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Orginal Article

Role and factors of solar facades shaping in contemporary architecture

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Abstract: The article deals with the issue of solar facades as the main external walls of a building, adapted to make use of solar energy. The aim of the article is to define the role of the facades and the factors that influence shaping thereof. The goal is of cognitive nature, whereas its implementation may contribute to strengthening the relationship between presumptions related to energy and architecture in the design of buildings. The need for the article results from the necessity to search for a possible balance between technical and humanistic spheres while shaping contemporary pro-ecological architecture, especially one aimed at receiving solar energy as a renewable energy source.

In the article, both analytical and comparative methods are applied. The research was conducted on the example of four designs with solar facades of different characteristics, including two buildings planned by the author.

The research results are observations that define relationship between the energy-related role of solar facades and urban, functional and aesthetic issues. These observations lead to the conclusion that the energy aspect, is not the only one to be considered while shaping solar facades in contemporary architecture. The solar facade combines both functional and artistic features.

Keywords: solar facades, solar architecture, pro-ecological architecture, energy-saving architecture, photovoltaics

1. Introduction

The design and material solutions of external walls as barriers between the interior and the surroundings exert an impact on the use of solar energy in the building. The main emphasis is placed on the walls subjected to direct insolation, the so-called solar-active walls. This, in turn, is associated with the introduction of technological, constructional and architectural solutions, uncommon in the case of other walls. The dynamically developing technology of glazing combined with advanced solar technology solutions (shading systems, PV modules, etc.) is significant in this respect. In this case, solar facades are now under discussion while a secondary role is assigned to the remaining elevations.

There are various definitions of the facade. As stated by Joanna Tymkiewicz [1], "the concept of facade is becoming more and more popular in works in the field of architecture. In dictionary definitions, this term denotes the most important front elevation of the building, which usually houses the main entrance, and is distinguished from the remaining elevation by its composition and richness of details" [Author's own trans.]. Further, the author quotes Scruton, Rewers and Knack. According to the first author mentioned, "the facade is the face of the building, it is something that stands in front of us and has all the buildings' expression" [Author's own trans.]. Rewers, in turn, draws attention to the twentieth century disappearance of the facade in favor of the modernist elevation. He further states that "the abandoned concept (of the facade – author's note) was annexed by the social sciences, followed by cultural studies". On the contrary to Rewers, Tymkiewicz notices that "the concept of a facade in architecture has not been completely abandoned, but has changed its meaning and expanded its capacity" [Author's own trans.]. He quotes Knack, who maintains that "the facade appeared as soon as the architects managed to separate the external structure of the building from its load-bearing function" [Author's own trans.].

The way in which the term 'facade' is understood in the present article is closer to the dictionary definition and the above-cited observation by Tymkiewicz. By adopting this point of view, a number of solar buildings can be distinguished that are characterized by a facade which can be labelled a solar facade. It is the facade of the building, the shape of which assumes controlled solar gains. Here, modern technological solutions are applied, such as solar protection glazing, thermal insulation glazing, photovoltaic (PV) technology, or various systems that comprise solar element. The accumulation of these components causes the solar-active wall to dominate, not only in terms of construction and technology, but also in terms of its form and aesthetics.

The phenomenon of solar facades as external walls adapted in order to make use of solar energy stems from functional and energy-related reasons. Such attitude is commonly adopted in contemporary projects like e.g. Solar City by Elon Musk and Peter Rive [2] At the same time, pro-ecological architecture seeks balance between technical and humanistic spheres [3]. The question thus arises whether solar facades result entirely from considering the functional aspects related to optimization of solar energy use. Do they take into account or ignore issues of shaping the architecture of the building as regards aesthetics, elements of urban planning, as well as the functional purpose of the rooms?

It becomes important to examine and compare the contemporary shaping of solar facades of buildings more broadly, i.e. both the constructional, technological and energy solutions of the building, as well as the functional purpose of the rooms, the relationship of the building with the surroundings and its aesthetics.

For this purpose, examples of four buildings with solar facades were used. The buildings reflect various approaches and assumptions to shaping of the facades, as well as they showcase certain limitations associated with it.

2. Analysis of solar facade solutions in contemporary buildings with various functions

2.1. Public utility building ”Solar-copper house” in Wrocław (concept), arch. author (2013)

The project of the “Solar-copper” house (SCH) was created with a view to creating a prototype public utility building with an area of approx. 250 sq. m. The building was supposed to contribute to constituting future architectural and construction-technical standards in the field of energy conservation. In line with these standards, it was assumed that the facility would produce energy exclusively from renewable sources and that the energy yield would exceed its demand (plus energy building).

The energy-related goals were accompanied by the assumption to create modern architecture with a strong connotation of ecology and energy saving. The main measure towards attaining these goals has become the implementation of solar techniques and solutions with the main role of photovoltaic technology [4].

The building has a strongly defined and exposed solar facade equipped with PV modules (photovoltaic facade). It is marked with southern orientation that provides the most advantageous exposure in terms of energy gains.

Already at the pre-design stage, preliminary decisions were made to select a plot of land that would make it possible to achieve the assumed goals, as well as to secure optimal functioning of the PV facade. The project is located in the heart of the city, to the west of the Pomeranian Bridge. The advantage of the location lies in the fact that the plot is located directly on the Odra River embankment, it borders the river to the south. This location and the spatial conditions of the plot itself guaranteed full solar exposure of the southern facade, while ensuring the possibility for unlimited observation of the building from the other side of the river. The vicinity of the river is also important due to microclimatic benefits, including lower air temperature outside the building during warm periods, which has a positive impact on the efficiency of PV modules operation.

In addition to the energy-related targets, efforts were made to give the PV facade characteristic aesthetic features. The aesthetic concept is based on the diagonal breaking of the visual and painting composition of the facade with the use of different types of PV modules and traditional glass transparent panels. PV modules made of amorphous silicon cells of varying colors and translucency were applied, i.e. non-transparent (ASI opaque) and semi-transparent (ASI-thru). Owing to the modules, original artistic and painting effects were created in the form of a “colored mosaic” contrasted with a curtain wall made of transparent glass with a PV print. This special feature distinguishes the building from previous BIPV projects implemented worldwide. The uniqueness of the solution lies in the combination of multi-colored PV modules, not only marked with a varying degree of translucency (0%, 20%, 30%), but also in shape, which, together with traditional glass panels, form a glass curtain wall. This solution uses the latest achievements of photovoltaic technology that consist in the use of colored films in the glass laminate from the outside of the PV cells. Unlike previously, his modification does not cause unreasonably large energy losses [5].

Semi-transparent PV modules and traditional fully transparent glazed panels offer a valuable element of the aesthetic concept, but also provide a compromise between energy and utility demands. Such modules allow to increase the share of natural light in the lighting of the interior of the building and provide eye contact with an attractive environment. The transparent glazed panels in the PV facade eliminate the false tint of natural light that comes through the colored PV modules. Their introduction next to semi-transparent PV modules, however, is associated with a reduction in the power of the entire PV system, and thus lower energy gains from the sun.

At the same time, it should be assumed that, although compensated by a significant share of neutral-colored glazing, including glazing with PV print, the quality of lighting is not satisfactory to house permanent work stations in the elevation space (only simplified simulations were conducted at the concept stage). Removing work stations from the vicinity of PV modules results also from thermal reasons. The PV facade, being a smooth glazed curtain wall, creates a problem of protecting the interior from direct solar radiation, as the use of external shading systems would negate the application of PV modules. Thermal protection was provided by introducing a buffer space, designed as a large-space interior over the entire height of the building . The solution is aimed at increasing the efficiency of air exchange, which plays important role in passive solar cooling [6]. This space may be seen as the "lungs of the building" and offers benefits in terms of cooling the surface of the PV modules from the inside as well. This contributes to an increase in their efficiency. During the heating season, the space acts as a thermo-buffer zone, whereas in the sunny periods, it serves as a passive heat collector. The decision to introduce a thermo-buffer space, however, resulted in the need to move the offices deeper into the building plan and locate them towards the less favorable sides: the eastern and western sides.

The design of the PV facade, created largely by the aesthetic factor and constituting a kind of "showpiece" of the building, did not provide sufficient energy gains, as expected in line with a plus energy building concept. The implementation of this aesthetic goal forced the introduction of the aforementioned spatial and architectural solutions (passive systems) and other installation solutions (including a heat pump) in combination with energy-saving technical and construction solutions. One of the features of the building is its high thermal insulation properties of the remaining external walls combined with a radical reduction in the share of glazing, especially in the northern elevation. This influenced a simplified aesthetic vision of these walls, which emphasized the leading importance of the described southern facade as a solar facade.

Fig. 1. "Solar-copper house" in Wrocław (concept): solar facade with PV modules of various colors and translucency. *Source: author*

2.2. Single family building – Solar house in Bytom, arch. Author + design office ”Atlant”(2007)

The Solar house (SH) was designed in accordance with solar architecture design principles. The project assumes the maximization of natural lighting, passive thermal gains from sunlight, while maintaining a high level of thermal insulation, as well as natural ventilation of the rooms. Active and passive solar measures were introduced. The active measures are represented by a vacuum solar collectors system intended for the preparation of domestic hot water. The connection with the solar facade is provided by a passive measure in the form of built-in greenhouse, which is designed on the southern side of the building.

The spatial form of the building is defined by two solids – a one-storey one with a flat roof and a two-storey one with a sloping roof. The two components form the “L” shaped plan of the building. The shape of the construction is derived from the classical trend of solar architecture. In line with the principles of shaping forms of helioactive buildings [7], the two-story body descends towards the north – the surface area of the northern elevation has been decreased and has been provided with a reduced amount of glazing. On the opposite direction – i.e. the sunny southern side – the outer wall is the largest one – it forms the solar facade (additionally, the facade glazing stretches towards the eastern wall).

The solar facade should not be understood as a front facade in the traditional sense, i.e., it is not oriented towards the entrance or the driveway. It is visible mainly from the side of a semi-open courtyard that functions as a private garden. However, such facade serves as the dominant external wall of the building in the aesthetic sense, which factor somehow defines the architecture of the building.

The two-storey high glass curtain wall that forms the facade is responsible for passive solar gains that are utilized room heating in winter and stimulate natural vapour ventilation in warm periods. The combination of the glass curtain with a massive internal brick wall as the so-called “thermal mass” provides an important feature in terms of optimizing the use of solar energy. These elements create a thermal system based on indirect solar gains. The massive wall serves to accumulate heat from solar gains. In winter, the heat is radiated to the surroundings, which supports the building’s heating system. In summer, the heat is transferred to the outside by means of circulation panels designed in the solar facade. During the warm seasons, these panels remain in the open position, which allows air circulation; the lower panels are responsible for the inflow of cooled outside air near the ground, whereas the upper ones let the heated air out. For this purpose, the front of the facade was designed in the form of biologically active areas favourable in terms of microclimatic conditions, including those that alleviate the daily temperature amplitude, i.e. cooling down near the ground during warm periods.

The space between the curtain wall and the brick wall is intended for the implementation of the corridor and has the character of a thermo-buffer space. It protects rooms against the negative effects of direct insolation and losing thermal energy on cold days with little solar radiation. In the corridor space, right behind the curtain wall, floor nooks were designed for greenery to act as a modifier of the microclimatic conditions in the interior.

Originally in the project, the facade was equipped with an external shading system with a certain slant and an arrangement of fixed slats, with account to the apparent path of the sun across the horizon. The slant was set so as to let in the sunlight falling at a lower angle in winter and to reflect the summer rays outwards. Finally, for financial and aesthetic reasons, the facade was implemented as a smooth wall equipped with solar-protection reflective glazing with a coefficient of $g = 35\%$. Glazing in the graphite colour was considered to exert a positive effect on the aesthetics of the building. The architectural expression was enhanced by the colour contrast between the glazing and the bright body of the building. This solution, however, is less favourable than originally anticipated, due to the reduction of thermal gains from insolation during the heating period, although it represents a passive measure to prevent he building from overheating [8].

Fig. 2. Single-family building in Bytom: solar facade as an element of a passive solar system. *Source: author*

2.3. Administrative building MDK in Lahr (Germany), arch. Harald Roser, Günther Pfeifer, Christoph Kuhn (1999)

The cuboid structure on an elongated rectangular plan is characterized by the dominant areas of the northern and southern external walls. The southern elevation, which forms the solar facade of the building, has been fully glazed. Such a large glazing area required protection against the sun from the side exposed to solar radiation. The function of solar-protection measure is served by an extensive system of shading lamellas. These elements were extended over the face of the wall by several dozen centimetres. They form as many as 5 rows in the upper part of the glazing of each floor and the same amount of rows in the lower part. Additional support is provided by horizontal footbridges, which serve as a kind of balconies and technical platforms. The lower set of lamellas serves also as a railing. The lamellas are made of translucent, smoked glass. They have been permanently fixed on a steel structural frame.

The arrangement of the lamellas allows for the use of solar radiation for passive heating in winter and takes advantage of the benefits of daylight. In the period from May to August, the lamella system creates a complete barrier for direct sunlight to enter the interior. The building is not equipped with mechanical air conditioning. Opening balcony doors helps to avoid overheating of the interior.

In the aesthetic aspect, the facade is characterized by an expressive “play” of rhythms created by sections of the glazed wall and the shading system. The accumulation of these elements creates an illusory image that blurs the physical border between the inside and the outside. Thus, the facade acquires three-dimensional features. Owing to the elimination of lamellas in the strip above the main entrance, the area is perfectly exposed. An impressive forefield with greenery and a water reservoir has been designed. It is conducive to cooling and maintaining high quality of the air flowing into the building.

The northern facade is also made up of a fully glazed wall, but no shading system has been introduced, due to its location in relation to the corners of the world. The composition of glass panels and opaque blends, as well as openable vents offer a certain liveliness to the composition. As a result, the whole creates an interesting effect, which, however remains inferior to the southern facade in terms of aesthetic values.

In the northern zone, a winter garden has been designed, which functions as a heat buffer in winter, as well as a reservoir of cool air in summer. Opened vents are used for this purpose. In addition, air in this area is supplied from an underground heat exchanger located in the southern part of the plot.

The solution applied for the northern elevation can be considered consistent with the internal function of the building. However, it should be assumed that the decision to introduce a large-area glazed wall on the north side, controversial in terms of energy efficiency of the construction, forced the interior to be arranged in a particular manner. It seems that the decision to introduce a fully glazed elevation is based on an aesthetic reasons resulting from urban-planning and location conditions. The northern elevation, rather than the southern one, is an intuitive front of the building, adjacent to one of the main access streets that lead to the city center. Thus, the building is subject to the strongest visual perception from the northern side. This elevation, therefore, is most strongly predestined to be the showpiece of the whole construction. For this reason, in an aesthetic sense, the northern elevation required particularly careful approach.

However, this elevation is not equipped with the main entrance and is less decorative. The southern wall can only be viewed from the parking lot of the building. There is no way for it to be observed from a greater distance. The urban context decreases the role of this particular wall as a facade [9].

Fig. 3. Administrative building MDK: solar facade (left) and northern elevation (right). *Source: author*

2.4. Xicui Entertainment Hall in Beijing, arch. Simone Giostra & Partners Inc. (2008)

Xicui Entertainment Hall (XEH) is currently one of the most recognizable buildings with a solar facade worldwide. The building was implemented within dense development of the Chinese capital, on the Xicui Road that runs along the north-south direction. Due to the existing urban conditions, most of the buildings located by this street have front elevations that face the west and the east. The remaining elevations are poorly exposed. This is also the case with the 9-storey building with an original, first facade to use the PV technology and LED lighting worldwide. The facade is oriented towards the east, which is not most favourable in terms of energy gains generated by the PV system. Nevertheless, it uses cladding of semi-transparent PV modules on the surface of the elevation wall that measures 2,200 sq. m, which at the time of the building's construction made it the largest such wall in China. Glass-glass modules with spaced polycrystalline silicon PV cells inside were used. The 89x89 cm PV modules were moved away from the external wall and attached to it with steel brackets [10].

The spacing of PV cells is varied, thanks to which the cells create an individual graphic pattern on each of the modules. Such a solution introduces the division into elements of "low", "medium" and "high" transparency among the PV modules. The greater the distance, the greater the transparency, although certainly it comes at the expense of the built-in power of the PV module, and thus the entire PV system [11].

The PV cells spacing is correlated with the needs for natural lighting of the interior, as traditional elevation glazing has been introduced within the inner skin (behind the PV modules). Thus, in the vicinity of rooms that require sun protection or access to natural light is not particularly important, PV cells are densely arranged, while rooms with high requirements for the light environment (e.g. offices) are equipped with modules with PV print of lower density.

The described solution results also from clearly legible aesthetic factors. By juxtaposing individual PV modules with different cell configurations with each other, the facade acquires an original pattern, which is intended as an artistic image called "seascape". To enhance the effect, the PV modules, owing to their cantilever structure, are inclined at various angles – i.e. 5 degrees to the left or to the right, which is a metaphor for sea waves. This effect is visible during the day. It should be noted, that only the deviation towards the south is rational from the energy point of view (maximization of solar gains) and it is only on these panels that PV cells were introduced [12].

At night, artistic effects created by PV cells are complemented by LED lighting. Multi-coloured LED diodes in the form of 2,292 spot lights are used behind the rear surface of the PV modules, so that the semi-transparent PV modules are illuminated from the rear. As a result, the facade illuminated by points radically changes its image in relation to the daytime graphics. Its surface creates a huge screen – a kind of billboard that dynamically changes the displayed image [10].

The facade has been nicknamed "organic wall" and "self-sufficient wall". This is due to the fact that it fits in with the idea of sustainable development. PV modules indirectly cover the energy demand of the LED lighting, i.e. the energy consumption associated with powering the LED lighting is compensated by the daily production of electricity by the PV system, which is fed back to the municipal electricity grid.

The aesthetic features of the facade and its connotations with environmental protection have a strong marketing and symbolic overtone. First of all, the colourful, dynamic facade, clearly visible at a distance, is an element that attracts the attention of passers-by. It is a kind of message to inform the viewer what is happening in the building. It is also a factor that promotes the integration of advanced technology with the architecture of the building. However, it seems that the more important aspect related to the integration of LED as energy-saving lighting with PV technology based on renewable energy source is related to the image of Beijing as a city of technological innovation and growing environmental awareness.

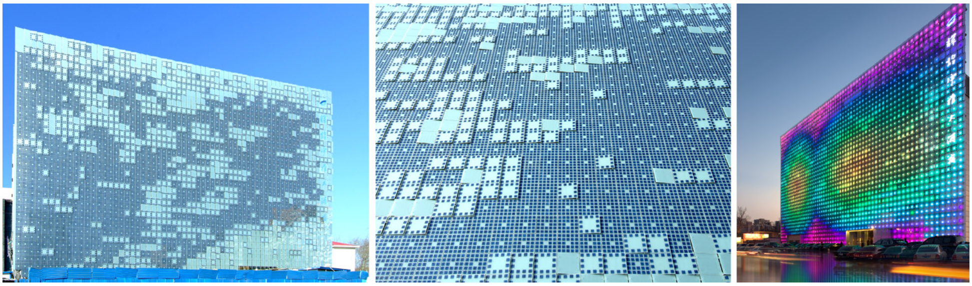

Fig. 4. Xicui Entertainment Hall in Beijing: solar facade as a screen composed of PV modules and LED lighting. *Source: Simone Giostra*

3. Definition of the relationship between energy-related role of a solar facade and the urban, functional and aesthetic issues

Table 1. Definition of the relationship between energy-related role of a solar facade and the urban, functional and aesthetic issues in the discussed buildings – collective juxtaposition. *Source: own study*

		SCH	Solar house (SH)	MDK	XEH
Type and orientation of the facade		Photovoltaic (PV) facade/ southern	Glazed smooth facade – greenhouse structure partition (passive solar system) / southern	Glazed facade with the external shading system – solar windows (passive solar system)/ southern	Multimedia facade PV+LED/ eastern
Main energy-related role of the facade		Production of electricity for utility purposes of the building	Passive solar heat gains (indirect gain)	Passive solar heat gains and natural lighting (direct gain)	Electricity production for the lighting supply (LED) of the facade
Urban relations	Urban issues impact	The urban conditions were an important factor to decide on the choice of a plot in order to create a well-exposed (representative) facade from the south	Due to the orientation and shape of the plot, as well as the access road location, the solar facade could not have become the front facade	Conflict in meaning: the northern elevation on the street side is subject to the strongest visual perception and is intuitively perceived as a facade – the function which it does not serve, in fact (the effect of turning the building „with its back to the street")	Not optimal in terms of energy gains east orientation, forced by the layout of the street and buildings
	Influence on the buildings surroundings arrangement	Removal of vegetation potentially shading the PV facade, its foreground in the form of low greenery without high-rise street furniture	The dominance of unhardened and green areas (lawn) to improve the microclimate parameters by the facade	As in the case of SH + water reservoir in front of the facade, as an element to improve thermal conditions in summer (air cooling and humidification)	No clear impact

		SCH	Solar house (SH)	MDK	XEH
Functional relations	Influence of functional issues	The need for natural lighting of the interior: reduction of the PV system power due to the introduction of semi-transparent and traditional glass panels within the facade	No influence	Southern part of the building as a quiet zone intended mainly for the main rooms that require high parameters of the thermal and lighting environment – influence on the shape of the solar facade (densely arranged lamellas)	PV cells print density (PV module transparency) dependent on the functional purpose of the room at the PV facade
	Impact on the functional arrangement	The need to create a buffer space – moving offices away from the immediate proximity of the PV facade	The functional layout accounts for the principle of thermal zoning – in the zone in vicinity to the facade, the corridor acts as a passive heat collector and the „lungs of the building” – the residential part is moved to the other side of the corridor	No clear impact	No clear impact
Aesthetic relations	The influence of aesthetic issues	Aesthetic solutions (colour, transparency of PV modules) at the expense of maximizing the PV system power	Dark reflective glass contrasting with the bright facade, considered a valuable aesthetic element, is not conducive to maximizing heat gains during the heating period	No clear impact	Diversification and elimination of PV cells print as measures to reduce the power of the PV system
	Impact on the aesthetic function of the building	The facade as a multi-coloured „photovoltaic mosaic” of various shapes and transparency, combined with traditional translucent glazing and with the PV overprint - Original material and composition features of the facade defining the building’s architecture	Glazed large-area smooth solar facade – different (from the rest of the walls) colour and texture as well as the reflection of the the surroundings – these features make the facade a characteristic aesthetic element of the building	Dense rhythms of exposed lamellas create expressive compositional effects; the effect of doubling the facade and the illusory image blurring the physical border between the interior and the surroundings	The original composition of PV modules combined with multi-coloured LED lighting: expressive compositional and artistic-painting effects, image variability – these features determine the uniqueness of the PV facade aesthetics and the entire building, which is a characteristic point in the surroundings

3.1. Relationship between energy-related role of the solar facade and urban issues

- Energy considerations exert a strong influence on the orientation of solar facades, i.e., the emphasis is on their southern exposure. In situations where its domination is possible also in the urban context, the energy-related and urban role of the solar facade is consistent. It happens when, while ensuring optimal orientation to create favourable conditions for insolation, the facade serves as the formally most important wall, in the urban sense, e.g. subject to the strongest visual perception (SCH).

When the situation is different (MDK), the pursuit of southern exposure of the solar facade leads to inconsistencies. The elevation perceived as a facade in an urban sense is not one in an aesthetic sense.

- A strongly defined urban context (location of buildings, roads, etc.) may force the resignation of the optimal exposure of the solar facade in terms of energy (XEH).
- There is a difference in the approach to shaping the forefields of buildings with solar facades. The forefield of facade that uses passive solar systems (solar windows, greenhouse structures) requires more attention in terms of the impact of its development on the thermal and lighting conditions of the building. Biologically active areas are preferred. The winter (solar thermal gain) and summer (solar protection) scenarios are considered separately. For this reason, natural elements are often designed that are characterized by seasonally changing properties, e.g. deciduous trees, lawns and water reservoirs that reduce the temperature amplitude, as well as the variable seasonal albedo that depends on the angle of sunlight angle of incidence (MDK). The preferred solution are also unhardened surfaces, non-susceptible to absorb and radiate solar heat in summer (SH).

Forefields of facade with active solar systems, incl. PV facade require undisturbed exposure to solar radiation (also in summer), which translates into the elimination of all spatial objects, including tall trees in the development of the forefields to solar facade. The needs for active solutions dominate in facade solutions that combine passive and active solar systems (SCH). The influence of solar radiation on the thermal and lighting environment is controlled by design methods, other than shaping the forefield (e.g. by using PV modules as shading systems).

3.2. Relationship between energy-related role of the solar facade and functional issues

- Requirements related to the functional purpose of the rooms in the area in vicinity of the facade exert a strong influence on the shape of the solar facades. This is related to the desire to ensure comfortable thermal, lighting and visual conditions inside the rooms. A particularly visible impact concerns PV facades, in which the above-mentioned goal is implemented through irrational actions in the energy-related sense. These include, for example, reducing the number of PV cells (XEH), mixing PV panels with traditional glass panes or selecting PV modules with a lower built-in power, such as semi-transparent modules (SCH).

The functional purpose of the rooms is also a factor that influences the shaping of solar facades with passive solutions. Facade surfaces intended for permanent human residence (MDK) may require particularly careful design of solar windows as solutions with direct benefit, i.e. the most sensitive ones to the effects of solar radiation energy. The goals of energy and comfort are, however, more similar than in the cases when PV facades are used.

- The introduction of solar facades, especially the highly glazed ones, may have an impact on the functional zoning of the interior. In the case of such facades as the walls that gain large, difficult to control amounts of solar radiation energy, a recurring phenomenon is to create thermal buffer spaces (SCH, SH) in the internal zone by the facade. These are intended to serve functions not related to the permanent use by the users. As a consequence, zones of constant use are shifted to other areas of the building.

3.3. Relationship between energy-related role of the solar facade and aesthetic issues

- The influence of aesthetics is especially clear in the case of solar facades, in which aesthetic decisions are in opposition to energy premises, such as the resignation of PV cells in the case of panels that are unfavourably oriented to the sun (as a component of the "seascape" (XEH) effect), selection of coloured semi-transparent PV modules with a low built-in power compared to traditional PV modules (SCH), or solar protection glazing with a distinct colour, that reduces thermal gains from insolation (SH).
- Solar facades have great potential to influence the aesthetic function of a building. This is related to the creation of original artistic effects: flat composition and tectonics (3-d effect), with the use of various configurations, geometry, colours and construction of solar solutions, including PV modules, displaying the elements that acquire and control the inflow of solar energy (glazing, shading systems). An interesting direction is to integrate PV with other systems in order to obtain an enriched aesthetic effect, e.g. integration of PV with LED lighting (XEH).
- In the broad sense of the relationship between solar facades and the aesthetic function of a building, their roles may be connected with areas related to creating a non-verbal message, symbol, and creating pro-environmental connotations (SCH, XEH). In addition, it may also be the subject of direct communication used for information or marketing purposes (XEH).

4. Conclusions

The aforementioned examples of buildings confirm that the energy aspect of shaping solar facades, which underlies their application, is the leading aspect in their implementation. It accompanies each of the discussed buildings. Energy aspirations that consist in creating optimal conditions for the use of solar energy in a building have a significant impact on the shaping of not only the facade itself, but indirectly on solutions on a micro-urban scale (plot arrangement) and the function of the building. At the same time, energy issues are influenced by these factors. The examples of XEH and MDK show that mutual relationship between the facade as a helioactive wall and the context of the place may require compromise solutions.

The development of solar facades is related to the needs to create comfortable microclimatic and lighting conditions for the rooms that are hidden behind the facade. There is a strong relationship between design of these facades and the needs concerning environmental conditions, depending on the purpose of the rooms. Therefore, consistency of formal solutions for the facade with the function of the object may be noticed.

At the same time, a strong role of aesthetics is observed, even a tendency towards decorativeness. Emphasis is shifting from strictly utilitarian aspects towards aesthetic aspirations. This is especially visible in the example of the XEH building, in which the desire to create an aesthetically attractive solar facade resulted in a number of decisions that, from the energy-optimization point of view, may be considered irrational. A similar approach was demonstrated by the author in the SCH concept.

It seems that the evolution of solar facades is aimed at tightening the relationship between their utilitarian, including energy-related, role and their aesthetic function. This is favoured by the technological development of elements of solar measures oriented towards integration with architecture (e.g. BIPV) and the search for new areas for cooperation with related technologies (e.g. LED). Assuming that this trend continues, it may be expected that an enrichment in the architectural language is to be observed in the coming years. This will bring new, unique solutions for solar facades.

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