POLITECNICO MILANO 1863

SCUOLA DI ARCHITETTURA URBANISTICA
INGEGNERIA DELLE COSTRUZIONI

EXECUTIVE SUMMARY OF THE THESIS

A tool for assessing thermal resilience in Italian school buildings

Parametric evaluation and mitigation strategies for overheating

MASTER'S THESIS IN BUILDING AND ARCHITECTURAL ENGINEERING

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1. Introduction

Italian school buildings are characterised by poor envelope performances and low availability of cooling systems. This, coupled with the high occupancy rates, causes high and rising overheating risks in the classrooms during the intermediate and summer seasons. The thesis aims to assess the magnitude of the problem and to guide school owners and users towards an improvement of the existing building stock, suggesting actions that can allow the use of school spaces in the hotter months, especially focusing on day and night natural ventilation and the use of fans or external shading. The evaluations are done first for standard weather files, and additionally for future climate projections and local effects weather files.

The results presented in the study are obtained through the use of a parametric simulation tool, which enables the comparison of a wide range of classroom configurations, assessing the reduction potential derived from the application of several passive mitigation strategies.

The results are in the end gathered in a user-friendly tool that enables school owners to verify the condition of the building and of the classrooms, providing possible mitigation strategies and their reduction potential.

2. Context and state of the art

The research lays its foundations and acts as an extension of the RERoadS project for the renovation of the Italian school building stock, starting from the energy efficiency requirements at national and European levels and analysing the current state of the art in terms of passive and active mitigation strategies. From the analysis of the SNAES database [1], it is demonstrated that only 10% of the Italian school building stock is equipped with a cooling system, while the results for what concerns the overheating condition of the classrooms confirm the high temperatures reached in the internal spaces in the intermediate and summer season, proving the need of facing this risk with alternative strategies, to enable comfort during the school period and improved conditions also for a possible use during the summer break.

3. Methodology

The overheating risk of schools is assessed through the calculation of the internal operative temperature of single standard geometry classrooms, depending on the location and climatic zone, on the position of the classroom in the building and on the characteristics of the envelope and its operation. A parametric simulation tool is scripted, leveraging IESVE 2024 simulation software, in order to obtain results from multiple classroom configurations in an automated way.

The classroom is modelled as a free-floating shoebox of dimensions 9x6 meters and height 3.5 meters, with an occupation rate of 2 m^2/person, and sensible and latent people loads of 90 W/person and 60 W/person respectively. Ventilation and infiltration rates are accessed as parameters by the tool, and their load is calculated consequently. Lighting load is set to 10 W/m^2. Occupancy and lighting profiles are set to ON between 8 AM and 6 PM from Monday to Friday. Envelope and internal constructions are modelled according to the UNI TR 11552, representing typical conduction values as in Figure 1 for the base cases and improved values from D.M. 2025 for the improved stratigraphies. Single- and double-glazed windows are modelled to represent the average performance of the current building stock's ones, respectively, with 5.75 W/m^2K and 2.59 W/m^2K as conductivity.

	Typology	Insulation	U-value [W/m² K].
Walls	Cavity wall	Not insulated	1.10
Roof	Flat roof	Not insulated	1.35
	Reinforced concrete-brick	Insulated	1.01
Internal slab	Reinforced concrete-brick	Not insulated	1.30
Ground floor slab	Ground floor on pilotis or ventilated crawl space	Not insulated	1.30
Window	Single glazing	-	6.00
	Double glazing Air filled	-	3.60

Figure 1: Base stratigraphy conduction values

A total of 24,768 simulations are performed, considering 6 classroom positions (ground, middle and top floor, middle and corner positions) and combining the values assumed by the different parameters:

- Climatic zone (A, B, C, D, E, F)
- Natural ventilation rate (8 l/s/p, 1.2 ACH)
- Envelope construction (base-case, or wall, roof or window refurbishment)
- Window-to-floor ratio (12%, 14%, 16%, 18%, 20%, 22%)
- Orientation (north, east, south, west)
- Solar heat gain coefficient (high – 0.87 for single and 0.75 for double glazing, or low – 0.35 for single and 0.33 for double)

Algorithm 1 summarises the structure of the Python code tool. In the internal loop, the parameter combination list represents the list of all the possible combinations of the WFR, orientation and SHGC parameter values.

Algorithm 1 Parametric simulation tool

```
parameters_initialization
for location in location_list:
    for ventilation_rate in ventilation_list:
        for construction in construction_list:
            if construction == window_ref:
                infiltration = 0.5 ACH
            else:
                infiltration = 0.25 ACH
            for parameter_combination in list:
                VEApache.simulate()
save_results()
```

For each simulation, the internal operative temperature is extracted as a result, and the following indicators are elaborated:

- Comfort bands: share of occupied hours in each adaptive comfort band, according to EN 16798-2 [2], for the various periods.
- Frequency and cumulative frequency of temperatures above the II category of comfort upper temperature threshold.
- TM52 compliance: share of hours and days that do not comply with the three CIBSE's TM52 criteria and overall compliance with the regulation [3].
- Heat stress days: number of total and intermediate season days that exceed the threshold and do not present the possibility of ventilating the spaces for more than three consecutive days.

Additional simulations are run to verify the reduction potential of passive mitigation strategies: 0° louvres, 45° louvres, and night ventilation, setting a ventilation rate equal to the daytime one during the non-heating period from 6 PM to 8 AM only if the external air temperature lies between 15°C and 26°C. Results connected to fan use to increase the air speed and thus the comfort condition are derived considering an increase of 2°C in the upper comfort threshold due to air speed increase to 1.2 m/s. Comparisons with worst-case scenarios, future weather projections and Urban Heat Island effect results are also performed, to determine the impact that climate change and local effects can provide.

These results are calculated for each configuration and compared in the results chapter, while single-case results can be accessed through the results visualisation tool. Moreover, rules are set to determine the overheating condition of entire school buildings, in which classrooms can be clustered for exposition and position. For what concerns the intermediate seasons, a school is considered at high overheating risk if more that 25% of the classrooms is at high overheating risk, while in the summer break season, in which attendance could be increased, 60% of high risk classrooms is set as an acceptability threshold for sporadic and low attendance use, whereas schools with less than 25% of classrooms at high overheating risk present a good usage potential, and shares between the two thresholds make the school usable discontinuously.

At the end of the chapter, a comparison between different simulation software is performed, and a sensitivity analysis on the principal variables is presented. The comparison between IESVE 24, IESVE 25 and EnergyPlus simulations software yields comparable results, following careful alignment between the different software's settings. As far as the sensitivity analysis is concerned, tornado charts are used to compare the effect that numeric parameters have when changed of ±30%. As seen in Figure 2, natural ventilation rate increase determines the highest discomfort reduction effect, while the WFR ratio is the least influencing variable among the four analysed ones.

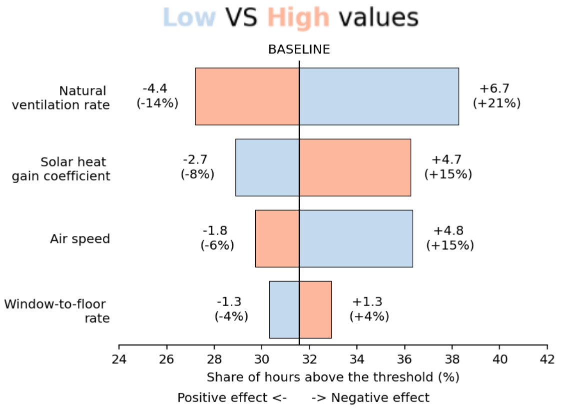

Figure 2: Sensitivity analysis tornado chart

An analysis of the effect of the alignment between the weather temperature's peaks and the occupancy loads is moreover performed, observing that higher effects are registered with north-exposed classrooms, which present lower solar gains influence.

4. Results

The results of the analysis are first of all presented for example cases, then comparisons between different configurations are performed on all the considered outputs, and in the end, an example of application of the tool is provided for a real case school building.

From the analysis of example cases, it can be seen that, in general terms, the decrease in the SHGC value provides high increases in the internal comfort, while the WFR variation (represented by the clustered columns in Figure 3) determines a slight and almost linear impact on the results.

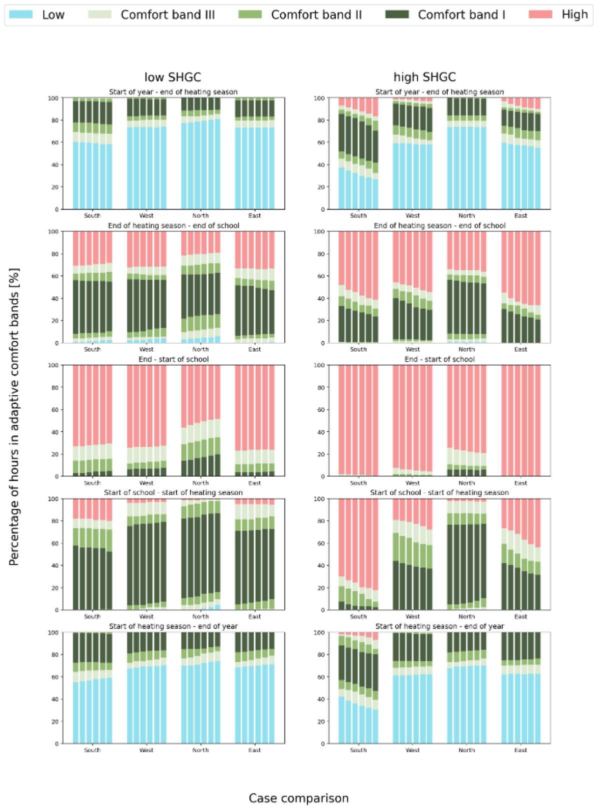

Figure 3: Comfort bands results example with comparison of different WFR, SHGC and orientations

To compare the results of all the simulations, different heatmaps are created, averaging the results that correspond to the same climatic zone, classroom position, retrofit condition and natural ventilation rate, for each of the metrics used in the study. Figure 4 displays an example for the share of hours with temperature higher than the upper comfort band threshold. As far as the classroom position is concerned, G indicates ground floor, M the middle floor and T the top one, while M and C indicate the middle and corner position on the floor.

Analysing the heatmaps, it can be concluded that refurbished buildings, especially in the cases of double windows, present higher internal temperatures, also due to the lower infiltration rates. In general terms, rooms in the middle position present higher temperatures, as the ground, top and corner classrooms present higher dispersing surface areas. Ventilation rate decrease determines a drastic decrease in the internal comfort condition, while climatic zone does not influence the results considerably, as adaptive temperature thresholds are defined according to the running mean external temperature.

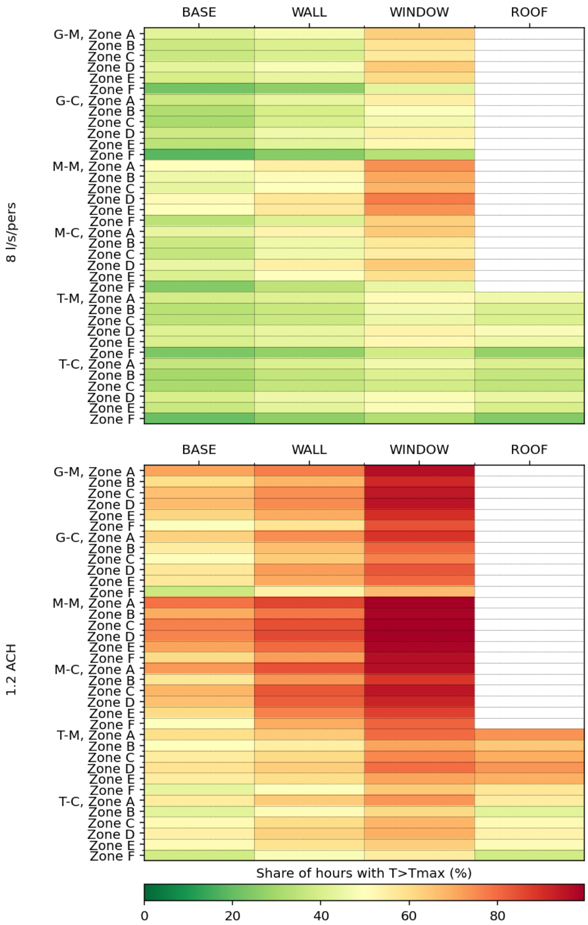

Figure 4: Average of the share of hours outside the comfort bands heatmap

Similar comparisons are plotted for the additional passive strategies simulation results, highlighting that night ventilation strategies provide a drastic decrease in the discomfort hours, more than both shading configurations.

Future weather scenarios simulations for the IPCC SSP5-8.5 weather scenarios in 2050 and 2080 highlight the share of discomfort hours average increases of 10 and 17 percentage points, respectively, while UHI simulations only return 1 or 2 percentage points increases, depending on the presence of night ventilation, as temperature only increases of a few centigrade fractions.

Figures 5, 6, 7 show the comfort bands comparison for different scenarios for an example case.

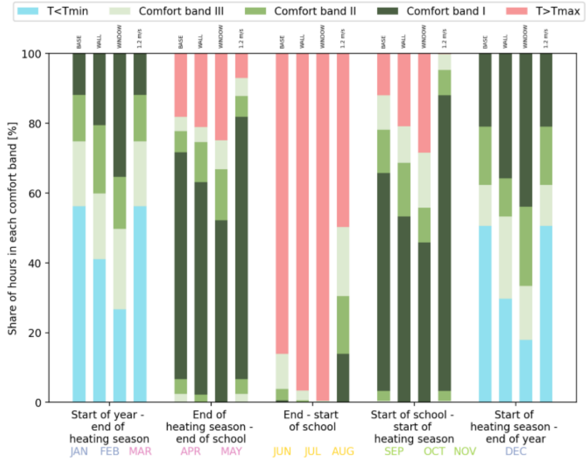

Figure 5: Comfort bands comparison for different retrofits and higher air speed for an example case

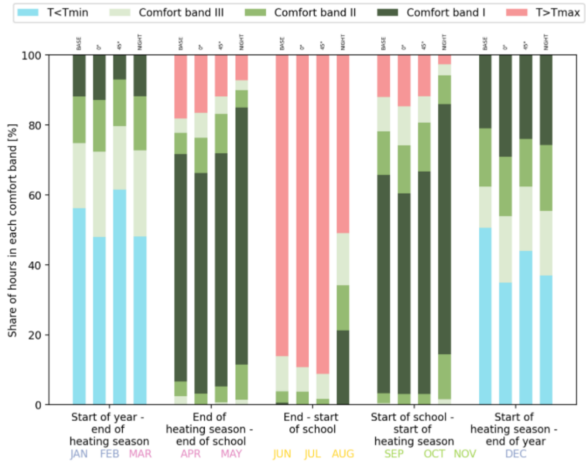

Figure 6: Comfort bands comparison for different shading configurations and night ventilation

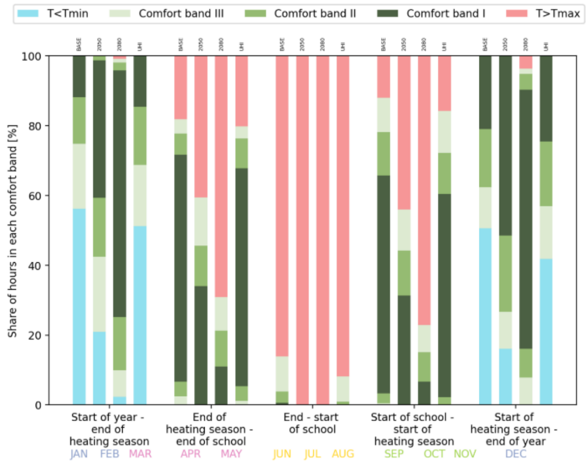

Figure 7: Comfort bands comparison for future weather and UHI scenarios

At the end of the chapter, the results elaboration tool is presented, with fictitious examples and a real school application. All the classrooms, clustered based on orientation and position in the building, are considered at high overheating risk, making the whole school scarcely comfortable during the intermediate seasons and not usable in the summer. Nevertheless, the tool also points to particular passive strategies that can improve the comfort of the different classroom groups, thus making the school more accessible.

5. Limitations and future works

Different assumptions affect the discussions that are presented in the thesis, and the results need to be interpreted as comparative results, which enable the identification of overheating conditions and the reduction potential of different mitigation strategies. Nevertheless, geometrical, envelope and loads characteristics are based on assumptions, as well as weather conditions.

Future expansion of the work done until now could implement additional parameter variations to the simulation tool and the possibility of determining the behaviour of intermediate configurations that were not simulated. Moreover, the feasibility of ventilation and night ventilation rates could be verified with more accurate ventilation simulations. In the end, additional evaluation metrics could be added to the thermal comfort one, such as Life Cycle and Return On Investment Analyses, to provide the user with all the information for the evaluation of the alternatives.

6. Conclusions

In conclusion, the assessment of the summer performance of school buildings is identified to be of crucial importance for the use of school buildings in the near future, as high temperatures might decrease the learning performance of students and prevent the use of those public buildings during the summer. Analysing and comparing the results of the different cases' configurations, a cascade process is proposed for coping with the overheating issue in classrooms, starting from the natural ventilation, then adding night-time ventilation, the use of fans to increase the speed of air and thus the maximum acceptability temperature, the application of external shading devices and, in the end, in the cases where the passive strategies are not sufficient to maintain the building in the comfort range temperatures, the addition of a cooling active system, starting from mechanical ventilation. It was indeed observed that increasing the ventilation rates and the air speed substantially decreases the discomfort hours, and moreover, that the night-ventilation strategy is very effective in terms of temperature reduction. The effectiveness of night ventilation is nevertheless proved to be less effective in urban environments, where UHI effects increase the temperatures, especially during the night, reducing the possibility of night purge effects.

References

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[2] 'EN 16798-2:2019 "Energy performance of buildings - Ventilation for buildings - Part 2: Interpretation of the requirements in EN 16798-1 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics"'. Accessed: Nov. 26, 2024. [Online]. Available: https://sd.ds.dk/Viewer/Standard?ProjectNr=M297459&Status=90.20&VariantID=41&Page=1

[3] 'TM52: The Limits of Thermal Comfort: Avoiding Overheating in European Buildings | CIBSE'. Accessed: Oct. 31, 2025. [Online]. Available: https://www.cibse.org/knowledge-research/knowledge-portal/tm52-the-limits-of-thermal-comfort-avoiding-overheating-in-european-buildings