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Issues relating to the efficient application of passive solar protection in multi-family residential buildings

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Abstract

The following article is intended to discuss the issues concerning the introduction of passive measures aimed at improving solar protection in multi-family buildings. A system of classifying these methods into two groups of solutions (architectural and material-building) was applied. The first group includes issues concerning facade design, the spatial features of which (such as loggias, balconies and other overhangs) can be treated as one of the solar protection methods. The authors' own studies are presented and expressed in a sequence of formulas. The formulas enable assessment of the effectiveness of the above elements, depending on external conditions. As far as the second group is concerned, material-construction solutions for building facades and roofs are discussed. The solutions mentioned include solar-control glazing, spatial shading elements (such as venetian blinds, roller blinds), roof and façade vegetation, and the thermal mass of the building. The essence of the functioning of the analysed solutions in relation to the characteristic functional specificity of multi-family buildings is discussed. Problematic areas of application of the above methods are indicated. As shown in the study, problematic areas may include a group of utilitarian-operating, economic and aesthetic issues, in the case of which the use of passive solutions encounters limitations. In conclusion, the possibilities for alleviating these limitations are highlighted. The authors' own solutions presented in the following paper can contribute to energy savings and may thus prove beneficial for environmental reasons, thereby serving the aims of sustainable development.

Keywords: energy-efficient architecture, solar architecture, multi-family buildings, passive solar protection, passive solar protection measures

1. Introduction

The low mesoclimatic quality of large cities poses a serious problem for their residents who, in turn, account for a significant part of the population. The most worrying symptoms include a noticeable increase in summer air temperature observed in cities in comparison to peripheral areas. As a result, the needs of buildings with regard to cooling and air conditioning also tend to increase. It is believed that this trend will remainon the increase in the future (Kolokotroni, Ren, Davies, Mavrogianni, 2012). Gradually, an increasing number of residents of multi-family buildings (specifically, buildings that require no air-conditioning systems in temperate climate conditions) decide to install cooling installations in their apartments at their own expense. This fact gives raise to questions of how residential buildings can be protected against overheating through the use of passive methods, without the need to introduce special energy-consuming installations. One of the ways to achieve this goal could be solar protection measures applied for glazing exposed to intense insolation. Such protection affects not only the reduction of energy consumption during building usage but also the thermal, light and visual comfort of the building interior (Hausladen, Saldanha, Liedl, 2006; Carletti, Sciurpi, Pierangioli, 2014).

The issue of solar protection is most often mentioned in source literature concerning public buildings, especially office buildings (Hausladen, Saldanha, Liedl, 2006; Prieto, Knack, Klein, Auer, 2017; González, Fiorit, 2015; O'Brien, Gunay, 2015). This is justified by high costs, both financial and energy-related costs, incurred for the air conditioning of such buildings, as well as by the requirements of major investors who can dictate the conditions they need and thus, exert a genuine impact on the standard of the buildings in question. In the case of multi-family buildings, the problem is much less recognised. In practice, the issue is often overlooked by a lack of legal principles with which the problem would be regulated, by the financial policies of developers, by low levels of awareness, and by the low impact of individual buyers on market laws. Most frequently, the subject of solar protection in residential buildings is raised in relation to hot climates, where the problem of interior overheating is severe for most of the year, regardless of the fuction of the buildings (Nedhal, Fadzil, 2011; Monge-Barrio, Sánchez-Ostiz Guttiérez, 2018; Netam, Sahu, 2018). In moderate and cool climates, it has only been since the end of the 20th century that, along with the spread of the pro-ecological approach and the growing problem of urban spaces overheating in the summer, the focus has shifted towards passive methods of protection against excessive insolation in the case of residential buildings. As a result, this subject remains relatively rarely discussed in literature (Laouadi, 2010; Kobylarczyk, 2018b; Marchwiński, Zielonko-Jung, 2013), although increasing attention is being paid to it in, for example, the context of energy savings (Chua, Chou, 2010), the comfort of the interior environment (Pisello, 2015; Skarning, Hviid, Svendsen, 2016), and new tools enabling simulation tests for specific solutions (Kirimtat, Koyunbaba, Chatzikonstantinou, Sariyildiz, 2016). However, there are still no studies that would take into account numerous criteria, including architectural criteria (e.g. functional or aesthetic) corresponding to the specifics of multi-family housing. Notably, experience gained in the field of constructing public and office buildings is not transferable to multi-family buildings. This is due to the disparate functional and usable characteristics of these types of objects. This fact gives rise to restrictions that fail to occur to such an extent or may even be absent in the case of buildings designed for other purposes.

This article refers to passive solar protection methods for multi-family buildings.

Such methods should be understood as being architectural and material--construction solutions that enable the creation of thermal and light environment parameters that meet user needs. Existing studies available in source literature clearly indicate that solutions of this type can reduce the demand for cooling of the building, both in the summer and in the transition seasons

(Hausladen, Saldanha, Liedl, 2006; Zielonko-Jung, Poćwierz, 2018; Pisello, 2015; Skarning, Hviid, Svendsen, 2016).

Architectural solutions include; the appropriate orientation of the building in relation to north, south, east and west; appropriate layout of the functional and spatial arrangement (including the idea of thermal zoning); deliberate shaping of the building form, including elements such as eaves, roofs, cornices and balconies. This article refers only to the protruding elements of the facade mentioned above, which have been called architectural solar control measures. Other elements were omitted, because in designing practice, decisions related to the overall shape of the building or its location on the plot result from a variety of criteria, especially in the case of the developed conditions encountered in the highly urbanised environment.

Material-construction solutions include elements within the facade and roofs (e.g. spatial shading elements, solar control glass), as well as internal partitions and interior furnishings which eliminate or reduce the negative effects of solar thermal gains (Marchwiński, Zielonko-Jung, 2013).

The article is aimed at recognising and systematising restrictions regarding the possibility of introducing solar protection measures in multi-family buildings. Such a study will offer the possibility to make more deliberate design decisions that would directly affect solar protection. As demonstrated in this article, decisions of this kind concern solutions developed at various stages of the project, including the conceptual phase. Therefore, giving consideration to the solar protection criterion at an early design phase may enable rational replacement solutions or a compromise between the design chosen strategy and the causes of these limitations.

The present article refers to Polish conditions in terms of climate, the specifics of modern multi-family housing, but the research material comprises solutions applied in various countries with similar climatic conditions[1].

2. Study method

In order to achieve the assumed goal, an analysis of the conditions of multi-family housing was conducted in terms of the possibility to apply the acknowledged solar-control solutions used in buildings of various purposes (these solutions currently tend to be applied in buildings related to office work) (Hausladen, Saldanha, Liedl, 2006; Pisello, 2015; Bellia, Marino, Minichiello, Pedace, 2014). These solutions have already been systematised by the authors (Marchwiński, Zielonko-Jung, 2012: 142–162).

Cognitive methods were used, including analysis and criticism of source material, and comparative and observational analyses was conducted.

In the first part of the article, the existing solutions are discussed and divided into architectural and material-construction solutions. Within the scope of this discussion, the results of the authors' research on the relationship between shaping the form of architectural solar control elements (e.g. eaves, roofs, balconies) and the scope of the building façade shading are presented. The second part of the article identifies problems that arise from the specifics of multi-family housing, which, in turn, constitute a barrier to the possibility of applying the discussed range of solar protection methods. The result of the research comprises a separate group of restrictions on the use of the acknowledged solar protection solutions which is divided into three problem areas:

- utility-operational solutions,
- economic solutions,
- aesthetic solutions.

[1] These tests were performed, among other research, as part of the 'Municipal Building of Tomorrow 2030' project, which consisted in scientific multidisciplinary co-operation for the implementation of an eco-friendly residential building in Warsaw.

3. Possibilities for solar protection of buildings

In Polish geographical conditions, maximum solar gain is provided by the southern orientation with an acceptable deviation from this direction of up to 15° (Laskowski, 1992). The southern conrner, although it is seemingly unfavorable in terms of protection against room overheating, provides the desired thermal gains in winter. In the summer, by contrast, high incident solar rays cause a lower risk of overheating than the rays falling from the east and the west at a lower angle. The western orientation poses a particular threat. From this side, overheating is the effect of not only insolation conditions, but also temperature (the outside air temperature is relatively high – the rays from the east operate in the morning when the temperature is generally lower). To sum up, facades with southern, eastern and western orientation require solar protection, which differs depending on their façade orientation (Chwieduk, Bogdanska, 2004).

3.1. Architectural solutions

The architectural elements of buildings that create a kind of 'tectonics' of its walls can serve the function of shading. Usually, these include horizontal elements such as eaves, strongly protruding ledges, which, in addition to the decorative function, play an important role for moderate climates with regard to protection against rainfall. Facades can also be shaded by various types of balconies or loggias, i.e. functional elements that complement the interior of the building. Due to the horizontal orientation, these elements can only protect against high radiation. Therefore, despite the fact that they usually appear on either a large part or the entire perimeter of the building, such elements only play the role of solar protection on south-oriented facades. The possibilities to use these elements for shading the glazing can be assessed whilst taking into account the shade range from the neighbouring buildings. The proximity of neighbouring buildings on one side can protect against excessive sun. It should however be noted that the greatest shading does not occur in the summer, when the largest insolation takes place, but in the period from late autumn to early spring, when the inflow of solar radiation is desired. The proximity of buildings to each other, especially in long streets is also unfavorable due to the obstruction they pose to air exchange (Taseiko et al. 2009; Jędrzejewski, Poćwierz, Zielonko-Jung, 2017; Zielonko-Jung, Poćwierz, 2018).

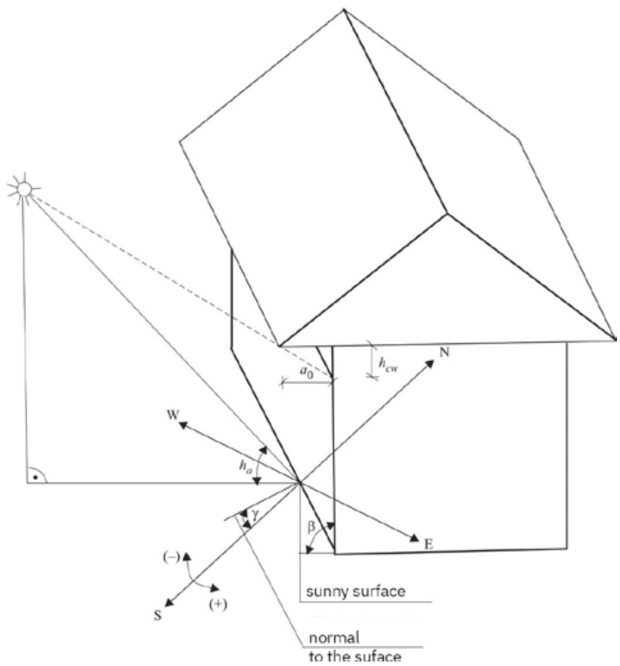

Fig. 1. Determination of the solar altitude in relation to the examined building – determination of angular parametres (source: Kobylarczyk, 2017a; 2018a)

To sum up, the extent of shading provided to glazing by architectural elements protruding beyond the face of the facade depends on factors such as the location of the object in relation to its positioning in relation to compass points, the season of the year, the time of day, and the overhang reach. The extent to which the building is shaded by the neighbouring buildings should also be taken into consideration. This is influenced by the orientation of the building and its neighbourhood with regard to compass points, as well as the ratio of the building height to the distance between buildings. The impact of the parameters listed here and the relationships between them have been demonstrated using the authors' own formula (Kobylarczyk, 2018b; 2017b; 2018a).

On the basis of observations and measurements regarding solar operations in Poland (O'Brien, Gunay, 2015), it can be stated that their values should be calculated on the basis of the azimuth and angle at which sunrays fall in summer, mainly for the western orientation. In order to demonstrate the relationships in question, the angle of declination δ and the angular height of the sun h_a were taken into account. The height h_a can be calculated from the formula (1). The listed values are shown in Fig. 1.

In order to demonstrate the above-mentioned dependencies, the declination angle δ and solar angular height h_a were taken into account. It can be calculated from the formula presented below (1). It is assumed in the formula that ϕ indicates the exact latitude of the point at which the analysis is being conducted. This latitude is assumed to be of positive value if the analysed point is located in the northern hemisphere, whereas if the analysed point is in the southern hemisphere, the latitude value is negative (Kobylarczyk, 2018b; 2017a; 2017b; 2018a)

$$h_a = 90^\circ - \phi \pm \delta \tag{1}$$

Declination is calculated by providing the exact day (d) on which the analysis is conducted, counting consecutive days from 1st January. These calculations are made using the formula given below:

$$\delta = 23.45 \sin\left[360 \frac{284 + d}{365}\right] \tag{2}$$

Both the solar angular height and the size of the declination angle are variable, which is observed throughout the year. The angular height of the sun differs not only depending on the latitude at which the parameter is analysed, but also because of the time, including the part of the day for which the analyses are performed. Therefore, various values may be achieved at different times, taking into account the hour and the exact day of the month. These differences occur due to the variable position of the sun with respect to the equator (Kobylarczyk, 2018b).

The highest solar angular height occurs at noon, while the lowest values are obtained at sunrise and sunset. At these times of the day, the height is zero. The given formulas, therefore, relate to the computational capabilities present at noon.

The angle of the solar altitude varies throughout the day. This can be taken into account by introducing the ρ_t coefficient that may be calculated using the formula:

$$\rho_t = \cos(90 * t / t_p) \tag{3}$$

where:

t – the time under consideration for which we determine solar angular height calculated for the hours from noon onwards; before noon, the time value is positive and in the afternoon, it reaches negative values (analogy to another formula)

t_p – time (number of hours) from sunrise to noon or from noon to sunset.

The dates on which the position of the sun is specific should also be taken into account. So, on 21st March, the sun is above the equator ($\delta = 0$) and its angular altitude equals:

$$h_a = 90° - \phi \tag{4}$$

On 22nd June, the angle δ is 23o27 ‘ and totals:

$$h_a = 90° - \phi + 23o27‘ \tag{5}$$

on 22nd December, $\delta = -23o27‘$ and totals:

$$h_a = 90° - \phi - 23o27‘ \tag{6}$$

whereas on 23rd September, and on 21st March, it is:

$$h_a = 90° - \phi \tag{7}$$

The degree of shading is regulated by the angle at which sunrays fall at zenith. The greater the angle is, the more it reduces shade coming from neighbouring buildings, and the more shade resulting from overhanging elements increases. The degree of shade resulting from the proximity of the neighbouring buildings also depends on the height of the buildings and on the distances between them. In cases in which limitation to insolation by the operation of the eaves or balconies occurs, the extent of their reach plays a significant role. The value of shadow value h_{cw} falling from the eaves with a distance of a_o at noon ($\omega = 0$) can be calculated using the following formula:

$$h_{cw} = \alpha_o \frac{tg(h_a)}{\sin(90° + \gamma)\sin\beta - \cos\beta tg(h_a)} \tag{8}$$

where:

α_o – radius of the overhanging element relative to the facade,
h_a – angular height of the sun,
β – angle between the level and the wall surface under consideration,
γ – azimuth (angle between the normal to the considered surface and the local meridian, zero at noon (S), from sunrise to noon (E) the value of this angle is assumed to be positive, while it is assumed negative in the afternoon (W)).

The formula stems from the geometric dependencies between particular values presented in Fig. 1. At $\beta = 90°$ (vertical wall) the shadow height at noon will be:

$$h_{cw} = \alpha_o \frac{tg(h_a)}{\sin(90° + \gamma)} \tag{9}$$

Taking into account the change of the angular position of solar altitude over time during the day, the actual solar altitude should be approximated using the function $\rho_t = \cos(90{*}t/t_p)$ (Kobylarczyk, 2018b; 2017a; 2017b; 2018a). This is described by formula 10:

$$h_{cw} = \alpha_o \frac{tg(h_a) * \cos(90 * t / t_p)}{\sin(90° + \gamma)} \tag{10}$$

The values of h_{cw} are calculated from formulas 8, 9 and 10, which provide the absolute values of shade altitude and are expressed in the same measures as α_o. It is sometimes more beneficial to express values relative to h_{cw} to the α_o radius. Assuming that:

$$\kappa_{cw} = \frac{h_{cw}}{\alpha_o} \tag{11}$$

we obtain relative altitude of the shade κ_c related to the α_o radius. This amounts to:

$$\kappa_{cw} = \frac{\tan(h_a) * \cos(90 * t / t_p)}{\sin(90° + \gamma)} \tag{12}$$

The analysis concerning the height of the h_{cw} wall shading from the overhanging elements is presented in Figs. 2a. and 2b.

In Fig. 2a, the height of the façade shading from the overhanging element is presented taking into account the location of the building with regard to the compass points (angle γ), assuming different values of solar angular height.

In Fig. 2b, the value of facade shading depending on the solar angular height is presented taking into account the different locations of the building with regard to the compass points (γ) (Kobylarczyk, 2017a; 2018a).

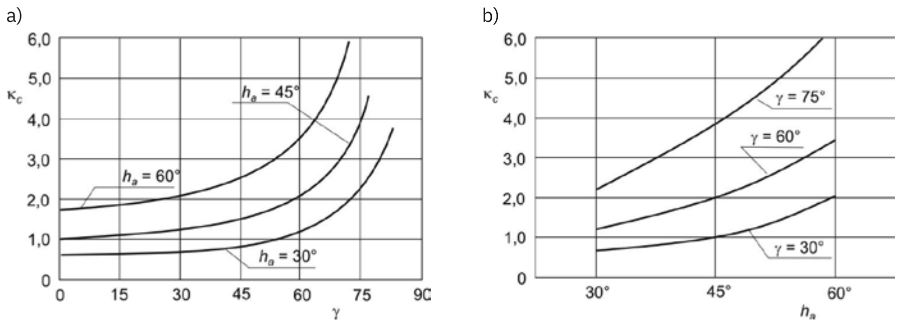

Fig. 2a. The value of the facade shading measured from the overhanging elements, with respect to the location of the building relative to the four compass points (angle h_a), assuming different values of solar angular height h_a

Fig. 2b. The value of the facade shading, depending on the solar altitude h_a, taking into account different locations of the building depending on the assumed compass point (γ)

Based on the results of experimental studies, it can be concluded that the appropriate spatial shaping of the façade directly affects the degree of shading.

Elements such as eaves, loggias, balconies, etc. introduce shade, the amount of which depends on a number of factors, including:

- location of the object relative to the compass points,
- seasons,
- time of day,
- extension of eaves,
- the ratio of the height of the building that provides shade to the distance between the buildings.

It should be noted that at different times of the day, the amount of shade from the overhanging elements and the neighbouring buildings changes. The mentioned sources of shading affect various situations expressed in the value of shading (Kobylarczyk, 2017a).

At noon, the value of the shade coming from the overhanging elements radius is greater than the amount of shade created by the neighbouring object. A different situation can be observed in the morning and the evening hours. During the time from morning to noon, shading from the neighbouring object decreases, whereas the shading from the overhanging elements increases; in the afternoon, the opposite situation is observed.

The authors' own presented formulas can be applied to analyse the value of shade in each location at a given time of the year (Kobylarczyk, 2017a). The application of the formulas enables the researchers to assess the impact of the geometric parameters of buildings (dimensions) and the location relative to the compass points, as well as the dimensions of the eaves of buildings, balconies or loggias on the extent of shading. The calculations can be used in the practice of designing new buildings, as well as in the analysis of existing buildings.

4. Material/construction methods

Material/construction methods may be defined as the appropriate use of building materials and construction products, both within the building envelope, and in its internal space, as tools applied for the sake of protection against overheating. These include elements of solar protection (shading) and elements that facilitate the decreasing of high temperatures caused by heat gained from insolation.

The former of these two groups is comprised of the following material elements:

- solar control glazing,
- spatial shading elements.

Indirectly, this group also includes all elements characterised by low reflexivity, which helps reduce the amount of solar radiation that reaches the external walls.

The group of materials used in order to reduce the temperature levels (passive cooling materials) includes materials intended for the role of thermal mass, as well as facade and roof greenery. Although it should be noted that greenery belongs to both groups.

The basic method of protecting rooms against excess solar radiation in the summer is by means of the selection of such glazing parameters that make it possible to maintain low values of the g coefficient (total solar energy transmittance). The most widespread solutions include solar control glazing, the production technology of which has been developing intensively over the last dozen or so years (tinted solar glass, reflective glass, printed glass, diffuse glass).

The latest generation of solar control glazing comprises selective glazing technologies that are capable of selectively blocking solar radiation (e.g. at specific incidence angles), as well as switchable glazing technologies which are capable of changing their physical properties. However, switchable glazing belongs to a group that we can label 'the solutions of tomorrow' due to the high cost of production and a number of operational restrictions (small sheet sizes, low resistance, unsatisfactory switching time, etc.) (Marchwiński, 2013a). However, if the technology is applied on a wider scale, its price is reduced.

When it comes to solar protection ability, external elements are the most effective as they block, or at least significantly reduce, the access of solar radiation to the glass surface and thus protect against the greenhouse effect that generates heat in the room. Such elements may include (Marchwiński, Zielonko-Jung, 2013):

- blinds, awnings and marquees,
- venetian blinds,
- louvres, solar control screens,
- shutters (splayed shutters, folded shutters, pleated shutters and sliding shutters).

Another source of great possibilities for reducing negative solar heating effects is sought in the use of massive, thermally non-insulated building partitions adapted for heat accumulation. They absorb excess heat and release it into the environment with a certain phase delay. This function is also sometimes performed by floor coverings with an accumulation tank located underneath, which is filled with a material characterised with a high heat storage capacity, such as gravel.

Further possibilities of solar protection are provided by the use of vegetation as a construction component of a given building. This notion involves:

- the creation of the so-called biotic roofs and walls covered with climbers, as well as the implementation of the so-called living walls,
- using greenery as a sunshield (shading greenery).

A further element applied for solar protection may be seen in biotic (green) roofs and walls. This concept entails the complete building envelope being covered with vegetation. The importance of such partitions for protection against room overheating lies in their ability to lower the air temperature in summer

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at room surfaces. This is due to the absorption of heat by vegetation. Heat is subsequently released back into the surroundings through transpiration in the form of latent heat.

Greenery can also be implemented within the glass partitions of the building, cognately the use of spatial shading elements. Greenery used as an element of solar protection should drop its leaves during the heating season and be characterised by dense foliage in warm periods, when solar heat gains in the rooms are undesirable.

Types of such greenery can include overhanging, slatted-wall greenery, climbing and potted greenery (Netam, Sahu, 2018). The benefits of using greenery stem from the advantages related to the above-mentioned use of greenery on roofs and within biotic walls, as well as from the solar protection that it can provide.

Research conducted at the University of Brighton in Great Britain (Lam Hoi Yan, 2005) proves the effectiveness of greenery for solar protection. The research concerned parthenocissus quinquefolia, which was placed externally on a steel construction grid to cover the entire height of windows oriented towards the south-west.

Research involved measurements of the dynamic shading coefficient, which undergoes changes along with the variable vegetation characteristics. Measurements have shown that the considered greenery acts as a shading element from May to October, i.e. in periods of potential excess heat gain due to insolation, the highest value of which (over 0.5) coincides with the strongest solar radiation that takes place in summer months, specifically July and August (Fig. 2). The value of the coefficient is determined by the density of the foliage the shading plant, the time of vegetation growth, the permeability of the foliage and its individual layers to solar radiation. In the performed experiment, the solar radiation permeability of the foliage amounted to 0.43–0.14, depending on the number of layers (Marchwiński, 2013b; Lam Hoi Yan, 2005).

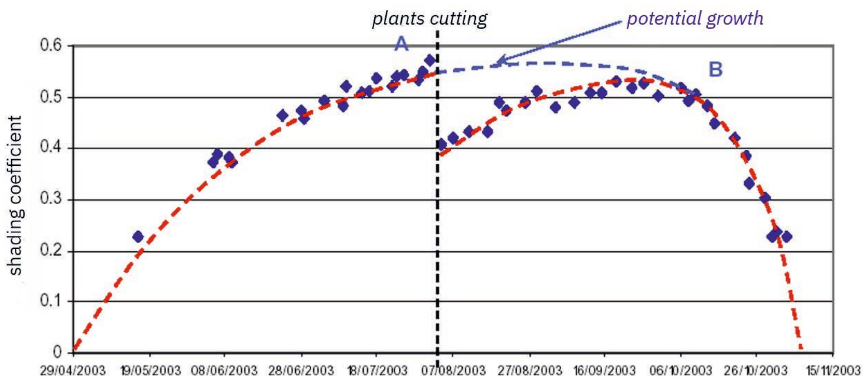

Fig. 3. The operation of vegetation as a shading element depending on time (based on: Lam Hoi Yan, 2005)

It should also be noted that greenery is regarded as an element positively shaping the view from overlooking windows. The results of research conducted on this subject in the Podkarpacie region make it possible to state that the presence of greenery is one of the most highly appreciated elements of the high quality housing environment from the perspective of residents (Kobylarczyk, 2013).

5. Issues concerning multi-family buildings and possibilities of applying solar protection measures

The wide range of passive solar protection elements discussed above is characterised by a varied level of usefulness in terms of the applications for residential buildings. Visual contact between a given element and the environment is one of the most important criteria concerning its implementation. Elements that permanently interfere with the visual contact should be considered disadvantageous to living spaces. They can, however, be reasonably applied in public spaces (e.g. staircases). Providing the access of daylight to living spaces constitutes a related problem.

In the case of residential buildings, ensuring comfortable natural lighting for flats, especially their daily zones, constitutes one of the project priorities. Some types of solar control glazing, such as tinted glass, can adversely reduce the light intensity in a room. Of spatial shading elements, only those that are adjustable and enable the setting of sunlight access at intermediate levels are suitable (e.g. louvre blinds are usually a more desirable solution than textile roller blinds because they are characterised by greater flexibility with regard to regulation). This issue is also related to design decisions regarding façade articulation, including the creation of balconies, loggias and terraces as permanent elements intended for solar protection.

Balconies and other overhangs are in practice effective with regard to sunrays of high incidence, i.e. falling from the south. In the case of sunrays from the western and eastern corners, their outreach is usually insufficient. Increasing the outreach may be considered irrational, not only because of limiting access to daylight, but also with regard to architectural and functional reasons. As a result, such a solution may be economically unreasonable. Intermediate directions, i.e. south-east and south-west orientations, require individual analysis. It can be assumed that in these cases, it is possible to arrive at an optimal solution (i.e. regarding the spatial shape of the façade) which will ensure a balance between achieving a satisfactory degree of shading to adjacent rooms and providing sufficient natural lighting. Another important criterion in the selection of solar protection measures is related to its predicted impact on the aesthetics of apartments, including the issue of colour. Glazed walls and spatial elements of solar protection, which are part of the façade concept, may not correspond to the individual preferences of building residents. In this sense, it seems reasonable to apply solutions that do not constitute an aggressive element of interior design.

The problem of user preferences also applies to the use of thermal mass in residential premises. The lack of a predictable, overall influence of the designer on the arrangement of flats (everyone can finish walls, floors and ceilings according to their own preferences) limits the use of thermal mass in flats, and in practice, renders its use almost impossible. In general, the function can only be fulfilled by partitions located in public areas, including general communication.

As far as another typical problem in the case of multi-family housing is concerned, the issue related to the implementation of a controlled solar protection strategy arises; this is understood as a systemic solution to collective regulation. However, automated collective solar control systems function in office buildings; in residential buildings, where each apartment has the character of an individual private utility unit, the implementation of this strategy is perceived by residents as depreciating their independence. Thus, the implementation of such systems is rendered difficult or even impossible.

The above issue is related to the reduction of the effectiveness of solar protection in the holistic energy strategy of the building. Yet another related problem concerns the unpredictability of the use and operation of internal solar protection elements within individual flats that are beyond the influence of designers. In practice, this factor makes it impossible to create energy--optimised solutions. In developed countries, some remedy to this problem is perceived in activities aimed at promoting energy and ecological knowledge among residents, including activities intended to raise awareness of behaviours that save energy.

The economic aspect poses another important problem. It applies to both of the discussed groups of solar protection measures. Among architectural solutions, large facade overhangs, including elements such as strongly protruding balconies, although effective in the sense of solar protection, can be assessed as being irrational in economical and operational aspects. This is due to the increased amount of building material and structural complexity they entail. Moreover, in the case of such elements, the potential requirements for repair and maintenance tend to increase. Furthermore, as previously mentioned, such overhangs place restrictions on the access of natural light to the interiors and, as a consequence, there are increases in costs generated by electricity consumption needed for artificial lighting, which can be seen as an adverse factor. This aspect, however, mainly concerns material-construction solutions, mostly those of glass partitions and shading elements of various kinds. In the case of spatial shading elements, mechanically controlled systems are individually cheaper than comparable solutions adjusted electrically, especially those equipped with weather automation units and other technically advanced devices. Electric systems for individual solar control are recommended in situations in which the ability for manual control is problematic, for example, in the case of solar protection for roof skylights.

A further element affecting the price may be seen in the level of technological advancement of the shading elements themselves. Among the relatively cheap solutions, tinted glass and reflective glass should be included, whereas in case of the spatial elements, unmovable elements (including solar control shelves) and relatively simple structures, such as most types of shutters, should be listed. Expensive measures include advanced selective glazing and switchable glazing technology, as well as moveable shading systems which are complicated in structure and made of expensive material (e.g. PV cell systems as 'shadow--voltaic systems'). The problem is that the effectiveness of protection against overheating is directly proportional to the technological advancement of glass and spatial elements implemented for solar protection, and thus also to the price of such elements. It is observed that solutions that make use of the most advanced technologies in housing construction are used relatively rarely, remaining rather in the domain of office buildings and public utility objects.

In addition to the economic aspect, the choice of solar protection measures may be related to the operating conditions, which constitute another factor determining the suitability of shading elements. In practice, extensive solar protection systems with complex construction and operation may prove inadequate not only with regard to the financial capabilities of users but also in the sense of maintenance, repair and cleaning. The problem concerning the operation of the building and residential premises also applies to the legitimacy of using roof and façade vegetation. In the operational aspect, extensive green roofing seems to be beneficial, requiring a relatively little amount of time and cost to maintain it. Facade greenery is justified in cases in which it is easy accessible, for example, within balconies or in their immediate vicinity.

6. Limitations to the use of solar protection methods in residential buildings

Based on the results obtained from the analysis of the information provided, limitations of the implementation of solar protection methods has been divided into three groups of issues:

- usable and operational issues,
- economic issues,
- aesthetic issues.

These issues are summarised in Table 1.

Table 1. A collective list of material-construction methods applied for solar protection in the case of multi-family buildings – authors' own suggestions

Problem area	Implementation limitations for passive methods (selected issues)
Utility and exploitation issues	• Balconies and other overhangs (eaves, roofs) are characterised by the limited effectiveness of solar protection – their usability for this purpose from the eastern and western directions is doubtful. In turn, increasing their reach to improve solar protection may result in negative operational effects including, most importantly, limiting the use of natural lighting in rooms. • Shading elements that permanently interrupt visual contact with the external environment should be considered unfavourable for flats (regarding shading elements with no ability to be regulated, such as louvres and traditional shutters). • Solar control glazing (especially tinted and printed glass) may unfavourably reduce the amount of natural light in the interior. With regard to spatial elements, the limitations of their application concern shading elements with low flexibility for regulation (including louvres, traditional shutters, textile blinds). • It is difficult to implement a strategy of controlled solar protection understood as a systemic solution to collective regulation (no possibility to control the flat use) and the associated unpredictability of applying and operating internal elements of solar protection in flats. There is also no possibility for the thermal mass to be put to controlled use in residential premises • Sophisticated solar protection systems of complex construction and operation may prove inadequate in terms of maintenance, repair and cleaning. The issue concerning the operation of the building and residential premises also applies to the legitimacy of implementing roof and façade vegetation. In the operational sense, extensive greenery seems to be beneficial as it requires relatively little time to be allocated for its maintenance. Facade greenery is a reasonable solution in the case of its easy accessibility, e.g. within balconies or in their vicinity. • Balconies and other solid building overhangs (e.g. eaves, roofs) are characterised by the limited efficiency of solar protection – their application as shading elements, when situated towards eastern and western sides, is doubtful.
Economical issues	• Economic constraints are associated with technologically advanced solar protection methods. These include: – advanced control automation of spatial shading elements (electrical regulation, especially equipped with weather automation devices and others), electric individual control systems are recommended only in situations in which there is limited possibility for manual adjustment (e.g. in the case of roof skylight shading); – technologically advanced solar protection measures (regarding, among other means, selective glazing and switchable glazing technology, as well as mobile shading systems with a sophisticated structure made of expensive material such as 'shadow-voltaic systems'). The problem is that the effectiveness of overheating protection is directly proportional to the technological advancement of glazing and of spatial solar protection, and thus is also dependent on the price of these elements; – sophisticated 'living wall' systems and structurally complex green roofs. Spatial shaping of the facades: balconies, loggias and other architectural solutions applied for solar protection often serve this fuction in addition to their major role – their shape is the results from aesthetic, functional, technical and economic premises. Economic conditions generally stand in opposition to providing the above-mentioned elements with the characteristics of effective solar protection.
Aesthetic issues	• The strategy of solar protection using architectural solutions may not correspond to the assumed artistic design concept. • Aesthetic features of the solar control glazing and spatial shading elements which are intended by architect as a part of the facade concept may not correspond to the individual preferences of the users of private residential areas. • The problem of aesthetic preferences of users also applies to the use of thermal mass in residential premises (anyone can finish walls, floors and ceilings according to their own preferences, excluding them from serving the purpose of thermal mass).

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7. Comments and final conclusions

The observations included in the table lead to the conclusion that the limitations concerning the introduction of solar protection mainly result from the unpredictability and diversity related to the manner in which residential premises are used by their inhabitants. In contrast to public buildings (including office buildings), it is not possible in practice to create solutions that apply integrated and organised models of room functioning, nor is it possible to stimulate the behaviour of premises users. This means that harmonising preferences, both usable and aesthetic, which are undoubtedly a factor conducive to the effective implementation of solar protection, is a more difficult task than in an organised work environment.

Another issue that accounts for these limitations is the economic constraint that results from the investment specificity concerning multi-family buildings. In the case of these buildings, the sale of usable floor space under preferential financial conditions is usually a priority. Therefore, investing in expensive advanced (and effective) energy-effective technologies proves impractical, as savings at the investment and non-operating stages become a priority.

The above observations lead to the conclusion that the general principles formulated in the literature relating to solar protection must be verified each time by the specifics relating to investment and the application issues of the planned residential building. Experiences obtained from buildings of similar location and size, but of different purposes, should not constitute an uncritically accepted pattern or a universal basis for design decisions. The effectiveness of implementing passive methods of solar protection proportionately decreases with increases in the number and diversity of flats. It seems that one of the most effective ways to reduce constraints resulting from functional and aesthetic issues lies in all initiatives related to education, specifically in raising awareness of the building's operation in terms of energy aspect among its users and investors.

One of the ways to reduce economic constraints is to strive for energy--efficient construction, which is helpful in the thorough analysis of the impact of climatic factors on the way the architectural forms are shaped and on the location of objects relative to the four compass points.

A clear – albeit slight – impact may be seen in the use of appropriate balconies and loggias, eaves and other overhangs that shade the walls of buildings. The degree of shading is greater in summer and lower in other seasons, which is advantageous for utility reasons. It should be noted that the greater the radius of the balcony and eaves and the deeper the loggia, the more visible the shadowing role of these solutions becomes. However, the use of these solutions requires a multidimensional approach because, in addition to added benefits such as increasing the usable area of balconies, the application of such solutions may result in negative effects in the form of deterioration in the aesthetic, operational and economic quality of buildings. The issue of multi-faceted optimisation related to architectural solutions for sun protection is a field that requires further research.

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Problemy skutecznego zastosowania pasywnych metod ochrony przeciwsłonecznej w budynkach wielorodzinnych

Streszczenie

Artykuł poświęcono zagadnieniom dotyczącym wprowadzania tzw. pasywnych metod służących ochronie przeciwsłonecznej w budynkach wielorodzinnych. Nacisk położono na rozwiązania materiałowo-budowlane w obrębie ich elewacji i dachów. Do rozwiązań tych zaliczono szklenie przeciwsłoneczne, elementy przestrzenne zacieniające (np. żaluzje, rolety), roślinność dachową i elewacyjną oraz „masę termiczną" budynku. Uwzględniono również zagadnienia kształtowania elewacji budynków jako jedną z metod ochrony przeciwsłonecznej z pogranicza rozwiązań projektowo-przestrzennych i materiałowo-budowlanych. Omówiono istotę funkcjonowania analizowanych rozwiązań w powiązaniu z charakterystyczną specyfiką funkcjonalno-użytkową budynków wielorodzinnych. Wskazano problematyczne obszary stosowania powyższych metod. Wykazano, że obszary te mogą obejmować grupę zagadnień użytkowo-eksploatacyjnych, ekonomicznych oraz estetycznych, w których stosowanie rozwiązań pasywnych napotyka na ograniczenia. W konkluzji stwierdzono, iż strategia ochrony przeciwsłonecznej musi uwzględniać specyfikę funkcjonalno-użytkową budynków wielorodzinnych i nie może być bezkrytycznie powielana ze wzorców o odmiennym przeznaczeniu funkcjonalnym, choć dotyczą zagadnień bardziej rozpoznanych. Zaproponowane rozwiązania własne mogą przyczynić się do oszczędności energetycznych, a tym samym są korzystne ze względów środowiskowych i służą zrównoważonemu rozwojowi.

Słowa kluczowe: architektura energooszczędna, architektura słoneczna, budynki wielorodzinne, pasywna ochrona przeciwsłoneczna, pasywne rozwiązania słoneczne

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