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**Selected Papers from the
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Photovoltaic and Thermal solar concentrator integrated into a dynamic shading device

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Abstract

This paper presents the design of a Photovoltaic/Thermal solar concentrator (PV/ST) integrated into a system for external shading device suitable for different building typologies such as office facilities or residential houses.

The paper addresses the problem of designing efficient shading devices for buildings. The novelty of this project is a dynamic design for shading devices, new in the market of photovoltaic and concentrator systems, that changing orientation and configuration, allows the best lighting comfort in buildings while producing energy.

This device consists of a series of linear low concentrator with monoaxial sun tracking and a semi-parabolic profile reflector providing the solar radiation concentration into a string of mono-crystalline cells PV, with 5,5x concentration factor. The thermal energy production is achieved through the cooling system of the device whereby hot water is produced.

The contribution of this study is a new concept and developments in solar thermal concentrator systems revealing new trend for the technology to be integrated into architecture, especially in dynamic solution for shading devices.

Keywords BIPV, Shading devices, dynamic integration, energy production, Integration of Photovoltaic/thermal (PV/T) system

1 Introduction

The reference framework for this project is the performance of the building envelope. In this context one of the most studied topics is the one of Kinetic Architecture¹: an architecture able to change its configuration adapting to the environment in which is situated, to the passage of time and to different climatic conditions.

The dynamic part of a building is principally the façade or the façade component. The step forward in comparison to static solutions is both technological and stylistic because it allows to minimize or maximize the thermal loads of a building while opening new possibility in terms of design and aesthetic qualities.

The dynamism in architecture can be reached with different technologies and materials. A popular case study is *The Arab World Institute* in Paris² in which the architect Jean Nouvel reinterprets the traditional theme of “Mashrabiya”, a wood grid widespread in Islamic architecture, transforming it in the characteristic element of the building able to regulate the light in the internal environment thanks to the movement of a series of diaphragms. In the *Beijing National Aquatics Center*³, the dynamism is obtained thanks to the use of the polymer ETFE⁴ that forms a pattern of bubble able to regulate the internal temperature by regulating the pumping of air inside the bladder formed by the two layers of ETFE. There are a lot of study cases to refer to and all of them show how the best results, both technological and stylistic, are reached in projects characterized by a high iconic value and big investments of money. At the level of common constructions instead, it is hard to find examples that are so technologically advanced and also successful from an architectural point of view: the dynamism of a façade is normally consigned to the possibility to move, manually or electrically, the shading systems such as curtains or brise-soleil. If we look to more advanced solutions it can be seen that the aesthetical appearance is quite overshadowed and the building appears than more as a facility than as an architecture. Example of this is photovoltaic brise-soleil that haven't achieved a wide dissemination due to a design hard to integrate.

2 Research Objectives

The idea for this project emerged from the will to design a dynamic component simple and versatile, adaptable to different construction categories and contexts: a component that can be an expression of technological innovation without overlooking both the economic sustainability and architectural integration.

The element brise-soleil has been taking in consideration a starting point for the development of the project due to its features of adaptability in both new buildings and renovation projects. Starting from this element, it has been thought a way to implement its technological potentiality without penalizing its construction simplicity. A common features of the shading system available in the market is the option to tilt the shovels so to change the brightness conditions inside a building according to user needs: the handling can be manual, mechanical or controlled by a sensor sensitive to external climate change so that the building's envelope can manage itself. A sector that has been already experienced is the one of photovoltaic brise-soleil: this element can be realized applying a photovoltaic film in the shovel's surface or using small-scale PV panels, in place of shovels, so to form a shading system.

Doing a research about the state of the art of photovoltaic brise-soleil, it appears clear that their use is quite restrained. Despite all the leading companies producing shading devices have PV products in their catalogs, their spread in the building sector is not comparable to the spread of standard products although they present the advantage to produce energy. This difference can be easily explained considering the PV brise-soleil also just from an aesthetic point of view: in comparison to standard product, the PV ones have bigger dimensions that reduce their versatility resulting often totally out of scale when applied in small/regular size constructions such as residential buildings. The replacement of shovels with PV panel negates the possibility to paint the elements so to create nice chromatic effects characterizing the façade. In this way, the building ends to look like an energy production facility without any aesthetic value.

The integration of PV in architecture is a thematic that a lot of architects had already tried to face, sometimes with very good results but more often it happens that the use of PV in buildings is just intended to the production of energy or, at most, to show a special attention to environmental issues.

This project tries to fill this gap in the design of PV shading device by using the technology of the concentrated solar system.

3 Methodology

CONCENTRATED SOLAR TECHNOLOGY

One part of the research in the field of PV and Solar thermal collector is focused in Concentrated technology: this system, thanks to mirrors or lens, concentrate sun rays in a small area where the active material is located. The active material is represented by photovoltaic cells or pipes in which an heat-transfer liquid flows.

The components of a Solar concentrated photovoltaic system are:

- _Receiver
- _Reflector
- _Tracking System
- _Inverter

The **Receiver** is located in correspondence of the focal line of the system, where all the sun's rays are concentrated. In this place is situated the PV material. Because of the high concentration of solar energy, the temperature goes up very fast so that a heat sink system is required. The heat sink prevents the PV cells from degradation and loss of efficiency (about -0,5% every degree exceeding the operating temperature of 40 degrees). The dissipation system can be active when cooling is achieved by using the flow of a low-temperature liquid, or passive in case an heat sink with straight fin is applied.

The **Reflector** is an optical system that can be "Imaging Optics" if consisting of a curved mirror and "Non-Imaging Optics" when using lenses as the Fresnel lens. Both the solutions use the principle for which when a surface **A** is hit by the sun's rays, it is possible to converge the rays onto a smaller surface **a** through a reflector so that the incident energy in **a** results the same of the incident energy in **A**. The ratio **A/a** is called **Concentration Factor C** and is measured in "suns" (x). The Concentration Factor subdivides concentration

system in Low concentration system (LCPV), and High concentration system (HCPV), when suns are higher than 300 x. Thanks to this principle it is possible to reduce the quantity of PV material used and thereby the costs of the system. As known, in a standard PV panel, the price of the photovoltaic material affects the final price for the 70%. Monocrystalline silicon cells are used for LCPV, and they still are the one with greater efficiency. For HCPV are used Multi-junction cells because of their character to endure deterioration when subject to high temperature.

The **Tracking System** is a fundamental device while concentration system can only converge direct solar radiation. The system's optical axis has to be aligned with the source of light so that the system can give the greater amount of energy. Tracking systems can be single or dual axis tracker: dual axis trackers adapt themselves both to azimuth and altitude while in case of single axis tracker the choice of the right axis must be done considering the features of the installation place. A system that follows the sun in North-South direction has the maximum performance during the central hours of the day and collects more energy in summer, vice versa a tracker that follows the sun in East-West direction catch collect energy steadily during the year.

Like in any other PV System an **inverter** is required to change the direct current in alternating current.

At this moment concentrated technologies are mainly used in big industrial facilities to produce heat or electrical power. Big plants, however, still have some points of criticism not completely solved and currently under study. The main problem is related to the non-competitive price of Multi-junction cells: originally used in the space sector, these cells have now a widespread use in HCPV since the high temperature reached with this system prevent the use of monocrystalline cells, easily subject to deterioration. Multi-junction cells use compounds of semiconductor elements as an alternative to Silicon, such as Gallium arsenide or Indium phosphide. Their efficiency is between 25% and 50%, they have better resistance to high temperature and less degradability but they present the big inconvenience of a price from 3 to 5 times higher than a monocrystalline cell due to the complicated production process and the reduced availability of the alternative elements. Other factors that affect the price of HCPV systems are the heat sink system, that is always required, and the continuous maintenance needed. These systems are based on the law of reflection and refraction, for this reason, mirrors, and lens have to be kept clean so to avoid loss of efficiency. The problems experienced in HCPV considerably decrease with small size and small concentration systems: smaller Concentration Factors correspond to lower temperature so that is possible to use monocrystalline cells, moreover, heat can be dissipated using heat-transfer fluids as in a classic solar thermal collector. Furthermore, because of the smaller size, costs for maintenance are significantly reduced.

For all these reasons the use of a low concentration system has been taken into consideration for the development of the project presented in this paper. On the current market, small size concentration systems are very rare although it is possible to find some more examples considering research projects. The aim of the products on the market is mainly energy production through renewable sources but less attention is paid to their appearance so that they look more like facilities than an architectural element. The topic of integration has a bigger importance in research projects although they present also bigger complexity regarding shape, gears, and technology so that their prices are not competitive and the use of normal brise-soleil combined with classic PV panel is still preferred.

4 Results

The guidelines from this project have been delineated starting from the study of the state of the art of concentration systems already existing in the market and in research projects. The basic idea was to design a prototype that, thanks to the link with a sensor, could modify its configuration, opening and closing itself, according to necessities so to significantly change its appearance as well the environment's perception from the point of view of a user located inside a building where the prototype is applied.

One of the most important goals was to keep the whole system very simple so to ensure a large-scale applicability. The first choice was to focus on a linear element, instead of that punctiform, so to minimize and optimize the number of gears required for the handling system. The device has been thought as composed of two specular semi-parabolic parts able to revolve around their focal line, with an opening-closing movement, and to move together revolving upwards and downwards so to follow the sun apparent motion. The first step was the geometrical study of a parabolic shape suitable as a profile for the component. In the selected shape the focal point results in internal respect the two semi-parabolic profiles so that the two wings forming the parabola can protect the most delicate part of the component represented by the PV cells.

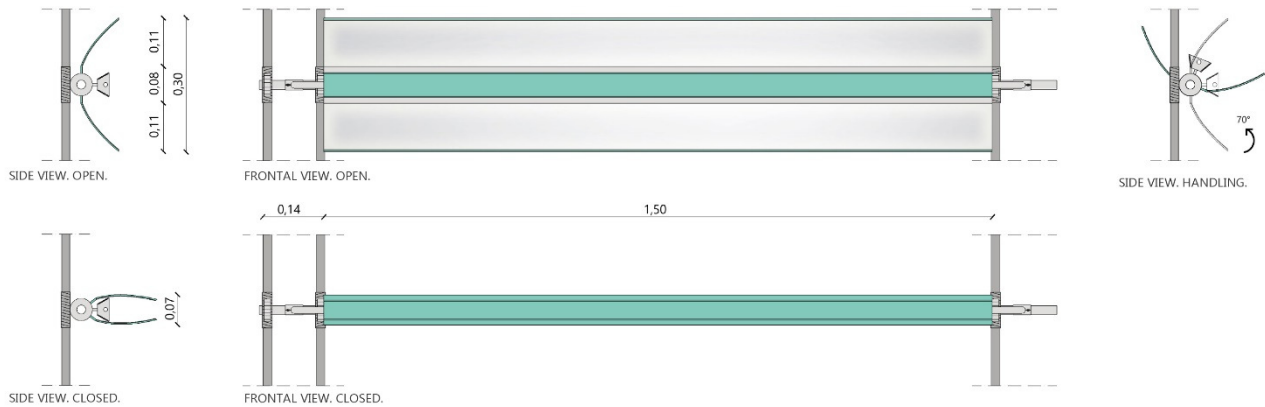


Fig.1 Section and elevation view of the system

The mechanisms responsible for the handling system are very simple: both the mono-axially tracking and the opening-closing movements of the parabolic wings are provided by the anchorage of the component to a central linear pivot. Three cogwheels are mounted around the linear pivot: one is welded to the pivot itself and regulate the integral movement of the whole device, the other two cogwheels are respectively welded to one wing of the device and regulate opening and closing of the brise-soleil. The motion is transmitted to the cogwheel by three screw pumps controlled by two small engines able to react to the impulse of a climatic sensor (or eventually controlled by internal users). The handling gears are hidden behind two aluminum carters through which the whole shading system is anchored to the building's façade. In the internal part of the carters, there are also notches in which the pivots are situated so to fasten their position and stability. The device has been designed to work as a brise-soleil producing energy in its open configuration by standing always perpendicular to the sun's rays, following the sun apparent motion and directing the sun rays, through its mirror part, to the focal line of the system. In case of absence of sun, during night time or in every situation in which the maximal brightness is desirable, the two parabolic wings can be closed so that the device's dimension results reduced for more than one-third in comparison to its dimension in the open configuration. This option not only solves a real need but also give to the device a changing appearance so that the whole façade can change according to clime and passage of time in conformity with the dictates of dynamic architecture. The internal part of the two aluminum wings is coated with a reflective film (reflectivity from 85% to 95% depending on the product) suitable for outdoor using thanks to its weather-resistant property. The external part can be basically coated at will, according to the aesthetic effect desired. More simply and economically it can be painted in every color and nuance.



Fig.2 Axonometric view of the component

Corresponding with the focal line of the parabola is mounted an extruded profile with a trapezoidal shape in which find place the PV cells and the electrical network required for the transport of the produced energy. As for every concentrator system, a cooling device is necessary due to the high temperature reached along the focal line. In case of low concentration system, an adequate cooling can be achieved by the flowing of an heat-transfer liquid along the focal line, in this case inside the trapezoidal profile. In this way, the liquid, not only works as cooler but can be also be used to produce domestic hot water from a renewable source that can be used in the building itself. To provide this dual use a simple distribution system is required, the same used in standard solar thermal collector usually located on the roof of buildings. The choice of this cooling system not only allows the shading device to produce both electrical and thermal energy but also does not

complicate its functioning because the technology used is common and run-in in the field of the classic thermal collector. Inside the trapezoidal profile, properly isolated so to not dissipate the heat, flows a conduct with a 1,5 cm diameter in which runs the heat-transfer liquid. This conduct is connected, through specific hoses, to a column pipe which diameter, of 3 cm, is adequate to ensure hot water's distribution. This pipes, one at the begin and one at the end of the parabolic element, are situated inside the aluminum carter that hides and protects also the screw pump and all the handling system's gears. The conduct inside the trapezoidal profile has also the function of structural pivot being connecting to the second pivot, a little bigger, where the two parabolic wings are mounted and are free to rotate. This bigger pivot allows also the simultaneous rotation of the shading system so to follow the apparent motion of the sun. The trapezoidal profile is designed so that the PV cell is mounted in its oblique sides having a surface of $3 \times 150 \text{ cm} = 450 \text{ cm}^2$ each. The surface corresponding to the bigger parallel side, the one visible in the front view, is completely free so that can be painted or coated according to the will planners.

Once defined the concentrator dimensions, the Concentration Factor **C** has been calculated as follows:

$$C = \text{Collecting Surface} / \text{PV surface}$$

$$\text{Collecting Surface} = 0,11 \times 1,5 \text{ m} = 0,165 \text{ m}^2$$

$$\text{PV Surface} = 0,02 \times 1,5 = 0,03 \text{ m}^2$$

$$C = 0,165 / 0,03 = 5,5 \times$$

C is referred to one of the two specular parabolic wing.

Once completed the design of the single shading element, the linear devices have been assembled together so to form a shading module. The module's dimensions are 1,5 m width x 3 m height so that one module is high enough to cover the standard floor's height. The width has been determined considering both aesthetical and technical reasons: the largest dimension would have influenced too much the total weight of the module so that more complicated handling systems would have been required. On the other hand with a smaller dimension, the building's façade would have appeared too fragmented. The 1,5 m width results moreover suitable for the building of different dimensions and proportions. Every module is assembled with 7 linear shading elements, placed at a calculated distance so that they can't shade with each other and the global efficiency of the system is not reduced. This calculated distance allows also the internal user to have always the perception of the outside environment also when the elements are in the open-working configuration.

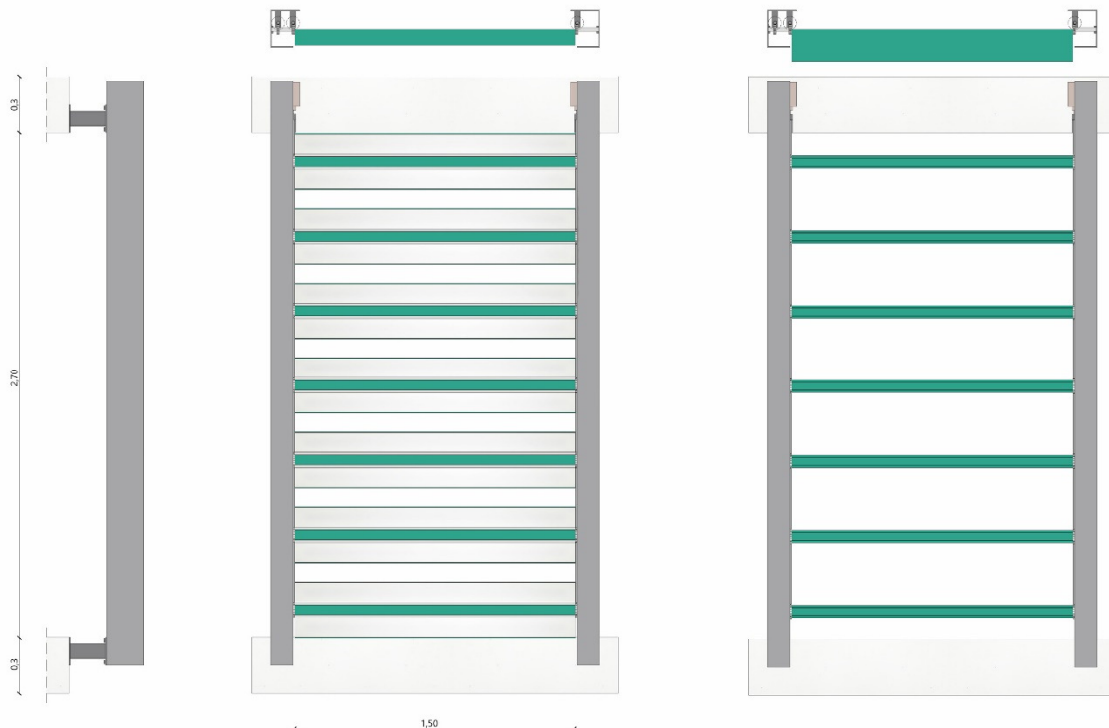


Fig.3 Elevation system in the two positions: open and close

THE DISTANCE BETWEEN THE LINEAR SHADING ELEMENTS:

The choice of a suitable distance between the shading elements affect both the aesthetic and the energy production: the shading of part of them can indeed be the cause of a drastic loss of efficiency if not attentively calculated. Empiric studies carried out about horizontal prototype⁵ facing south, 30 cm height, has shown that the loss of efficiency is less than 98% when the elements are situated at a distance of 20 cm. Being this project firstly a shading device, a distance of 20 cm between the linear element has been rejected because of the big quantity of light allowed inside the building. On the other hand, also the option of having no distance between the element has been rejected due to the big loss of efficiency related to energy production. A distance of 10 cm has been chosen why the mutual shading within the element is not present in winter time, when there is a bigger need of electrical and thermal energy, while during summer time efficiency losses are around 50%.

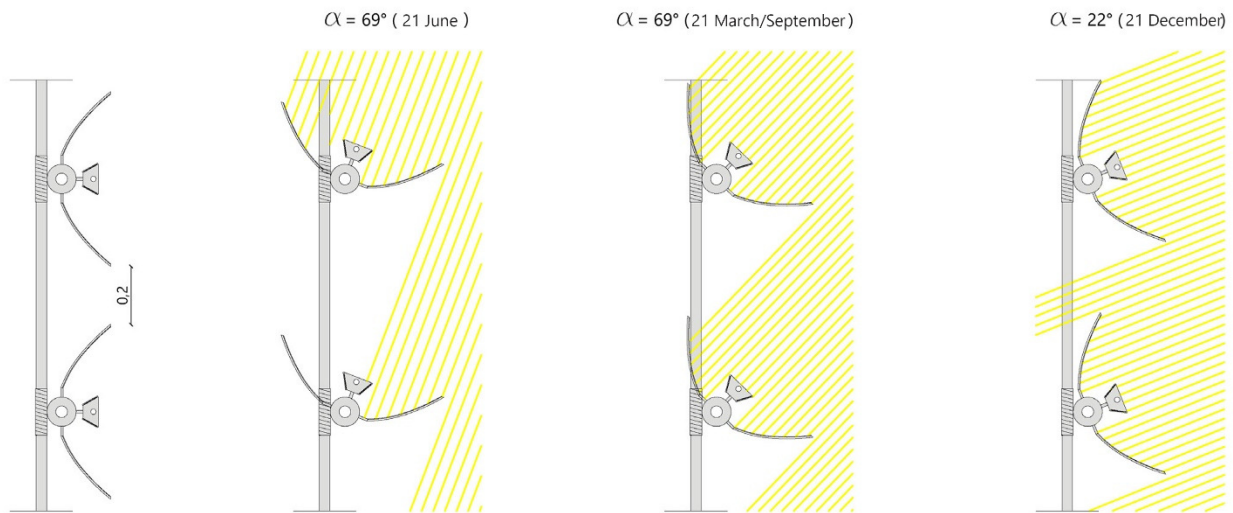


Fig.4 Position of the receiver of the solar concentrator during sun exposition

PRODUCTIVITY OF A LINEAR SHADING ELEMENT (RELATING TO A HORIZONTAL ELEMENT FACING SOUTH)

Since the impossibility to carry out test directly on this project, due to the absence of a prototype, data related to the energy production has been calculated by interpolating experimental data derived from tests conducted by a team from the Engineering Department of the Florence University⁶. These tests concern a concentrator prototype which features are comparable with one of the projects presented in this paper.

ENGINEERING PROTOTYPE		PROJECT	
Colletting Surface	0,25 m	Colletting Surface	0,22 m
Lenght	3 m	Lenght	1,5 m
Distance between elements	0,2 m	Distance between elements	0,1 m
Annual Production	600 Thermal kWh	Annual Production	265 Thermal kWh
Annual Production	120 Electric kWh	Annual Production	53 Electric kWh



Fig.5 Few photomontages of the integration of the solar concentrator in facade

5 Conclusions

The link between technological innovation and architecture is nowadays very strong although not always their integration is efficient and successfully designed, especially in case of common constructions. The main goal of this project is to experiment new technologies not in special cases but in standard architecture for common clients with ordinary investments.

During the design process has been paid attention to try to keep the project very simple although innovative. Simplicity not only affects the spreading of a new technological solution positively but also can reduce the costs of a product, and this was the other big purpose of the project. Until this moment, there has not been the chance to produce a prototype so that the estimation of energy production and costs has been done, with proper proportions, through the comparison with the results obtained by the team of Engineering Department of the Florence University testing a similar and comparable device. Despite this, during the project phase, the device has been simplified in comparison to the University's prototype, both concerning materials and handling gears used, so to be sure that the final product could be more affordable in the market.

The final goal was to design a technological device that was easy to integrate into a lot of buildings typology, in the same way as standard brise-soleil are used but providing a new value to a classical shading solution. It was very important for the first design phase that the concentrator device would not appear as a facility system but that could interact with architecture representing instead an added value also from an aesthetical point of view. The possibility to connotate the single linear element with a different color, in both the open configuration and the closed one, facilitates the dialogue with the building and the environment around. The contained dimensions, similar to the dimensions of a lot of shading system already existing in the market, assures that the device does not impose its presence overriding the architecture.

The choice to use the concentration technology avoid the problem of the photovoltaic integration in building's façade, a topic that has not been well assimilated yet in the architectural field. Moreover by focusing on the use of a low concentration system the critical issues concerning high prizes for materials and maintenance, easy deterioration and heat disposing of has been prevented.

Notes:

- 1- Also called Dynamic Architecture
- 2- Jean Nouvel, *The Arab World Institute*, Paris, 1981-1987
- 3- PTW Architects, CSCEC, CCDI and Arup, *Beijing National Aquatics Center*, Beijing, 2004-2007
- 4- Ethylene tetrafluoroethylene (ETFE) fluorine-based plastic.

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