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Development of a Shading Devices Efficiency Verification Method using Software Simulations

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Development of a Shading Devices Efficiency Verification Method using Software Simulations

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Abstract

This study aims to determine a verification procedure of solar shading devices efficiency in buildings. Currently, there are large amounts of technical shading solutions on the market. However, choosing a specific system does not always guarantee a correct shading effect on the façade. The first part of this work is focused on the development of a shading devices classification system. The shading efficiency verification method is developed through the analysis of two reference buildings: the Ahmedabad Mill Owners' Building, by Le Corbusier, and Bologna's town hall building by MC Architects. Tridimensional models of the buildings are made using the software Ecotect in order to analyze shading effects during the summer solstice and other significant days. The study also evaluates solar diagrams related to glass surfaces protected by shading devices. These diagrams allow to verify the sun-light exposure time frames that represent possible local overheating effects. A monthly average sun exposure tool is also used in the tests in order to assess the value of incident solar radiation on the examined surface. The simulation is performed either with and without the shading systems in order to analyze the reduction of direct radiation on the windows. The verification method allows to define the shading system effectiveness and to identify the time frame in which overheating problems could exist. Furthermore, this method can also be used as a practical tool during the design phase, helping the designer to choose the right shape and orientation of shading devices.

Key words: solar shading systems, shading efficiency, software simulation

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Introduction

The correct design of a solar shading device is a complex problem that involves several thermal and visual comfort aspects of a building. As reported by Lechner (2001) 'shading is a key strategy of achieving thermal comfort in the summer' but, at the same time, it plays also an important role on controlling light and passive solar gain during winter seasons. For this reason, the type and shape of a sun shading device must be linked to the local climate conditions. In warm or hot climates sun heating and glare have to be avoided through the use of shading devices that allow the natural ventilation inside the building. However, in coldest climates free sun energy gains are an important contribution to the thermal balance of buildings and should be encouraged. The global efficiency of a shading system depends on many factors like orientation, position and climate conditions. The big number of different available solutions creates the problem of choosing the correct shading device to optimize the shading effect, without losing the free gains when they are useful (Fathy, 1986). This study tries to define a verification method of solar shading devices effectiveness. The ultimate goal is to determine how a particular shading system works and how it can be improved.

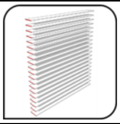
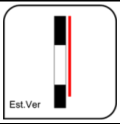
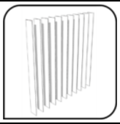
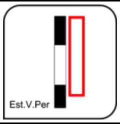
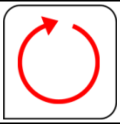
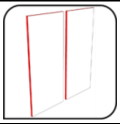
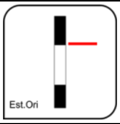
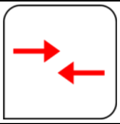
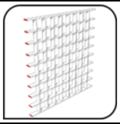
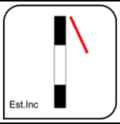
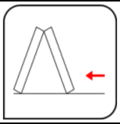
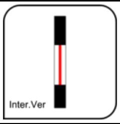
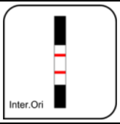
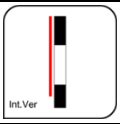
Description of Methods

In order to determine a verification method for the sun shading effectiveness, the first step is to define a classification of shading devices. European and Italian[1] standards propose a terminological classification of shutters, sun screens and blinds. They are divided into many categories based on several variables. Many studies try to classify shading devices using the standards as model (Lechner, 2001; Ceccherini Nelli, D'Audino & Trombadore 2010; Arbizzani, 2010). However, such a terminological classification does not define an efficiency classification; furthermore the use of too many variables does not help in the choice of a specific device. For that reason, in this study four main variables are obtained from the standards and a typological classification of shading devices is defined (Tatano & Rossetti, 2012). The first variable is the morphology, which is divided into horizontal elements, vertical elements, panels or grids. The next two variables are linked to the position of shading devices in relation to the façade (internal, external or included) and in relation to the vertical plane (vertical, perpendicular, horizontal or oblique/slope). The shading devices can be classified into seven categories obtained from the combination of these different positions. The movement system is the last considered variable. Sun shading device can be fixed, rotating, sliding or could be characterized by complex movement obtained by sliding and rotation. Some other secondary variables, that can be considered in

[1]EN 12216:2002 'Shutters, external blinds, internal blinds - Terminology, glossary and definitions' and UNI 8369-4:1988 '*Classificazione e terminologia degli schermi*'

a typological classification of sun shading systems, are their materials and their potential for use or produce electricity. These four main variables are defined by the comparison of several European case studies. They were analyzed in order to determine how they are made, how they work and to describe their main characteristics. In this way it is possible to define the matrix in Table1 which shows the available combinations of the four described variables.

Table1. *Typological Classification of shading Devices*

Morphology		Position		Type of movement	
	Horizontal elements		External vertical		Fixed
	Vertical elements		External perpendicular		Rotating
	Plans/Panels		External horizontal		Sliding
	Grids		External slope		Sliding + Rotating
			Included vertical		
			Included horizontal		
			Internal vertical		

After that, two reference buildings are defined for the second part of the study. The first one is the Ahmedabad Mill Owners' Building designed by Le Corbusier in 1952-1956. This is one of the first examples of shading devices used as architectural elements in a building. This choice is made with the aim of investigating the efficiency of a system built more than fifty years ago, without any software use. The second one is the Bologna's municipal building, built by Mario Cucinella Architects in 2003-2008. This case study is an example of contemporary building with an architectural shading device designed with the aid of a software calculation. The analysis of these two buildings is performed with the software Ecotect (release Autodesk Ecotect Analysis 2010). Thanks to this software it is possible to check and compare the effects of sun-light on the building facades and to obtain several information about the effectiveness of the shading system used.

Verification Procedure

The verification procedure is split into four steps. The first one consists in modeling the reference building in a simplified way. Only the most important building elements are performed in the model while elements not related to the sun-light, for example internal structures or furniture, are excluded. In this phase, it is very important to model shading devices in a correct way to obtain accurate results. All shading components must be inserted in the model according to the real dimension, position and characteristics. In the second step the model has to be oriented in the right geographic position and the weather climate data file[1] of that place must be uploaded using the weather and solar tools. In this way the software is able to show the sun position and to generate the shadows effects in different moments of the day and year. The third step consists in analyzing the shading distribution on the façade. During the day, the sun position changes determine different screen effects on the façade. This preliminary analysis of shadows gives the possibility to define which parts of the glazed surfaces are directly exposed to solar radiation. By selecting them into the model, it is possible to define the sun-path diagrams that show the shading effect on the surface during the year time. The sun-path diagram is a spherical, stereographic or orthographic graph which illustrates the complete path of the sun during the year (Mazria, 1979; Tatano & Rossetti, 2012). Ecotect tool is able to overlay the sun-path diagram with shadows diagram, using a gray scale pattern to define different range of shading . In this way, it is possible to define the sun-light exposure time frames in which the building may present overheating problems. Such a phenomenon can be verified comparing the sun-air temperature in that time frames with the set point temperature of the period. If the sun-air temperature is higher than the internal set point, overheating problems are possible. The last analysis phase consists in the quantification of the shading benefits. Using the monthly average sun exposure tool, it is possible to determine the value of incident solar radiation on the examined surface. To evaluate the sun shading effectiveness the exposure test must be performed twice: the first one using the model of the real building, and the second one using the same model without shading devices[2]. In this way it is possible to analyze the influence of sun shading devices and collect the monthly values of incident energy on the glass surfaces. The result of this simulation is not the exact value of incident energy on the glass because the method does not consider dynamic effects like the reflected energy. However the test gives the designer a reference number that can be compared with other shading solutions to obtain a classification based on their performances.

[1]The Ecotect software use .wea files that are located in the software database. For a specific place it is possible to create a .wea file using the official EnergyPlus weather files .epw at: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm.
[2]Ecotect works like a CAD software. In the modeling phase it is possible to set different object into different layers. To make the analysis without sun shading devices is sufficient to exclude their layers from the model.

Results and Discussion

In order to validate it, the verification procedure was applied to two case studies. The results of this procedure give the possibility to define a method to perform a shading system device analysis.

The first building analyzed was the Ahmedabad Mill Owners' Building by Le Corbusier, Figure1. This building consists of a concrete squared building, organized in three levels with offices, meeting rooms and a conference room at the top; the two lower floors are enclosed with a glass façade while the last one is an open space with a bar and the conference room. The second level, in which the president offices and some meeting rooms are located, is directly linked to the ground through a long access ramp. The building façades are completely closed on the south and north fronts while they are completely opened towards east and west, according to the dominant winds. On these fronts Le Corbusier inserted a sun shading system in order to prevent indoor overheating effects during the hot seasons. The shading system is made of concrete too. It is composed of a fixed external grid made up of horizontal and vertical concrete elements. On the west side the vertical elements are oriented with a 45° angle in relation to the façade. The horizontal planes are made up of some planters, corresponding to the floor levels, and some concrete slabs. The sun shading device is 3.4m deep. A similar system is placed on the east side but it is only 2.0m deep and the vertical planes are perpendicular to the façade. They are spaced 5.3m each-other while on west side the distance between two vertical elements is only 2.5m.

Figure 1. *Mill Owners' Building. West and East Fronts*

Two sun-path diagrams were produced for each side and for each level of the building. To perform the analysis, a window for each level was selected to be tested. Then, the test was performed in two specific points: at the bottom and in the window centre. The differences between the two diagrams show if the shading system gives a complete protection on all the façade. Figure2 shows the results for the west ground level (bottom and center point), and Figure3 for the west first level (bottom and center point). The white areas on the graphs indicate the time frame in which the sun can hit the glass. The white areas are focused in the late afternoon hours (after 3.00pm) and only in the coldest period of the year (November - January) so the sun shading system prevent overheating effects. Figure4 shows the same graphs for the east side ground level[1]. In this case the white area is bigger than in the west graphs and the sun rays hit the glass during all the year from 6.00am to 10.00am. At the center of the windows, shading efficiency is higher thanks to the horizontal elements that form the grid. Models in Figure5 allow to compare the shadows on the two sides when the sun is in front of them (9.00am for east side, 6.00pm for west side). On the east front it is possible to identify a single shadow component, the horizontal one. Otherwise, two different shadows components are shown on the west side: the horizontal one, similarly to the east side, and a vertical one, caused by the vertical oblique concrete elements. This means that shading device on the west side is more efficient that the east one, thanks to the position and orientation of vertical elements. A different test was preformed for the top level. This is not a closed space so overheating is not possible, primarily thanks to the right orientation of windows that allow natural ventilation. Otherwise, such a problem could exist in a closed space, like the conference room, if reached by the sun-light. For that reason, the shadows path of top level was analyzed. The simulation was performed without the building roof, in order to isolate only the shadows created by the concrete grid. During the day the sun-light never reach the walls of the room, so there will be no indoor overheating problems. Finally, it is possible to assert that this building shading system is useful and correctly designed. It has only a local problem on the east side, during the morning, anyway the overall efficiency is good. Le Corbusier chose the right orientation of the windows to exploit natural ventilation and the right shape and orientation for the shading devices to reduce sun irradiation. At the same time, the concrete system is well integrated in the building and it has also an important architectonic impact.

[1]The result for the east first level is similar to the ground level one shown in the Figure3.

Figure 2. *Mill Owners' Building. Sun-path diagrams of west side at ground floor. Windows center (right) and bottom (left)*

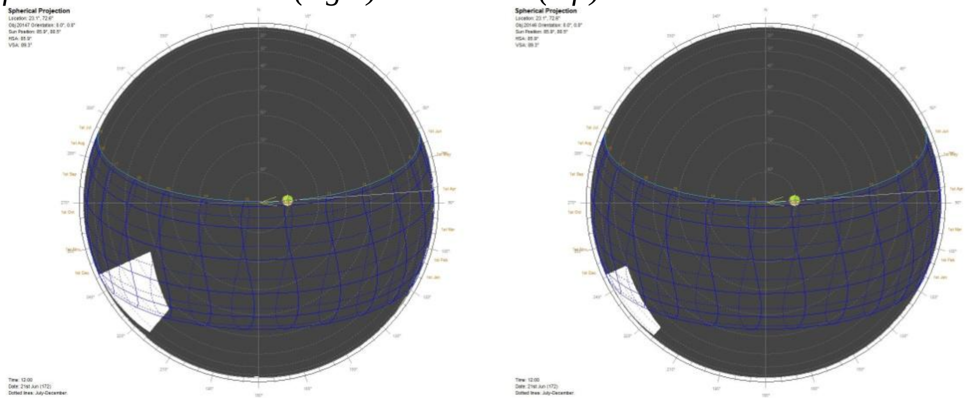


Figure 3. *Mill Owners' Building. Sun-path diagrams of west side at first floor. Windows center (right) and bottom (left)*

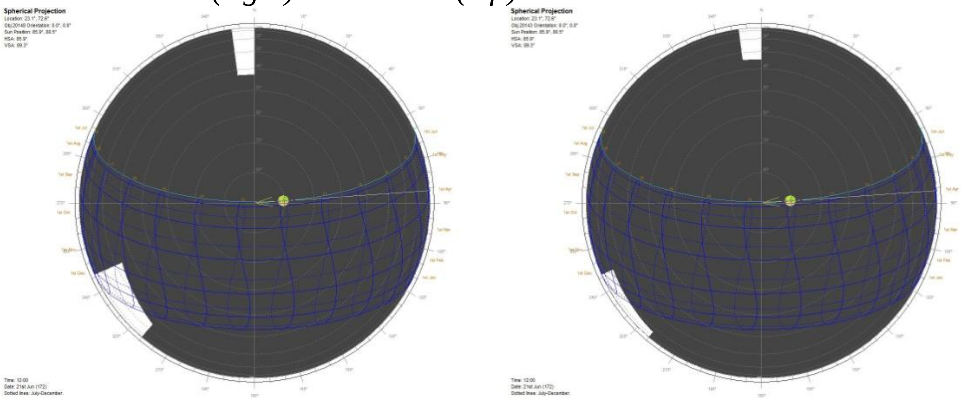


Figure 4. *Mill Owners' Building. Sun-path diagrams of east side at ground floor. Windows center (right) and bottom (left)*

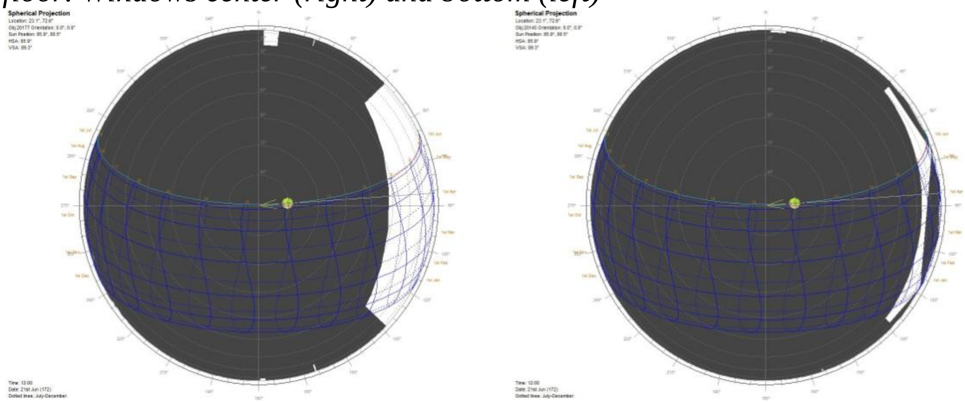
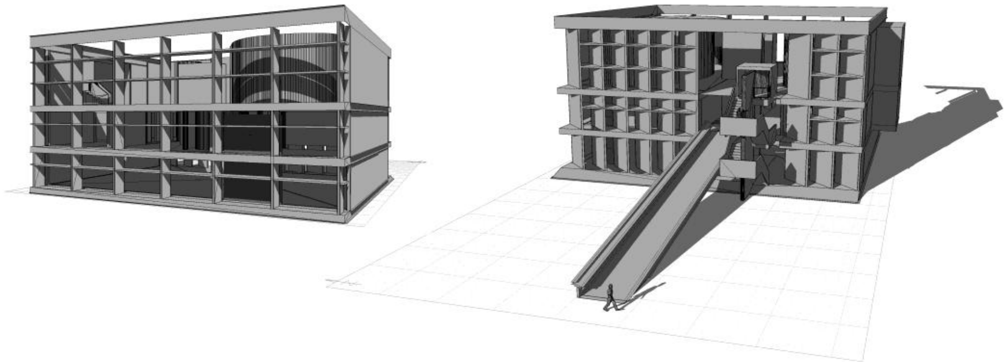


Figure 5. *Mill Owners' Building. Shaded model of east front (left) and west front (right)*



The second case study is the Bologna's municipal building by MC Architects, Figure 6. This office building, completed in 2008, consists of three glass volumes covered by a metal sun shading roof. Such a solution creates a visual unity of the three buildings that have different shapes and height but, at the same time, it helps to shade their façades. This roof is made up of a metal structure and a complex system of aluminum tubular elements with a diameter of 180mm. The pattern of these elements, that have different distances between each-other starting from a minimum range of 600mm, was defined by a software calculation. The shading system is fixed and it can be vertical, slope or horizontal respect to the building façade. Thanks to the shadow analysis, in the 3D models, it is possible to define the areas where shading problems can exist. The study was focused on the central triangular volume that is exposed on south, east and west. The three façades were analyzed separately using sun-path diagrams. The south front is exposed during all the day time but it is partially covered by a lower frontal block. A sloped part of the shading roof screens it. The best shading effect is reached between 11.00am and 2.00pm. The characteristic pixelated sun-path diagram, in Figure 7, shows the effect of a shading device made up of linear elements; they let pass a different amount of light in relation to the incident angle of rays. The gray scale pattern illustrates the screening rate in different hours and months. Looking at this graph it is possible to see that the shading effect is stronger in the winter period than in summertime. This means that the building does not take advantage of the free heating gains that are useful in Bologna's temperate climate during the colder months. To better understand the effects of the sun shading roof a monthly average sun exposure analysis was also performed. This analysis shows, through a chromatic gradation, the monthly average incident solar radiation on the south facade in Wh/m^2, with (Figure 8) and without (Figure 9) the shading roof. The roof reduces the incident solar radiation during all the year. The reduction value is higher in the hottest months (from 7.600 Wh/m^2 to 6.700 Wh/m^2 in August at noon) but it is relevant also in the winter months with an important loss of free heating gain. The same analysis were performed on east façade. It is exposed only until 11.30am. Looking at its sun-path diagram, Figure 10, the shading effect is higher than on the south front. The average screen rate is about 60% related to the 50% of south side. Furthermore, in the winter period, from 9.00 to 11.00am the shading effect is lower than in summer so free heating gains are possible. This is also noticeable in the monthly average sun exposure graphs. In Figure 11 and Figure 12 the two diagrams with and without the shading system are compared. During the summer there is an important reduction of incident radiation, about 1.100 Wh/m^2, while in the colder months the reduction is not higher than 300 Wh/m^2. The last façade, the west one, is exposed only in the afternoon starting form 1.00pm. However, the roof covers only a minimal part of it and it does not produce a real shading effect. The monthly average sun exposure graph shows that, in the summer, there is an amount of over 6.000 Wh/m^2 of incident radiation on glass. For that reason, overheating problems during summer can exist on this side. To reduce this effects, architects used solar control glasses and internal blinds to prevent dazzle problems. A last analysis was performed on the roof floor, in the place where the external units of the cooling system are set. These machines normally work better if the external air is not too hot. In order to reduce the incident solar radiation on this area, the shading metal roof cover also this part of the building. The test shows a reduction of 4.400Wh/m^2 of incident radiation in the summer period. In this case study the shading system has a strong architectural impact, since it creates the formal unity of the building. Otherwise, it is not perfectly efficient in all its parts. On the west façade the shading roof is not able to perform its function, so it is necessary to integrate it with other systems like blinds or special glasses. During the year the fixed roof shades the building without the possibility to regulate it. It causes the loss of many free gains in winter. However, the system is effective in many areas; without it the overheating problem inside the building could be more relevant.

Figure 6. *Bologna's municipal building. East front (by Daniele Domenicali) and tridimensional model*

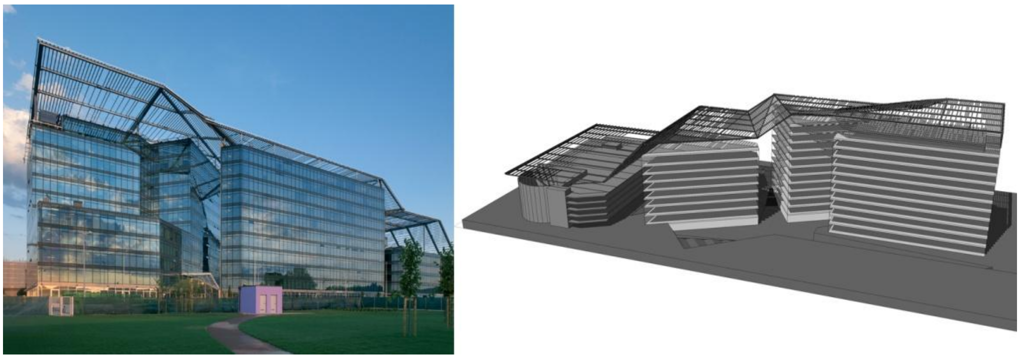


Figure 7. *Bologna's municipal building. Sun-path diagram of south façade*

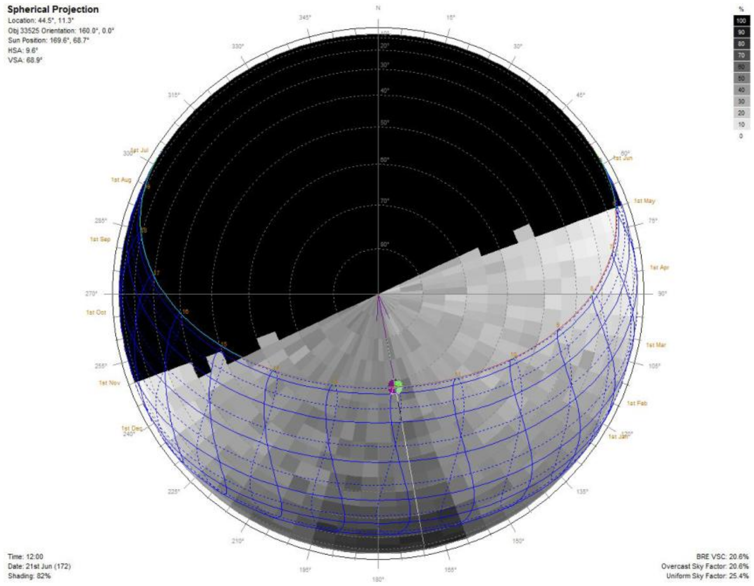


Figure 8. *Bologna's municipal building. Monthly average sun exposure diagrams of south façade with shading system*

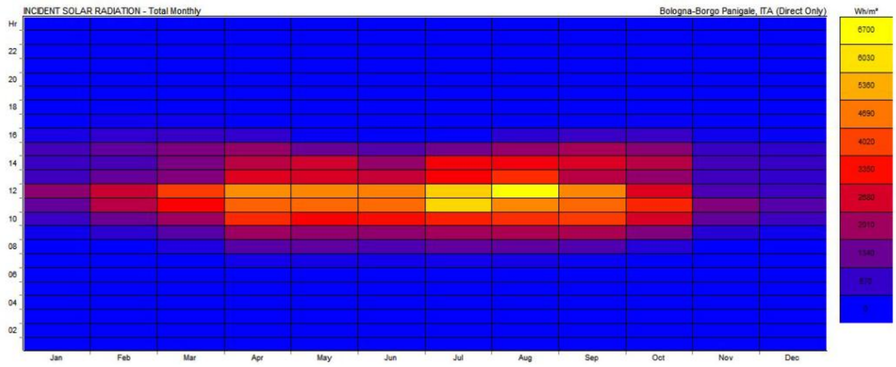


Figure 9. *Bologna's municipal building. Monthly average sun exposure diagrams of south façade without shading system*

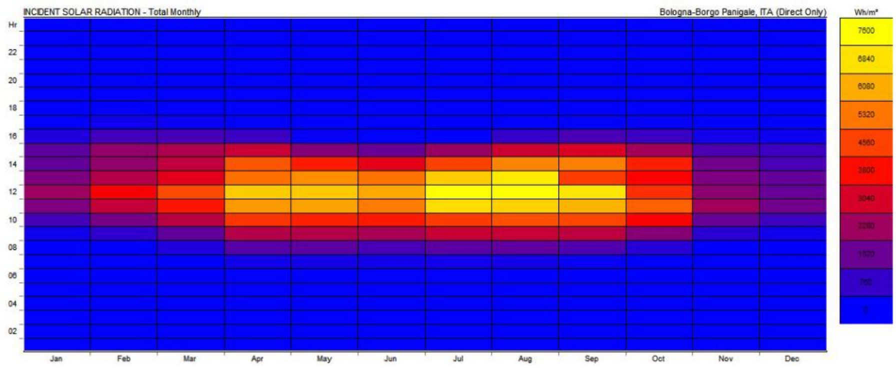


Figure 10. *Bologna's municipal building. Sun-path diagram of east façade*

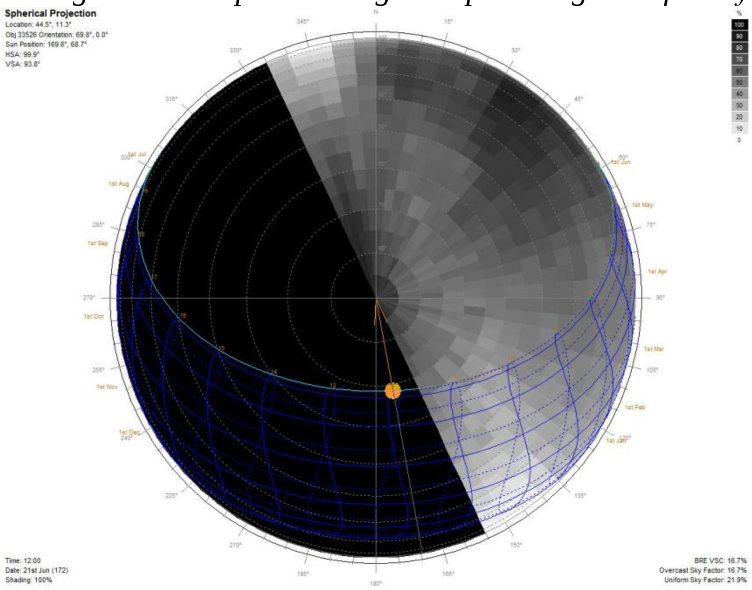


Figure 11. *Bologna's municipal building. Monthly average sun exposure diagrams of east façade* with shading system

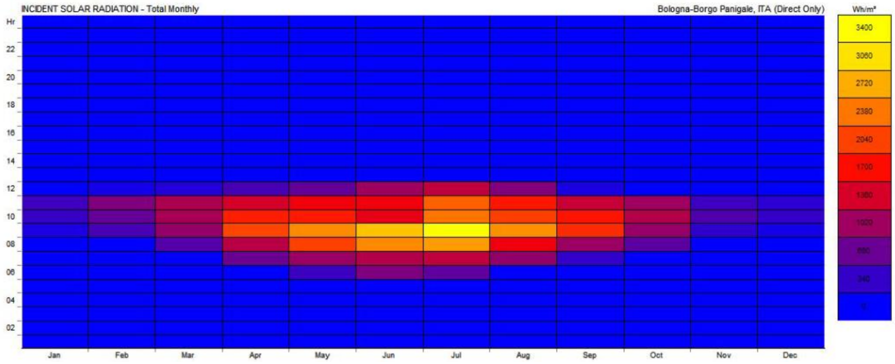
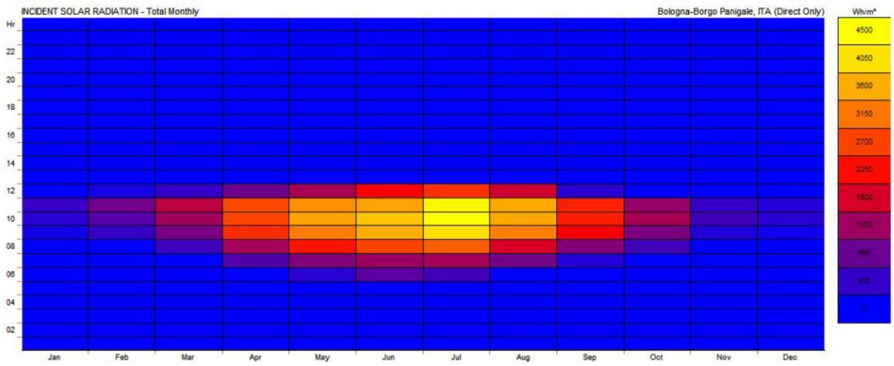


Figure 12. *Bologna's municipal building. Monthly average sun exposure diagrams of east façade* without shading system



Conclusion

The case studies described in this paper are different as regards age, materials and morphology. The shading systems are also different in materials and structure and, in addition, they work differently. However, it is possible to analyze their functioning using three simple tools. The study of the shadows, thanks to a 3D models, is a really common tool included in every modeling software; it gives the possibility to analyze how shadows change along the time. This simple operation allows to understand where and when a sun overexposure problem can exist. The analysis of shadows can also give information on how to correctly orientate shading elements. It can demonstrate which type of shading device is better to use. Just to give an example, it is possible to know if a vertical or an horizontal element is better to screen different sun ray angles. The use of sun-path diagrams gives more specific information about time frames in which overheating problems are possible. They allow to analyze the shading device effectiveness in different seasons and hours. Moreover, different types of shading device give a specific sun-path diagram result; a pixelated graph is related to a discontinuous system, for example Bologna's grid roof, while a clearly defined graph is linked to a monolithic system made up of planes or wide elements. Finally, the monthly average sun exposure graph gives a quantification of the sun radiation stopped by the shading system. It also allows to identify the months in which sun exposure is higher. These information are useful to describe how the system works but they can also be used during the design phase. It is possible to make comparisons between different shading systems applied to the same building. It is also possible to study the final efficiency of the system and define which device is better to use in relation to changes in its position, dimension or orientation. For example, in the Ahmedabad's case study, a deeper shading concrete grid could solve the identified overexposure problem on the east side. In the Bologna's building the use of a mobile system could be recommended to prevent summer irradiation and to allow winter free gains.

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