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ADVANCED SOLAR SHADING METHODOLOGIES IN APPLIED BUILDING SCIENCES

Massimiliano NASTRI
Politecnico di Milano, ORCID 0000-0003-3465-0039
massimiliano.nastril@polimi.it

ABSTRACT: The study examines the typological, physical and applicative composition of the solar shading within the evolved scenario of architecture and buildings, with respect to the way in which they function with respect to thermal, light and airborne stresses, determining the elaboration criteria aimed at both “selective” environmental control and “dynamic” interaction and as “environmental filters”: this affirming the protective and reactive capacity of the shielding devices (also with the regulation of functional supports, “passive” or “active”, fixed or variable) to changes in climatic conditions. The development, production and execution of functional devices combined with the window surfaces of the building envelope (for windows and for façade systems) takes on, in the contemporary scenario, the methodologies and procedures related both to the environmental and ergonomic design of interior spaces, and to the energy calibration and containment of consumption due to technical systems. At the same time, the functional devices combined with the glazed surfaces participate in the overall morpho-typological composition of the architecture, according to the application and expression of the “equipment” capable of regulating the incidence of the solar radiation and light conditions.

Key words: Building envelope technology, Solar shading, Façade integrated systems.

INTRODUCTION

The contribution with respect to the *Materials Science and Engineering* focuses on the study and articulation of the typological and functional, material and applicative devices for the control and regulation of solar radiation within the architectural technology and advanced construction. The functional devices, in the form of solar shading, are defined according to the principles of the mediation between the light transmission and thermal conduction (without affecting transparency). Moreover, the study involves the regulation of the ergonomic and energy conditions, according to the reflection, capture and diffusion of external environmental loads. In this respect, the analysis examines the contributions to the “solar gain” conditions and the reduction of thermal losses, due to the high conductivity and low thermal inertia value of the glass enclosures (Schittich, 2003; Syed, 2012).

Objective of the study
The study of the solar shading is focused on the multi-layer envelope systems, determined according to the acquisition and transformation of the external environmental stresses. The objective is to define the main types of solar shading in the design, production and, above all, construction scenario of the evolved type. In this regard, the contribution intends to formalize itself in the form of a methodological orientation and in-depth study tool, also with the support of the cited and selected bibliographical references (Aksamija, 2013; Freewan, 2014).

Structure of the study
The structure of the contribution, proposed in the form of a technical guide for the analysis, identification and application of solar shading with respect to the main performance and executive needs, is articulated through:

- the typological and functional determination of the solar shading, then articulated into the external, internal and integrated installation to transparent surfaces of the building envelopes;
- the combined installation of the solar shading with photovoltaic modules;
- the executive calibration and functional control of solar shading, in order to explain how to obtain the homogenous diffusion and distribution of the light contributions generated by the solar radiation towards the interior spaces, according to devices capable of reflecting and transmitting the flows towards the surfaces away from the transparent perimeters.

SCIENTIFIC ANALYSIS

1. The state-of-the-art research on the advanced solar shading

The state-of-the-art on the operation of the solar shading devices is delineated, according to the way in which they act against radiation and brightness requirements in interior spaces (Boswell, 2013; Loonen, Trčka, Cóstola, Hensen, 2013; Lovell, 2010), with respect to:

- the "active" devices, which allow the ratio of incident solar radiation to transmitted solar radiation to vary in accordance with the change in the solar angle α, producing an increase or decrease in the shading surface or the ratio of the opaque surface to the open surface. This supports the use of the "active" type especially in the case of discrete variations of the solar angle α or the need for precise control of the transparent surfaces (Hraska, 2018; Nagy, Svetozarevic, Jayathissa, Begle, Hofer, Lydon, Willmann, Schlueter, 2016);
- the "passive" (i.e. fixed) devices, which concern situations of stability of solar radiation during different seasonal periods or the need for shading for a specific period (Fiorito, Sauchelli, Arroyo, Pesenti, Imperadori, Masera, Ranzi, 2016; Littlefair, 2018);
- the "dynamic" devices, which allow the portions of the shading surface to be varied in an automatic or programmed manner with respect to the transparent surfaces (Aelenei, Aelenei, Vieira, 2016; Bellia, Marino, Minichiello, Pedace, 2014; Daniels, 2003).

2. The typological and functional determination of the solar shading: proposal of a technical guide

1.2. The external installation of solar shading to transparent surfaces

The external installation provides a frontal barrier to the glazed surface and dissipation of the absorbed thermal energy, involving:

- the critical conditions due to the operation, with particular relevance in the case of high rise buildings;
- the effectiveness against the direct and diffuse solar radiation;
- the determination of the variable *solar factor g* (in general, between 0,10÷0,25), depending on the material constitution of the shading and the glazed surface.

In the case of installation in the "in projection" type, the following are noted:

- the effectiveness against the direct solar radiation, with respect to the solar angle;
- the functional decrease against the diffuse solar radiation.

The typological and functional articulation observes:

- the constitution of the "passive" (i.e. fixed) vertical and horizontal shading devices, which produce the shadow sections towards parallel interior spaces (at an angle to the prevailing solar angle α of the context). These devices are composed of the pre-oriented slat or blade elements (of different material compositions, e.g. wood, metal and glass) applied vertically and at a reciprocal distance less than the size of the elements themselves;
- the constitution of the azimuthally oriented devices (in the "active" form), which produce the shadow sections according to the direct rotation to control solar radiation with respect to the azimuthal path, producing reflection or refraction towards the interior spaces. These devices are composed of the elements with blades (e.g. made of aluminium with an ogival cross-section) applied vertically and operated in mechanical modes;
- the constitution of the blade-operated sun-shading devices (in the "active" form), which produce the shade sections according to the rotation aimed at controlling the solar radiation by running horizontally and parallel to the transparent surfaces, producing reflection or refraction towards the interior spaces. These devices are composed of blade elements with an ogival or wing section (e.g. metal sheet, extruded aluminium, wood and glass) applied horizontally and operated in mechanical (manual or motorized) modes;
- the constitution of the sunshade devices with adjustable slats (in the "active" form), which produce the shadow sections according to the rotation directed to control solar radiation with respect to any solar angle α. These devices consist of the slat elements, in the "venetian blind" type (of different material composition, e.g. aluminium or other metal, wood) applied horizontally and operated in a mechanical mode, with the possibility of packing in the upper position. The geometric configuration takes place according to the curved type (possibly with longitudinal ribs, for the general width between 50÷80 mm), the "Z" type (for the general width between 75÷90 mm), the inverted "C" type (for the general width between 75÷150 mm);
- the constitution of the packable shutters (or *folding shutters*), according to the execution by contiguous segments connected by hinges. These devices are made up of opaque or perforated panels (.e. expanded steel sheet), the frames supporting a filtering fabric, with different opening factors, with the possibility of packing by lifting or by lateral dragging by means of the pulling system inserted in the guide profiles;
- the constitution of the sliding shutters (in the "active" form), consisting of the panels and the frames supporting a filtering fabric (in fixed or adjustable metal slats, of different material composition, e.g. aluminium,

expanded metal mesh, metal fabric, perforated sheet metal, wood), with different opening factors, with the possibility of sliding (in mechanically motorized mode) within the guide profiles;
- the constitution of the roll-up shading devices (in the "active" form), which produce the shadow sections towards parallel interior spaces by means of planar (where the consistency determines the opaque, obscuring or filtering formulation) and adjustable placement. These devices consist of the sheets (e.g. in textile, plastic or metal form) that can be operated via the cable or steel slat guides, or via the mullion profiles;
- the constitution of solar blinds (in the "active" form), consisting of the drop awnings, characterized by the gravity-operated roller blind arrangement, the lateral guide profile arrangement (with the lower fastening) or the rotating arms (with the pulling and tensioning outwards) (Schittich, 2001) (Fig. 1).

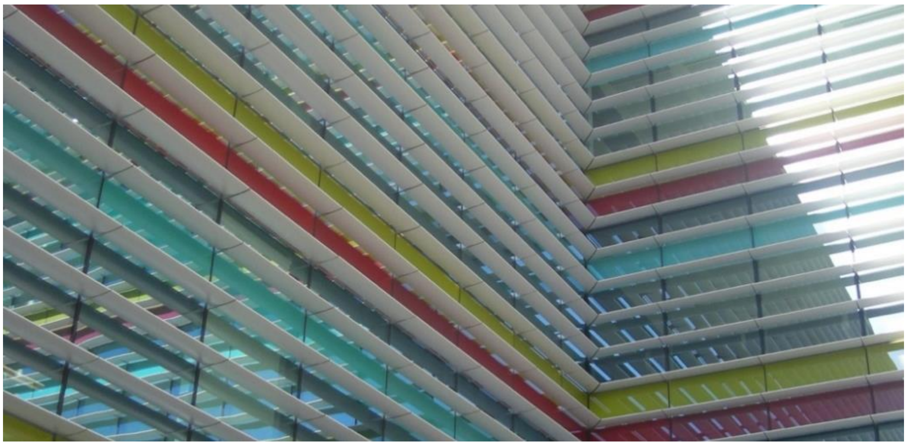

Figure 1. Fixed external installation of "passive" horizontal sunshade devices, as result of the aggregation of extruded aluminium shading devices (lenticular type) to façade curtains.

1.2. The internal installation of the solar shading to transparent surfaces

The indoor installation provides a reduced solar performance compared to the glazed area, resulting in:
- the ease of construction and operation;
- the effectiveness against the diffuse solar radiation, even in the case of north-facing exposure;
- the determination of the variable *solar factor g* (in general, between 0,40÷0,65), depending on the material constitution of the shading and the glazed surface.

The internal devices are applied by means or without the contribution of the supporting structure (in the form of a frame or by linear joints). The typological articulation observes the constitution of blinds in the "venetian blind" type (in the "active" form), which produce the shadow sections according to the direct rotation to control solar radiation with respect to any solar angle α. These devices are made up of slat elements (of different material composition, e.g. aluminium or other metal, wood, for the general width between 15÷50 mm) applied horizontally and operated mechanically (manual or motorized), with the possibility of packing in the upper box (in which the drive mechanism is located) (Hausladen, de Saldanha, Liedl, 2008) (Fig. 2).

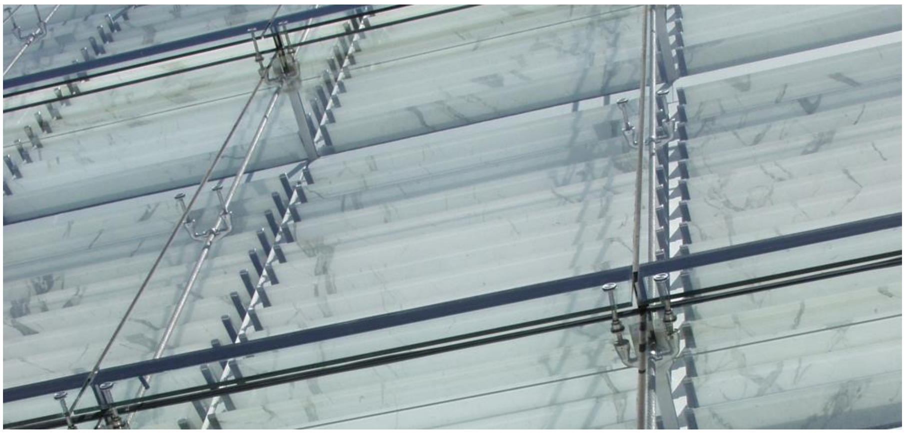

Figure 2. Integrated installation consisting of the internal curtain wall in double-glazed sheets, the cavity with sun-shading devices and the external screen in monolithic tempered glass sheets.

1.3. The integrated installation of the solar shading to transparent surfaces

The integrated installation, within the cavity between the transparent surfaces that provides an intermediate solar performance with respect to the external and internal installation, results in:

- the effectiveness against the direct and reflected solar radiation;
- the functional decrease towards diffuse solar radiation (due to the double reflection triggered by the insertion between the glazed surfaces);
- the determination of the variable *solar factor g* (in general, between 0,30÷0,45), depending on the material constitution of the shading and the glazed surface (Oesterle *et alii*, 2001).

The typological and functional articulation observes:

- the constitution of the adjustable slat blinds (in the “active” form), which produce the shade sections according to the direct rotation to control the solar radiation with respect to any solar angle α and which contribute to mitigating heat loss from the transparent surfaces. These devices are made up of slat elements (generally 12,5÷16 mm wide, made of aluminium) applied horizontally and operated in mechanical modes (motorized, magnetic slide, magnetic and electrically driven);
- the constitution of pre-oriented micro-slat screens (in the “passive” form), aimed at the reflection or diffusion of the solar radiation in interior spaces towards the specific solar angle α;
- the formation of the filtering films applied to the glass surfaces (in the “passive” form), aimed at the reflection or diffusion of the solar radiation into the interior spaces. These devices consist of polyester or mylar films, on which a layer of metal oxide is deposited (under vacuum) (Agathokleous, Kalogirou, 2016).

The integrated installation on the envelope, within the cavity between the curtain wall and the external enclosure in the *double skin façade* type, which provides a solar performance similar to the external installation, involves:

- the conditions of easy construction and operation (considering adoption for high rise buildings), as the devices are protected from wind loads and external climatic conditions;
- the determination of the *solar factor g* comparable to the case of outdoor installation, variable (in general, between 0,10÷0,25) depending on the material constitution of the shading and the glazed surface.

The solar shading devices (in adjustable form), placed inside the cavity, are protected from atmospheric agents and external pollutants: furthermore, these devices reduce the heat input depending on the external temperature and solar radiation conditions, being particularly effective when the external temperature is lower than the temperature of the internal spaces and for low values of total radiation (Nastri, 2021) (Fig. 3).

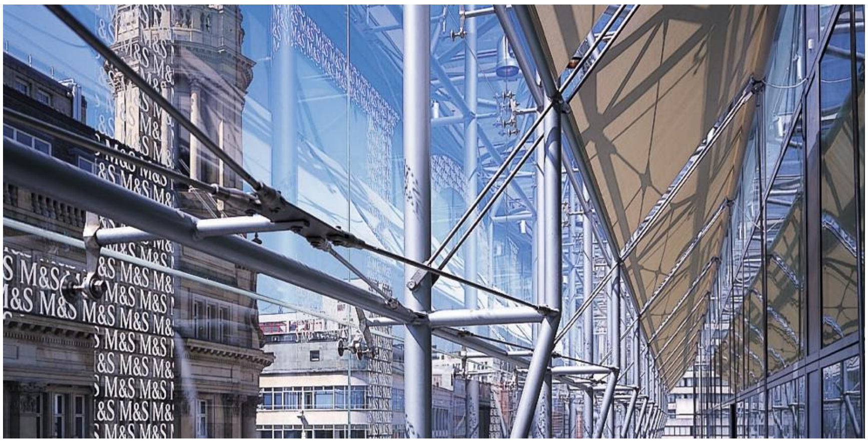

Figure 3. Inclusion of the shading within the *double skin façade* typology which contributes to the operating procedures during the winter period, with respect to the distribution of the heat accumulated by the air mass in the cavity, and during the summer period, with respect to the attenuation of overheating in the interior spaces.

3. The installation of the solar shading with photovoltaic modules: indications for a technical guide

The solar shading devices under consideration are considered as mediating tools between variable and relatively constant climatic conditions in indoor spaces, filtering and intervening on energy flows, to the point of accumulating them to obtain electrical energy. The devices are mounted in modules applied on sheets of laminated glass (through the interposition of transparent resin layers) and connected by conductors designed to absorb and transfer the electrical energy produced. The modules are transparent, translucent or opaque, depending on the connective configuration (which results in variable light transmission with respect to the distance between the cells) (Mandalaki, Tsoutsos, 2020). In addition, photovoltaic cells are made from:

- the *thin-film technologies*, for the manufacture of amorphous-type solar cells: in this case, the semi-conductor is deposited on layers that can be applied to various glass (by cathodic deposition of silicon), plastic or aluminium sheet substrates, with connection by wiring;
- the semi-transparent amorphous cells, produced by removing partial areas of a thin film, according to transparent strips that allow incident light radiation (12%) to pass through.

The use of *photovoltaic brise-soleil* allows for the calibration (by means of cell patterns) and absorption of light radiation: the distance between cells in a string is variable (between 2÷10 mm), as is the distance between the strings themselves, which can be thickened or spaced according to the visibility and shielding requirements. Even for modules produced in amorphous silicon, partially transparent areas are executed, with the inclusion of inactive sectors in the deposition of the film. The panels involve the realization:

- for crystalline silicon modules (mono or polycrystalline), glass-to-glass or glass-to-tedlar laminates;
- for amorphous silicon modules, of laminated sheets made of plastic material (Watts, 2010).

4. The executive calibration and functional control of solar shading: operative indications

The functional and executive procedures for the solar shading devices are defined through the detection of the main parameters related to the assembly at the façade plane, according to the extension of the support brackets, the height of the transparent surface and the critical angle of solar incidence. The devices are applied on the basis of the analytical relation between the incidence of the direct solar radiation, the light conditions during winter, the horizontal projective height, and the distance, width and angle of the slats. In general, the planar construction of the transparent surfaces is determined by the angle of the slats related to the vertical axis and according to the distance between the axes of the slats themselves, depending on the critical angle of the solar incidence. The perpendicular application is based on the arrangement of the slats with respect to both the critical angle of solar incidence and the angle of the slats with respect to the vertical axis and the running distance between the slat axes: this is determined by the conditions of horizontal or vertical orientation, fixed or movable, according to the production of the profiles (Konis, Selkowitz, 2017).

The main parameters related to the constitution regard: the extension of the support brackets (*D*); the height of the transparent façade surface (*h*); the critical angle of solar incidence, which determines the height at which the solar radiation directs illumination through the transparent surface (α). Solar shading is applied according to the analytical correlation of: the incidence of direct solar radiation, in relation to the most critical situation; the lighting conditions during winter, the glare effects in interiors; the horizontal projective height of the slats (*d*); the distance between the slats (*LA*); the slat width (*LB*); the angle of the slats (*LN*); the angle of solar incidence (α) (Fig. 4).

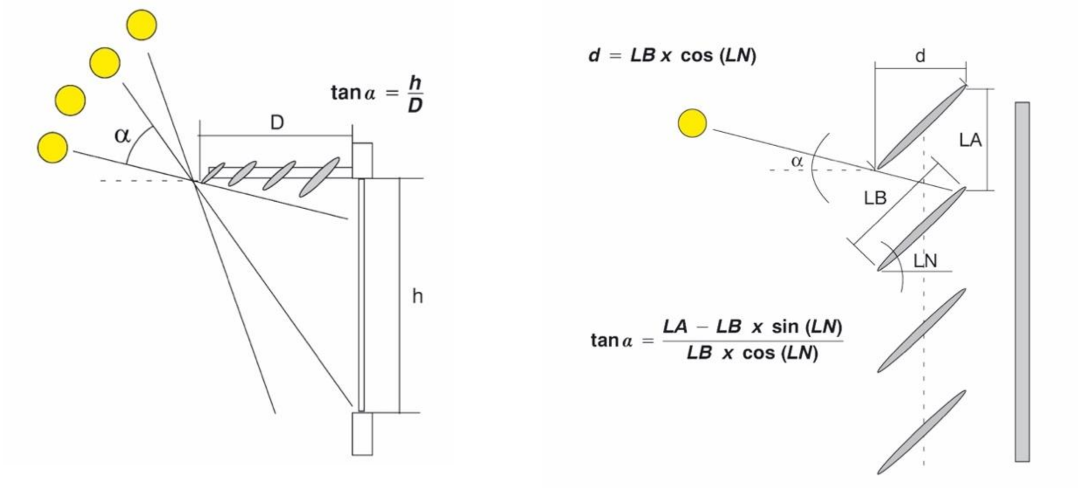

Figure 4. Execution and parameters of the solar shading at the façade plane.

RESULTS AND CONCLUSION

Based on the state-of-the-art research, the development of the contribution in the form of a technical guide focused on the design, production and construction of the solar shading, leads to the recognition as advanced tools to:

- the protection against the heat inputs generated by solar radiation (direct, diffuse or zenithal), leading to a reduction in the temperature increase in interior spaces;
- the reduction of the direct energy consumption for air conditioning during high temperature periods (also influencing the setting and sizing relative to the maximum power of the systems);
- the reduction of the solar radiation during periods of high temperature, whereby the adoption of shading (characterized by the reduced *solar factor g*, for example, equal to 0,20) contributes to limiting (by a value equal to 2/3) the solar contributions that can generate overheating situations;
- the generation of a ventilated cavity (in “passive” form) according to the external application of the window and façade systems, helping to reduce the temperature in internal spaces. The application of the solar shading increases both passive energy contributions and the thermal resistance of façade surfaces during periods of reduced temperature: in other words, solar shading, especially if made of a poorly airtight invoice, can generate a cavity capable of attenuating thermal dispersion through window surfaces, resulting in a parieto-dynamic type of operation (capable of activating not only conductive but also air mass) (Paoletti, Nastri, 2023).

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