shading device efficacy. To convert the energy needs in primary energy, we used 0.8 as seasonal energy production efficiency for heating and a seasonal Energy Efficiency Ratio of 3 for cooling. A value of 2.174 of primary energy content per unit of electrical energy has been assumed according to the Italian electrical system. Finally, the synthetic metric related to the energy performance has been built considering the ratio between the energy performance of a specific case with shade and the reference case without shade ($EP_{sh}/_{wo}$).

5. Results

5.1 Indoor thermal comfort

The $sTC_{10,90\%}$ metric calculated with the standard index (Fig. 2) highlights a thermal environment able to stay within the chosen limit, except for the internal shades. When we consider the contribution of the solar radiation (Fig. 1), with the small windows coupled with the external shades, we are always able to ensure the right thermal comfort conditions, but the unshaded configurations and the internal shades can respect the threshold only using the low SHGC glazing. With the biggest windows, the comfort conditions requested can be reached only through the TL glazing coupled with the external shades. The TDT_{PPD} index (Fig. 5) highlights the distribution of the thermal discomfort sensation through the space. In this case, if we analyze the results correlated with the standard index, the thermal environment keeps homogenous, regardless of the shade's presence. The irradiated TDT_{PPD}, instead, shows how and how much the thermal discomfort arises as we consider the positions closest to the transparent surfaces. Moreover, whereas the shade SH3, located externally, can reduce the thermal discomfort time up to 60% compared to unshaded configuration, the same shade located internally is not able to reduce the TDT_{PPD} more than 35%.

5.2 Indoor visual comfort and daylighting performance

For visual comfort and daylighting performance, we obtain very similar results regardless of the shade's position. The use of the roller shading system leads, globally, to a decrease of the $sDA_{500,50\%}$ (Fig. 3) for both the window's size and the DA_{500} (Fig. 6) decreases faster distancing from the transparent surfaces. The view's direction used for the simulation makes sure that even the unshaded combinations remain close to the limit chosen for the $sVC_{0.35,100\%}$ (Fig. 4), but only thanks to the shades can we ensure the visual comfort for all the positions analyzed. If we analyze the visual discomfort locally (Fig. 7), with the bare windows the points closest to the biggest windows can stay under discomfort conditions up to 29% of the annual working hours.

5.3 Primary energy use

With the smallest windows, the use of the roller solar shading systems leads to an increase in the primary energy needs except for the configurations with the glazing DH, TH or TL coupled with the shade SH1 located externally. With the biggest windows and the shades located externally we obtain for all the configurations analyzed a reduction of the overall primary energy consumption except for the glazing DH coupled with the shade SH3. Essentially, considering that the use of the roller shading systems cause, in all the cases analyzed, an increase in the primary energy consumptions related with the lighting and heating systems, we can obtain a reduction of the overall primary energy needs only when the cut of the cooling needs is important enough to overcome the other two increases.

6. Conclusions

As we underlined before, one of the aims of this study is the representation of the fenestration system's influence on the overall performance of the confined environment. To reach this goal, we tried to build a methodology able to take into account at the same time the requirements of indoor thermal and visual comfort, the maximization of daylight availability and the reduction of the energy consumption due to heating, cooling and lighting systems. From a graphical point of view, we

Configuration	$sTC_{10,90\%}$ - IRRADIATED																											
	WO				$SH1_{ext}$				$SH2_{ext}$				$SH3_{ext}$				$SH1_{int}$				$SH2_{int}$				$SH3_{int}$			
	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL
E_S1	56%	100%	67%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	89%	100%	89%	100%	67%	100%	67%	100%	67%	100%	67%	100%
E_S2	67%	89%	78%	100%	78%	89%	67%	100%	89%	89%	89%	100%	89%	89%	89%	100%	33%	78%	22%	78%	22%	67%	22%	78%	33%	67%	44%	67%

Fig. 1 – Spatial Thermal Comfort Irradiated

Configuration	$sTC_{10,90\%}$ - STANDARD																											
	WO				$SH1_{ext}$				$SH2_{ext}$				$SH3_{ext}$				$SH1_{int}$				$SH2_{int}$				$SH3_{int}$			
	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL
E_S1	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	89%	100%	89%	100%	67%	100%	67%	100%
E_S2	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	67%	100%	33%	100%	44%	100%	33%	89%	44%	67%	44%	67%

Fig. 2 – Spatial Thermal Comfort Standard

Configuration	$sDA_{500,50\%}$																											
	WO				$SH1_{ext}$				$SH2_{ext}$				$SH3_{ext}$				$SH1_{int}$				$SH2_{int}$				$SH3_{int}$			
	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL	DH	DL	TH	TL
E_S1	56%	44%	56%	44%	37%	33%	38%	33%	33%	31%	32%	32%	11%	22%	20%	22%	37%	33%	36%	33%	32%	31%	32%	32%	11%	22%	17%	22%
E_S2	73%	56%	67%	56%	44%	40%	42%	38%	33%	33%	33%	33%	11%	22%	11%	21%	41%	38%	41%	38%	33%	33%	32%	33%	10%	22%	11%	19%

Fig. 3 – Spatial Daylight Autonomy

Configuration	$sVC_{0.35,100\%}$																											
	WO				$SH1_{ext}$				$SH2_{ext}$				$SH3_{ext}$				$SH1_{int}$				$SH2_{int}$				$SH3_{int}$			
	DH	DL	TL	TH	DH	DL	TL	TH	DH	DL	TL	TH	DH	DL	TL	TH	DH	DL	TL	TH	DH	DL	TL	TH	DH	DL	TL	TH
E_S1	93%	96%	93%	96%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
E_S2	89%	94%	91%	93%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Fig. 4 – Spatial Visual Comfort

TDT_{PPD} - EXTERNAL SHADE

	DH_E_S2 STANDARD			DH_E_S2 IRRADIATED			DL_E_S2 STANDARD			DL_E_S2 IRRADIATED		
WO	8%	8%	8%	10%	16%	26%	8%	8%	8%	8%	9%	15%
	8%	8%	8%	13%	14%	37%	8%	8%	8%	9%	9%	19%
	8%	8%	8%	10%	14%	22%	8%	8%	8%	8%	9%	13%
SH_1	8%	8%	8%	8%	8%	11%	8%	8%	8%	8%	7%	8%
	8%	8%	8%	8%	8%	18%	8%	8%	8%	7%	7%	12%
	8%	8%	8%	8%	8%	10%	8%	8%	8%	8%	7%	8%
SH_2	8%	8%	8%	8%	7%	9%	8%	8%	8%	7%	7%	7%
	8%	8%	8%	7%	8%	16%	8%	8%	8%	7%	7%	11%
	8%	8%	8%	8%	7%	9%	8%	8%	8%	7%	7%	7%
SH_3	8%	8%	8%	8%	7%	9%	8%	8%	8%	7%	7%	8%
	8%	8%	8%	7%	8%	15%	8%	8%	8%	7%	7%	11%
	8%	8%	8%	8%	7%	9%	8%	8%	8%	7%	7%	8%

	TH_E_S2 STANDARD			TH_E_S2 IRRADIATED			TL_E_S2 STANDARD			TL_E_S2 IRRADIATED		
WO	8%	8%	8%	10%	15%	24%	8%	8%	8%	8%	9%	14%
	8%	8%	8%	12%	14%	34%	8%	8%	8%	9%	9%	17%
	8%	8%	8%	10%	14%	21%	8%	8%	8%	9%	9%	13%
SH_1	8%	8%	8%	9%	8%	11%	8%	8%	8%	8%	7%	8%
	8%	8%	8%	8%	8%	19%	8%	8%	8%	7%	7%	10%
	8%	8%	8%	8%	8%	10%	8%	8%	8%	8%	7%	8%
SH_2	8%	8%	8%	8%	8%	9%	8%	8%	8%	8%	7%	7%
	8%	8%	8%	8%	8%	18%	8%	8%	8%	7%	7%	9%
	8%	8%	8%	8%	8%	9%	8%	8%	8%	8%	7%	7%
SH_3	8%	8%	8%	8%	8%	9%	8%	8%	8%	8%	7%	8%
	8%	8%	8%	8%	8%	17%	8%	8%	8%	7%	8%	9%
	8%	8%	8%	8%	8%	9%	8%	8%	8%	8%	7%	8%

Fig.5 – Thermal Discomfort Time

Daylight Autonomy 500 lux - EXTERNAL SHADE

	DH_E_S1			DH_E_S2			DL_E_S1			DL_E_S2		
WO	25%	59%	88%	42%	69%	88%	15%	41%	85%	29%	54%	86%
	28%	61%	88%	44%	72%	89%	16%	43%	86%	29%	57%	86%
	22%	59%	88%	43%	70%	88%	13%	36%	85%	25%	54%	86%
SH_1	0%	27%	77%	7%	37%	77%	0%	12%	82%	0%	30%	81%
	0%	30%	78%	9%	40%	79%	0%	16%	83%	1%	34%	82%
	0%	25%	76%	8%	37%	78%	0%	7%	81%	0%	29%	80%
SH_2	0%	15%	71%	0%	27%	68%	0%	11%	69%	0%	20%	73%
	0%	19%	71%	1%	30%	68%	0%	14%	69%	1%	23%	73%
	0%	14%	70%	1%	26%	66%	0%	8%	64%	0%	19%	71%
SH_3	0%	13%	48%	0%	18%	42%	0%	11%	57%	0%	19%	54%
	0%	16%	47%	1%	20%	42%	0%	14%	58%	1%	22%	54%
	0%	14%	46%	1%	19%	41%	0%	8%	56%	0%	19%	53%

	TH_E_S1			TH_E_S2			TL_E_S1			TL_E_S2		
WO	25%	60%	87%	37%	64%	88%	19%	45%	85%	31%	58%	87%
	25%	61%	88%	39%	68%	88%	19%	48%	86%	32%	60%	87%
	20%	55%	87%	35%	66%	88%	13%	39%	85%	27%	57%	86%
SH_1	0%	29%	79%	4%	36%	77%	0%	17%	82%	1%	33%	79%
	0%	32%	81%	7%	40%	80%	0%	20%	82%	2%	36%	80%
	0%	24%	78%	5%	37%	76%	0%	10%	81%	0%	31%	79%
SH_2	0%	20%	72%	1%	26%	72%	0%	13%	74%	0%	22%	71%
	0%	22%	70%	1%	30%	73%	0%	15%	75%	1%	25%	73%
	0%	15%	67%	1%	24%	70%	0%	8%	73%	0%	19%	69%
SH_3	0%	19%	50%	1%	19%	46%	0%	13%	56%	0%	20%	51%
	0%	21%	50%	1%	23%	46%	0%	15%	56%	1%	22%	52%
	0%	15%	49%	1%	20%	45%	0%	8%	54%	0%	19%	50%

Fig. 6 – Daylight Autonomy

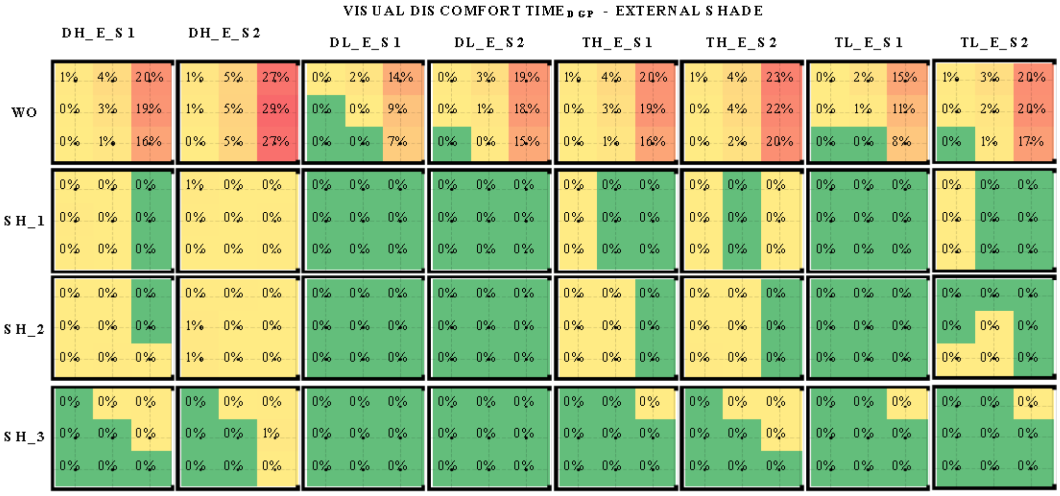

Fig. 7 – Visual Discomfort Time

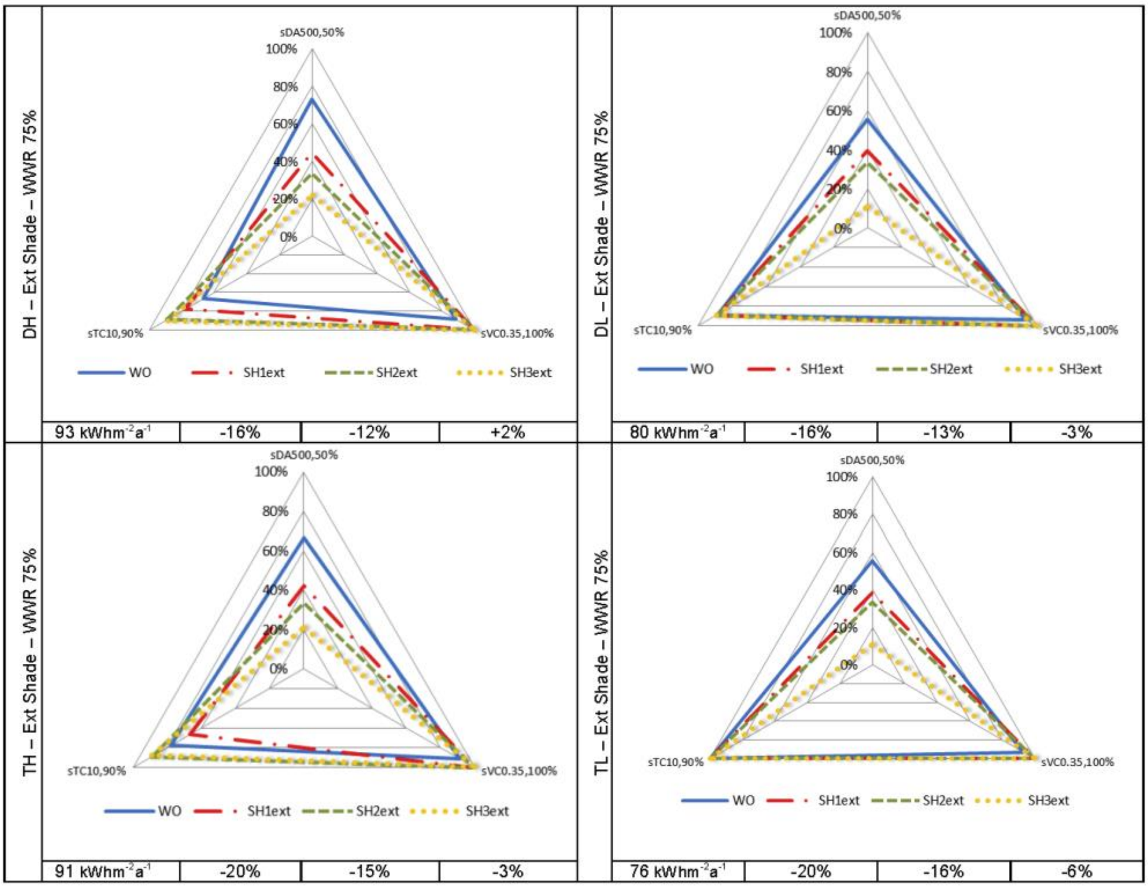

Fig. 8 – Integrated Performance

summarized through a single graph (Fig. 8) all the configurations analyzed by means of the variation of the synthetic metrics. We can notice that the settings used to ensure suitable internal visual and thermal comfort conditions for the occupants, with the specific orientation chosen, lead to a general increase of the total primary energy consumptions calculated. It is known that the building's energy consumption is related to the balance between gains and losses (climate, envelope and equipment) and this balance depends also on his operation. Whereas it is possible to predict the energy consumption related to envelope and equipment, the energy used to operate a building is strictly connected with the occupants' behavior, which is more difficult to predict. To maintain the building's energy use as close as possible to what we calculated, ensuring a satisfying internal environmental quality plays a very important role. The methodology proposed underlines:

i. the importance of analyzing together the overall performance of a building façade

ii. the contribution of simulation in the analysis of the integrated performance of façades and the necessity of using different simulation codes;

iii. the great importance of considering the effect of the direct and diffuse solar radiation on occupants well-being.

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