

CHAPTER 08. ASSESSING THE ROLE OF SOLAR SHADING DEVICES IN MITIGATING OVERHEATING IN HIGH SCHOOLS IN MADRID

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1. INTRODUCTION

Climate Change has emerged as the most critical threat to the resilience of the built environment. According to IPCC projections (2021), the sustained rise in global temperatures will increase the frequency and severity of heatwaves across Southern Europe, significantly exacerbating indoor overheating risks (OH) in high-occupancy buildings. In this context, educational facilities are particularly vulnerable. While European policy frameworks, such as the European Green Deal (European Commission, 2019) and the transition toward Zero Emissions Buildings (ZEB), have successfully driven reductions in winter heating demand, summer thermal performance and classroom comfort have historically remained secondary priorities in regulatory agendas, like the latest update proposal for the Spanish building technical code, CTE DB-HE, published recently on December 2025 (Ministerio de Vivienda y Agenda Urbana, 2025).

Educational buildings present a "perfect storm" for thermal stress: high occupant density, substantial internal gains, rigid operational schedules, and, in most cases, a total reliance on passive cooling. In Spain, a vast portion of the secondary school stock was constructed under outdated regulations, such as NBE CT-79 (Ministerio de Obras Públicas y Urbanismo, 1979), depending almost exclusively on natural ventilation for thermal control. However, recent studies emphasize that ventilation alone is becoming insufficient against increasingly extreme summer conditions, as its effectiveness is critically hindered by poor façade design and unmanaged solar radiation (Aguilar-Carrasco et al., 2025). The potential of natural ventilation to maintain adaptive comfort is critically hindered by solar exposure, façade design, and noise in schools, especially as warming scenarios push naturally ventilated buildings beyond their functional limits (EN 16798-1:2019). Other international studies in warm climates underline the importance of orientation and shading combinations. For

instance, a recent review study that collects international cases monitored data shows cooling loads reduction by between 11% and 23% in general, and reaches up to 44% in specific cases (Binti and Wantouw, 2025).

Among passive mitigation strategies, solar shading devices are recognized as one of the most effective tools for controlling solar gains and preventing indoor OH. Current research in Mediterranean contexts confirms that external movable solar shading systems outperform internal devices in reducing cooling demand. While internal blinds often trigger a "greenhouse effect" by trapping heat behind the glazing, external shading can reduce cooling needs by up to 60% and lower operative temperatures by several degrees during peak hours (Pérez-Carramiñana et al., 2024). On top of that, these strategies must be carefully calibrated, as excessive shading can compromise daylight quality, a key feature in schools, leading to a counterproductive increase in artificial lighting demand and indoor environmental quality.

Despite these benefits, most scientific literature has focused on purely Mediterranean coastal climates. There remains a significant knowledge gap regarding intermediate or continental-Mediterranean climates, such as Madrid (D3 climatic zone), where school architecture was traditionally designed to retain heat. Under current warming trends, these transitional regions are experiencing a rapid surge in OH hours, evaluating specific mitigation strategies a matter of urgency. A recent Spanish study of high schools in Madrid climate evaluated with simulation tools the balance of active and passive measures, and concluded that “a general shift in strategy is therefore necessary regarding the improvement of energy efficiency in school buildings” (Rodríguez-González and Barbero-Barrera, 2025, page 25). However, the simulations were done using only uncontrolled infiltrations instead of realistic natural window ventilation profiles. So, the results are still limited and don't reflect the actual use of schools.

In response to this challenge, several initiatives promoted by industry and research organisations are currently investigating the role of solar protection systems in improving summer performance in educational buildings. Among them, the Spanish Solar-Shading Organisation (AES-SO) has launched a technical research initiative to analyse the real impact of solar shading in school buildings under current climatic conditions.

This study addresses this gap through a parametric analysis of a representative classroom in Madrid. Sixteen scenarios are evaluated, combining construction periods, orientations, and dynamic solar shading devices. The objective is to quantify the impact of these solutions on indoor temperatures, OH hours and energy needs, providing essential data for the decision-making about retrofitting the school stock, which, as we know, must urgently adapt to the new climatic reality.

This research forms part of a broader technical investigation promoted by the Spanish Solar-Shading Organisation (AES-SO), aimed at evaluating the real impact of solar protection systems in educational buildings under current

climatic conditions. AES-SO is a non-profit professional association that brings together manufacturers, researchers and technical experts working in the field of solar protection systems in Spain. The organisation promotes research, technical dissemination and collaboration with universities and public administrations in order to improve building performance, indoor comfort and energy efficiency through the appropriate design and use of solar shading solutions. Within this framework, AES-SO actively contributed to the development of the present study by providing technical knowledge, sector expertise and guidance for the interpretation and presentation of the results.

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2. OBJECTIVES

The main objective of this study is to assess the potential of solar shading devices (SSDs, and DS in Spanish acronym) to improve indoor thermal comfort and control the energy needs in secondary school buildings under current climatic conditions. The analysis is conducted using detailed building energy simulation tools, which are officially recognised by the Spanish Ministry to conduct Energy Performance Certifications (EPC), to ensure an accurate representation of thermal behaviour and solar gains.

To achieve this objective, a parametric approach is adopted, considering four levels of solar shading, the climate of Madrid, two representative building typologies, and two façade orientations. These variables result in a total of sixteen simulation scenarios, enabling a comparative evaluation of the influence of shading configurations on OH risk and cooling demand.

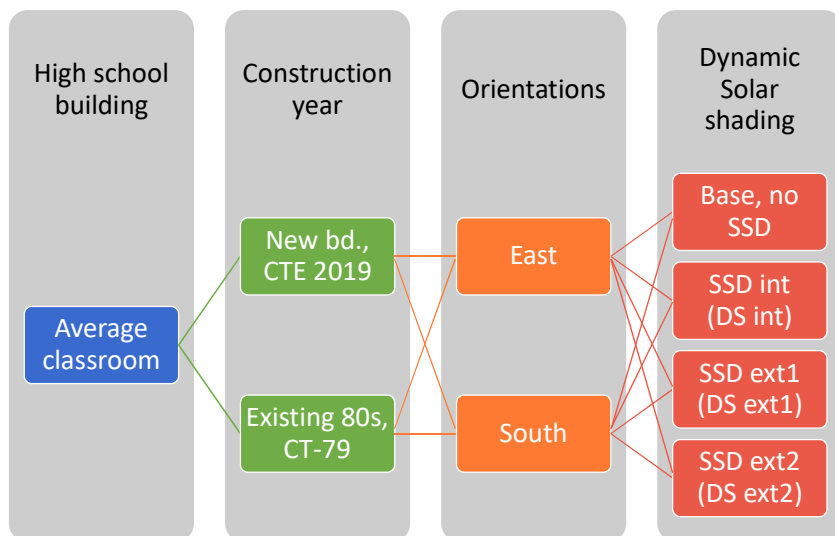
3. METHODOLOGY

This study focuses on secondary schools in Madrid, classified as D3 according to the Spanish Technical Building Code (CTE) and between BSk and Csa under the Köppen–Geiger classification for the 1990–2020 period data. This intermediate climate makes Madrid a relevant case to analyse OH risks and the effectiveness of passive mitigation strategies. A parametric simulation-based assessment is conducted in a representative classroom to evaluate the impact of different solar shading solutions on indoor thermal comfort.

Sixteen scenarios are analysed, combining two construction periods (new buildings with CTE 2019 and existing schools built in the 1980s), two orientations (south and east), and four solar shading configurations: no shading, internal roller blinds, external roller shutters and external venetian blinds. The tests are conducted with EnergyPlus (through CypeTherm HE Plus), and the model incorporates realistic assumptions regarding occupancy, internal gains,

ventilation strategies, and shading operation. Reflecting typical secondary school use. The combination of cases and SSD are depicted in Figure 1.

Figure 1: Definition of Simulation Scenarios.



Source. Own elaboration

3.1. Simulation Tool and General Approach

The analysis was carried out using an official simulation tool based on the general procedure for EPC of buildings in Spain. The selected software was CYPETHERM HE Plus (v.23.1), integrated in CYPE Ingenieros 2025.a, which is officially recognised by the Spanish Ministry for the Ecological Transition and the Demographic Challenge and the Ministry of Transport, Mobility and Urban Agenda. This tool allows detailed dynamic simulations of building energy performance and is suitable for both design-stage and existing building certification. It provides hourly, monthly and annual results, including Cooling energy demand (Q_c , kWh/m²·year), Solar heat gains through windows (Q_w , kWh/m²·year), Hourly indoor air temperatures and Monthly and annual energy balances.

The software also enables detailed hourly programming of solar shading operation, which is essential for accurately modelling shading performance during school occupancy.

Sixteen simulation cases were analysed. Indoor conditions obtained under each shading configuration were compared using the following main indicators:

- Cooling energy demand (Q_c , kWh/m²·year)

- Solar heat gains through glazing (Q_w , kWh/m²·year)
- Hourly indoor air temperature
- Overheating expressed in Cooling Degree Hours above 26 °C (CDH₂₆)

Results are first presented for all sixteen cases, followed by a more detailed analysis of the scenarios with the highest and lowest performance improvements. Intermediate cases show proportional behaviour.

South and East orientations were selected, as they represent the highest OH risk during school occupancy hours.

3.2. Analysed Solar Shading Devices

Four shading levels were considered. The shading performance was defined using representative total solar energy transmittance values ($g_{gl;sh,wi}$) according to UNE-EN ISO 52022-1:2017. For external shading systems (DS ext1), partial coverage was assumed to avoid darkening the room fully, and so an 80% effective global solar transmission reduction was estimated during its activation. Table 1 summarises the main parameters of each simulated SSD in different cases, since the glass properties affect the global solar transmission.

The SSD activation was automatic for working days and permanently activated in weekends and during the summer holiday (July and August). The automatic activation follows the UNE-EN ISO 52022-1:2017, that establish automatic control at solar irradiance levels of 200 W/m² (automatic) and 300 W/m² (manual control). So, this study represents a real school operation, where shading devices would typically function dynamically during working days, adjusting according to hourly solar exposure when needed, while remaining permanently deployed during non-working periods (weekends and summer months).

However, CYPETHERM HE Plus does not currently allow the combination of automatic and manual control modes within the same annual simulation, limiting activation to a single control strategy throughout the year. To achieve a more realistic operational behaviour, equivalent monthly schedules were developed to approximate automatic control conditions by façade orientation.

Monthly solar gains through windows were calculated under different activation schedules, enabling the definition of orientation-specific monthly profiles that reproduce solar gains comparable to the automatic activation threshold (200 W/m²).

Table 1: Properties of the evaluated solar shading devices (SSD)

SSD	Models	SSD efficiency ISO 52022:2017 (ggl;sh,wi)	Applied global transmission (ggl;sh,wi)
Base, no shading	-	-	0.70 (new)
			0.75 (existing)
Internal (DS int)	Light grey interior roller blind	0.47 (new)	0.47
		0.44 (existing)	0.44
External 1 (DS ext1)	White external roller shutter	0.05 (new)	0.20
		0.03 (existing)	
External 2 (DS ext2)	White adjustable external venetian blind	0.15 (new)	0.15
		0.12 (existing)	0.12

Source. Own elaboration

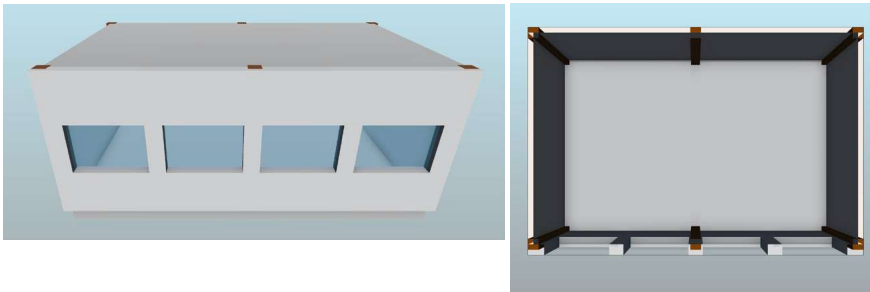
3.3. Definition of Classroom Typologies

Two construction periods were analysed to represent the Spanish secondary school stock: New building compliant with CTE DB-HE 2019, and existing building based on 1980s regulation, NBE CT-79.

A standard secondary classroom model was defined to allow comparison under equivalent geometrical conditions. That is an area of 6 m × 9 m ($\approx 53 \text{ m}^2$), for 25–30 students + teacher (occupancy ratio: $1.8 \text{ m}^2/\text{person}$). The minimum classroom surface required by RD 132/2010 ($37.5\text{--}45 \text{ m}^2$) was exceeded to reflect realistic conditions. Windows located on one façade, with 4 units measuring 1.1 x 2.1 m each, for a total window-to-wall ratio of 32.6%. The geometric model was developed in BIM using IFC Builder (v.2025.b) and stored in the cloud of BIMserver center, and it is presented in Figure 2.

The thermal envelope properties for both building typologies are summarised in Table 2. Non-façade enclosures were considered adiabatic.

Figure 2: Classroom BIM model views.



Source. Own elaboration in IFC Builder, Cype 2025.b

Table 2: Properties of the model thermal envelope

Elements	New building (CTE 2019)	Existing building (NB-CT 79)
Uwall (W/m ² C)	0.27	0.99
Uwindow (W/m ² C)	1.61	3.16
LTBwall-to-slab (W/mC)	0.11	0.92
LTBpillar (W/mC)	0	1.18
LTBsill (W/mC)	0.08	0.42
LTBjamb (W/mC)	0.03	0.48
LTBintel (W/mC)	0.04	0.89

Source. Own elaboration

The occupancy loads were defined according to Spanish standards of CTE and RITE. The total load is 130 W/person, being 75 W/person as sensible heat (57.7%) and 55 W/person as latent heat (42.3%).

The lighting power was defined according to present limits of CTE DB-HE 2019 (HE3), which means 3.5 W/m²·(per 100 lux) or 17.5 W/m² in total for the needed 500 lux in schools.

Same values of occupancy and lighting applied to both building typologies.

Finally, as the study focuses on the warm season, the use of heating is intentionally deactivated to analyse the building under free-running conditions and to avoid distorting the summer performance results with occasional heating contributions during transitional periods and natural ventilation.

3.4. Ventilation Strategy

Ventilation schedules were established according to estimated window opening airflow rates, reflecting realistic operational conditions for both winter and cooling seasons.

For the new building, ventilation rates were defined according to RITE requirements (6.7 l/s per person), complemented by additional natural ventilation through window openings. Window ventilation was scheduled for 30 minutes before classes, 10 minutes between classes, 30 minutes during break, and 2 hours after school hours. Given the significant mechanical ventilation due to high occupancy, the additional natural airflow was conservatively limited to a 30% increase over the nominal mechanical rate.

For the existing 1980s building, a base ventilation rate of 1 ACH was assumed, also complemented by window ventilation following the same opening schedule. In this case, natural ventilation was modelled with a global rate of 4 ACH, consistent with reference values for night-time residential ventilation.

An infiltration rate of 0.3 ACH was considered in both scenarios.

4. RESULTS AND DISCUSSION

Given the main objective of the study, results are primarily presented in terms of percentage improvements achieved with each solar shading device, rather than absolute values.

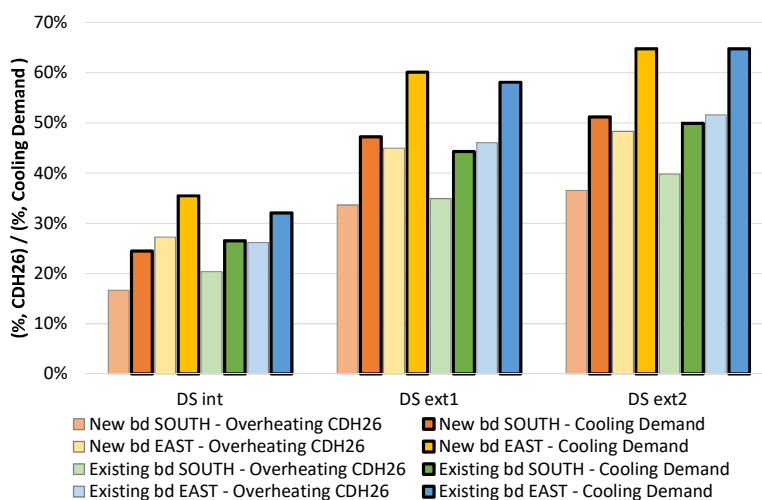
4.1. Global Performance of Shading Devices

Cooling demand reduction and overheating mitigation above 26 °C were analysed across the sixteen simulated cases. The results show consistent improvements for all scenarios, with improvements ranging from 17% to 52% in OH reduction and from 24% to 65% lower cooling needs, dependin on the case variables and the used SSD.

To understand how each SSD may provide a different range of protection, the average values are obtained for each SSD, and the findings are:

- DS int (Internal roller blinds): $\approx 23\%$ OH reduction and 30% lower cooling needs.
- DS ext1 (External roller shutters): $\approx 40\%$ OH reduction and 52% lower cooling needs.
- DS ext2 (External venetian blinds): $\approx 44\%$ OH reduction and 58% lower cooling needs.

Figure 3: Overheating reduction & savings in cooling needs

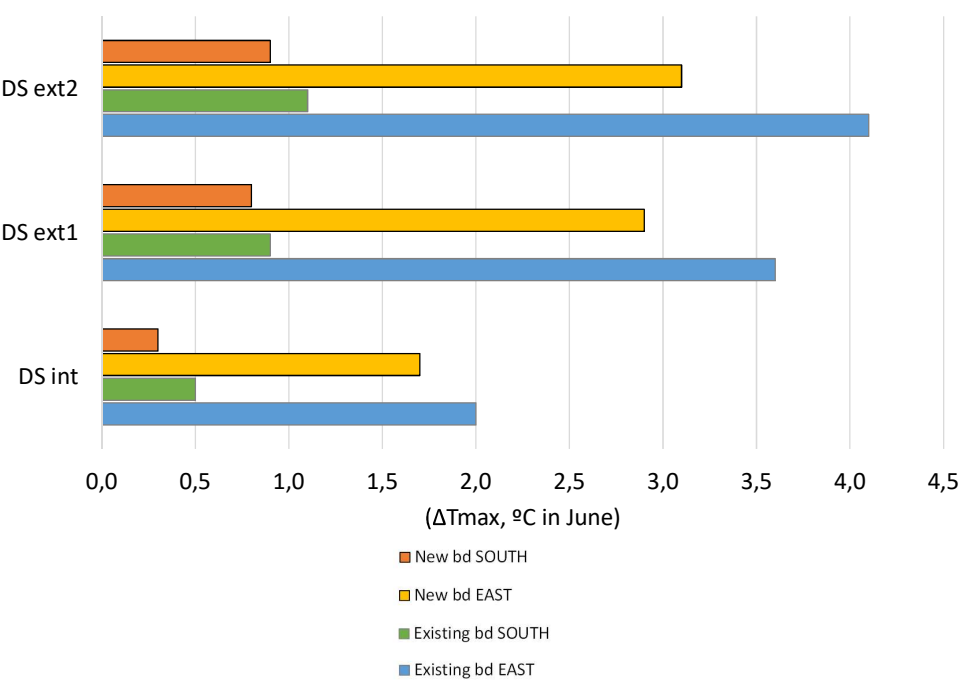


Source. Own elaboration

Peak indoor temperatures are also reduced. Since these are educational buildings with a limited activity timetable, the mean 24-hour temperatures are not representative; therefore, the analysis focuses on occupied hours. Considering these occupied hours, the reduction in peak temperatures in June is significantly more effective in East orientations than in the South-facing cases:

- East orientation: 1.7 – 4.1 °C
- South orientation: 0.3 – 1.1 °C

Figure 4: Peak temperature reduction



Source. Own elaboration

The improvements of all the cases are listed in Table 3. These findings are consistent with the aforementioned recent literature cases and confirm SSD potentials, also under realistic use.

Table 3: Summary of average improvements per case and average SSD

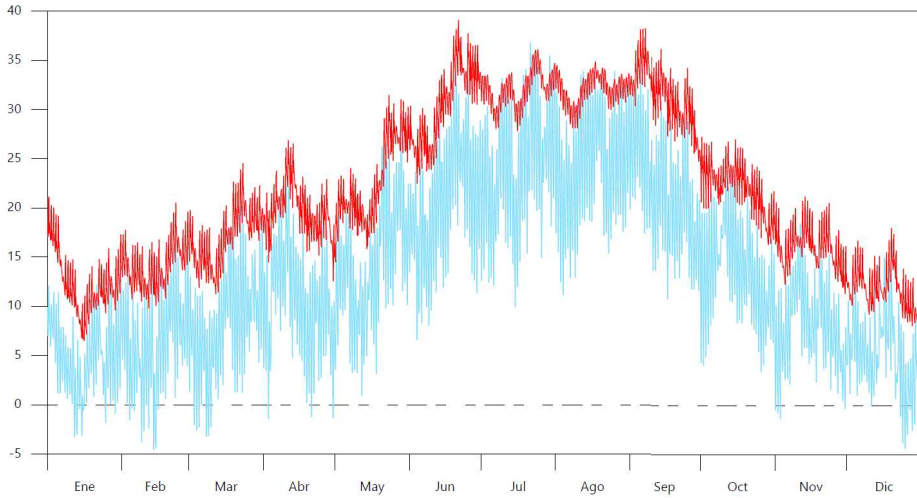
Building	Orientation	Solar Shading Device	OH reduction (%, CDH26)	Lower peak temperature (ΔTmax, °C June)	Cooling needs savings (%, Qcool)
Existing building (1980)	East	DS int	26%	2.0	32%
		DS ext1	46%	3.6	58%
		DS ext2	52%	4.1	65%
	South	DS int	20%	0.5	27%
		DS ext1	35%	0.9	44%
		DS ext2	40%	1.1	50%
New building (2020)	East	DS int	27%	1.7	35%
		DS ext1	45%	2.9	60%
		DS ext2	48%	3.1	65%
	South	DS int	17%	0.3	24%
		DS ext1	34%	0.8	47%
		DS ext2	37%	0.9	51%
SSD average potential		DS int	23%	1.1	30%
		DS ext1	40%	2.1	52%
		DS ext2	44%	2.3	58%

Source. Own elaboration

4.2. Detailed Case Study: Existing Building – East

For a better understanding of the general results, the performance of one case is presented in detail. The authors opted for a case with significant improvements. Bearing this in mind, the existing 1980s building and an east orientation were chosen. The base case (without solar shading devices) presents high solar gains through windows and substantial cooling demand, as shown in Fig.5. As expected, the worst indoor conditions happen in June and September.

Figure 5: Evolution of indoor air temperatures, Existing bd. – East

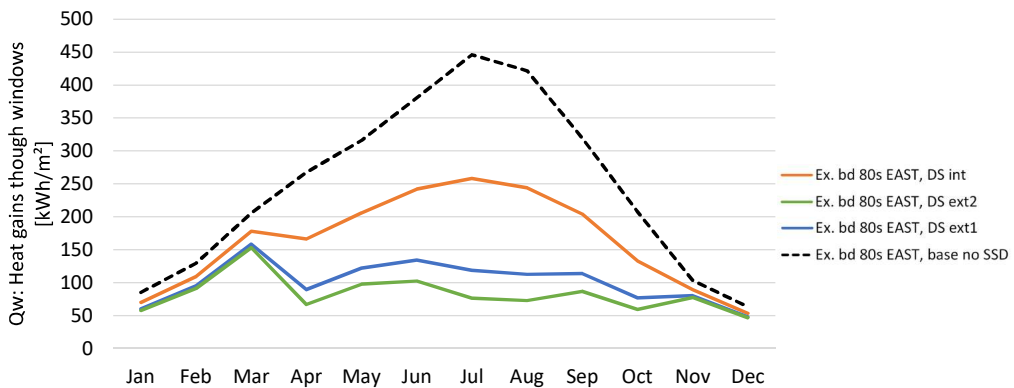


Source. Own elaboration in Cypetherm HE Plus, Cype 2025.b

The hourly temperature evolution and the main monthly variables obtained from the simulation software are shown. As can be observed, the heating system is off to avoid distorting the simulations with any occasional heating uses.

Solar heat gains through glazing are inversely proportional to the shading performance of each SSD, leading to corresponding reductions in cooling demand, as outlined in Figure 6.

Figure 6: Solar heat gains through windows (Q_w) per SSD, Existing bd. – East

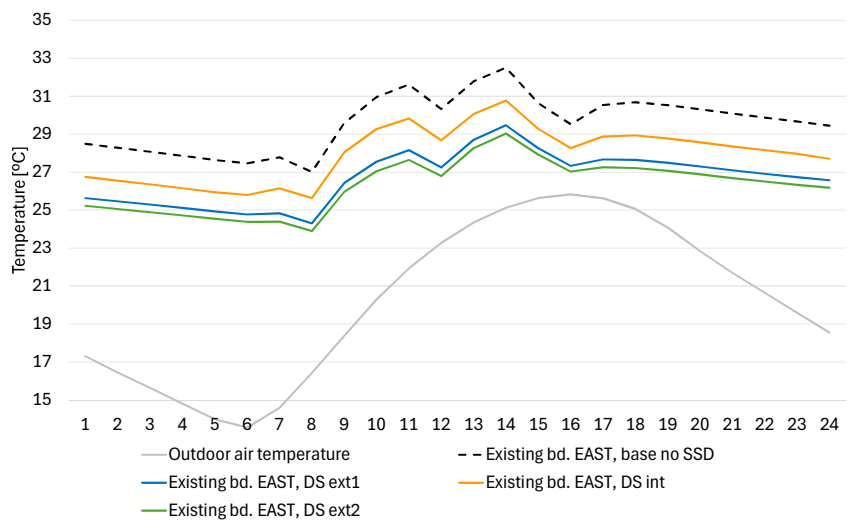


Source. Own elaboration

Hourly temperature profiles for typical school days in June and September reveal parallel behaviour between scenarios, with consistent downward shifts

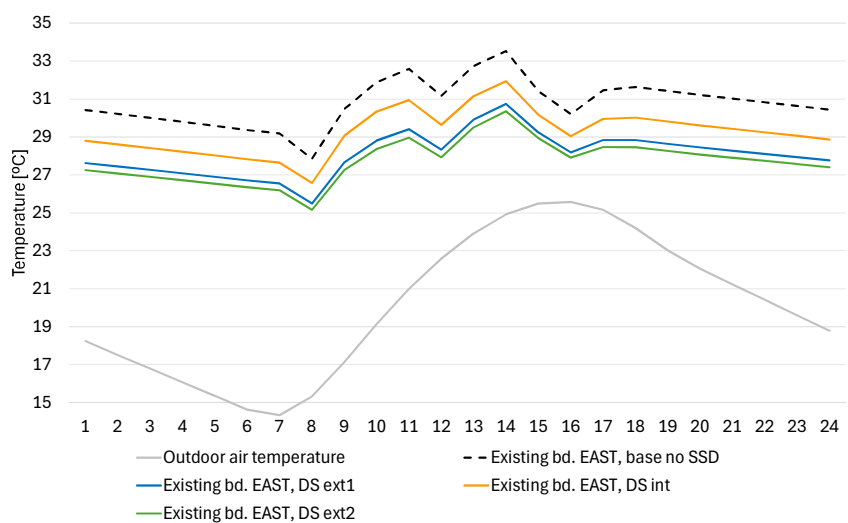
when SSD are applied. Peak reductions closely match average reductions during occupied hours, as presented in Figure 8.

Figure 8: Temperatures in an average school day in June per SSD, Existing bd. – East



Source. Own elaboration

Figure 9: Temperatures in an average school day in September per SSD, Existing bd. – East



Source. Own elaboration

In these graphs, the realistic operation of ventilation is clearly visible, as shown by a timetable distributed and a more realistic manual opening of windows by the school workers. Despite the applied ventilation rates and the solar protection, the internal gains provoke increasing trends that can surpass 30 °C inside in both months for several hours. The potentials of different SSDs are significant, as they can minimise these peaks down to manageable temperatures, perhaps with a more intensive use of other passive strategies.

To provide an overall perspective on indoor conditions, the temperature frequencies are plotted in the following graphs, showing the SSD effects. The indoor conditions improvement using different SSD are verified for three periods: the extended warm season (April to October) and the critical months of June and September. In all these periods, the reviews include, on the one hand, all the period hours and, on the other hand, only the teaching hours.

The performance during the extended warm season is presented in Figures 10 and 11, where the general trends in indoor temperature evolution can be observed.

Figure 10: Temperature frequencies, April to October, all hours [h], per SSD, Existing bd. – East

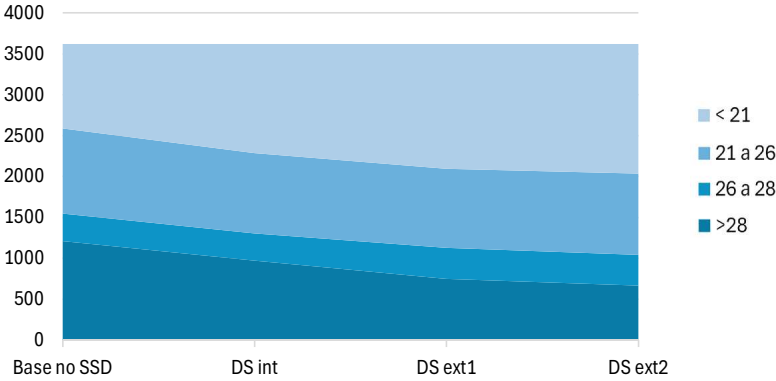
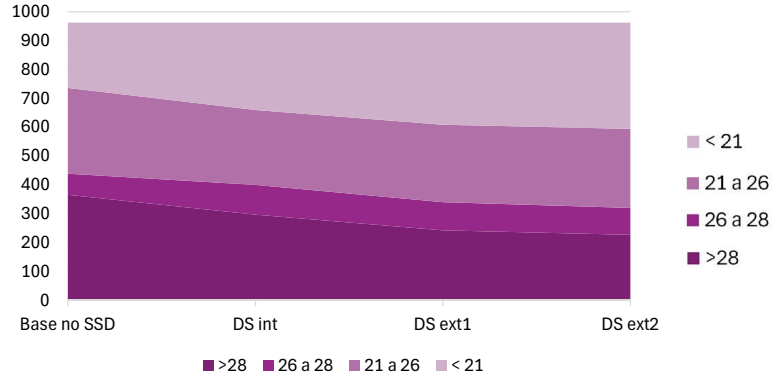


Figure 11: Temp. frequencies, April to October, teaching hours [h], per SSD, Existing bd. – East

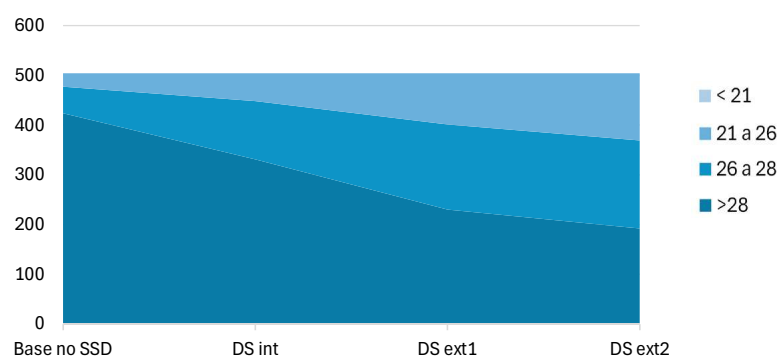


Source. Own elaboration

To provide a more detailed assessment of critical conditions, the results corresponding to the worst-performing month—September—are separately illustrated in Figures 12 and 13.

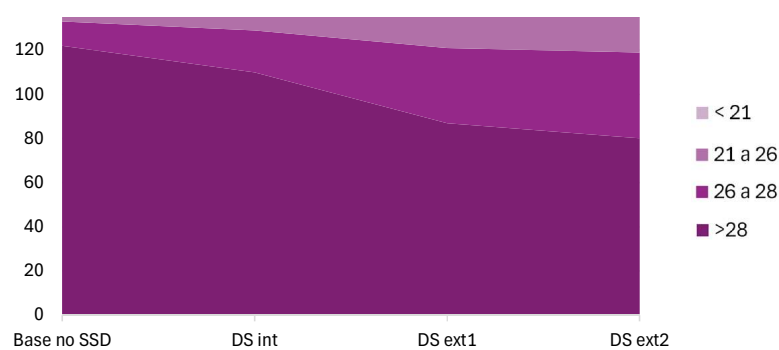
This month consistently shows the highest overheating risk during occupied hours, allowing a clearer comparison of the effectiveness of the different solar shading configurations under peak thermal stress conditions. The results suggest that under severe weather conditions, the applied realistic passive strategies are unable to maintain proper temperatures despite the use of the most efficient SSDs.

Figure 12: Temperature frequencies, all hours in September [h], per SSD, Existing bd. – East



Source. Own elaboration

Figure 13: Temperature frequencies, teaching hours in September [h], per SSD, Existing bd. – East.



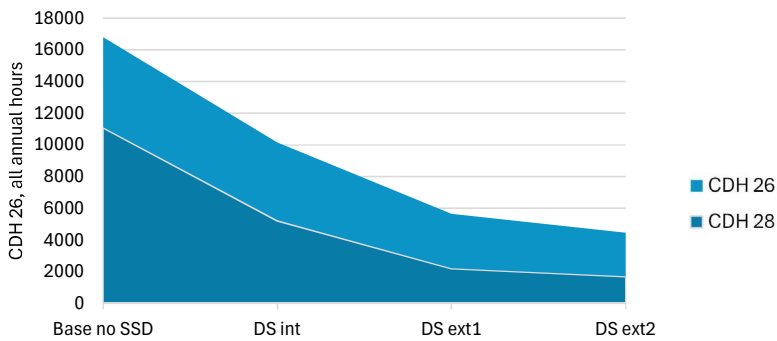
Source. Own elaboration

Overheating was further assessed using the Cooling Degree Hours (CDH26) methodology, which provides a more robust evaluation of thermal stress in

tertiary buildings than simple fixed temperature thresholds, as it quantifies both the intensity and duration of overheating events.

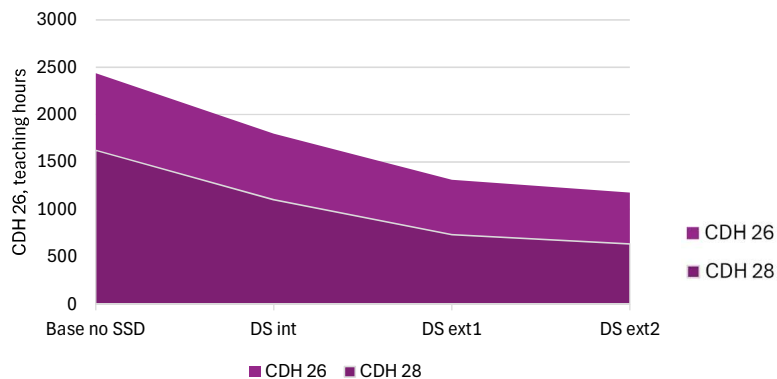
The results for the existing 1980s building with east orientation indicate that SSD can provide a high mitigation potential. All three shading configurations analysed lead to consistent improvements across all evaluated periods, including the annual assessment, the extended warm season (April–October), and the most critical months of June and September. Still under the most extreme conditions, there is a benefit of using SSD, despite being insufficient to control the indoor temperatures fully. These findings highlight the significant role that solar protection can play in reducing overheating risk in existing school buildings.

Figure 14: Overheating in all year hours CDH over 26 °C [°C·h], per SSD, Existing bd. – East



Source. Own elaboration

Figure 15: Overheating in all year, teaching hours CDH 26 °C [°C·h], per SSD, Existing bd. – East



Source. Own elaboration

The results for the main KPI of the study are:

- 26 – 52% reduction in overheating during occupied hours
- 2.0 – 4.1 °C reduction in peak indoor temperatures in June

- 32 – 65% reduction in cooling demand

To conclude this example in detail, it's important to underline that the assessment indicates that SSDs can facilitate the implementation of other local comfort solutions or small active systems. Although many existing schools currently lack active cooling systems, reducing indoor peak temperatures significantly improves comfort conditions and facilitates the potential integration of low-power active systems (e.g., local cooling units or fans). Additionally, lower peak temperatures reduce required cooling capacity, operational hours, noise levels and associated costs.

5. CONCLUSIONS

A parametric simulation study was conducted on a representative secondary school classroom in Madrid (D3 climate), analysing sixteen scenarios that combine two building typologies (1980s and CTE 2019), two façade orientations (south and east), and four levels of solar shading. Using dynamic EnergyPlus-based modelling under realistic occupancy, ventilation and shading operation schedules, the study quantified the impact of SSDs on overheating risk, peak indoor temperatures and cooling energy demand.

This study demonstrates that solar shading devices (SSDs) are a fundamental passive strategy for mitigating overheating in Madrid's secondary schools. The parametric analysis confirms that, although performance varies depending on orientation and building age, SSDs provide a consistent and significant thermal benefit across all cases.

The results highlight the clear technical superiority of external shading over internal solutions. External systems (roller shutters and adjustable venetian blinds) reduced overheating by up to 44% and cooling loads by nearly 60%, effectively doubling the impact of internal blinds. These findings challenge the common reliance on internal devices, which do not prevent solar gains from entering the building envelope. The highest impact was observed in east-oriented classrooms, where SSDs reduced peak temperatures by up to 4.1 °C, mitigating the combined effect of morning solar radiation and high internal occupancy loads.

Although shading alone cannot eliminate overheating during extreme heatwaves, it substantially lowers the thermal baseline. This reduction enhances the effectiveness of natural ventilation strategies and significantly decreases the required capacity—and cost—of potential active cooling systems or additional local passive strategies. This is particularly relevant for Spain's ageing school stock, where full HVAC retrofits are often economically unfeasible.

In conclusion, external solar protection should be prioritised as a key design and retrofit strategy in secondary schools located in intermediate continental—

Mediterranean climates. The integration of dynamic shading with realistic ventilation patterns provides a low-energy pathway toward thermal resilience.

Future research should expand the analysis to additional climatic zones, incorporate urban heat island effects and future weather files, detailed comfort model evaluations, and look at the balance between thermal comfort and daylight performance to refine automated control strategies for educational buildings.

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