HI-SMART

HI-SMART: HIGHER EDUCATION PACKAGE FOR NEARLY ZERO ENERGY AND SMART BUILDING DESIGN

MODULE #2

CHAPTER 5: ADAPTIVE SOLAR SHADING SYSTEMS OF NEARLY ZERO ENERGY BUILDINGS

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2.5.1 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 need to be built since begin of year 2021. In order to reach this target, new materials, concepts and technologies for further improving buildings' energy efficiency need to be developed. 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 (Loonen R. et al., 2013; Aelenei D. et al., 2016; Dakheel J. A., Aoul K. T., 2017; Fiorito F. et al., 2016; Nagy Z. et al., 2016, Shady et al., 2018 and many others).

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. 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.

Solar shading devices represent one of the passive design strategies that respond to variable climatic conditions with aim to balance indoor comfort requirements and energy efficiency of buildings operation. Recently, mobile adaptive shading systems have been widely used (Al-Masrani and Al-Obaidi, 2019; Barozzi et al., 2016; Lamontagne at al., 2009; Nielsen et al. 2011). This study aims to provide an overview of the adaptive shading systems and their design. Issues related to details of technical installation, mechanical and electrical components, automation and control strategies, cost and maintenance are not addressed in this study.

2.5.2 "STATIC" AND "DYNAMIC" SOLAR SHADING OF NZEB

Proponents of dynamic building facades often argue that buildings have been design 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 various changes that they are exposed to (for example Al-Masrani and Al-Obaidi, 2019). These claims are rather false myths, as is shown in Figure 2.5.1.

Figure 2.5.1. - Is the shutter a “static” shading system?

Shutters, curtains and other shading devices are able to respond to wide-ranging environmental changes when they are properly operated. A facade consisting of a well-insulated non-transparent part and a transparent part equipped with a suitable shading technique can not 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 with adaptive shading systems? Driven by new architectural paradigms and the need to maximize indoor comfort, particularly commercial and office building facades have become more transparent. In this context external shading devices would seem essential. Contemporary high-rise architecture shows 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 (Shen et al., 2015; Schleicher et al, 2011; Karanouh and Kerber, 2015). 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 meteorological conditions, occupancy and comfort wishes, 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 below). The concept of adaptive solar shading, with appropriate adjustment to changing external and internal conditions, allows flexibility in the integration of design considerations, and can balance of 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 paragraph 3).

Many technicians believe that the adaptive shading lowers the need for HVAC systems and consequently the total energy cost 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, ventilation, and lighting. User response is often neglected in energy analyzes of adaptive HVAC systems. The 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 if view.

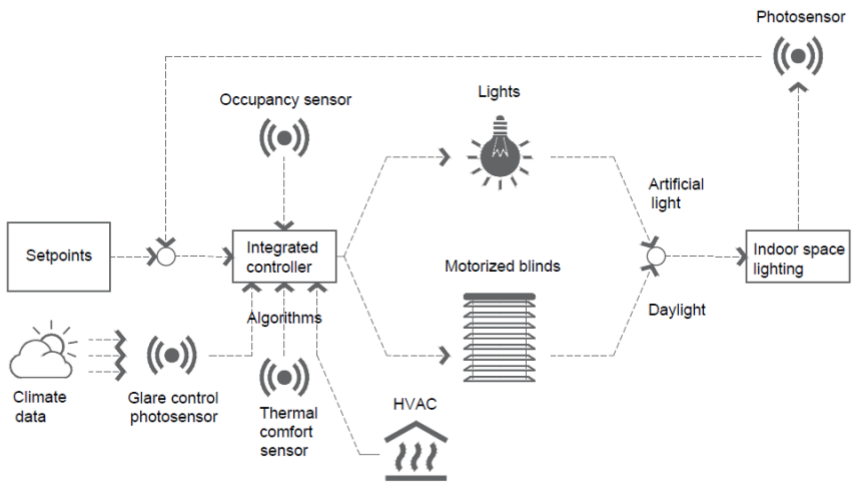

Figure 2.5.2. – Interactions of adaptive shading device with HVAC and artificial lighting of an „intelligent" building (Hraška, 2020)

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.

Figure 2.5.2 illustrates interactions of an adaptive shading device with HVAC and artificial lighting of an “intelligent“ building. An adaptive shading device includes functionalities such real-time sensing, kinetic elements, automation and the ability for user override. Advanced adaptive shading devices as a part of “intelligent” building skin need computational algorithms that allow the building systems to self-adjust and to control indoor environmental conditions. Information should be provided to the building’s users so they can modify their actions relative to indoor occupant comfort parameters and energy use.

2.5.3 TYPOLOGY OF ADAPTIVE 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 there is often a lot of confusion to make a clear distinction 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.

Mike Davies (Davies, 1981) presents the high-tech concept of dynamic façade which called “polyvalent wall”. He himself described his concept as follows:

“What is needed is an environmental diode, a progressive thermal and spectral switching device, a dynamic interactive multi-capability processor acting as a building skin. The diode is logically based on the remarkable physical properties of glass, but will have to incorporate a greater range of thermal and visual adaptive performance capabilities in one polyvalent product. This environmental diode, a polyvalent wall as the envelope of a building, will remove the distinction between solid and transparent”.

His suggest is shown in Figure 2.5.3 where each layer fulfils a specific function. This idea was never realized, but the concept is still very inspiring. Many new glazing systems and facade technologies draw on the reference of M. Davies.

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.

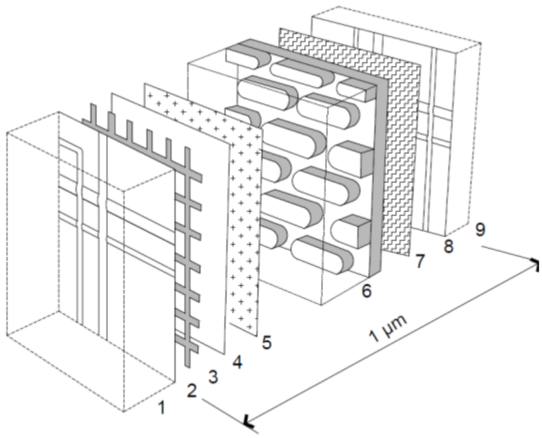

Figure 2.5.3. – Polyvalent wall (Davies, 1981)

1 - clear glass, 2 - outer sensor and control logic layer, 3 - photoelectric grid, 4 - selective heat absorber, 5 - electro-reflective coating, 6 - microporous gas-permeable layer, 7 - electro-reflective coating, 8 - inner sensor and control logic layer, 9 - clear glass

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 or both combined, Figure 2.5.4.

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 change depending on temperature or light intensity (i.e. chemically or electrochemically).

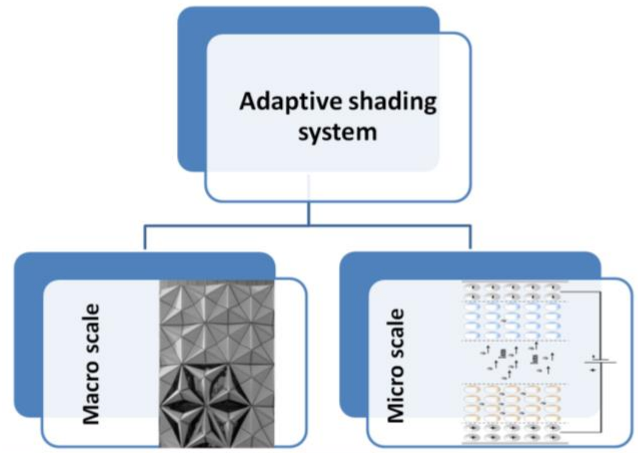

Figure 2.5.4.– Basic typology of adaptive shading systems

Advanced glazing at the micro scale changes light transmittance, spectral selectivity or light redirecting properties.

Position of shading systems in relation to the shading object can be external, internal and integral of building envelope (usually in glazing system). Adaptive solar shading system can also perform other functions, e.g. additional thermal insulation of building envelope, daylighting regulation, and transformation solar energy.

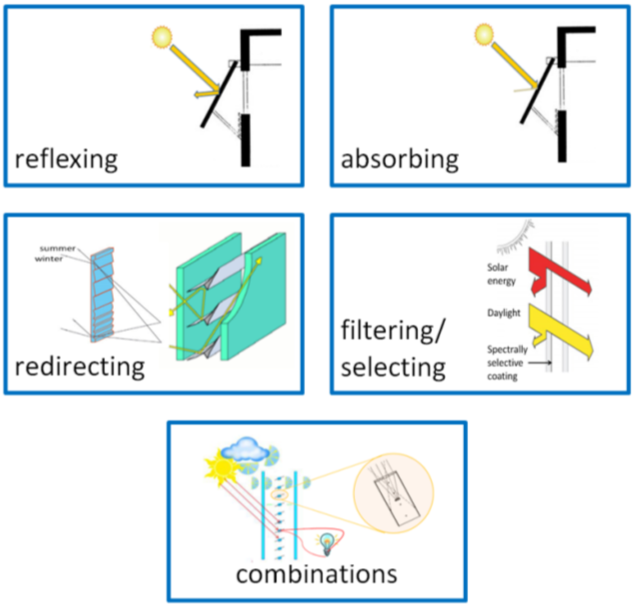

Figure 2.5.5. – Basic methods of solar control

Adaptive solar shading systems can be categorized by physical/optical processes that provide protection of a building from excessive solar radiation, Figure 2.5.5. Shading systems can regulate solar energy by 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 are used many smart materials such:

- 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, Figure 2.5.6. 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, user interaction and satisfaction are important factors that cannot be neglected.

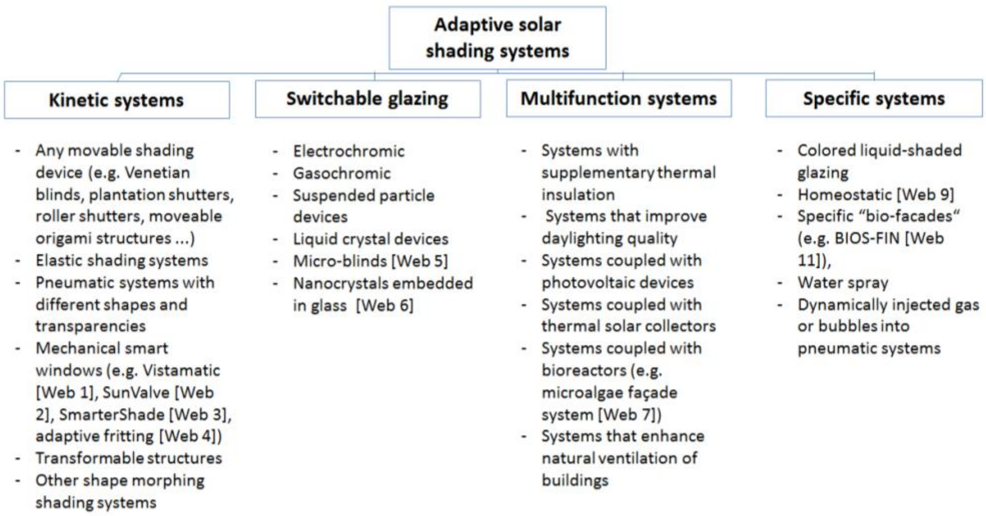

Figure 2.5.6. – Typology of adaptive solar shading systems (Hraska, 2018)

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.

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 used often as pretext for designing unique dynamic facades. The real motivation of these solutions is most often the prestige of the architect and the builder.

2.5.4 SELECTED TYPES OF ADAPTIVE SHADING SYSTEMS AND THEIR INCORPORATION INTO BUILDING ENVELOPE

Modern buildings are less specified for concrete climate conditions and material resources and become "international" and depended on technical systems to maintain indoor comfort. In this process, means are sought that can improve the performance of buildings. Adaptive shading systems seem to be a promising way to achieve these goals. Adaptive shading systems may or may not be part of adaptive building envelopes. Adaptive systems help to use the energy of the environment (sunlight, daylight) and at the same time regulate its excessive availability in order to reduce cooling costs or eliminate the risk of glare. It is known that nearly zero energy buildings have an increased need for cooling. Solar shading of nZEB is one of the most energy efficient solutions to eliminate excessive overheating. Adaptive solar shading systems can be controlled mechanically or by means of smart materials. Using simulation tools, adaptive shading can be designed and operated to take into account all urban, architectural, climatic, technical and other requirements so that the parameters of the indoor environment are achieved in an energy-efficient manner.

In Figure 2.5.6, many types of adaptive shading systems are listed. In this publication, we will mention only some of them in more detail. We will explain the principles of operation of shading technology based on nanotechnologies on a few examples and also we show newer variants of solar shading, which belong to the category of macro scale.

Electrochromic glazing

We know several variants of electrochromic glazing, the development of which is still ongoing. They are based on the electrochromism of some materials that can reversibly change their color. In the current market there are mainly types of electrochromic glazing based on the movement of lithium ions, Figure 2.5.7. Due to the low electrical voltage, lithium ions move between two transparent electrodes through a separator and an electrolyte from one electrochromic layer to another, and then the glass darkens. If the electric voltage stops or the polarity is reversed, the ions return to the original layer and the glass becomes clear. The state change takes about 5 minutes. In the clear state, electrochromic glazing transmits about 60% of the light. Figure 2.5.8 shows the relative change in the spectral transmittance of light from a clear state to a blue state, which significantly changes the spectral composition of daylight in the interior. Interior view of an electrochromic glazing with panes in fully clear and fully dark states is in Figure 2.5.9 (Pacheco-Torgal et al., 2019).

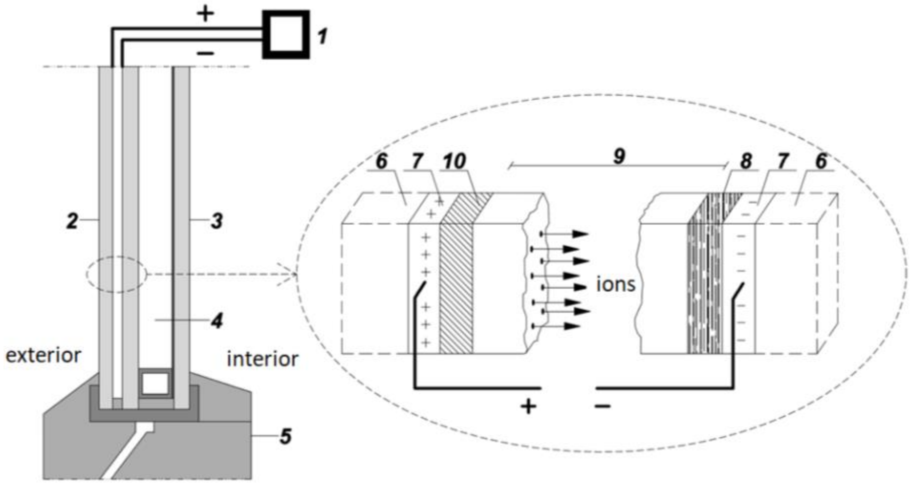

Figure 2.5.7.– Electrochromic triple glazing system (Hraška, 2020)

1 - power supply, 2 - electrochromic pane glass, 3 - inner panel with low-emission surface treatment, 4 - cavity filled with noble gas, 5 - window frame, 6 - glass, 7 - transparent electrical conductor, 8 - electrochromic layer, 9 - ion conductor (electrolyte), 10 - electrochromic layer (ion accumulator)

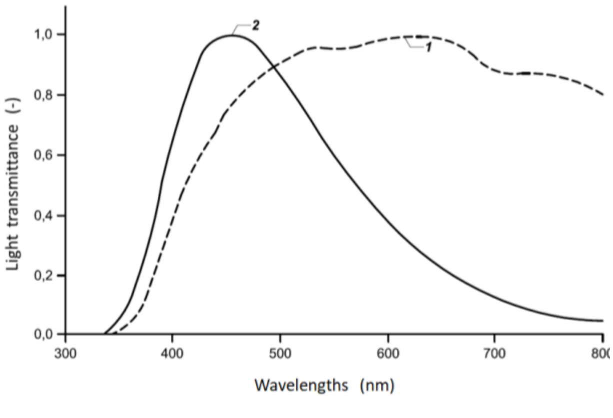

Figure 2.5.8. – Relative transmittance of light through electrochromic glazing

1) clear state, 2) maximum colouring state

Gasochromic glazing

Figure 2.5.10 illustrates the principle of gasochromic glazing. If the gasochromic coating (WO_3 – tungsten trioxide) is exposed to a low concentration of hydrogen contained in the carrier gas (argon or nitrogen), it turns blue. When gasochromic coating is exposed to oxygen, it returns to its initial transparent (clear) state. This allows the user to tint glazing panes to change the amount of solar heat passing through. The electrolyser and the pump are connected to the glazing by means of tubes which form a closed loop. The change from clear to color (and vice versa) takes 2 to 10 minutes. In particular, the high cost of these types of glazing and the relatively short service life compared to conventional building glazing prevent their wider use. Because glass changes its color, chromogenic glazing is not suitable for many types of interiors.

Figure 2.5.9. – Interior view of an electrochromic glazing with panes in fully clear (left) and fully dark (right) states. (Pacheco-Torgal et al., 2019)

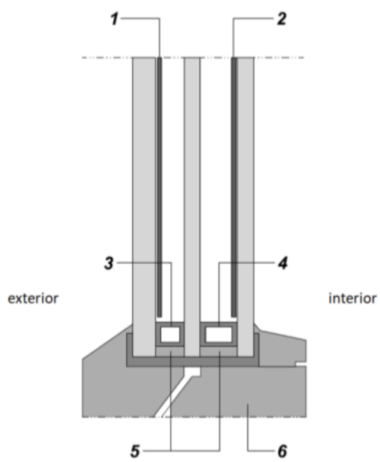

Figure 2.5.10. – Gasochromic glazing

1 - gasochromic layer, 2 - low-emission coating, 3 - special spacer bar allowing gas supply, 4 - standard spacer bar, 5 - seals, 6 - window frame

Solar thermal venetian blinds

Solar thermal venetian blinds (STVB) combine solar thermal collector with adaptive solar shading, Figure 2.5.11 (Denz et al., 2018). Heat pipes are integral part of conventional venetian blinds. The heat pipes transfer heat to the collecting pipe, which is part of the building hydraulic loop. The rotation of the blinds can be controlled automatically based on instructions from the central control system. It is a complex moving mechanical system with many components and fluid. There are a number of fundamentally similar adaptive shielding systems. Such systems are costly, maintenance-intensive, and less effective than the expected efficiency, which is usually based on optimistic theoretical assumptions.

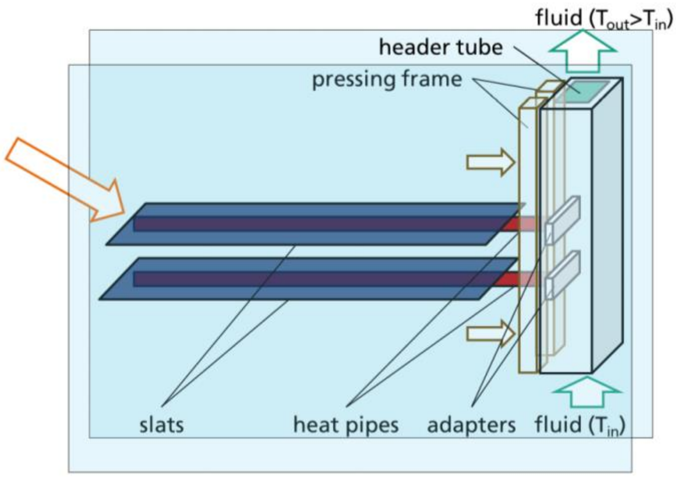

Figure 2.5.11. – Solar thermal venetian blinds (Denz at al., 2018)

Figure 2.5.12. – Architectural shutters on a new building in Bratislava (Slovakia). Photo: Jozef Hraška, 2018.

Architectural shutters

Recently, shading devices called architectural shutters have been used very often. The most commonly used are simple architectural shutters, which can be seen in the Figure 2.5.12. The shutters are usually moved horizontally by hand. Shutters can be operated automatically (with manual override). In this case, however, their application becomes much more expensive. The architectural shutters can effectively shade the glazed parts of the façade, regulate daylight and eliminate glare. There are also more sophisticated versions of architectural shutters that increase the thermal and acoustic insulation of the facades and their airtightness. Architectural shutters can be used for both new and existing buildings. The architectural shutters are most often made of aluminium and wood. However, they can also be made of other materials or different materials can be combined in their production.

Figure 2.5.13. – **Automatized interior shading fabric in office complex Cassovar in Košice (Slovakia). Photo: Jozef Hraška, 2015.**

Shading fabrics

There are a number of textiles shading devices. Exterior or interior solar shades use a woven fabric to reflect, diffuse, or absorb solar radiation. In addition to protecting the indoor environment of buildings from excessive sunlight and elimination of glare, textile shades provide sufficient diffuse daylight. Motorized shading fabrics belong to adaptive solar shading systems. These smart motorized shades can be programmed as a part of a home or office automation system. Automatized interior shading fabric in office complex Cassovar in Košice (Slovakia) is in Figure 2.5.13. On cloudy days, the fabric shadings are rolled up in the pipes and unfolded on sunny days.

Improving the efficiency of shading lamellas by shaping them

Some of the possibilities of changing the transmittance of sunlight through lamella shades illustrate Figure 2.5.14 and 2.5.15. Micro lamellas in horizontal glazing (Figure 2.5.14) are open to the northern hemisphere through transparent plastic. The aluminium cross bars with high reflectance are concave in shape to reflect direct sunlight in a specified range of sun altitudes. Even by shaping static lamella blinds, a significant change in the transmission of solar radiation can be achieved, Figure 2.5.15. Of course, the movable slats can be even more efficient in this respect.

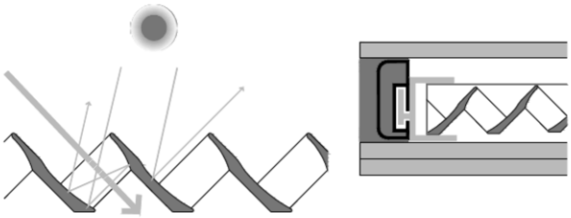

Figure 2.5.14. – Micro lamellas in glazing

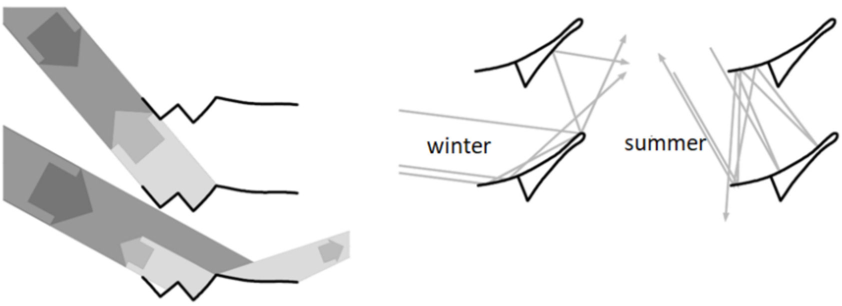

Figure 2.5.15. – Shaped blinds. Type RETRO (left, Arnesen et al., 2011), another type (right)

Design principles of adaptive shading devices

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To predict the energy and environmental performance of a building with solar shading many aspects need to be considered such as (Guide, 2015):

- Type and dimensions of the building,
- Requirements for a comfortable indoor environment (thermal, visual, and acoustic comfort, quality of air),
- Orientation and slope of the transparent parts of building envelope,
- Orography and urban structures around the building plot,
- Occupancy schedules,
- Weather data,
- U-values of building components (roof, external and internal walls, ground and internal floors and windows),
- Thermal storage properties of building structures and building equipment,
- Ventilation system,
- Optical parameters of glazing and shading device,
- Internal gains,
- Utilisation factor,
- Gain utilisation factor for heating,
- Loss utilisation factor for cooling,
- Space heating requirement,
- Space cooling requirement,
- Day and night profiles during a complete year.

So, the properly designing of shading devices depends not only of the sun and window geometry. Knowing the geometry of the sun's rays is important when designing especially fixed external shading elements. In the case of automatically control of adaptive shading systems, we need to optimize a number of parameters. Some parameters are contradictory or are mutually exclusive. For example, the penetration of direct sunlight into the interior in winter is welcome in terms of energy savings for heating, but may be unacceptable in terms of glare. It may be unacceptable when the room is occupied by its users, but when the room is empty, we can let direct sunlight into the room during the heating season. Therefore, if we design adaptive shading systems and their automatic regulation, we must take into account all the above mentioned parameters of the building and the occupancy schedules. At the same time, it is necessary to leave the users of indoor spaces the possibility of interfering with the automatic regulation. This is because user needs are dynamic variables. On the one hand, this measure increases the possibility of adapting the indoor environment to the needs of a specific user at a given time; on the other hand, the expected energy savings for cooling, heating and artificial lighting of the building may not be achieved.

When designing adaptive shading devices, their architectural and aesthetic aspect is often at the forefront. Architectural reasons for the application of a particular shading system may reduce its technical advantage. Installation, operation and maintenance of many adaptive shadings systems is more expensive than a standard shading technique. In practice, adaptive shading systems often cause deterioration of daylighting of interior spaces and also often impair the view from the building.

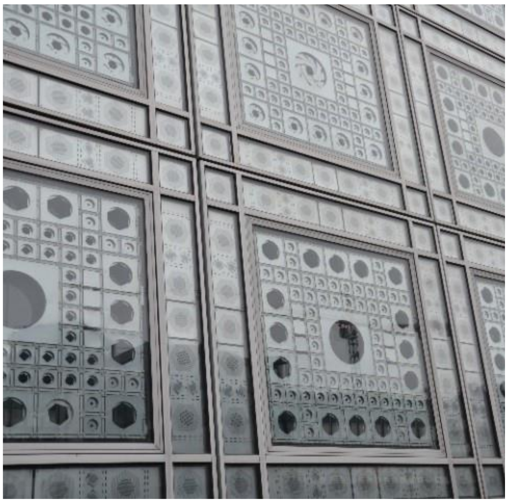
2.5.5 EXAMPLES OFCOMPLEX ADAPTIVE SHADING SYSTEMS

Most of the existing adaptive solar shading systems are specific solutions for and individual case. Despite the trendiness of these solutions it is doubtful that they are energy-efficient and more effectively improve indoor comfort compared to traditional solutions. Unfortunately, detailed monitored data on the performance of adaptive facades/adaptive shading systems and post-occupancy evaluations are missing in the available literature.

Here are some adaptive solutions with a brief commentary.

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 (constructed between 1981 and 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, Figure 2.5.16 and 2.5.17. Elements are individually controlled by small motors connected to a central computer control. Users can not overrule the system. The 30,000 light-sensitive mechanical control diaphragms resulted in constant maintenance and serious mechanical problems.



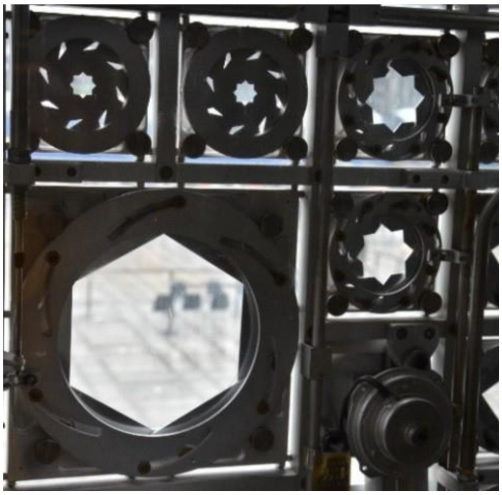


Figure 2.5.16. – Adaptive shading system of Arab World Institute in Paris (Murray, 2009)

Figure 2.5.17. – Adaptive shading system of Arab World Institute, view from the interior

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

Q1 Building: ThyssenKrupp Quarter

Adaptive solar shading system of ThyssenKrupp Quarter (known as Q1) in Essen in Germany consists from many stainless steel louvers and triangular, square, and trapezoidal fins (totally 400.000 centrally controlled slats), which open and close according to sun position in real-time, Figure 2.5.18. The movement of the shading elements is ensured by a total of 1600 motors. 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.

The mobile sunshading system gives the Q1 building specific appearance. The Q1 building has been awarded a gold certificate by the German Society for Sustainable Building and also won several other awards. The evaluation highly rated the concept of efficient energy supply, the use of locally available or manufactured materials and efficient heating and cooling systems of the building.

Architect: JSWD Architekten + Chaix & Morel et Associés
Project Year: 2010
Facade Consultants: Priedemann, Berlin and Werner Sobek

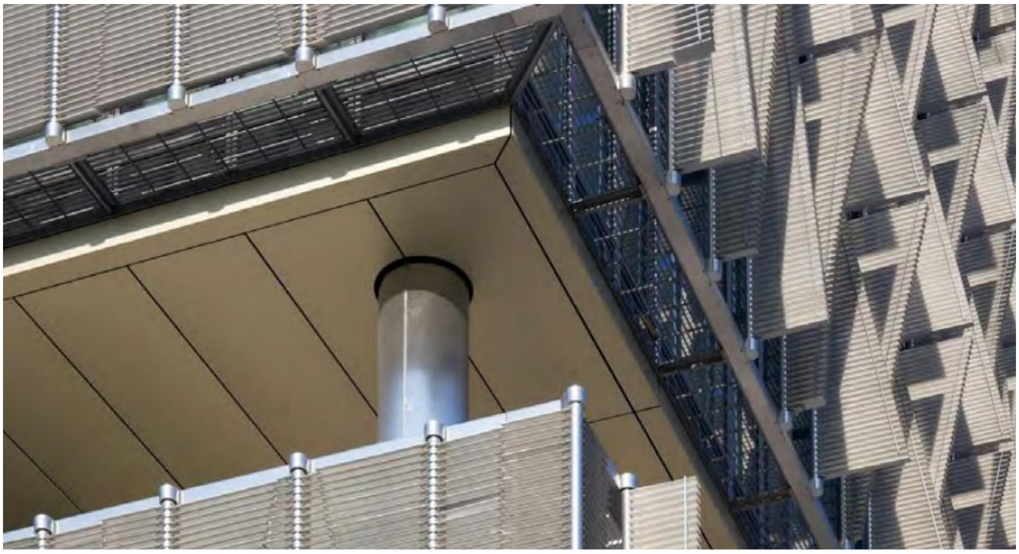


Figure 2.5.18. – **Adaptive shading system of Q1 Building, ThyssenKrupp Quarter (Balascakova, 2016)**

Al Bahr Towers

The sliding and rotating components of adaptive shading system of Al Bahr Towers in Abu Dhabi is very complex. Adaptive modules with servomotors and hydraulic pistons must be perfect synchronized. The system is very expensive and difficult to maintain. The system is inspired by traditional Arabic sunscreen called masharabiya, Figure 2.5.19. It is made from metal frames and fiberglass panels. When a panel is damaged it is easy replaceable. All components of the sunscreen have been tested in wind tunnel and for fatigue. The shading system should reduce 50% of solar heat gains.

Figure 2.5.19. – **Adaptive shading system of Al Bahr Towers in Abu Dhabi (United Arab Emirates) (Web 12)**

Kiefer Technic GmbH Showroom

Kiefer Technic Showroom is an exhibition space and office in Bad Gleichenberg in Austria. The building is used for presentation products of metal company. Adaptive shading system consists from 112 folding elements made of perforated aluminium, Figure 2.5.20. Elements are electrically driven and can be adapted individually to changing outdoor conditions and users needs. Shading device can also be controlled by optimizing program if users are not present in indoor spaces. So, façade changes continuously and shows a new "face" practically each hour. Some technical details of the Kiefer Technic Schowroom façade are in Figure 2.5.21.

Video that shows how this shading device works is in (Web 15).

Figure 2.5.20. – Adaptive shading system of Kiefer Technic Schowroom in Bad Gleichenberg (Austria) (Web 13)

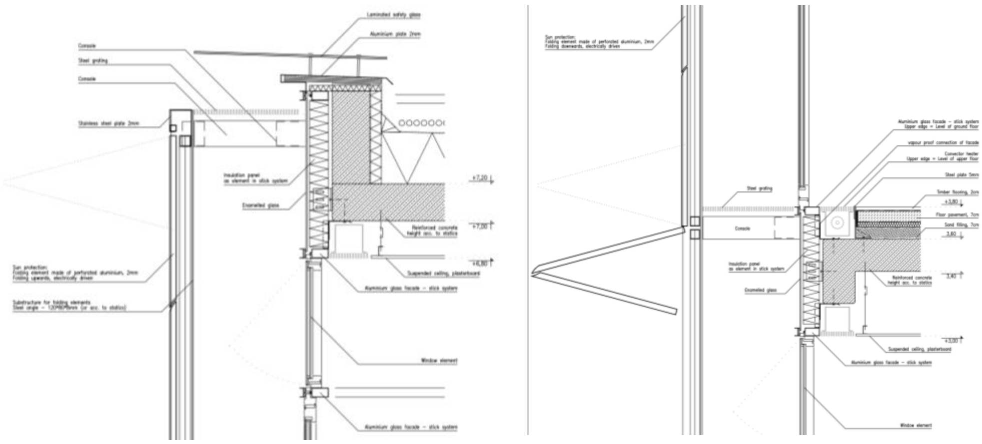


Figure 2.5.21. – Adaptive shading system of Kiefer Technic Schowroom – technical details (Web 14)

Homeostatic Facade System

The experimental prototype of Homeostatic Facade devised by Decker Yeadon (architectural practice firm based in New York, USA) was inspired by homeostasis in biological systems. The shading system is based on principle of dielectric elastomers, which create swirling ribbons, Figure 2.5.22. When solar energy warms up indoor environment, the surfaces of the ribbon expand and shade the interior. System works automatically; user has no control on the system.

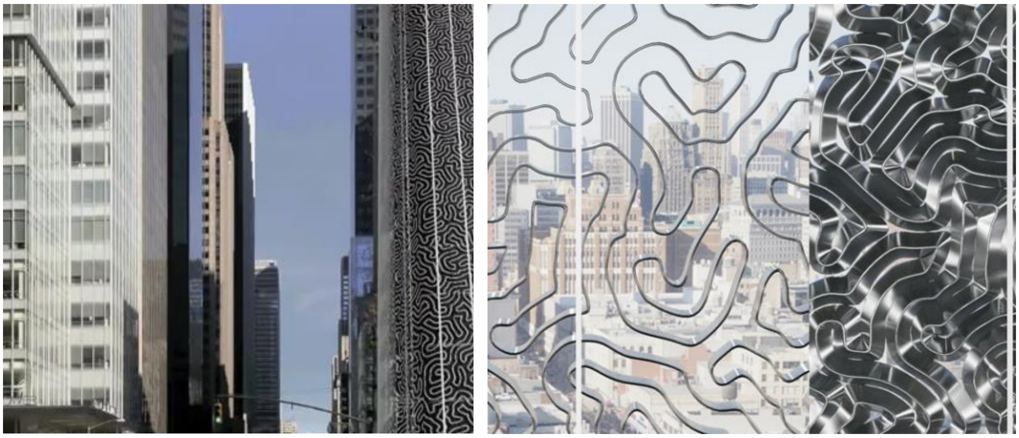


Figure 2.5.22.– Homeostatic adaptive shading system by Decker Yeadon (Cooling, 2013)

Homeostatic façade 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.

2.5.6 CONCLUSION

Adaptive shading systems or modular, dynamic and flexible adaptive solar facades are often solved at a high technological level and comprehensively. One of the reasons of such situation is that many architects and developers of today's buildings are fascinated by technological innovations. Adaptive facades should maximize passive winter heating, lowering energy for cooling, enhance natural ventilation, thermal and acoustic insulation, and let enough glare-free daylight into the indoor environment of buildings. Effective regulation of these parameters leads to a reduction in energy consumption for the operation of buildings. The adaptive shading systems usually create unique and aesthetically attractive coverings of building envelopes. This property is often the main reason for their application. From a technical point of view, the application of adaptive shading systems is justified by the need to eliminate glare and high energy consumption for cooling caused by the fully glazed facades. The use of glass curtain walls on high-rise buildings is determined by structural and budget reasons. Thus, we can say that the design of adaptive shading devices on high-rise buildings is to some extent a necessity.

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 over-glazed 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 by adaptive shading systems is required to increase their use in future nearly zero energy buildings.

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