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ADAPTIVE SOLAR SHADING OF BUILDINGS

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Adaptive solar shading systems have in comparison with the traditional systems of shading increased potential ability to improve the quality of the indoor environment and to increase the energy performance of buildings. Their extension allows all-around technological progress, but also the extensive application of large-scale glazing in building envelopes almost in all climatic regions. The literature review shows that the characteristics of the individual adaptive shading systems differ. Some have better performance in the sun protection or in improving the building's energy balance; others for example are better in glare elimination or in redistribution of daylight. The main purpose of this contribution is to provide a classification of the adaptive solar shading systems. In the article are compared merits and shortcomings of adaptive shading systems and are shortly analyzed assumptions of their wider application in central European climate conditions. Attention is also given to advantages and disadvantages, which brings the application of some kinds of adaptive solar shading systems. Several examples of adaptive shading systems are shown and briefly characterized.

Keywords: *adaptive shading systems, solar energy, high-performance envelopes, typology, daylighting, indoor comfort*

1. Introduction

Within contemporary architecture, there is a growing interest to shift buildings envelope design from „static" to „dynamic" to improve energy performance and indoor comfort. In the European context, this process is stimulated by the energy performance of buildings policy, by which buildings with nearly zero energy needs to be built after 2020. This goal requires development of new materials, concepts and technologies for improving buildings' energy efficiency. It is believed that very promising strategy to achieve that objective is design building as a responsive and dynamic system. In addition, this strategy opens new aesthetic possibilities for designers. The main feature of this concept is to equip buildings with elements and systems that can permanently respond to weather changes and the demands of building users. The issue of designing and evaluating dynamic facades has taken on a broad scientific and professional community in recent years [1–10]. Adaptive solar shading devices, characterized by a high degree of adaptability and responsiveness, are typical part of the dynamic building envelopes (mainly its transparent parts). From a purely physical point of view, their behavior is connected with solar radiation, daylight and heat. All these physical quantities are dynamic in nature. Unfortunately, most of the evaluation building physics metrics and criteria are not developed with a dynamic system in mind. For example, main criteria of daylighting in buildings in actual codes are based on overcast sky. Under these conditions the availability of daylight on exterior horizontal plane is several thousand lux. In fact, the availability of daylight changes greatly in short periods of time and in case of direct sunlight can exceed 100.000 lux. Until now, there has been no general agreement on the way of assessing daylighting of buildings with the consideration of dynamic light climate. There are currently a gap in tools and broader frameworks that allow architects and engineers to design the most appropriate adaptation shading technique for concrete building in particular climatic and urban conditions.

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Terminology and systemization of adaptive building shading systems is far from complete [9, 10]. The main goal of this article is to analyze the adaptive solar shading systems, compare them with the "static" systems, and propose a system for classifying adaptive buildings shading. This paper also informs about several adaptive shading systems applied in the world.

2. "Static" and "dynamic" shading of buildings

Proponents of dynamic building facades often argue that buildings have been designed in the past as "static", that is, those that have failed to respond to weather or seasonal changes. We also meet with the claim that traditional facades are not capable of adapting and responding to changes of wheather and the demands of building users [3]. These claims are rather false myths, as is shown in Fig. 1. Shutters, curtains and other shading devices are able to respond to wide-ranging environmental changes when they are proper operated. A facade consisting of a well-insulated non-transparent part and a transparent part equipped with a suitable shading technique cannot be considered as "static". Traditional passive strategies and their various innovations are still promising trend in the design and operation of buildings.

What are the arguments of those who favor the trend of designing dynamic building facades? Driven by new architectural paradigms and the need to maximize indoor comfort, particularly modern commercial building facades have become completely glazed. In this context external shading devices would seem essential. Contemporary high-rise buildings show also a trend towards complex curved and shape irregular facade systems. It follows that shading devices must be shapely and functionally more complex. The advances in information, mechanical and electrical technologies create the prerequisites for expanding the concept of responsive architecture. It is believed that responsive architecture can provide step-change improvements in the energy performance of buildings and the use of renewable energy while improving the comfort of the users of indoor spaces. Responsive architecture is fundamentally determined by performance-based design strategies and by the design of dynamic (active) building envelopes. Dynamic facade refers to the design of control algorithms and the control operations that directly impact its performance and the physical properties. The essential element of the dynamic facade is an adaptive solar shading system. The adaptive shading system must be able to change in response to variable wheather, occupancy and comfort requirements, energetical and environmental parameters. Adaptive ("dynamic") shading technologies often refer to conventional moveable shading devices such as louvers, venetian blinds, roller blinds, etc. But there are also many principally innovative ways of shading buildings (see Section 3). The concept of adaptive solar shading, with appropriate adjusment to changing external and internal conditions, allows flexibility in the integration of design considerations, and can balance positive and negative impacts of solar energy on building performance. High-performance facade equipped with an advanced adaptive shading system opens new possibilities for interaction between the external and internal environments. Adaptive shading technologies open also new possibilities for environmentally-conscious, sustainable and expressive architectural design. The new possibilities of aesthetic layout of building facades are often the dominant motive for the practical application of adaptive shading (see Section 3).

Many technicians believe that the adaptive shading reduces power performance of HVAC systems and consequently the total energy consumtion of the building. However, there are complex non-linear physical and non-physical (users' comfort and amenity) relationships between the configuration of such shading systems and energy demand of cooling, heating, lighting, and ventilation. User response is often neglected in energy analyses of adaptive HVAC systems. The

Fig. 1. Is the shutter "static" shading system?

human factor is important because it is not only linked to technical or environmental criteria. Moreover, the geometrically complex and moving shapes of shading elements are very problematic to simulate from energy point of view. There are not enough reliable tools available and no generally applicable evaluation criteria. Adaptive architecture is under development and it is a question of whether it is necessary to achieve a state of being capable of responding to any external or internal stimulus.

Improving adaptability means increasing complexity, which is associated with increased installation costs and maintenance costs. Too sophisticated systems generally affect their lifespan and are the cause of their mechanical problems. There is also considerable energy consumption for the operation of adaptive shading systems.

3. Typology of adaptive solar shading systems

General technical progress has expanded the possibilities of designing and operating building envelopes that can dynamically change their properties. Adaptive shading systems (also known as dynamic, kinetic, responsive, active, adjustable, smart, advanced, intelligent, switchable, interactive and suchlike – these terms are not pure synonyms, but it is often difficult to distinguish between them) are usually an integral part of adaptive (dynamic) facade. In many cases, just adaptive shading device is the essence of a dynamic facade.

Adaptive shading systems can change their shape, or spaciousness, or location, or properties. They can change several of these properties or all at once or in a time sequence. The primary function of adaptive shading systems is usually actively to regulate the indoor environment and energy performance of a building. Adaptive shading systems are based on the change of properties or behavior at a macro or micro scale (Fig. 2).

Macro scale changes mean that the building envelope is shaded by some shape changing or movable elements (e.g. mechanically). The micro scale means that optical and thermophysical changes generally occur in the shading material, which increase the shading effect. Typical example is glazing with coating that changes depending on temperature or light intensity (i.e. chemically or electrochemically).

In general, adaptive solar shading systems can perform a variety of other functions, e.g. regulate daylighting, additionally thermally insulate the building shell, regulate natural ventilation, transform solar energy into other forms of energy, humidify or clean the air and the like. These tasks can be accomplished by a single shading unit or several building elements with separate functions that may differ in form and in material. Adaptive shading systems can leave the other systems of the building intact or are designed in interactions with other systems. Also system of sensors, actuators, and real-time environmental response cannot be neglected in the systematization of adaptive shading technique. For these reasons, it is very difficult to develop a general classification of adaptive shading systems. In spite of the above, we try to typologically sort the current adaptive solar shading systems.

Traditionally, shading systems are assorted according to their position in relation to the shaded object: external shading, internal shading and integral shading systems (usually in glazing).

Adaptive solar shading systems can be categorized by physical/optical processes that provide protection of a building from excessive solar radiation (Fig. 3). Shading systems can regulate solar energy by

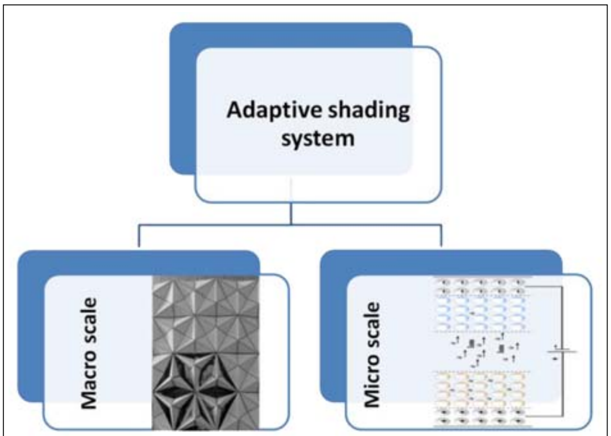

Fig. 2. Basic typology of adaptive shading systems

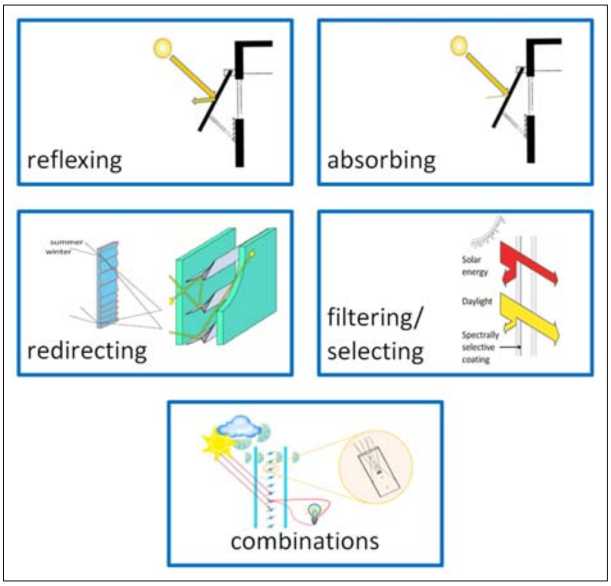

Fig. 3. Principles of solar control

reflexing (specular or diffuse), absorbing, redirecting or filtering and by combination of these possibilities. Absorbed solar energy is transformed into thermal energy. Part of the absorbed energy can be converted into other forms of energy, for example electricity, chemical energy, biofuel, accumulated heat.

For adaptive solar shading systems many smart materials are used, such as:

– Temperature reactive materials (shape memory alloys, shape memory polymers, shape memory hybrids, thermochromic polymers, termotropic materials, phase change materials (PCM)),
– Materials that react to solar radiation (light responsive polymers, photochromic materials, photovoltaic cells),
– Chromogenic materials (electrochromic glazing, gasochromic materials, liquid crystals, suspended particle devices),
– Other materials (electroactive polymers, piezoelectric materials, materials changing their magnetic properties).

Adaptive solar shading systems may be categorized into four classes: kinetic shading, switchable glazing, multifunction systems and specific systems (Fig. 4). Control of adaptive solar shading systems can be manual, motorized with central up-down commands, fully automated or self-regulating. Manual control will not provide standardized parameters of indoor environment or/and required energy savings. On the other hand, fully automated and self-regulating adaptive systems have limited manual control capabilities based on current user needs. This may be inconsistent with one of the basic tasks of the shading device, which is to provide a comfort indoor environment. Therefore, the satisfaction of users with light and thermal comfort and the possibilities of their interaction with shading systems are important factors that cannot be overlooked.

It is self-evident that adaptive solar shading system and its control need to be optimized for the concrete climate, zones of a building and other relevant factors. These factors concern the human comfort (visual comfort, thermal comfort, indoor air quality, acoustic comfort, intimacy) as well as the technical aspects of the solution (durability, reliability, energy efficiency, easy of use, etc.).

From the point of view of protecting the building from excessive solar radiation, the decisive parameter of adaptive shading system is the range of solar factors (*g* values) that it can provide. For example for electrochromic glazing typical range of *g* values is from 0.64 (clear state) to 0.16 (fully dark state).

Many external adaptive shading systems, mainly bio-inspired types, are inspired by nature, and their design is considered to be in consistency with the economy of nature. The real motivation of these solutions is most often the prestige of the architect and the builder.

3.1. Examples of adaptive solar shading systems

Most of the existing adaptive solar shading systems are specific solutions for an individual case. Despite the trendiness of these solutions it is doubtful that they are energy-efficient and more effectively im-

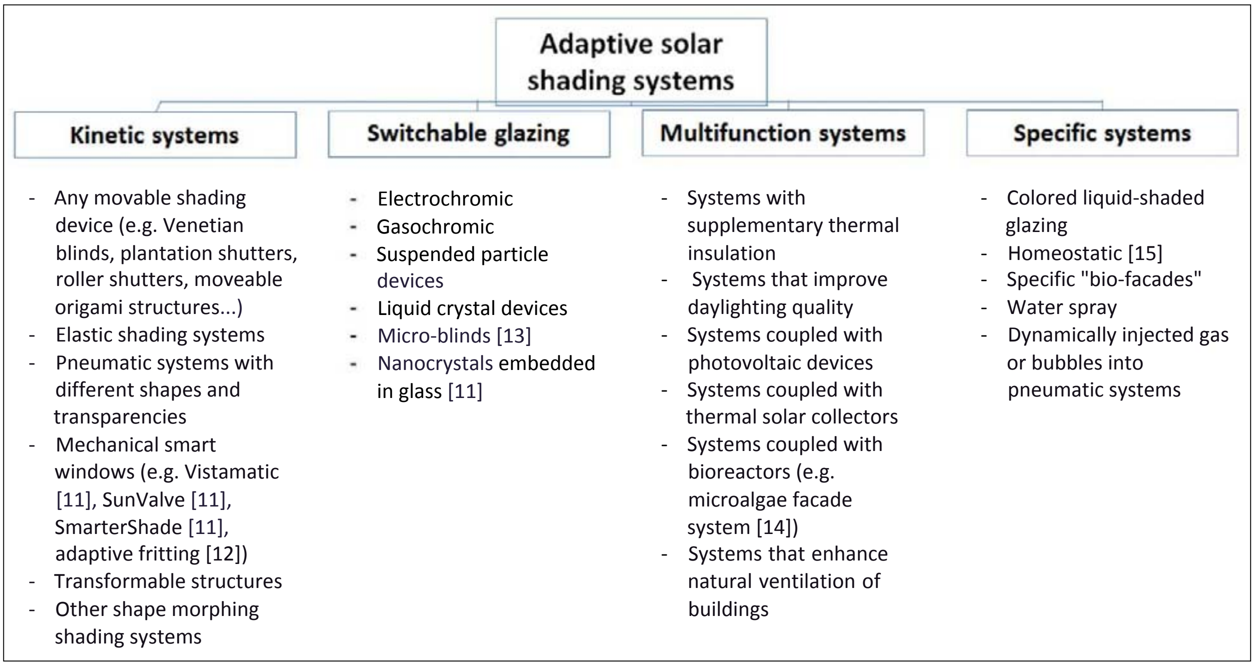

Fig. 4. Typology of adaptive solar shading systems

prove indoor comfort compared to traditional solutions. Here are some adaptive solutions with a brief commentary.

3.1.1. Arab World Institute

Probably the most known example of adaptive solar shading system is the Arab World Institute (Institut du Monde Arabe) designed by architect Jean Nouvel and completed in 1987 in Paris, France. The architect drew inspiration from an archetypal element of Arabic architecture (the mashrabiya) and between two glass sheets of southwest facade suggested metal elements like the camera shutters (Fig. 5). Elements are individually controlled by motors connected to a central computer control. The 30,000 light-sensitive mechanical control diaphragms resulted in constant maintenance and serious mechanical problems.

This system has highlighted the need for extraordinary attention to the functionality of adaptive solar facades/shading systems in real life.

3.1.2. Q1 Building: ThyssenKrupp Quarter

Adaptive solar shading system of ThyssenKrupp Quarter (known as Q1) in Essen in Germany consists of many stainless steel louvers and triangular, square, and trapezoidal fins, which open and close according to sun position in real-time (Fig. 6). This system also tries to maximize the views for the users, but users have no preference override the control system.

Daylighting in Q1 is kept at a level that meets standards for artificial lighting. It is questionable whether it responds to people's biological needs. It is also a question whether such a solution of adaptive solar shading is consistent with sustainable construction. From a technical point of view shading system of Q1 Building overcomes the adaptive facade of the Arab World Institute. This is due to the tremendous technical progress and advance in IT technology that has been achieved since the construction of Arab World Institute.

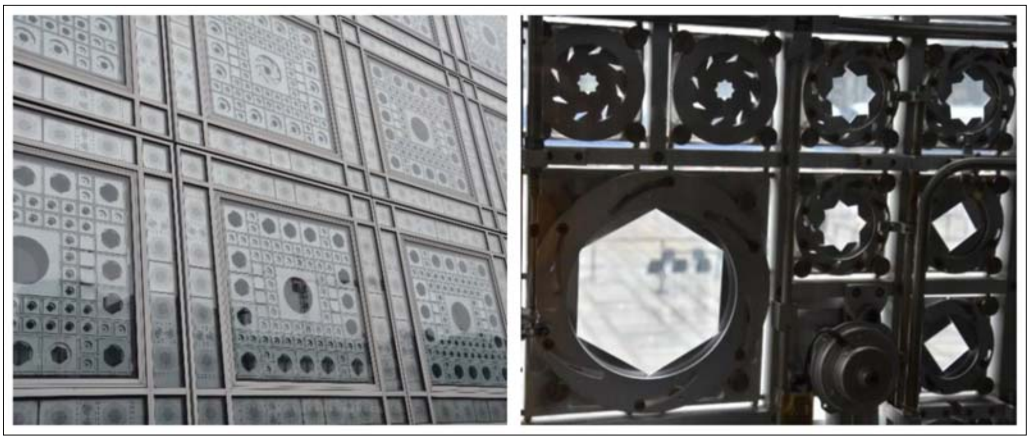

Fig. 5. Adaptive shading system of Arab World Institute in Paris [16]

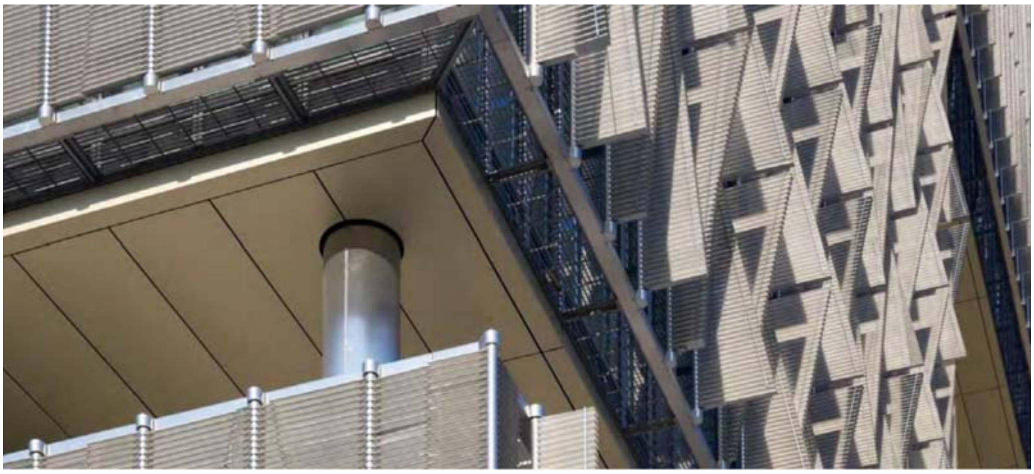

Fig. 6. Adaptive shading system of Q1 Building, ThyssenKrupp Quarter [17]
Architect: JSWD Architekten + Chaix & Morel et Associés
Project year: 2010, *Facade consultants:* Priedemann, Berlin and Werner Sobek

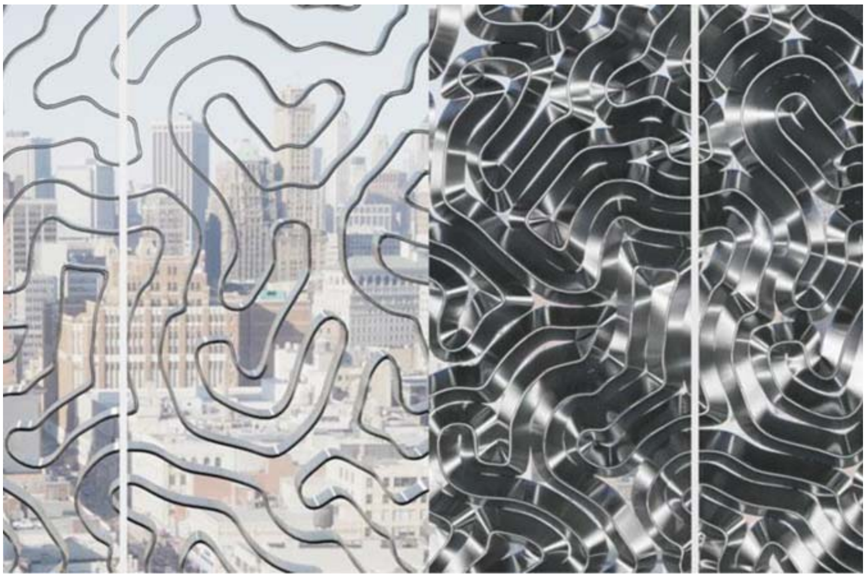

Fig. 7. Homeostatic adaptive shading system by Decker Yeadon [15]

3.1.3. Homeostatic Facade System

Homeostatic facade system responds too quickly even to small changes of solar energy intensity such as floating clouds, shadows casted by surrounding buildings, trees and the like. The system cannot be individually regulated. In the case of changes in using of indoor spaces its function cannot be adjusted to change. The great advantage of the system is exceptional energy efficiency.

4. Conclusion

The article brings a proposal for a fundamental typology of adaptive solar shading systems. The classification of adaptive shading systems can be used to guide their selection in design processes. The adaptive shading systems have the trend to become high-technological and complex because many contemporary buildings are designed too complex and often over-glazed. However, an accurate design of common buildings and their facades in middle Europe could work effective without sophisticated shading systems. On the other side, high-rise buildings require smart technologies among which the adequately designed adaptive solar shading systems can also be applied. More data from monitoring of operating buildings equipped with adaptive shading systems is required to increase their use in future buildings.

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References

[1] Schleicher S., Lienhard J., Poppinga S., Masselter T., Speck T., Knippers J. (2011), Adaptive facade shading systems inspired by natural elastic kinematics. Proceedings of the International Adaptive Architecture Conference Building Centre, London, March 2011. pp. 1–12.
[2] Nielsen M. V., Svendsen S., Jensen L. B. (2011), Quantifying the potential of automated dynamic solar shading in office buildings through integrated simulations of energy and daylight. Solar Energy, 85(5), 757–768.
[3] Loonen R., Trčka M., Cóstola D., Hensen J. (2013), Climate adaptive building shells: State-of-the-art and future challenges. Renewable & Sustainable Energy Reviews, 25, 483–493.
[4] Shen H., Tzempelikos A., Atzeri A. M., Gasparella A. (2015), Dynamic commercial facades versus traditional construction: Energy performance and comparative analysis. Journal of Energy Engineering, 141(4), 04014041.
[5] Fiorito F., Sauchelli M., Arroyo D., Pesenti M., Imperadori M., Masera G., Ranzi G. (2016), Shape morphing solar shadings: A review. Renewable & Sustainable Energy Reviews, 55, 863–884.
[6] Barozzi M., Lienhard J., Zanelli A., Monticelli C. (2016), The sustainability of adaptive envelopes: developments of kinetic architecture. Procedia Engineering, 155, 275–284.
[7] Cecchi M., Naticchia B., Carbonari A. (2014), Development of a first prototype of a liquid-shaded dynamic glazef facade for buildings. Procedia Engineering, 85, 94–103.
[8] Dakheel J. A., Aoul K. T. (2017), Review building applications, opportunities and challenges of active shading systems: A state-of-the-art review. Energies, 10(10), 1672, 32 p.
[9] Nagy Z., Svetozarevic B., Jayathissa P., Begle M., Hofer J., Lydon G., Willmann A., Schlueter A. (2016), The adaptive solar facade: From concept to prototypes. Frontiers of Architectural Research, 5(2), 143–156.

[10] Aelenei D., Aelenei L., Vieira C. P. (2016), Adaptive facade: concept, applications, research questions. Energy Procedia, 91, 269–275.
[11] Smart glass, https://en.wikipedia.org/wiki/Smart_glass, retrieved: July 17, 2018
[12] Drozdowski Z., Gupta S. (2009), Adaptive fritting as case exploration for adaptivity in architecture. Proceedings of the 29th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA), pp. 105–109.
[13] Lamontagne B., Barrios P., Py Ch., Nikumb S. (2009), The next generation of switchable glass: the micro-blinds. Proceedings of Glass Performance Days Conference, 11–12 June, 2009, Tampere, Finland, pp. 637–639.
[14] Elnokaly A., Keeling I. (2016), An empirical study investigating the impact of micro-algal technologies and their application within intelligent building fabrics. Procedia – Social and Behavioral Sciences, 216, 712–723.
[15] Cooling concepts (2013), Alternatives to air conditioning for a warm world. Environmental Health Perspectives, 121(1), A19–A25.
[16] Murray S. (2009), Contemporary curtain walls architecture. New York: Princenton Architectural Press.
[17] Balascakova P., Comes J., Veloso M., Heřmánková P., Luca A., Tramblin L. R-M., Sirotnjak M., Álvarez B. T. (2016), Energy Design Vol. IV/I – Adaptive Facade Systems. Institute of Buildings and Energy (IGE), Graz University of Technology, 107 p.