STUDY ON SOLAR SHADING SYSTEMS FOR DESIGNING NZEB KINDERGARTENS IN ITALY

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Highlights

Solar shading energy and environmental performance for kindergartens are evaluated.
The visual link between classrooms and the external environment is guaranteed.
Different types of control for automated internal blinds are studied.
Overhang and internal automated blinds are advisable for southern configurations.
The illuminance uniformity and average daylight factor are verified for classes.

Abstract

The use of solar shading in buildings necessarily affects the energy balance and energy demand. The aim of this study is to evaluate the efficiency of the most common solar shading for kindergartens to improve their energy and environmental performance. The research considers different types of solar shading for a southern orientation, their possible implementation with automated control systems, the relation with the window-to-wall ratio and finally the addition of vertical solar shading for eastern and western orientations.

Keywords

TSchools, nZEB, Solar shading, Energy savings, Low carbon.

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1. BACKGROUND

The use of shielding systems in buildings necessarily affects the energy balance and the energy demand for heating, cooling and lighting [1]. Evangelisti et al. calculate an index dependent on the surface temperature of the window glazing and demonstrate that a 38.7% reduction in the energy demand for cooling is obtained during the summer season using a shading system characterised by horizontal louvres [2].

As for lighting, the use of solar shading could also lead to a significant reduction in energy requirements, and this is obviously linked to the intended use of the building as well. Most of the studies pertaining to solar shading are related to office buildings since their energy demand for artificial lighting is significant. David et al. demonstrated that the use of a large number of vertical sun shadings for windows on eastern and western facing façades results in a daylight illuminance index (UDI) value below 20%, leading to an increase in the energy demand for artificial lighting to ensure proper indoor visual comfort [3]. Zuo et al. [4] also use the value of the UDI to optimise a control system for automated solar shading to minimise the glare and to maximise the natural lighting, by reducing the annual energy demand.

Furthermore, solar shadings are one of the most important bioclimatic passive strategies for a façade. Salva et al. define such passive solar shadings as those that do not consume any energy [5]. Based on this, the construction of an nZEB (Nearly Zero Energy Building) kindergarten in Italy cannot ignore the use of shading systems since they inevitably contribute to guarantee internal comfort, significantly affected by the entry of natural light and solar gains, and to help both visual comfort and hygrothermal well-being [6, 7]. Their proper design can avoid overheating problems through the regulation of the solar gains inside the rooms during the summer season [8, 9]. In a building where visual activities are carried out at predetermined workstations, visual and hygrothermal comfort strongly influence the productivity of the occupants. Therefore, this aspect is essential for school buildings.

There are different types of solar shading systems: the active systems change the ratio between the incident and transmitted solar radiation, the passive fixed systems are mainly used in climates where the incident solar radiation does not change significantly during the year, and finally, the dynamic systems change their position through an automated control mechanism [10]. Many studies favour active or dynamic shielding systems, that can adapt to real external climate conditions [11], to improve both the building energy performance and internal visual comfort for the occupants [12]. However, other studies claim that such systems could lead to glare problems [13]. Some studies also state that it is essential to consider the possibility of using active systems, especially in relation to users' satisfaction with respect to their internal comfort and the opportunity for them to adjust the solar shading system according to their needs, which is essential for visual comfort [14, 15]. Finally, other authors link the use of automated solar shading systems to the evaluation of a building environmental impact. Al Touma et al. consider the use of an automated solar shading in an office building with South-facing openings and they state that it is possible to reduce CO_2 emissions due to the consumption during the operational phase by 24 $kgCO_2/m^2a$ [16].

2. RESEARCH AIM

First, solar shadings are an element that strongly characterises the appearance of the buildings' fronts. Furthermore, by regulating the entry of solar gains into rooms, they necessarily and significantly influence the energy balance. Finally, their proper design ensures the hygrothermal and visual well-being of the occupants. For a school building, it is essential to maintain adequate internal conditions to ensure the comfort of students both during school time and during periods in which extracurricular activities or neighbourhood activities are carried out. Due to the "2030 climate & energy framework", the "2050 long-term strategy" and the obligation to build new nZEB buildings starting since January 1st 2019, it is necessary to properly define all the features that characterise and influence buildings energy and environmental performance, especially during the preliminary design phase.

Consequently, the main objective of the study reported in the article is the evaluation of the efficiency of the most common solar shading systems for the new typological models of nursery schools in Italy [17], which were defined in a previous phase of the research. Three different models for kindergartens were identified. These represent the synthesis of the analysis of the environmental and technological system of many sustainable school buildings built from 2003 to 2015. The identified models meet the current morphological, dimensional, aggregation and spatial distributional needs and requirements of both new teaching and pedagogical methods and the public administrations that build schools. The survey included the assessment of the energy efficiency of each different model that was defined and the different technological solutions that can be adopted in relation to the different Italian climate zones, with reference to the primary energy demand and environmental impact through the calculation of the Global Warming Potential. This also allowed to establish which model is the best performing in each climate zone according to the main design features. The study described precedes the one proposed in this work, and it has been the subject of some publications.

The analysis is aimed at reducing the energy demand of the typological models in question, which is represented by the sum of the energy needed for heating, cooling, lighting, auxiliary systems, internal equipment, and domestic hot water. Furthermore, it is essential to understand, in relation to the intended use of the building, whether a fixed shielding system or an automated movable one, with a relative control device, is better in terms of energy requirements and CO_2 emissions. Furthermore, it is necessary to evaluate: the natural lighting conditions inside classrooms to establish the most advisable arrangement of the openings in the façade; the optimal configuration of the shielding systems to ensure the proper amount of daylight; the uniformity of the lighting to avoid glare in the areas where visual tasks are performed. The study has been developed considering the models located in five cities (Milan, Florence, Rome, Naples, Palermo) belonging to different Italian climate zones.

3. METHODOLOGY

Initially, the analysis applied to the 3 new typological models for kindergartens [17] compared the most common shielding systems for a southern orientation, where indeed the classrooms are located:

– internal venetian blinds with slats with a high reflection coefficient and control of the incident solar radiation – 120 W/m^2;
– fixed shielding made with an overhang equal to 2.00 m;
– horizontal louvres;
– a combination of an overhang and internal blinds with slats with a high reflection coefficient and control of the incident solar radiation – 120 W/m^2;
– external venetian blinds with control of the incident solar radiation – 120 W/m^2.

The influence of the different solutions was assessed not only in relation to the energy demand, but also considering the specific heating, cooling, and lighting contributions as well. Subsequently, the possibility of using a fixed or automated system with horizontal slats with different types of control was analysed, as illustrated in Table 1. The study was performed considering both the primary energy demand and CO_2 emissions in the atmosphere, with respect to each type of control. This analysis was carried out for the city of Florence, and it also considered the variation of the window-to-wall ratio. Indeed, in order to perform a comparison, the study was also developed with respect to the advisable WWR (Window-to-Wall ratio) for the southern orientation of an nZEB kindergarten in Italy, as defined by previous studies (southern WWR = 50%) [18].

Type of solar shading control system	Control definition (Design Builder contents)
Always on	Shading devices are always activated
Schedule	It is defined by a time using a schedule (if the schedule is equal to 1, then the shading operates)
Solar	Solar radiation > 120 W/m^2
Glare	Maximum glare index > 22
Outside air temperature	External temperature > 24°C
Inside air temperature	Internal temperature > 24°C
Cooling	Shading is on if zone cooling rate in the previous time step is non-zero
Night outside low air temperature	Air temperature < 0°C
Night inside low air temperature	Air temperature < 15°C
Horizontal solar	Solar set point >120 W/m^2

Tab. 1. *Definition of different types of solar shading control systems.*

The influences of vertical shields to the East and West and the variation of the WWR for the different typological models also were considered on the evaluation of energy performance of a building. The study that was carried out allows determining the advisable solar shading system that should be adopted during the construction of nZEB school buildings in Italy.

Finally, to evaluate the proper natural lighting inside the classes, the natural light maps of the classes were built. The daylight factor was calculated in order to verify the minimum value that complies with the UNI (Italian National Agency of Unification) 10840 [19] for schools. In addition, the uniformity ratio was calculated using the minimum and average values of the daylight factor and according to the different façade openings positions and the advisable WWR value, previously determined for each city. Since the classes have the same shape and planimetric organisation in all the models, the analysis was carried out considering two of the three typological models to evaluate the natural lighting for June 21st and December 21st at 12:00 with the sky model of the CIE (International Commission on lighting) (clear sky) and a worktop height of 75 cm. The energy simulations in the dynamic regime with hourly steps for calculating the total energy demand and the different contributions and the simulations for making the maps of the illuminance and the daylight factor of the classes were conducted using Design Builder. The primary energy demand was calculated with the following conversion factors for the different energy carriers: gas $f_{P,tot}$ = 1.05 and electrical energy from the public grid $f_{P,tot}$ = 2.42 ($f_{P,nren}$ = 1.95 and $f_{P,ren}$ = 0.47). The calculation of the CO_2 emissions in the atmosphere was carried out considering the following conversion factors: 0.210 $kgCO_2$/kWh for gas and 0.544 $kgCO_2$/kWh for electrical energy from the public grid.

4. MODELS AND INPUT DATA

As already specified, the analysis has been carried out considering 5 different cities belonging to different Italian climate zones, as reported in the Decree of the President of the Republic 412/93, and they were identified using the number of heating degrees days. Florence, characterised by a temperate climate with hot summers and cold and humid winters, may also be representative of Milan and Rome with reference to the results reported in this paper. On the other hand, Palermo, with a temperate Mediterranean climate with dry summers, is also representative of the city of Naples. Three basic typological models for kindergartens (Figure 1) were considered in the study: one with a compact shape with three sections (I1) and an area of approximately 890 m^2, and two with prevalently linear shapes with three (I2) and six sections (I3) and areas of approximately 950 m^2 and 1730 m^2, respectively [17].

A construction system with a wooden structure with cross-laminated timber (XLAM) was used for both the vertical perimeter wall and the roof. This solution has been utilised because the technological analysis, which has been carried out on many example buildings, has shown that it is one of the most recurrent for the construction of kindergartens in the Mediterranean area. Table 2 shows the main characteristics of the materials that constitute the stratigraphy of the technological solution adopted for the wall and the roof. The table shows the minimum thickness of the insulation necessary to meet the thermal transmittance of the reference building, as defined by the current Italian regulations, and the value of the thermal transmittance of the wall and roof for each respective climate zone. After comparing it with other materials, wood fibre insulation was chosen since it is a natural material that obtains low CO_2 emissions for the construction phase, and also allows to guarantee a proper value of the thermodynamic characteristics of the wall, without using a high thickness.

For the ground floor layers, the solution with plastic formwork for the underfloor ventilation was used, and it was completed with an expanded polystyrene (EPS) insulation layer. Finally, an aluminium thermal break frame was adopted (Thermal transmittance U_f =1.7 W/m^{2}K) for the windows, completed by double glazing with different properties depending on the climatic zones to comply with the thermal transmittance required for the reference building. The minimum value of the WWR was defined according to the current health-hygiene regulations in Italy. In all the models, a fixed solar shading system built with an overhang of 2.00 m for each southern functional unit was used. For each different thermal

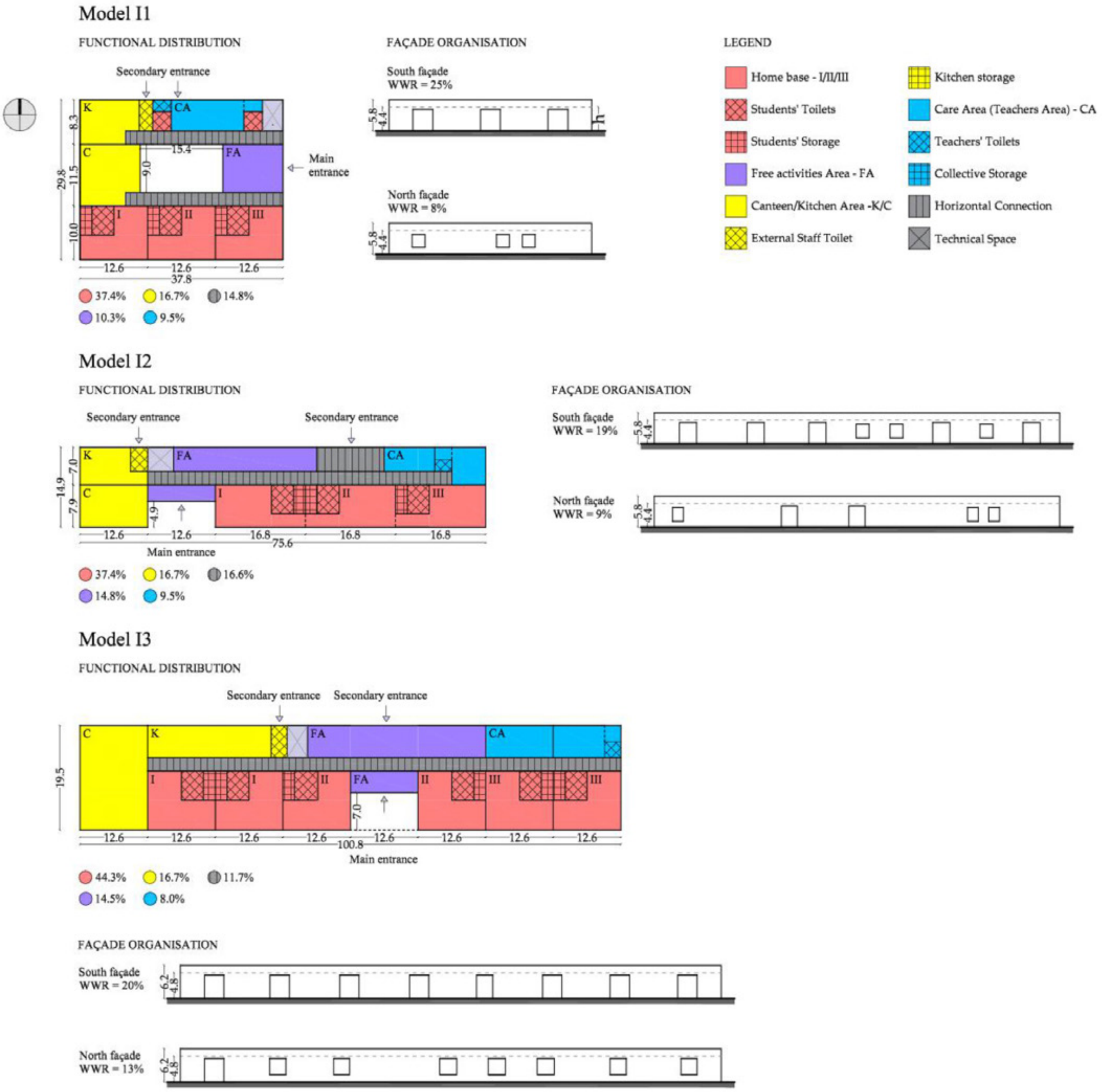

Fig. 1. *Three new typological models for kindergartens.*

zone, in which the building was divided, the occupancy (person/m^2) is determined according to Appendix A of UNI 10339 [20], the minimum airflow rate is taken from the same legislation in Table III, and finally, the internal gains are taken from UNI/TS (Technical specification) 11300-1 [21]. Regarding the level of illuminance, UNI EN (European Standard) 12464-1 was considered [22]. The lighting efficiency was considered to be equal to 120 lm/W. Regarding the simulations, the lighting control was used with the maximum glare allowed. The system was simulated using a simple HVAC (Heating, Ventilation and Air Conditioning) system with a condensing gas boiler with efficiency equal to 90% for heating, a heating pump for cooling with an energy efficiency index equal to 2.5 and a mechanically controlled ventilation system with heat recovery equal to 50%.

	Layer	Material	Climate zone	t [m]	λ [W/mK]	U [W/m²K]
External wall	1	External plaster		0.025	0.9	
	2.1	Wood fibre	B	0.04	0.038	$U_B = 0.42$
	2.2	Wood fibre	C	0.08	0.038	$U_C = 0.29$
	2.3	Wood fibre	D	0.10	0.038	$U_D = 0.25$
	2.4	Wood fibre	E	0.10	0.038	$U_E = 0.25$
	3	XLAM panel		0.13	0.12	
	4	Air cavity		0.05	-	
	4	Gypsum board		0.015	0.21	
Roof	Layer	Material	Climate zone	t [m]	λ [W/mK]	U [W/m²K]
	1	Metal sheet		0.00005	1.07	
	2	Air cavity		0.5	-	
	3	Waterproof sheet		0.004	0.2	
	4.1	Wood fibre	B	0.06	0.038	$U_B = 0.30$
	4.2	Wood fibre	C	0.06	0.038	$U_C = 0.30$
	4.3	Wood fibre	D	0.10	0.038	$U_D = 0.23$
	4.4	Wood fibre	E	0.12	0.038	$U_E = 0.21$
	5	Vapour barrier		0.0003	0.17	
	6	XLAM		0.125	0.21	

Tab. 2. *External wall and roof stratigraphy.*

5. RESULTS

To demonstrate the influence of the use of solar shading (fixed overhang of 2.00 m) on the energy demand for heating, cooling and lighting for the South-facing functional units of the different typological models, a comparison was made with the models with the same characteristics, but without the inclusion of a solar shield. The results of this analysis show that the use of shielding on the South-oriented façade significantly influences the energy demand for cooling in both climatic zones (climate zones D and B), especially for model I2, while it affects the need for lighting to a lesser extent. By contrast, in model I1, the most significant highlight is the decrease in the energy demand of approximately 55% for the city of Palermo. Regarding the city of Florence, the energy demand for heating decreases by approximately 3% for the I2 model. It is necessary to stress that the use of southern solar shading is required by the current Italian legislation on energy and it allows to obtain an adequate value for the ratio between the equivalent summer solar area of the building ($A_{sol,east}$) and the useful surface of the building ($A_{sup,useful}$), in relation to the summer performance of the external envelope.

With regard to the variation in the type of shielding on the southern front, the simulations carried out on the 3 typological models in each city show that this change has a negligible influence (~1%) on the energy demand of the building models analysed, compared to the corresponding reference model. However, for the sake of completeness, an analysis was carried out with respect to the individual contributions of the energy balance in order to understand which parameters have been mainly influenced by changing the type of solar shading, considering the three models located in the cities of Florence and Palermo. Figure 2, referring to the city of Florence, shows the variation in the percentage of the energy demand for cooling and heating for the three typological models, with respect to the model with fixed shading (overhang of 2.00 m), considering different alternatives of solar shading that can be adopted for the southern façade.

It is possible to notice that for the models with mainly horizontal development (I2 - I3), the use of an internal

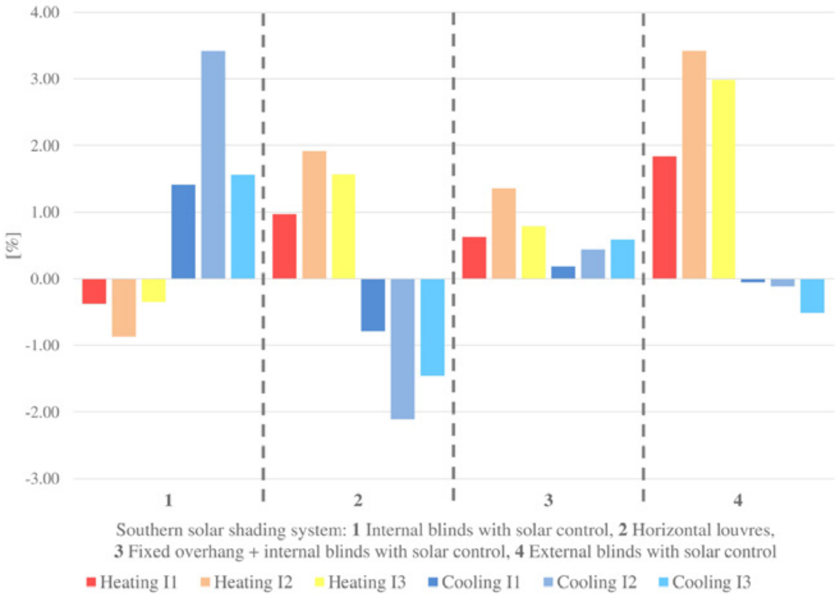

Fig. 2. *Variations in the percentages of the energy demand for heating and cooling for Florence for the 3 models and different solar shading systems.*

shield with solar control (120 W/m^2) involves a significant increase in cooling (~ 3.5%), while the use of the same external shielding implies an increase in the heating requirements on the same order of magnitude. For cities belonging to the climate zones E and D, where the contribution of the energy required for heating prevails in the energy balance, the optimal solar shading for the southern façades is the internal one with control of the maximum solar radiation (120 W/m^2).

Figure 3 shows the percentage change in the energy demand for heating and cooling compared to the reference model with the overhang in the city of Palermo. The graph shows that for cities such as Naples and Palermo, which are characterised by a mild climate with very hot summers, especially for the models with elongated floor plans (I2 and I3) in the East-West axis direction, the recommended solar shading for the southern façades is the one with an overhang of 2.00 m and internal venetian

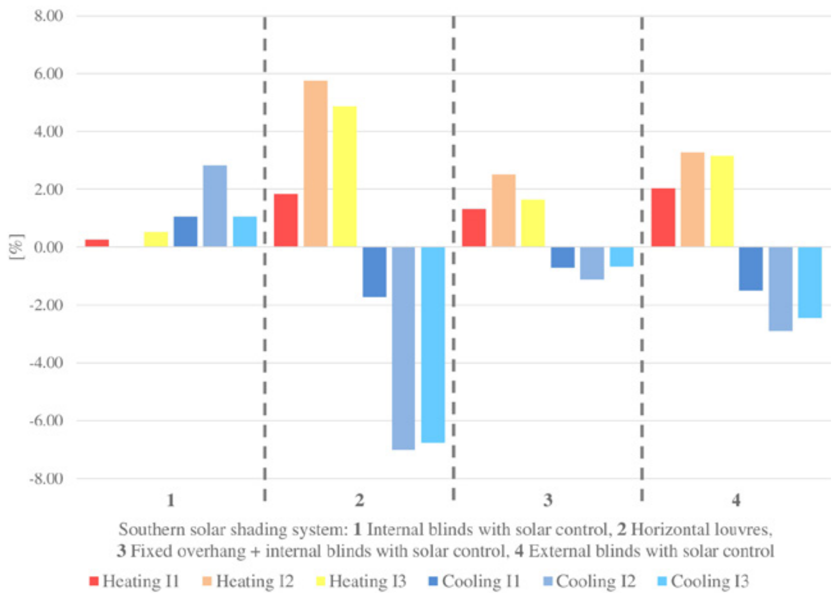

Fig. 3. *Variations in percentages of the energy demand for heating and cooling for Palermo for the 3 models and different solar shading systems.*

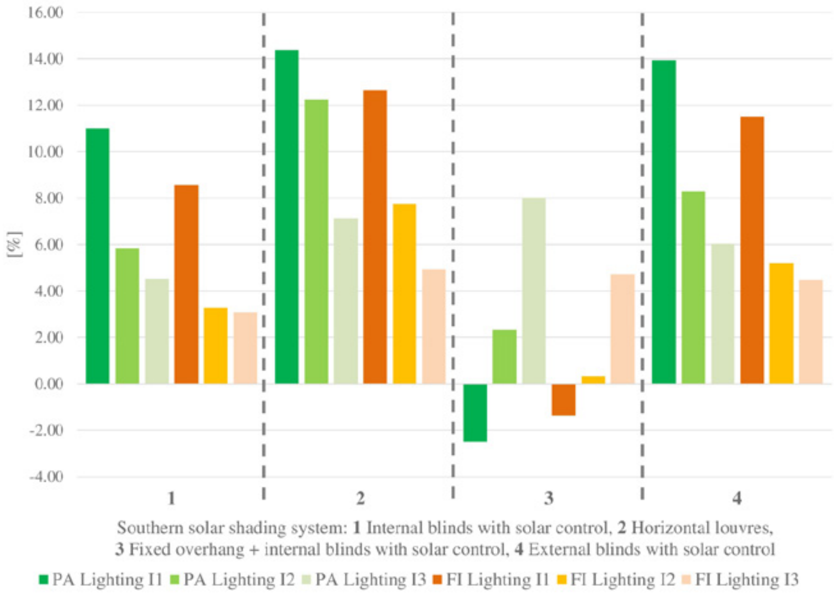

Fig. 4. *Variations in the percentages of the energy demand for lighting for Florence and Palermo for the 3 models and different solar shading systems.*

blinds with control of the incident solar radiation (120 W/m^2) since the energy needs for cooling decreases by approximately 6.5%.

Finally, compared to artificial lighting (Figure 4), the use of a 2.00 m overhang is the solution that allows for greater savings in all the models studied and for all the considered climate zones. It is important to stress that for a school building, the energy demand for lighting is a contribution that minimally affects the energy balance compared to the needs for ventilation, heating, and cooling.

With regards to the different control systems, horizontal slatted shielding was considered for the Southern oriented classes and the study was carried out only on the model I1 located in the cities of Florence and Palermo. From the energy simulations and the calculation of the environmental impact [kgCO$_2$/m^{2}a] for the operating phase only, it can be seen that for both climate zones, the use of an automated movable shading system results in a decrease in the energy demand compared to the reference fixed solar shading (always on) and a reduction

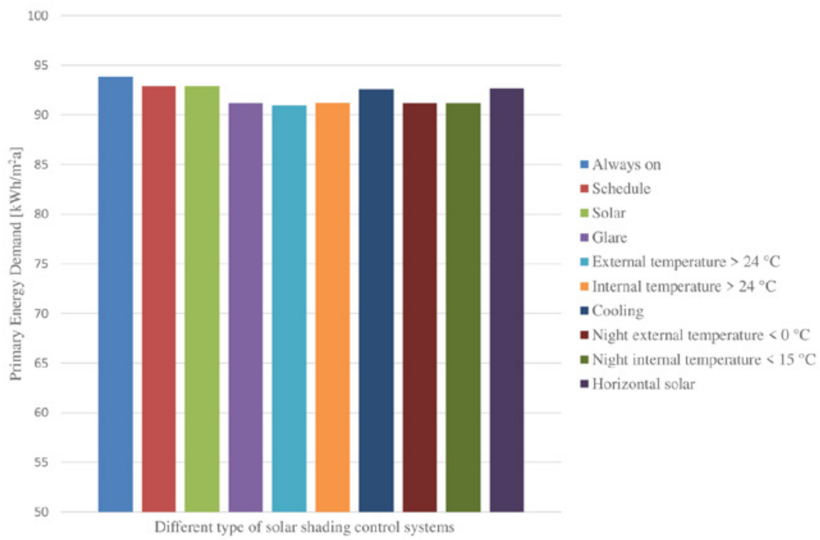

Fig. 5. *Primary energy demand for the different types of solar shading control systems for Florence for model I1.*

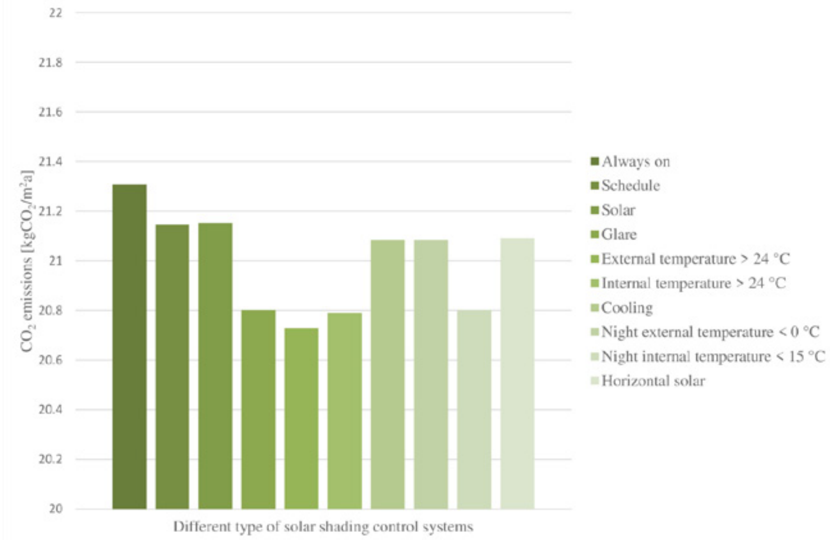

Fig. 6. CO_2 emissions for the different types of solar shading control systems for Florence for model I1.

in CO_2 emissions. This happens for any type of control analysed. Figures 5 and 6 respectively show the variation of the primary energy demand and the CO_2 emissions produced during the operational phase for each type of control system considered for the city of Florence.

The best type of control system for automated shielding is for both climate zones, the one which imposes a limit on the external temperature equal to a maximum of 24 °C. The assumption of this outdoor temperature limit value for the control of the shielding system is independent of the climate zone. In fact, the choice of the value is closely linked to the conditions that must be maintained inside the rooms. Since the internal temperature is one of the parameters that have the greatest impact on the comfort conditions of the rooms, which is conventionally equal to 26°C, the activation of solar shading at 24°C outside avoids to use the systems to compensate for the heating from direct solar radiation, in addition to the inevitable heating from direct heat exchange. Therefore, this is independent of the climatic zone.

For climate zone D, the second-best solution, in this case, is the one that controls the glare with a Discomfort Glare Index (DGI) [19] equal to a maximum of 21 according to the regulations for kindergartens.

For climate zone B, which is characterised by warmer summers and a more limited heating period, the second-best solution is the one with cooling control.

To complete the study of the shielding for the classes, the ideal value of the WWR, which was calculated in a previous phase of the research, was considered for each climate zone and the analysis on the type of control to be adopted for the horizontal slatted shielding was repeated. The study was carried out only for the cities of Milan, Florence, and Rome, in which the recommended WWR for the southern façades is 50% and is therefore different from the minimum required by the current health-hygiene regulations in Italy. In this case, as well, the trend of the variation in the energy demand compared to the control systems used is the same as in the previous case, even if the decrease in the energy demand is slightly higher.

The simulations concerning the use of vertical shields to the East and West, for the compact typological model with an internal courtyard (I1), show that their use does not entail significant benefits in terms of energy consumption for heating, cooling and lighting (<1%). This situation is more evident in models I2 and I3 that have most of the openings along the East-West axis. It must be emphasised that the results presented are inevitably influenced by the orientation and distribution of the functional bands and units in the floor plan in the various models, and by the high ventilation flow rates required by the regulations for buildings with this intended use.

To assess the visual comfort within the classes, maps of the natural lighting have been built for the daylight

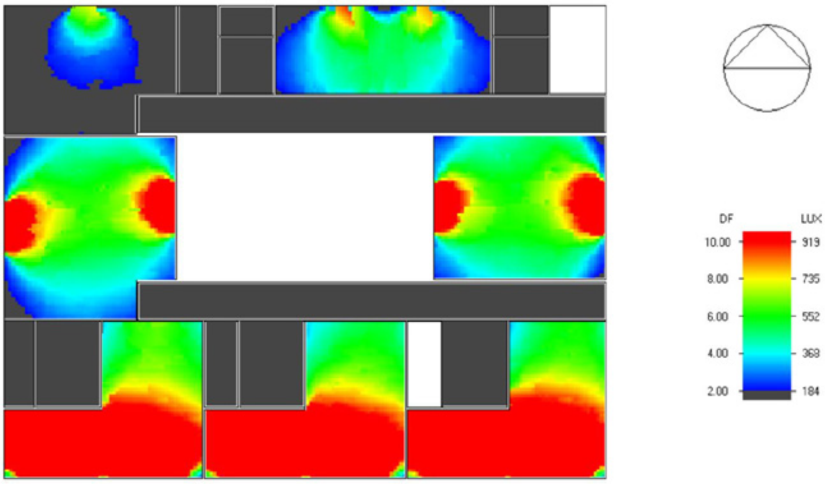

Fig. 7. *Maps of the natural daylight for the model I1 in the city of Florence for June 21st with the advisable WWR and 2 windows.*

factor and illuminance uniformity [23]. The analysis was carried out, taking into account the solar shielding with a 2.00 m overhang for the southern front for 2 typological models (I1 – I2). The choice of this shielding is, even if only slightly, the most advantageous in terms of energy consumption and it allows to maintain continuous visual contact with the external environment as well, as required by the current pedagogical methods. Furthermore, to face the glare problem, internal solar shading with blinds with control for the DGI was considered in order to ensure the proper illuminance of the area where visual tasks are performed. The WWR considered for making maps for natural lighting is the advisable one: the southern WWR = 50% (I1 – I2) for Florence, Milan, and Rome; and the southern WWR = 25% (I1) and 19% (I2) for Naples and Palermo. Figure 7 illustrates the natural illumination map for the I1 model for the functional bands of the classes on June 21st at 12 noon for Florence.

Table 3 shows the values of the average daylight factor (η_m) and the illuminance uniformity (η_{min}/η_{med}) related to models I1 and I2 for each class in Florence and Palermo considering the advisable value of the southern WWR. For the sake of brevity, only the data relating to these two cities are reported, since they are also representative of other climate zones. The values of the illuminance uniformity are calculated based on the area of the entire class and not where the visual tasks are mainly concentrated.

		η_m [%]		η_m Uniformity [η_{min}/η_{med}]		η_m [%]		η_m Uniformity [η_{min}/η_{med}]	
		Model I1				Model I2			
City	Class	21.06	21.12	21.06	21.12	21.06	21.12	21.06	21.12
Florence	1	14.50	20.40	0.20	0.10	15.70	24.00	0.14	0.09
	2	13.90	19.80	0.16	0.08	17.60	24.90	0.125	0.09
	3	13.77	19.90	0.18	0.085	18.00	25.40	0.13	0.10
Palermo	1	5.70	8.50	0.15	0.06	5.90	9.40	0.10	0.05
	2	5.50	8.30	0.11	0.07	6.50	10.00	0.145	0.07
	3	5.30	8.20	0.12	0.06	6.40	9.70	0.10	0.05

Tab. 3. *Daylight factor and illuminance uniformity for the 3 classrooms with the advisable WWR.*

Table 3 shows how the minimum value of the average daylight factor required by UNI 10840 [19] is followed in each class, and for both models, it is higher than 5% in the two climate zones considered. As it regards the illuminance uniformity within the classes, especially during the winter season and mainly for the city of Palermo, it must be guaranteed through the use of artificial lighting mainly due to the closure of the internal solar shading. However, it is important to underline that the minimum value of the illuminance during the winter season takes place in the corners of the classroom, on the side of the windows, and in the furthest part of the classroom from the window where the children's rest area is usually organised, as shown by the map above. By observing the values for the two models, it can be seen that, although both have two openings for each class, the I1 model has more advantageous performance in terms of natural lighting since it guarantees better illuminance uniformity and an appropriate value of the average daylight factor in both climate zones (B and D).

6. CONCLUSIONS

The use of the fixed overhang allows obtaining a summer performance of the external envelope equal to the medium standard according to the requirements imposed by the Ministerial Decree of June 26th 2015 [24] for the construction of nZEB buildings. It also permits to comply with the requirements of the new teaching and pedagogical methods, that prefer a visual link between the classroom and the external natural environment. In addition, the inclusion of interior sun shading in the South-facing classrooms is done to avoid glare and, at the same time, it guarantees an appropriate average daylight factor. The adoption of a double opening in the façade for each class allows for the correct illuminance uniformity, in both seasons, in the area where the visual tasks are carried out. By using an automated shielding with control for the external temperature for the southern front, energy savings and reduced environmental impacts are achieved in every climate zone considered, even with a WWR higher than the regulatory minimum. Finally, as it regards the eastern and western façades for the typological models considered, the use of vertical shading does not lead to an improvement in the energy performance of the building, not even increasing the WWR.

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