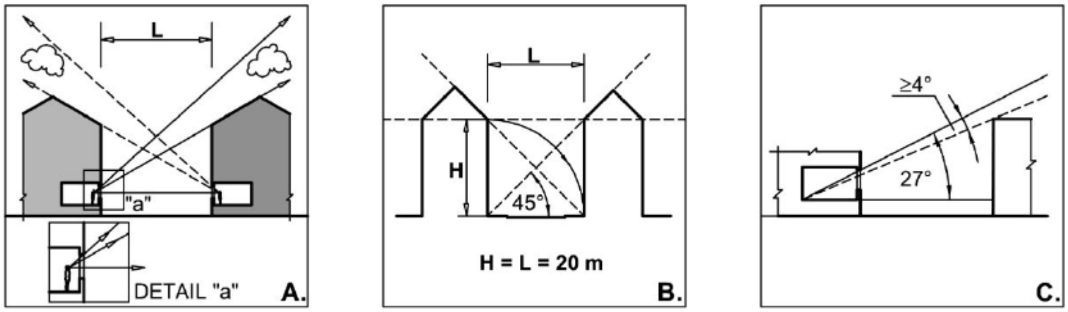


Figure 1.
Chosen historical methods of establishing building-to-building distances in the context of daylighting and access to the sky view
A. More than 200 years ago, Prussian land law clearly regulated the distances between adjacent residential buildings, requiring that the sky was visible from the ground floor windows of each of these buildings. Source: author, based on [30].
B. New regulations concerning the buildings and streets of times of the Haussmannian transformation of Paris (1853–1870) – the facades couldn't exceed 20 meters in height in streets 20 meters in width and the roofs had to be diagonal at 45 degrees. Source: author, based on [31].
C. The principle of opening angle 4° and incidence angle 27°, as a method of determining the daylight illumination of living quarters according to DIN . Source: author, based on [32]

from the provisions of Prussian Law. A simple visual-optical method was used to determine the distance between the buildings. Namely, it was required to provide a view of the sky above the newly erected building from the ground floor of the existing building, Fig. 1(A).

Only the industrial revolution brought significant changes in the functional and spatial organization of cities. The flagship example of this is the great reconstruction of Paris (1853–1870), Fig. 1(B). From the point of view of the subject of this work, the precise rules of shaping the transverse profile of a city street, introduced at that time, are important. They strictly determined the height of the buildings and the distances between their opposite frontage [29]. In this way, they regulated the access of daylight to the apartments on individual floors, and also provided a view through windows with access to the sky.

In European urbanism, these principles survived until the renewal movement initiated by the Athens Charter and the CIAM conferences, known as Modern Architecture. Due to the subject matter of the presented research, the most important was the introduction of the then common in estate planning rule that the minimum distance between residential buildings should be twice their height, Fig. 1(C). After World War II, the urban planning of housing estates in the countries of the Soviet-dominated Eastern bloc was based on the rigorous application of this algorithm, and these principles survived until the 1990s [33].

1.4. A breakthrough meaning of the 2018 European Lighting Standard

Until recently, the standards specifying the requirements for daylight in shaping the interiors of residential buildings resulted only from elementary physiological and health conditions of the human body. The term "window" was used only in relation to its dimensions due to the amount of light introduced into the interior and not due to the viewing opening. Matters related to visual perception, with the role of light as a carrier of images of the outside world, were not subject to unambiguous normative regulation. In this context, the 2018 edition of the European Lighting Standard should be considered a breakthrough. For the first time, a building code clearly indicates the need for a view of external environment. It also tries to define the view from the window in terms of its essential elements, specifying the minima required in this respect [34]. The most important of the three elements of the view presented in the standard is, according to the author, the image of the sky. Its lack in the view from the window significantly weakens the visual relationship of the user of the residential interior with the outside world.

1.5. Goals, scope and basis of the research

It is obvious that in the psychological dimension it is the sky that is the basic reference element in the human perception of natural space. Therefore, one of the most important criteria for sustainable housing construction should be to ensure that every apartment user has access to a view of the sky through the window. The implementation of this postulate is closely related to the problem of the distance between buildings that make up the urban spatial structure of housing estates. The above statements were the basis for determining the goals and scope of the undertaken research. The main goal is to identify the broadly understood full spectrum of conditions for ensuring access to the sky view from apartments in buildings of high-intensity housing estates.

The undertaken research topic concerns the key issue in the field of architectural design of housing estates. This issue is the rules for determining the distance between buildings in the context of qualitative and quantitative factors ensuring physical and mental comfort, health and well-being of residents. Among them, the most important factors are provided by the window. The most important of them are: daylight, direct sunlight and eye contact with the external environment. The design conditions of the first two are precisely defined in the relevant building standards. The same cannot be said for the view through the window, however. It is true that the new European Lighting Standard for Buildings raises issues related to the view through the window in general, but they cannot be treated as strict normative regulations.

The applied research methods are based on the use of previous scientific works as well as theoretical and practical experiences of the author in the design and implementation of visibility profiles of large-size stadium stands [35–38]. The author, focusing strictly on the phenomenon of visual perception, has developed a research apparatus capable of simulating the real visual perception of images of the external environment space through a window opening [39]. It was possible thanks to the use of the method of the relative image of the retina and the underlying conceptual apparatus [40a].

In this framework, the main attention is on the spatial and physical nature of the sky, as a component of the external landscape. The field of work interest also included the determinants of access to its view through the window. The subject of research is the image of the sky, which is an important element of the image of the wider external environment, reflected on the retina of the eye of the observer looking through the window from inside the living space. The assumed goal, scope and methodology of the research required the use of strictly optical principles of the functioning of the human visual apparatus and the definition of the view through the window adequate to these principles. In this context, this view can be thought of as a flat image projected onto a plane simulating the retina of the eye. Thus, an important research tool was created on the basis of the author's concepts developed in earlier works. This allowed for a series of analyzes, which are presented in detail later in the paper. They include issues such as:

- The dependence of the image size in the window opening on the observer's position in the residential interior;
- The dependence of the height of the sky image on the elevation of the upper edge of the window opening above the plane of the horizon;
- The dependence of the height of the sky image on the elevation of the obscuring objects above the plane of the horizon;
- Sky view access relations depending on the distance between buildings;
- Minimum vertical viewing angle of the sky in the window opening;
- The relationship between the provisions regulating the permissible distances between buildings and the access range to the sky view.

2. MATERIALS and METHODS

2.1. The terms used and definitions of their meaning

The following presentation of the terms used and the definitions of their meanings is intended to facilitate the understanding of the analyzes described in the following chapters of the paper.

Terms used in the works preceding current research:

- **Line of sight** – A straight line connecting the observed material point in the external space to the centre of the retinal yellow spot, passing through the geometric centre of the eye's lens
- **Central line of sight** – line of sight lying on a vertical plane perpendicular to the horizon line and at the same time on a horizontal plane passing through the horizon
- **Theoretical eye point** (Cyclops Eye) – A point lying at the intersection of three mutually perpendicular planes – the vertical plane of symmetry of the observer's body (xz), vertical plane passing through the geometric centres of the left and right eye lenses (yz) and the horizontal plane of the horizon (xy).
- **Retinal image** – An image of the material external space projected onto the surface of the eye's retina
- **Viewing angle** – The angle between the lines of sight of the extreme points of the perceived object. When these lines lie on a vertical or hori-

zontal plane, they will define accordingly the vertical or horizontal viewing angles.

- **Line of sight plane –** The plane on which the lines of sight lie. For the purposes of the undertaken research, two planes are used – vertical and horizontal.
- **Ranges of view of the human visual apparatus –** The angular ranges of human vision in the vertical and horizontal planes, achieved thanks to the movement of the eyeballs, head and torso.
- **The back or front projection planes –** simulating retina of the eye, vertical planes, perpendicular to the central line of sight and equidistant from the eye point, in front of and behind that point.
- **Relative retinal image –** An image of the object of observation plotted on the projection plane through the lines of sight opening and the higher edge of the obscuring object.

Terms created for the purposes of the current research:

- **The horizon plane –** The horizontal plane through the line of the horizon and the theoretical eye point.
- **Horizon –** is the theoretical edge of a horizontal plane passing through the point of the eye and the central line of sight, formed at the intersection with the vertical infinitely distant background plane perpendicular to the central line of sight. The intersection of these planes marks a horizontal line called the *horizon line*, on which there are the so-called vanishing points known from the principles of *linear perspective*.
- **Sky view entry angle –** The vertical viewing angle determining the height of the sky image reflected on the retina of the eye. It is marked by the sight lines of the upper edge of the window.

2.2. Theoretical basis of the relative retinal image method

The method of simulating real images recorded by the human visual apparatus is based on the use of a simple optical and geometric principles of the eye's operation, which we owe to the perspective vision. The lines of sight of observed objects pass through the centre of the lens and hit the retina inside the eyeball. The most important geometrical fact is that the distance between the lens and the retina has a constant dimension, while a distances from the lens of the points situated in the external space can be arbitrary. The angle between the lines of sight of the extreme points of the observed object is called the viewing angle, and its value on both sides of the central point of the lens is the same. It follows from the above-mentioned relationships that the viewing angles of objects of the same size will be different depending on the position in relation to the eye. This angle will be larger for object of closer distance to the eye, than the one lying further. Due to the differences in the sizes of the described angles of view, the images of objects displayed on the retina of the eye have the characteristics of an optical perspective. Images of objects of the same height or width decrease when moving away from the observer, and the lines of sight of their edge points converge on the horizon line, at the so-called vanishing points. The finding of the principle of the constant distance of the central point of the lens from the retina in the inside of the eye became the inspiration for the original graphic concept called the relative retinal image method. It involves the use of a back or front projection plane that simulates the retina of the eye. These planes should be perpendicular to the central line of sight and equidistant from the eye point, in front of and behind that point. This distance should have a constant value for all analyzed images, which is an indispensable condition for their comparability.

Details of image formation on the back and front projection planes are shown in Fig. 2. For simplified research models of the sky image size in the window opening frame, the analysis of the vertical viewing angle was the most useful. They were achieved by graphs made in the vertical plane, passing through the observer's theoretical eye point and the vertical axis of the window opening. The width of this images was obtained by examining the horizontal viewing angles in a horizontal plane, passing through the eye point and the horizon line.

2.3. Dependence of the external environment image size and scope in the window opening frame on the observer distance

Several factors (parameters) simultaneously determine the size and scope of the image of a sector of external space, seen by an observer from of a residential interior. They are: observer's distance from the window opening; the size and shape of the window opening; relation of the position of the window opening in regard to the central line of sight and the horizon line.

Fig. 3 shows an example analysis of these relationships performed using the relative retinal image

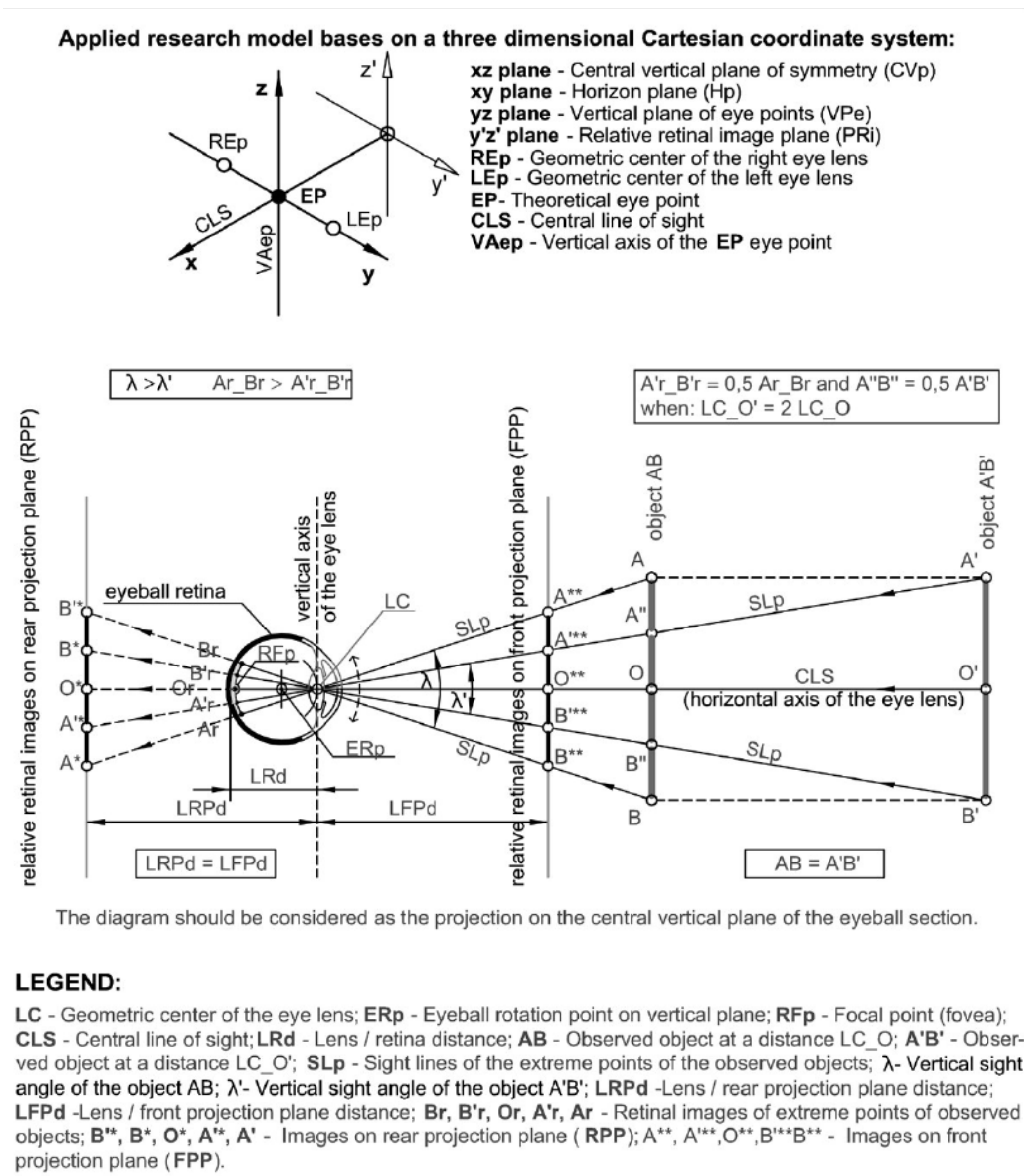


Figure 2.
Basis of the Relative Retinal Image Method. Source: author, based on [40b]

method. In order to make it easier to read, a simplified, synthetic model based on the following geometric assumptions was tested:

The window opening is a square with a side equal to 1.4 m, (approximate to the most popular size and proportions meet in a mass housing construction);

The Central Line of Sight elevation is 1.6 m, (the mean anthropometric elevation of the eye of the observer in a standing position);

The horizon line divides the height of the window opening in half;

The vertical plane of the graph passes through the vertical axis of the window opening;

The positions of the theoretical points of the eye in relation to the outer plane of the window opening are determined by the multiplicity of the 1 m scale;

The distance of the projection plane for individual points of the eye is constant and amounts to 1 m.

These assumptions mean, that characteristic for individual points of the eye, a horizontal and vertical viewing angles, are the same. The results of the conducted research show that the most important factor influencing dramatically the size and scope of the image recorded in the frame of the window opening is the distance of the observer from the outer plane of this opening. This is due to the fact that the values of vertical and horizontal viewing angles rapidly decrease as the eye point moves away from the window, with the former being the most important for the view of the sky.

Fig. 3 presents a summary of the graphs of relative retinal images of the window opening for points of the eye distant from this opening by the values of 1 m, 2 m, 4 m and 8 m. As seen, both the dimensions of the images of the sides of square window openings and their surfaces are rapidly decreasing, being respectively 1/4, 1/16, 1/64 part of the sizes registered from a distance of 1 m. The vertical and horizontal viewing angles of the images in the window frame decrease in similar proportions, and so do the viewing angles of the sky segment contained in them.

The above conclusions played an important role in the further stages of the search for the definition of the criterion of minimum access to the view of the sky from the windows of living quarters. They contributed, inter alia, to the definition of the essential parameter in the research which is the distance of the eye point from the outer plane of the window equal to 1 m.

2.4. The issue of access to the sky view – definition of general theoretical basis of the analyzes

Applied research model is based on the three dimensional Cartesian coordinate system, (see Fig. 2 at the top). The traces of the line of sight are examined in two planes: vertical (xz) known as the central vertical plane of symmetry and horizontal (xy) defined as the horizon plane. The intersection of the x, y, and z axis marks so-called the theoretical eye point, being the common point of three planes xz, xy, and yz. The edges of the window opening delimit a bundle of lines of sight of the external space converging at the theoretical eye point. In the case of a square-shaped opening, the beam will be in the form of a pyramid. When the hole is circular, the beam will be a cone. In both cases, the point of the eye is the apex of these forms. For the purposes of this description, they are given the names of a pyramid or a cone of vision. Due to the subject of the research, the most important are the lines of sight running in the plane of the central vertical section (in the xz plane). They allow for the analysis of determinants affecting the height of the sky image that is part of the image defined by the window opening frame.

As shown in Fig. 3 the height of the image of the external space is determined by two extreme sight lines – from the top, the line tangent to the upper outer edge of the window opening, and from the bottom, it is tangent to its lower edge. In this image, an important reference is the horizon plane on which the central line of sight lies.. The image recorded by the visual apparatus is divided into two parts, the one above the horizon and the one below it. It follows from the laws of the eye's optics and human range of vision that the maximum height of the sky view extends upwards from the horizon plane, represented by the central line of sight, to the vertical line of sight, reaching a vertical viewing angle of 90°. In the view through the window, the vertical angle of the sky view (β) is significantly limited by the presence of a lintel. Another limitation of the size of this angle may also be the presence in the image of the window frame of an object exceeding the height of the horizon plane. This height difference is represented by the vertical viewing angle γ. In the described situation, the height of the sky image is reduced to the size defined by the so-called sky view entry angle (δ).

Fig. 4 also shows the method of analysing the relationship between the human vertical range of vision and the vertical viewing angles of the external space through the window opening specified in the research model. It shows that below the horizon, these angles fall within the range of vision achieved solely by eyeballs movement, and above it slightly fall within the normal range of vision achieved by a combination of eye movements and head movements [40c].

2.5. Presentation of the research model

The research was based on the analysis of the theoretical model. Using the previously developed conceptual apparatus in order to conduct more detailed analysis, a research model was created. Its basis is presented with a vertical and horizontal cross-section, of a window opening, together with a fragment of the interior of the theoretical apartment. The obscuring object is drawn on the same scale as the residential interior, in terms of height, elevation above the horizon and distances. Reflecting the real viewing angles requires that both the interior and the obscuring object are plotted on the same scale. As shown earlier, the size of the image in the frame of the window opening depends on the distance of the theoretical point of the observer's eye from the outer plane of the opening. In the research model, it was assumed that for the first eye point this distance is 1 m. Subsequent analysed positions of the eye point are

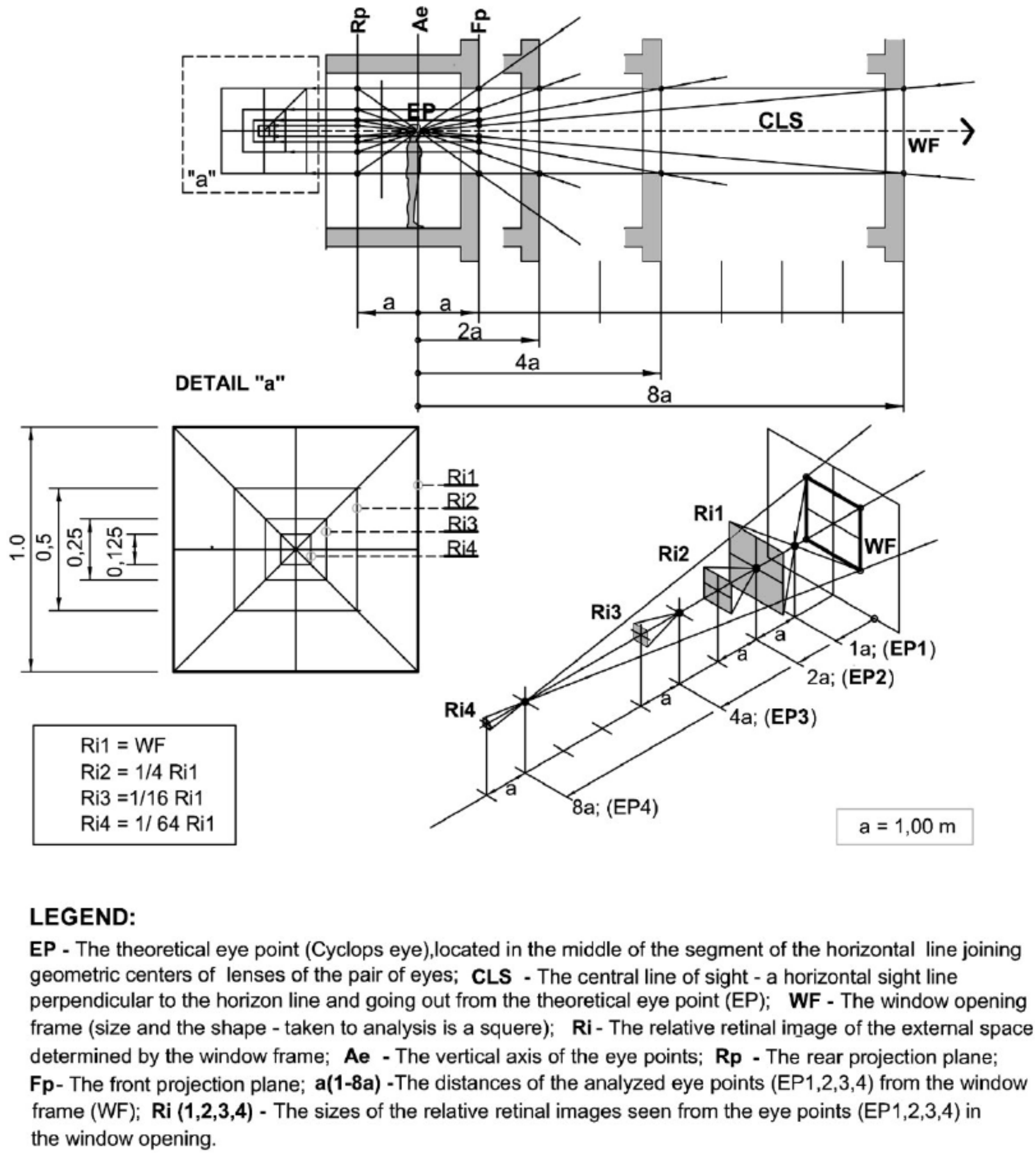
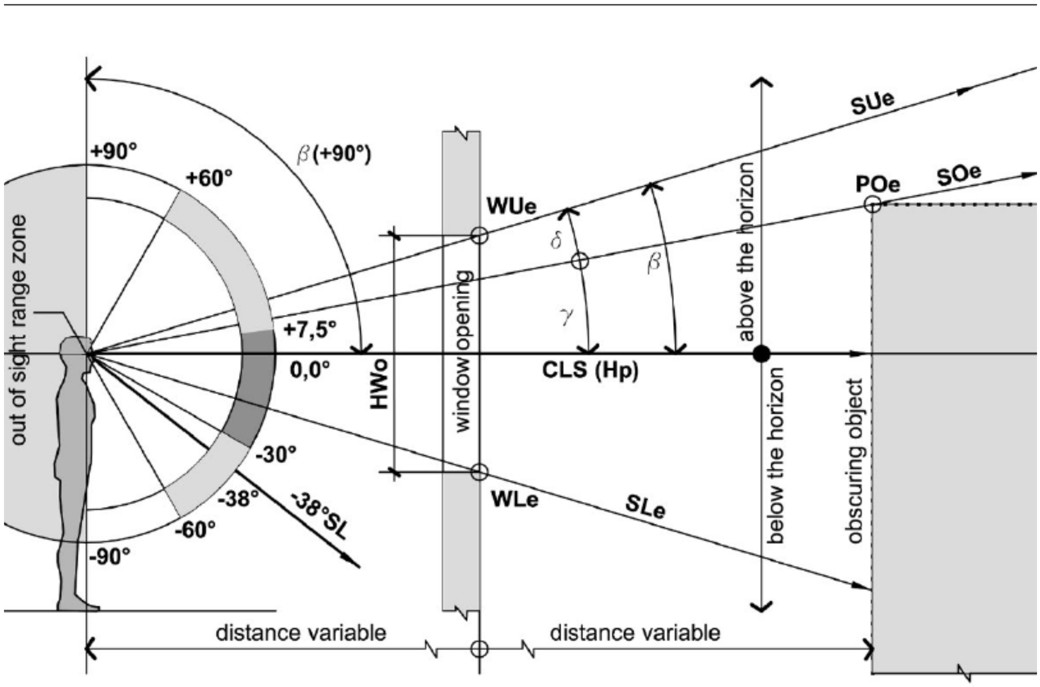


Figure 3.
Dependence of the external environment image size and scope in the window opening frame on the observer distance. Source: author

a multiple of this distance.

For the research model, strict assumptions were made for the creation of relative retinal images. Accordingly, the front projection plane lies on the outer plane of the window opening and is thus distant from the first point of the eye by 1 m. The rear projection plane coincides with the vertical axis of the next point of the eye, which runs at a distance of 1 m. The method of constructing the relative image of the retinal view through the window is shown in Fig. 5 (detail "a"). It consists in transferring the course of three lines of sight: tangent to the upper edge of the opening (Sue), tangent to the lower edge of the opening (SLe) and tangent to the highest edge of the screening object (SBe), to an enlarged drawing of the vertical cross-section of the window opening.

The first two pass through the extreme edges of the opening, while the third cuts off the boundary between the sky view and the view of the obscuring object, on the front projection plane (Fp). Extending these lines to the intersection with the trace of the rear projection plane creates an image identical to the above, but inverted. Plotting the horizontal dimension, i.e. the width of the window opening



The above diagram should be considered as a projection onto a central vertical plane CVp (xz plane).

LEGEND:

EP - The theoretical eye point (*Cyclops eye*), lacated in the middle of the segment of the horizontal line joining geometric centers of lenses of the pair of eyes; **CLS (Hp) -** The central line of sight - a horizontal sight line perpendicular to the horizon line and going out from the theoretical eye point (EP); **WUe -** Window opening upper edge; **WLe -** Window opening lower edge; **SUe -** Sight line tangential to the upper edge of the window opening; **SLe** -Sight line tangential to lower edge of window opening; **POe -** The point of obscuring object upper edge; β**(+90°) -** Maxiumum angle of vertical vision range of the sky in the open space; β - vertical vie - wing angle of the sky image in the window frame when obscuring objects do not exeed the horizon line; δ - Sky view entry angle - vertical viewing angle of the sky limited by the window frame and an objects located in external space; γ - Vertical viewing angle of the part of obscuring building exceeding the horizon line; **HWo -** The height of the window opening; **SOe -** Sight line of POe point.

HUMAN VERTICAL RANGE OF VISION:

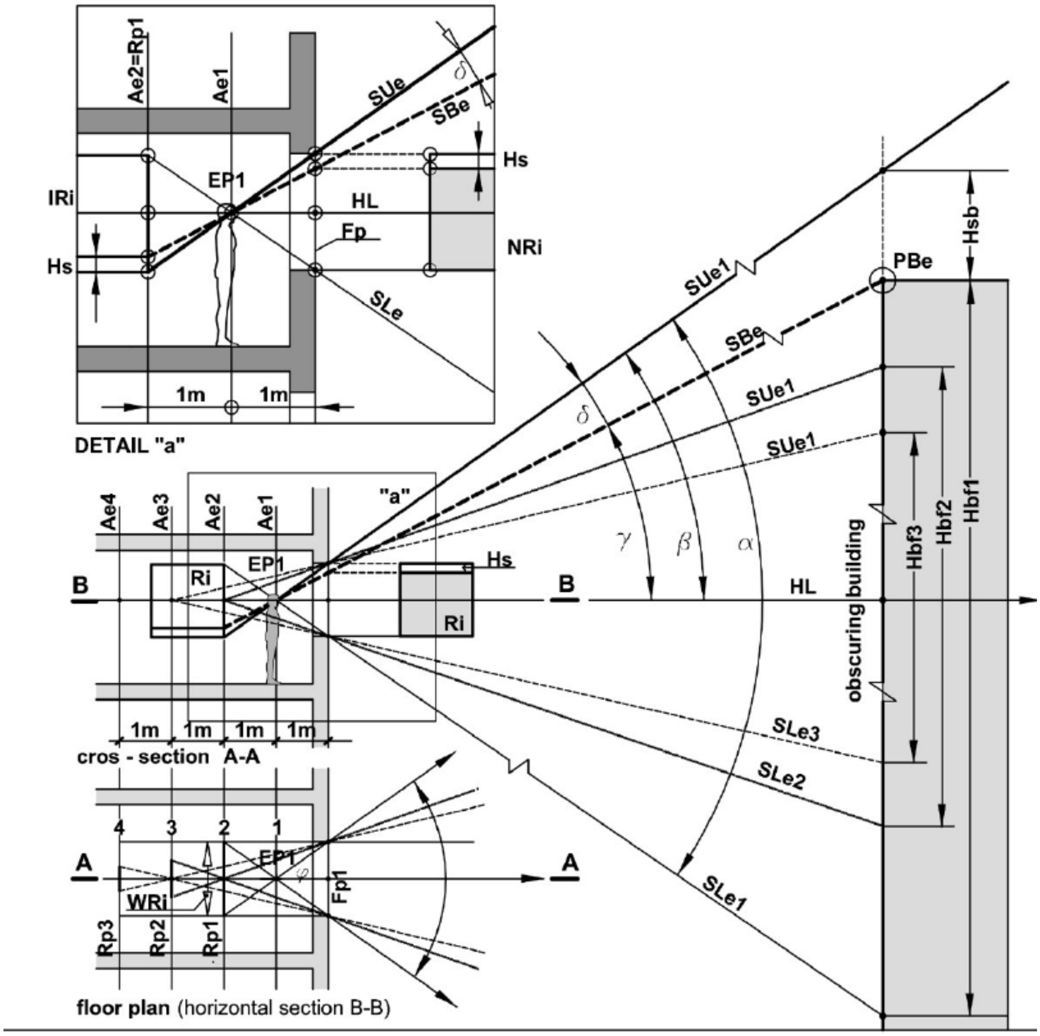
+7,5°, -30°, (37,5°) - The vertical range of vision achieved just by the eye movement ;
+60°, - 60°, (120°) - The normal vertical range of vision, achieved as a result of optimal combined eye and head movement;
+90°, - 90°, (180°) - The maximum vertical range of vision. The ranges from -60° to -90° and from +60 to +90° require the combined movement of the eyes, head and torso;
-38° SL - The sight line of vertical angle -38° ensuring optimal, the most natural, positioning of the eyes and head (requiring the least effort).

Figure 4.
The issue of access to the sky view – definition of general theoretical basis of the analysis. Source: author

image, is carried out on the plane of the horizontal, central cross-section of the window opening. It is defined by the points of intersection of the line of sight of the side edges of the opening with the front and rear projection planes. The full image of the sky in the image of the window opening is obtained by combining both image parameters, i.e. its height and width.

2.6. Analysis of the impact of the criterion of minimal sky view entry angle on the distance between buildings

Fig. 6 illustrates an example of the application of the previously presented research methodology on the issue of access to the view of the sky from residential interiors. The conducted analysis concern the relationship between the sky view in the window frame image and the distance between neighbouring resi-



LEGEND:

EP(1,2,3) - Eye points; **HL - H**orizon line; **SUe** - Sight line tangential to the uper edge of the window opening; **SLe** - Sight line tangental to lower edge of the window opening; **PBe** - Point of the obscuring bilding upper edge; **SBe** - Sight line tangental to PBe point; α - Vertical viewing angle of an image of external space framed by a window opening; β - Maximal vertical viewing angle of the sky image in the window frame; δ- Sky view entry angle, limited by obscuring buildng (object) in the window frame; γ- Vertical viewing angle of the part of obscuring building exeeding the horizon line; φ- Horizontal viewing angle defined by the EP1 eye point distance from the window plane and the width of window opening; **Ae** -Vertical axis of the eye points; **Fp** -Front projection plane; **Rp (1,2,3)** - Rear projections planes; **Ri** - Relative retinal image of external space in the window frame; **NRi** - Normal Ri; IRi - Inverted Ri; **WRi** - Width of Ri for EP1 eye point (projection on a horizontal plane; **Hs** - Hight of the sky image in the Ri; **HsB** - Height of the sky view image on the facade plane of the obscuring building; **Hbf** - Hights of the obscuring building facade in the Ri images, recorded by the EP1, EP2 and EP3 eye points, as limited by frame of the window.

Figure 5.
The research model based on the application of the relative retinal image method. Source: author, based on [40a]

dential buildings. The goal defined in this way required the extension of the research model to include the possibility of stacking individual modules of residential interiors. The subject of research in this case are not only individual apartments, but also entire, multi-storey buildings. Their representation in the model is the vertical cross-section through the building, including the living spaces, adherent to the external façade wall with windows.

In the research, a specific height module of a building story was adopted (M = 2.85 m). An important role in the analysis is played by the central lines of sight, lying on the horizon planes, which are parallel to each other and characteristic for each storey. Their mutual elevations have the dimension of the M module. The eye points are located at the intersection of the horizon lines and the eyes vertical axis, distant from the building face by a constant value (1 m). Their location is the same on the individual storeys of the building. The horizon plane passes through the points of the eye and is raised 1.6 m above the floor. This height is called the standing position eye height in anthropometry, and its value corresponds to the median of the percentile distribution. Its counterpart for a sitting position is value equal to 1.2 m.

For the purposes of increasing readability of this analysis, it was assumed that the window opening is a 1.4 m square and the central line of sight passes through its geometric centre, which means that the central planes, horizontal (xy) and vertical (xz) are dividing it symmetrically. The upper edge of the analyzed buildings is above the eye point of the highest storey at the distance of the M module. This assumption allows for the treatment of parallel horizontal central lines of sight as a modular grid, which is useful in determining the heights and distances of an obscuring buildings.

The parallelism of the central lines of sight of observers on individual storeys results from the general laws of optics of the eye. According to them, the planes of the horizon on which these lines lie rise in parallel as the point of the eye rises, the line of the horizon rises and the range of view increases. Using the research model described above, detailed analysis of access to the sky view from apartments of opposite residential buildings, depending on their distance, were carried out.

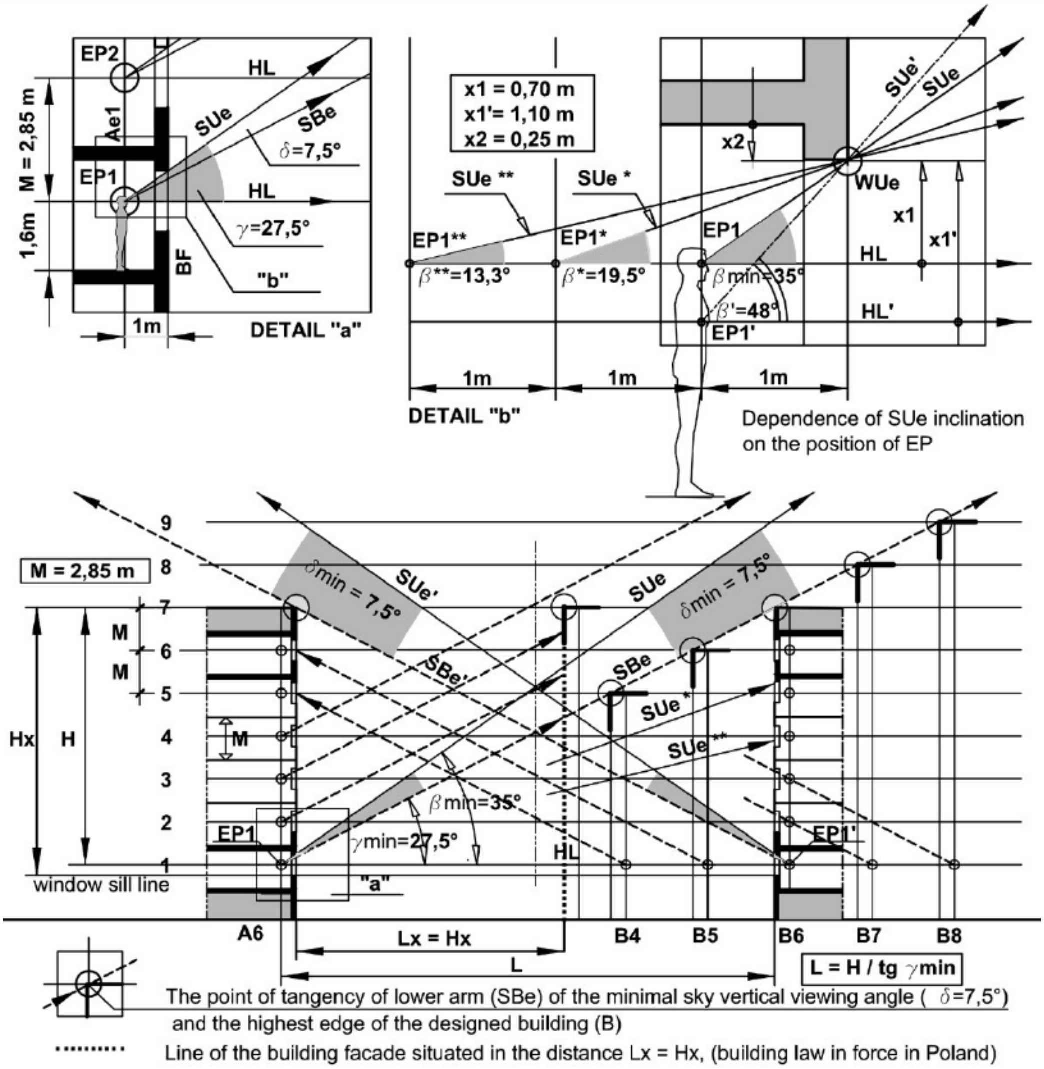
The initial assumption for these studies was to determine the acceptable, minimum vertical angle of view of the sky from the lowest apartments, previously named as the minimal entry angle of the sky view. Based on his previous research on the issues of visual perception, the author assumed that this angle should not be smaller than 7.5°. It is the upward viewing angle that is achieved by humans solely through the movement of the eyeballs. The second important assumption was that the study should focus on the impact of the designed building on the existing one. It was also established at the outset that the existing building consists of 6 residential storeys and its height, measured from the horizon of the lowest eye point, is 6 modules M.

It follows from the above-described conditions that ensuring the minimum entry angle of the sky view (δmin = 7.5°) for the lowest point of the eye in the existing building (A6) requires that the highest edges of the designed building do not exceed the line of the lower arm of this angle (SBe}, and were at most tangent with this line. The intersections of the SBe line with the lines of the horizon planes of individual storeys determine the potential heights of the designed building B (4–8), which meet the above condition. They also define its potential distances from building A.

However, it turns out in the summary that not all the positions of the designed building B determined in this way can be taken into account, which results of the influence of building A on building B in terms of meeting the criterion δmin = 7.5°. This is evidenced by the analysis of the route of the SBe line derived from the eye points of the lowest storey of building B. It shows that only the location variant of B6 and the subsequent ones provide their lowest apartments with access to the sky view. The eye points EP1' in buildings B4 and B5 are completely deprived of this access. At this point, it should be noted that the condition of having an equal view of the outer space from the lowest apartments of both, existing and planned, buildings is fulfilled when they are of the same height, and their distance (L) results from the course of the SBe line, derived from the lowest EP1 eye point.

Fig. 6 (Detail "b") shows the analysis of the vertical angles of the line of sight of the top edge of the window opening (Sue). These angles depend on three parameters: the elevation of the lintel above the horizon line of sight (x1), the height of the lintel (x2) and the distance of the theoretical eye point from the outer plane of the window opening. The study were carried out for the assumed values of these parameters, such as: x1 = 0.7 m; x2 = 0.25 m; distance of the eye point, as a multiple of 1.0 m modulus. For these values, the slope of the SUe line (β) for the eye point EP1 is 35°. This value was considered minimal for the standing position of the observer, 1 m away from the outer surface of the window. As the observer moves away from the window, these angles quickly decrease – for a distance of 2 m the angle β is equal 19.5°, and for 3 m equal 13.3°. For a sitting position, these angles increase significantly, e.g. for point EP1 this angle reaches the value of 48°. The value of the sightline SBe inclination angle (γ = 27.5°) is the difference between the value of the sightline SUe inclination angle (β = 35°) and the assumed minimal sky view entry angle (δ = 7.5°).

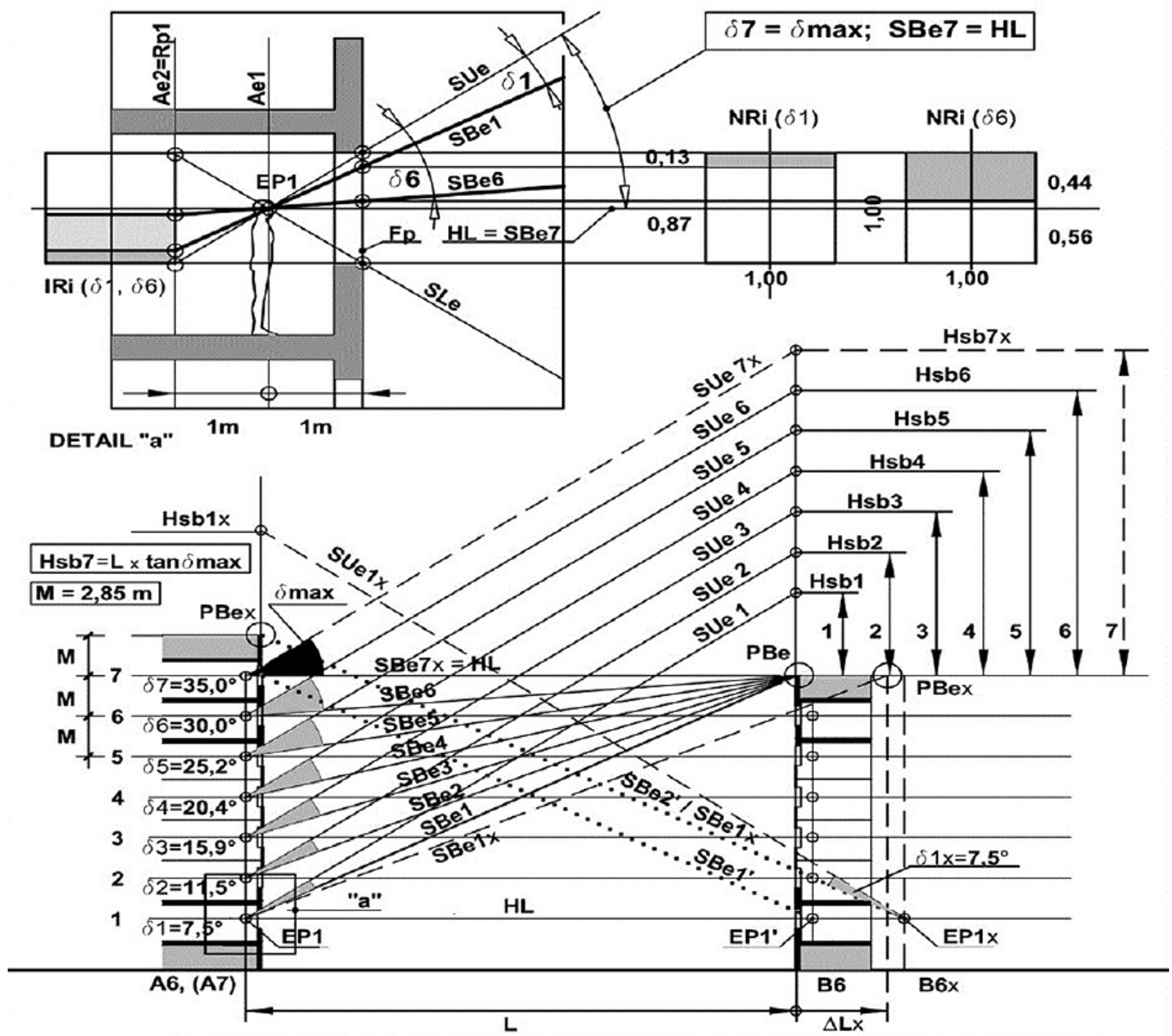
Knowing the value of the inclination angle γ = 27.5° allows to present the relationship between the height



LEGEND:

1÷9 - Numbers of floors and horizontal sight lines (HL); **A6 -** Existing building of 6 floors; **B(4÷8) -** Designed buildings of 4 up to 8 floors, established by the SBe line of 27,5° inclination; **SBe -** Sight line beeing the lower arm of the assumpted minimal sky viewing angel (δmin=7,5°); **SUe -** Sight line tangential to the upper edge of the existing building (A) window opening, beeing the upper arm of minimal sky view entry angle δ**min**; **EP1', SBe', SUe' -** Eye points, sight lines and vertical angles of view in the designed building (B6), symetrical to the existng building (A6); **EP1 -** The theoretical eye point on the lowest floor of an existing building (A6), the vertical axis of which is 1m away from the building face; γ**min = 27,5° -** The minimal inclination of SBe line ensuring for the EP1 point assumed minimal sky view entry angle δmin=7,5°, when SUe line inclination βmin = 35 °; **SUe*, SUe** -** Boundary lines of sight of the upper edge of the window opening (top edge of the retinal image) from EP1* and EP1** points. Moving these points 2 and 3 metres deep into the room causes a sgnificant reduction of the β angels, which resultes in the lack of a view of the sky, and even the upper parts of the opposite building; **M -** Vertical, modular distance between the central horizontal sight lines, specific to the eye points on particular storeys, also the modular height of the storey; ; **WUe** - Window opening upper edge point; **x1 -** Distance between WUe point and horizon line (HL); **x2 -** Height of the window opening lintel; ••• **"M", "x1"** and **"x2"** parameters significantly affect the sky view entry angle ; EP1', HL', SUe', x1', β' - Notations concerning the seated position of the observer.

Figure 6.
Analysis of the impact of minimal sky view entry angle on the distance between buildings. Source: author



— — — — Dashed lines and the index "x" next to their markings and markings of points means that they apply to the analysis of building "A" with 7 floors.

LEGEND:

A6,(A7) - Existing building of 6 or 7 storeys; **B6 -** Designed building of 6 storeys; **HL -** Horizon line, also horizontal sight line; **1÷7 -** Numbers of storeys and horizontal sight lines (HL); **M -** Vertical, modular distance between the central horizontal sight lines, specific to the eye points on particular storeys, also the modular height of the storey; **EP1 -** The theoretical eye point on the lowest floor of an existing building (A6), its vertical axis is 1m away from the building facade; **EP1'-**The theoretical eye point on the lowest floor of a designed building (B6); **δ(1÷7) -** Sky view entry angles, limited by obscuring buildng in the window frame, characteristic for EP(1÷7) eye points; **δmax -** Maximal sky view entry angle; **PBe -** Point of obscuring building upper edge; **SBe(1÷7) -** Sight lines tangental to PBe point, characteristic for EP(1÷7) eye points; **SBe(1',2') -** Sight lines of EP1' and EP2" eye points, tangental to PBe point; **SUe(1÷7) -** Sight lines tangential to the uper edge of the window opening of EP(1÷7) eye points; **Ae1(2) -** Vertical axis of the EP1 and EP2 eye points; **L -** The distance between Ae1 axis and the plane of B6 facade; **Hsb (1÷7) -** Heights of sky view images of EP(1÷7) eye points, projected on the plane of the obscuring building facade; **Fp -** Front projection plane; **Rp1 -** Rear projection plane of EP1 eye point; **Ri -** Relative retinal image of external space in the window frame; **NRi(δ1)-** Normal Ri resulted of δ1; **NRi (δ6) -** Normal Ri resulted of δ6; **IRi (δ1, δ6) -** Inverted Ri resulted of δ1 and δ6; **SLe -** Sight line tangental to lower edge of the window opening.

Figure 7.
Analysis of the height of the relative retinal images of the sky for eye points EP (1-7) of building A. Dependence of the size of the sky view entry angles on the position of the EP eye points on individual storeys of the building under study. Comparison of the extreme sizes of the retinal sky images in the window frame for the eye points EP1 and EP6, (Detail "a"). Source: author

of the analyzed buildings (H) and the distance between them (L) in the form of a trigonometric function $\tan \gamma = H / L$ or $L = H / \tan \gamma$. Since the tan 27.5° is 0.5206 (very close to 0.5), the above equation shows that with a high approximation, the value of "L" is almost equal to value of two "H", where: "H" is the height of the upper edge of the building elevation (multiplicity of "M" modules), calculated from the lowest horizon plane (HL) of the lowest point of the eye (EP1, EP1'), and "L" is the distance of the face of the obscuring building (B6) from the eye point EP1 in the existing building (A6). Summing up, it should be stated that providing a view of the sky from the lowest storeys in both opposite buildings requires that the distance between them should be twice the height of the higher one, and with the same building heights, the height of one of them. This statement is consistent with the findings of the algorithm used by architects and town planners in the period of modernism. In Poland, this rule was in force for nearly 30 years (from 1966 to 1994) [33].

One more conclusion about the distance between the buildings comes from the analysis. It concerns the relationship between the observer's distance and the perception of objects in terms of the ability to recognize image details. The described geometrical features of the examined building arrangement enable the conclusion that the distance Lx is 17.5 m. This value is within the margin of the distance of the farthest viewer, which is commonly used in designing drama theaters, which is 24 m, and determines the limit of legibility of the actors' facial expressions.

2.7. Analysis of the height of the relative retinal images of the sky for eye points EP (1–7) of the building "A"

2.7.1. Raising the height of building "A" by one story

Providing the maximal sky view entry angle requires that the horizon plane of the observer coincides with the horizontal plane of the roof of opposite building. In the analyzed example, this means that the observer must be at least one storey higher than the last floor of the adjacent building. Raising the height of building "A" by one story causes that it becomes an obscuring building and leads to the loss of the view of the sky from the EP1' eye point. In order to meet the condition of sky visibility from the lowest floor in building "B", its distance from building "A" should be increased by the value of delta L. The new position of the eye point EP1x can be established by extending the line SBe2' to the junction with the horizon line HL appropriate for the lowest story. The consequence of establishing the new position of the face of the Bx building is the new position of its upper edge of the PBex. This in turn causes the lowering the line SBe1x of the angle of view of the sky for the eye point EP1 and as a result leads to an increase in the value of this angle above the minimum value. The presented argument shows that in a situation where two adjacent buildings have different heights, in order to ensure the minimum parameters of sky vision from their lowest storeys, two principles should apply simultaneously:

Principle 1 – The distance between buildings should be twice the height of the taller one;
Principle 2 – Minimal sky view entry angle ($d = 7.5$) should be provided in lowest apartments in the lower building.

2.7.2. The dependence of the size of the sky view entry angle on the location of theoretical eye points

The last, closing phase of the research work is presented in Fig. 7. Based on the research model used so far, an analysis of the dependence of the size of the sky view entry angle on the location of theoretical eye points on individual storeys of the building "A" was carried out. The analyzed graph consists of bundle of sight lines of the upper edge of the designed building SBe (1–6), tangent to the point PBe and the bundle of sight lines SUe (1–6), which are mutually parallel, tangent to the upper outer edges of the window openings and vertically shifted relative to each other by the value of the "M" module. The inclination angles of the SUe lines are constant, while the slope angles of SBe are variable. They decrease when the positions of eye points are lifting up with raise of storeys. As a result, the smaller the difference between the height of the eye point and the point PBe, the greater the sky view entry angle. When this difference amounts to one module "M", which in the case of the analyzed model means that the eye point in the building "A", is located on the sixth floor, this angle reaches value of 30°.

Discussed dependencies can also be presented in the form of the height of the sky images in the plane of the face of the building "B", above the PBe point. This can be achieved by extending the Sue lines to the intersection with a vertical line extending above point PBe. The points of intersection mark, measured from the highest edge of the building "B", indicate the heights of the sky images (Hsb), reached from the individual floors of the building "A". These heights can be expressed with a specific value in measurement units, as the height increments of the images are times the value of the "M" modulus, and the height Hsb1 can be calculated using trigonometric functions.

2.7.3. The Relative Retinal Image

The basic tool for presentation of the results of analyzes of the sky image sizes in the window frame is the relative retinal image method. Its advantage is operating with the image of the window opening and the view of the sky inscribed in it. Fig. 7 (Detail "a") presents the principles of their formation on the example of images recorded by two extreme points of the eye – the lowest one EP1 and the highest EP 6. This method use the theoretical foundations previously described (Fig. 2 and Fig. 5). Plotting relative retinal images requires the transfer to the theoretical eye point (EP1) in the apartment research sample model of two lines of sight, i.e. line SB1 and SB6. The inclination angles of these lines were established earlier in the basic analysis of visual relations characteristic of the tested buildings layout. These lines, crossing the trace of the front projection plane in the face of the building "A" elevation (Fe), mark the points of the lower edges of the sky images in the window views of an external environment.

The heights of the images in a window view are determined by the traces of horizontal planes, passing through the lower and upper edges of the window opening. Their intersections with the vertical plane of projection (ẏz' at Fig. 2), marks the images of the upper and lower edge of the window opening. The earlier assumption of the window opening shape entitles to inscribe the left and right sides of the square into the creating image. Finally, the projection of the lower edges of the sky views onto the windows openings images is carried out in the same way. In effect the complete image of a window view with the sky view inscribed in it is created.

If it is assumed that the side of the window opening image is equal to 1.00, then the sky image heights included in it can be expressed as a fraction. As can be seen in Fig. 7 (Detail "a"), the height of the sky image for the lowest flat is 0.13 of the entire height of the image in the window frame, and for the highest, sixth floor, this value is 0.44. These results can also be expressed as a percentage. These would be 13% and 44% respectively. At this point, it is worth noting that the maximum height of the sky image equal to 0.50 (50%) in the case of the analyzed model (A6 and B6) could be achieved when the observer's horizon plane in one of these buildings was aligned with the highest edge of the other building. This condition would be met if the observer was one story above the height of the opposite building.

Providing the maximum angle of entry to the sky view requires that the observer's horizon plane coincides with that of the roof of the opposite building. In the analyzed example, it means that the observer must be at least one storey higher than the last storey of the neighbouring building. Raising the height of building "A" by one story causes that it become an obscuring building and leads to the loss of the view of the sky from the eye point EP1. In order to meet the condition of sky visibility from the lowest story of building "B", its distance from building "A" should be increased by the value of DL. The new position of the eye point EP1x can be determined by lengthening the line SBe2' to the junction with the horizon line HL appropriate for the lowest story. The consequence of establishing a new position of the face of the Bx building is the new position of its upper edge of the PBex. This in turn decrease inclination of the SBe1x line. As a result, with a constant slope of line SUe1, the sky view entry angle for EP1 will increase, reaching a value higher than the minimal one.

The presented arguments show one more time that in a situation where two adjacent buildings have different heights, in order to ensure the minimum parameters of sky vision from their lowest storeys, two rules should apply simultaneously:

Rule 1 – The distance between buildings should be equal two heights of the higher of them.

Rule 2 – Minimum entry sky view angle (d = 7.5) should be provided for the lowest flats in the lower building.

3. RESULTS

One of the results of the research undertaken is the creation of a research apparatus capable of simulating the real visual perception of images of the external environment space through a window opening. In this framework, the main focus was on the spatial physical nature of the sky as a component of the outer landscape and the determinants of access to its view.

In search of the most appropriate analytical tools author focused strictly on the phenomenon of visual perception and its role in assuring the relationship between a human being in a protected residential space and external environment. These relationships are made possible by the images that the brain captures with the eye through the window. That is why the essence of the developed research method is based on analysis of external environment images transmitted by the lines of sight focused at the theoretical point of the eye and then projected onto the plane simulating the retina of the human eye.

The applied research methods are based on the use of previous scientific works as well as theoretical and practical author's experiences in the field of designing and implementing large stadium stands. The conceptual apparatus developed at that time and the method of the relative retinal image turned out to be particularly useful in undertaken task.

The vertical size of the sky image in the window frame is influenced by three factors: the presence of obscuring objects in the external space extending above the horizon plane, the height of elevation of the upper edge of the window opening above the horizon plane and the observer's distance from the window opening external plane. The extent of obscuring the sky view depends on the distance of the obscuring object and the elevation value above the horizon plane of the highest edge of this object.

The primary parameter in the analysis of access to the view of the sky from residential interiors through a window is the vertical viewing angle, called the sky view entry angle. This angle determines the height of the sky image reflected on the retina of the eye. It is contained between the lines of sight running in a vertical plane perpendicular to the plane of the window and passing through the theoretical eye point. The upper line is tangent to the upper outer edge of the window opening, and the lower one to the highest edge of the obscuring object.

In the research model, the minimum value of the entry angle was assumed to be 7.5°, which corresponds to the normal vertical range of vision achieved by the human vision apparatus solely due to the rotation of the eyeballs upwards from the horizontal, central line of sight. The width of this image is determined by the horizontal viewing angle contained between the lines of sight running in the horizontal plane, passing through the horizon line and the theoretical eye point. The next fixed parameters of the research model are the distance of the theoretical eye point from the outer plane of the window opening, which was assumed to be 1 m, and the height of the eye point elevation equal to 1.6 m.

Analysis of the impact of the new designed buildings on the existing buildings, in the context of access to sky view, indicate that into account must be taken simultaneously the reverse interaction. The study of geometric dependencies show that providing minimum sky view entry angles (7.5°) on the lowest storeys of the both considered buildings requires that the distance between them should be twice the height of the higher one, and with the same heights of the buildings, twice the height of the one of them. This statement is consistent with the findings of the algorithm used by architects and town planners in the modernism period.

4. DISCUSSION

As presented earlier in the introduction (point 1.5), the research methods used are an extension of the earlier practical and theoretical achievements in the field of designing stadium stands developed and published by the author. These tasks required the creation of a unique, proprietary notional apparatus and research methodology, which also turned out to be useful for the analyzes presented in this paper. The most important of these is the concept of *a relative retinal image*, which enables a graphical simulation of real images displayed on the retina of the human eye. To the author's knowledge, this method does not appear in the scientific and practical literature in the field of architecture and related fields. The graphical theoretical analyzes contained in the paper can become the basis for computer programmers to create an easy-to-use application supporting the architectural design of buildings and housing estates, not excluding the possibility of including it in the BIM system.

In the presented analyzes, the research scope was limited to the vertical viewing angle of the sky considered in relation to a strictly defined geometric research model. The significant assumptions of this model included the adoption of the central vertical plane of the lines of sight (xz) as running symmetrically and perpendicularly to the plane of the window opening and perpendicularly to the face of the building obscuring. The purpose of introducing the above limitations was to facilitate the explanation of the research method used and the principles of its use.

The most important achievement of the research work undertaken is the creation of a simple tool for simulating the work of the human visual apparatus. A tool that enables the construction of images of the material external space corresponding to the image that arises in the process of visual perception in the observer's brain. The concepts of the theoretical eye point and the relative retinal image personify a specific observer who can change the position with respect to the window opening in the residential interior, as well as the viewing direction.

The results of the analyzes presented in this paper confirm the usefulness of the research methodology used. The developed methods have a much wider potential. In the next stages of work on the issue of view through the window, and within this framework of access to the view of the sky, the author plans to undertake a number of topics expanding recognition of this issue, such as:

- The horizontal viewing angle of the external environment through the window in the context of the sky view;
- Directing of the central line of vision not perpendicular to the plane of the window;
- The non-parallel location of the building blocking access to the sky view;
- Trees as objects that block the view of the sky through the window;
- Relations between the view of the sky and the position of the sun in the frame of the window opening;
- Relationship between the position of the window in relation to the north direction and the view of the sky;
- Impact of legally binding building distance regulations on access to the sky view;
- Relations between the day lighting standards and access to the sky view in housing;
- Dependence of the vertical viewing angle of the sky on the height of the upper edge of the window opening above the horizon plane and on the construction form of this edge;
- Balconies and loggias versus access to the sky view;
- Importance of the latitude of the location of the apartment building for access to the sky view from residential interiors.

5. CONCLUSIONS

Referring to the paradigm of sustainable development, the author postulates the need to include a new criterion in the urban and architectural design of residential buildings – the criterion of access to the view of the sky from residential interiors. This criterion should be taken into account on a par with the already common provisions on daylight, sunlight and shade. The review of the state of knowledge in this field shows that one of the important elements of a real strategy for the implementation of the concept of sustainable urban development are the statutory requirements to ensure access to the view of the sky and sunlight for city residents.

In this context, the issue of the view through the window is of particular importance, which is of interest not only to town planners, architects and builders, but also to specialists in many scientific disciplines, such as: Environmental Psychology, Environment or Behaviour, Built Environment, Research and Lighting Technology as well as the Human Factors.

Research undertaken by these scientific fields shows that the quality of the view of the external environment through windows from residential interiors is important for the mental and health comfort of residents. This is also confirmed by the experience of real estate companies being a source of practical knowledge in this field. According to their quotes, one of the factors having a serious impact on the market value of apartments is exactly the quality of the view from the windows.

The undertaken research refers to the European standard EN 17037: 2018 "Daylight in buildings" [34] in the context of the visual relationship of building users with the external environment. One of the three components of the view identified by this standard, namely the sky image, was subjected to detailed analysis.

The view of the sky plays the most important role in the psychological aspect of perception of external environment. Its lack in the image of the out-door space in the window frame of the residential interior should be considered unacceptable. The sky is the archetypal, primal, fundamental, inalienable element of the human being life environment.

The conceptual apparatus, research methods and models, conclusions and postulates developed for the needs of the undertaken research are contribution to the theoretical and practical foundations of the architectural and urban design process. As such, they can be useful as:

- A tool supporting the architect and urban planner activity;
- A methods of analysis of design assumptions;
- A tool in assessing the quality of apartments in terms of the criterion of view through the window, including the sky view;
- A conceptual and methodological apparatus for the qualitative assessment of the existing residential functional and spatial structures;
- A tool in formulating legally binding conditions to be met by buildings and their location.

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