NATURAL VENTILATION STRATEGY POTENTIAL ANALYSIS IN AN EXISTING SCHOOL BUILDING

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ABSTRACT

Natural ventilation is increasingly considered a promising solution to improve thermal comfort in buildings, including schools. However in order to support its planning and implementation, quantitative analysis on airflow paths and heat-airflow building interactions are needed. This requires an adequate accounting of both internal effects, from building layout and structure, and external forcings from atmospheric factors.
The paper analyses the performances of natural ventilation strategies as retrofit solutions to improve thermal comfort in an existing school building in Lavis (Trento, Italy).
A climatic analysis is performed to define the potential of wind driven natural ventilation. Meteorological data collected on site are analysed to identify typical wind conditions during the cooling season. The resulting daily cycle of wind speed and direction in sunny days reflects the typical dynamics of a regular valley wind, but also displays the peculiar characteristic of being strongly affected by the outbreak of a lake breeze flowing from a nearby valley and originated from Lake Garda.
Based on these findings, three natural ventilation strategies are proposed (night cooling, wind driven cross ventilation and stack and wind driven cross ventilation), and their effectiveness on thermal comfort are compared by means of dynamic simulation tools.
The thermal comfort in classrooms is evaluated according to the standard UNI EN 15251. For a standard occupant behaviour, discomfort situations from overheating occur in 34% of occupational period hours in the spring-summer season. The proposed ventilation strategies allow to reduce this value by up to 4%. Natural ventilation turns out to be an interesting low cost solution to control indoor temperatures without mechanical cooling systems.

KEYWORDS

Natural ventilation, school building, passive cooling, thermal comfort, wind.

INTRODUCTION

Existing school buildings in Italy generally have no cooling system. However nowadays an increasing number of overheating discomfort situations occurs, as school building facilities are used also during the summer season for extra-scholastic activities. These situations are likely to increase, as a consequence of observed modifications of local atmospheric regimes, connected with either urbanisation [1] or global warming effects [2].
Natural ventilation seems a promising technique to improve thermal comfort in classrooms [3]. Besides requiring higher energy performances, the Italian legislation (D. Leg. 311/2006)

recommends the exploitation of natural ventilation to reduce cooling demand. A more recent regulation (D. Leg. 5/2012) promotes the modernization of school buildings, improving energy efficiency and reducing management costs.
Natural ventilation as passive cooling strategy is particularly suitable in school buildings, as they have a defined use pattern and a flexible indoor layout [4].The present paper analyses the performance of natural ventilation strategies as retrofit solutions to improve thermal comfort in an existing school building located in Lavis, a suburban zone near the city of Trento (Italy), in the Alpine Adige Valley.

BUILDING DESCRIPTION

The Lavis secondary school was built about seventy years ago, and renovated in the last years (Figure 1). There is no cooling systems or mechanical ventilation plants, except in the canteen underground. The four storey building has a very complex layout due to the recent extensions. The present analysis focuses on the southern building part, where the classrooms are located. Every floor has seven classrooms connected by a corridor to the rest of the building and to two stairwells. One of the stairwells is enclosed by fire resistive elements. Two classrooms are oriented eastward, two westward, while three classrooms face south. Each classroom has two windows with triple-casement and tilt and turn opening. No vents are installed. Teachers and students report discomfort situations during the middle season. The rest of the building is allotted to services, offices, library and laboratories for artistic and musical activities, and has not been modelled in detail for the purpose of the present analysis.

Figure 1. Lavis School location. Source: © Google 2012

WIND POTENTIAL ANALYSIS

In the design of natural ventilation it is mandatory to understand how and when a wind induced internal flow is exploitable. To accomplish this goal, the building orientation and the internal space layout with respect to the main surrounding wind directions must be considered.
The Adige Valley in the Alps, where Lavis lies, is north-south orientated. Furthermore two tributary valleys join the Adige Valley near Lavis: the Avisio Valley, east of the town, and the Lakes Valley, south-west of Lavis. Therefore wind speed and direction are expected to be strongly influenced by airflows occurring in this complex topography. During sunny days in the warm season valley winds generally blow in the above-mentioned valley. Valley winds,

which typically blow up-valley during the day and down-valley at night, develop as a consequence of the horizontal pressure gradients due to the temperature differences between different valley cross-sections or between the valley and the plain [5]. Moreover the local circulation blowing in the Lakes Valley is not a typical valley wind, but a combined "valley-lake" circulation, which starts blowing on the shores of Lake Garda, located in the southern part of this valley. This "valley-lake" breeze is generally rather strong and arrives into the Adige Valley from the Lakes Valley in the early afternoon.
In the present case typical daily cycles of wind speed and direction representative of the conditions occurring around the school building have been calculated from wind measurements acquired every 10 min by an amateur weather station located close to the school. A statistical analysis performed on wind speed and direction data for the whole 2011 shows that during the spring-summer season a typical daily cycle of wind speed and direction occurs (Figure 2). At night and in the early morning wind blows from east, following the down-valley wind flowing from the Avisio Valley, as the building is located close to the end of this tributary valley. Later in the morning and in the early afternoon wind blows from south-west, following the development of the up-valley wind and the outbreak of the "valley-lake" breeze from the Lakes Valley. Finally in the evening a transition can be seen from an up-valley wind, to a wind from east flowing from the Avisio Valley.

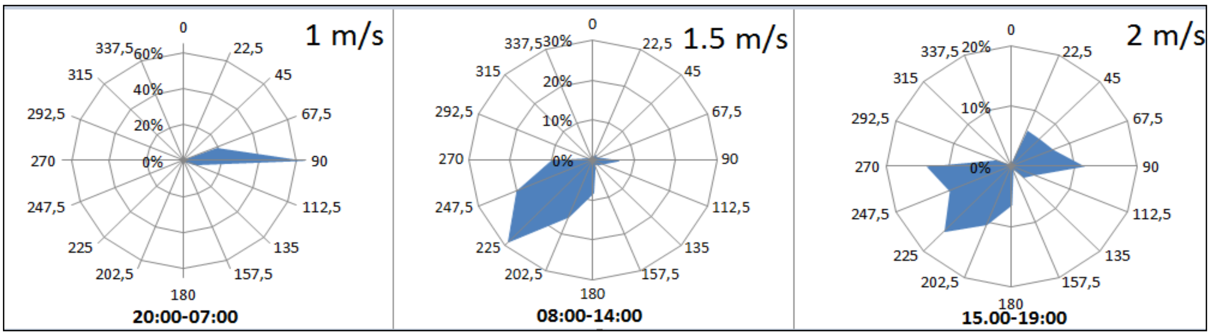

Figure 2. Average wind speed and directions in the typical day of spring-summer period.

NATURAL VENTILATION STRATEGIES

The three main strategies proposed here are based on foundamental principles of natural ventilation and implemented to the case study, namely (i) night cooling, (ii) wind driven cross ventilation and (iii) stack driven cross ventilation.
Night ventilation (Figure 3) rejects excess heat cooling the building structure, taking advantage of the lower night external temperatures [6][7]. Opening actuators can be applied to the existing windows, controlled by external temperatures and humidity sensors. Night ventilation is activated if:

- outdoor temperature is lower than indoor temperatures;
- indoor temperature is higher than 24°C;
- outdoor temperature is higher than 14°C;
- it is not raining.

During the day a venting schedule based on the current school occupation pattern and use has been set.

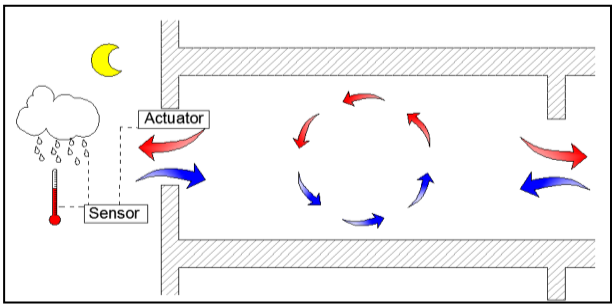

Figure 3. Night ventilation strategy.

During school time classroom doors stay closed, and single-sided ventilation occurs when windows are opened manually by the occupants. A wind driven cross ventilation (Figure 4) can be easily implemented by installing vents above doors, allowing airflow from one side to the other of the building even if doors stay closed. Specific vents that combine acoustic attenuation, to fullfil acoustic standard requirements in classrooms, with very low airflow resistance (discharge coefficient $c_d = 0.71$) are available on the market.

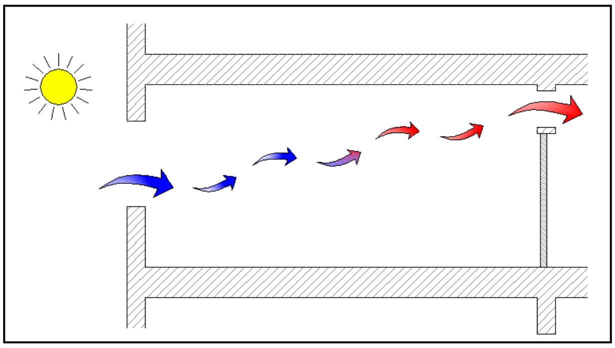

Figure 4. Wind driven cross ventilation strategy.

The third strategy proposed exploits the staircase in the South-East part of the building to increase the stack effect (Figure 5). A stack driven cross ventilation can be implemented by connecting corridors to the staircase through fire-resistant vents and adding a chimney on the top of the staircase. Classroom openings act as inlets allowing fresh air flowing through the building driven by the passive stack force of the exhaust air outlet at the top of the staircase. Some companies are specializing in the field of natural ventilation and provide specific products.

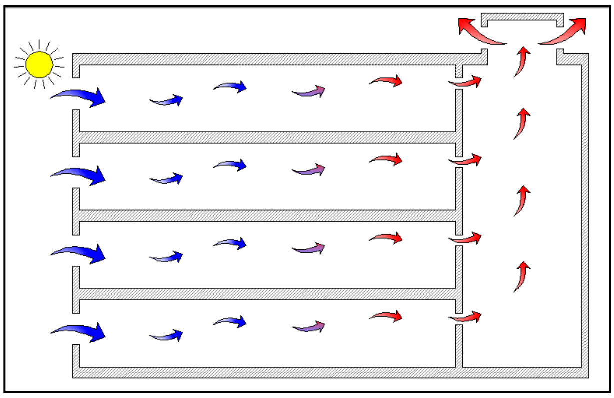

Figure 5. Stack driven cross ventilation strategy.

THE THERMAL – AIRFLOWNETWORK SIMULATION MODEL

The building model has been set up in Design Builder v.3, a graphical interface of the EnergyPlus building energy simulation engine [8][9]. The southern building part (grey volume in Figure 6) has been divided into thermal zones, according to occupation patterns, occupant activities, comfort needs, zone orientation and elevation [10]. The rest of the school building is modeled as an adiabatic block (red volume in Figure 6).
Standard year weather file data for the city of Trento are used [11]. Wind speed profile is modified by terrain roughness parameters for suburbs.

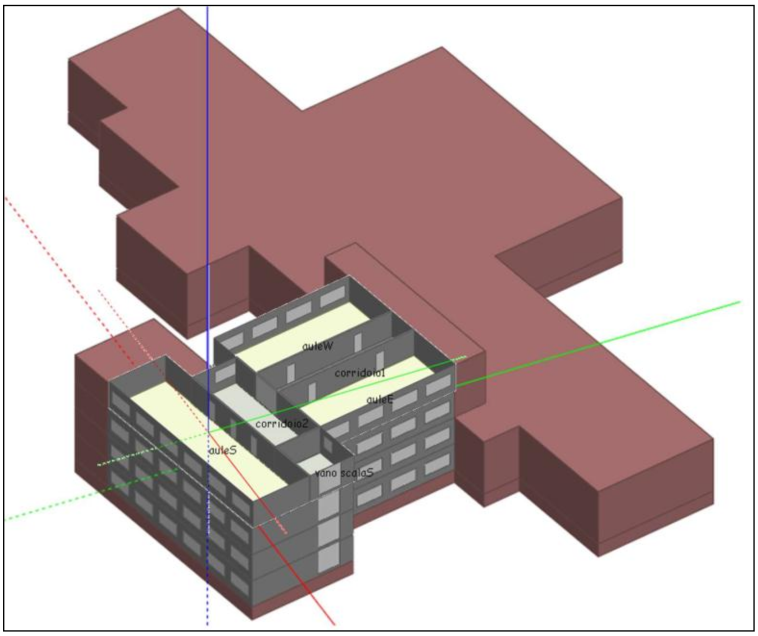

Figure 6. Lavis School model in Design Builder.

The proposed natural ventilation strategies were modelled by means of the AirflowNetwork object implemented in EnergyPlus [11] and compared. The airflow network object represents each thermal zone as a node of a network, characterized by a uniform temperature and a pressure varying hydrostatically (Figure 7). Windows, vents and cracks are represented as leakages, which link pressure differences due to wind or air density variations to power law equations. Each airflow path is calculated by Bernoulli equations and numerical solution of the problem gives the thermo-hygrometric conditions in the nodes. When temperatures and pressure are known, the program calculates airflow rates and latent and sensible heat exchanges. Thermal and airflow network model are coupled: they run in sequence and each uses the results of the other model (zone temperatures and pressures, airflow) in the previous time step [13].
The simulations are performed in free-running mode to analyse the passive behaviour of the building during the cooling season (15 April - 15 October). External openings are controlled by time schedules and by external temperature and humidity. Comfort temperatures are calculated from the CEN 15251 adaptive comfort model. Windows open if venting availability schedule allows venting and zone operative temperature is higher than the comfort one. Doors and vents are controlled by venting availability schedules according to a school standard occupation pattern. In general, doors must be closed during lesson periods and are a barrier to the natural airflows. Vents stay open everytime. AIVC wind pressure coefficient data sets [14] are used to calculate wind-induced pressure on each external node. They are defined for wind incidence angles in 45° increments for each surface in the model.

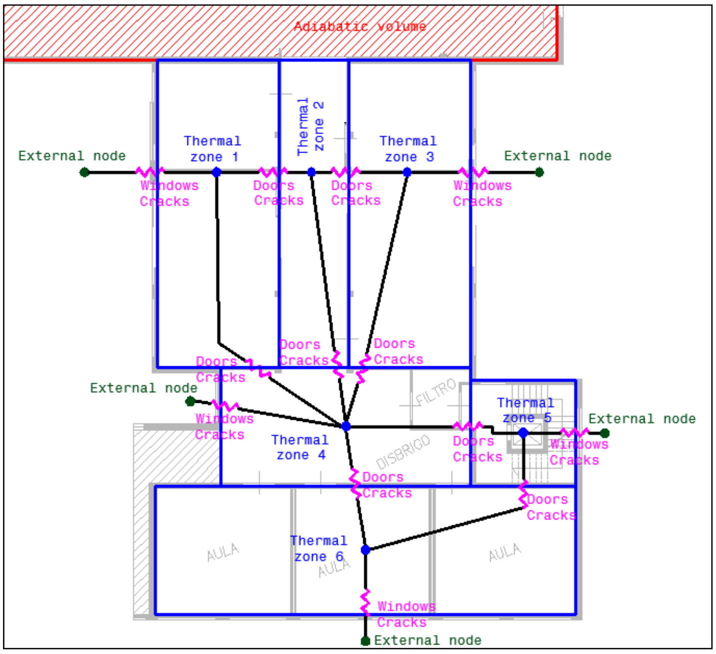

Figure 7. Schematic representation of AirflowNetwork in a floor type.

RESULTS

The three natural ventilation strategies proposed have been compared in terms of thermal comfort conditions. The european standard UNI EN 15251 defines three comfort categories limited by three temperature ranges. Thermal comfort is evaluated depending on the difference between the optimal operative temperature, according to the climate condition in the last week, and the simulated operative temperatures. The operative temperature outputs are compared with the comfort categories defined in the standard.

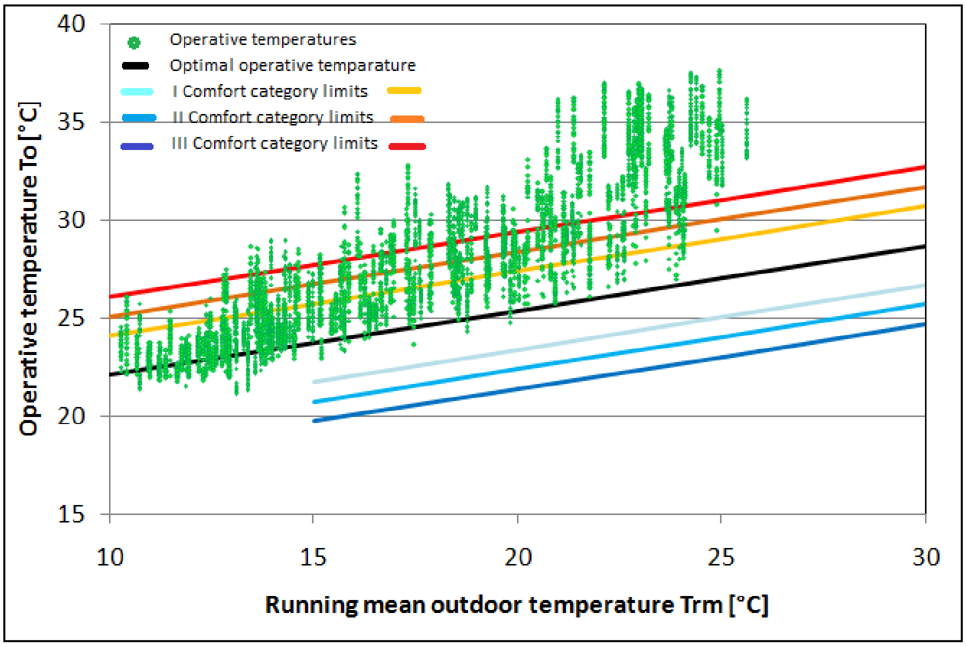

Figure 8. Base case simulation results. Operative temperatures of the most disadvantaged thermal zone (south oriented – third floor) are plotted against the outdoor running mean temperature. Green points above the superior limit of the third comfort category represent discomfort conditions due to overheating.

Simulations results of the most disadvantaged thermal zone, i. e. the one oriented to south at the third floor, were compared in the base case and in the natural ventilation strategies cases. In fact, the worst discomfort conditions are complained for that building part (Figure 8). Figure 9 shows the percentage of time during the occupation period when operative temperatures are within the comfort categories bounds.

Assuming a standard occupant behaviour, discomfort situations occur in the 34% of occupational period hours during the spring-summer season due to overheating.

Discomfort situations can be reduced to 5% by the natural night ventilation strategy, to 4% by the cross driven natural ventilation strategy and to 8% by the stack driven natural ventilation strategy. Furthermore, the percentage of hours when operative temperatures are within the first category boundaries increases significantly: from 43% in the base case, to 76% by natural night ventilation, to 69% by cross driven natural ventilation and to 59% by wind and stack driven cross ventilation. There is a 2% of time in which UNI EN 15251 standard comfort can not be applied as the Running Mean Outdoor Temperature is out of the required limits: upper limit temperature has to be between 10°C and 30°C and lower limit temperature has to be between 15°C and 30°C.

Simulation results show the global behaviour of the building in the assumed standard conditions. Mean values of solar and internal loads during the whole cooling season have been compared with the estimated heat rejected by airflow and the results are shown in Figure 10. It could be noted that the best results are reached by night ventilation, where the 90% of internal gains can be rejected.

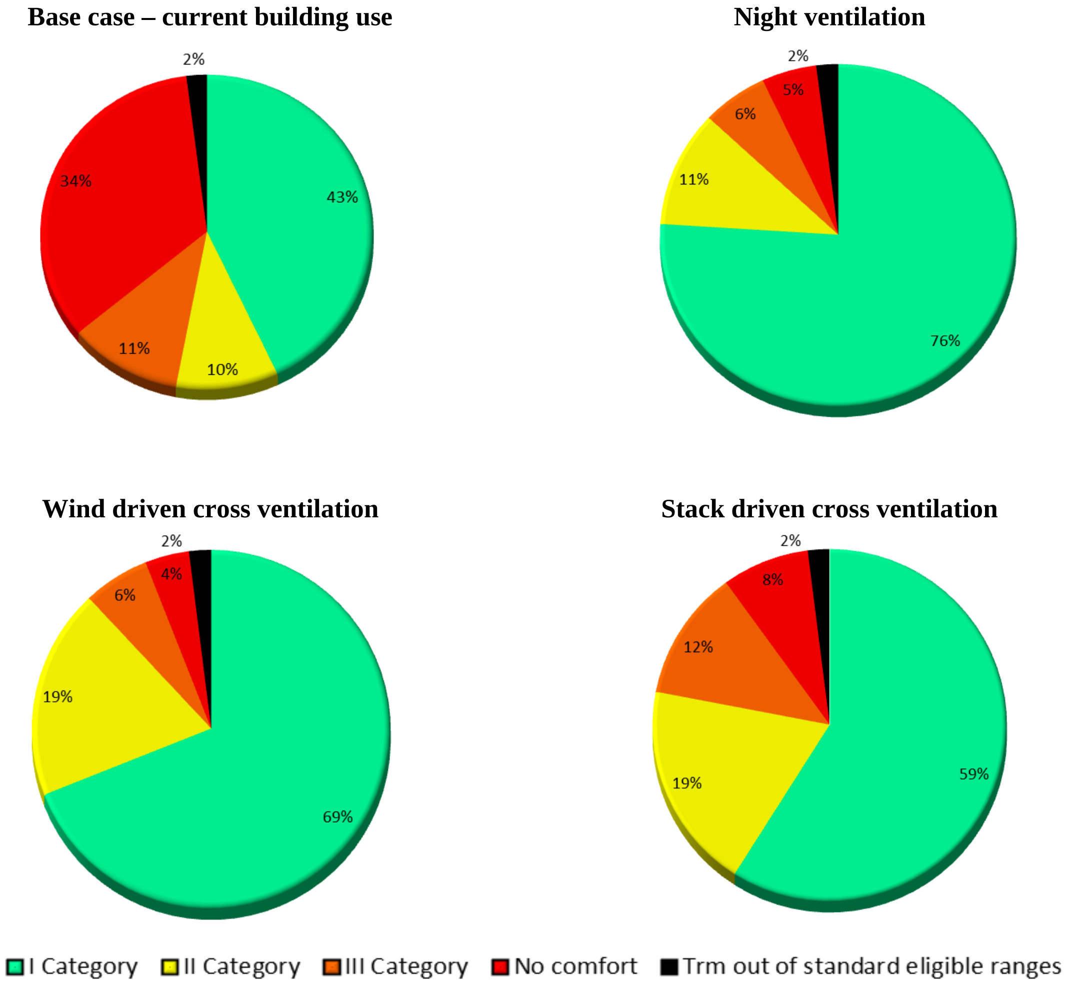

Figure 9. Comfort conditions in thermal zone considered according to UNI EN 15251 comfort standard.

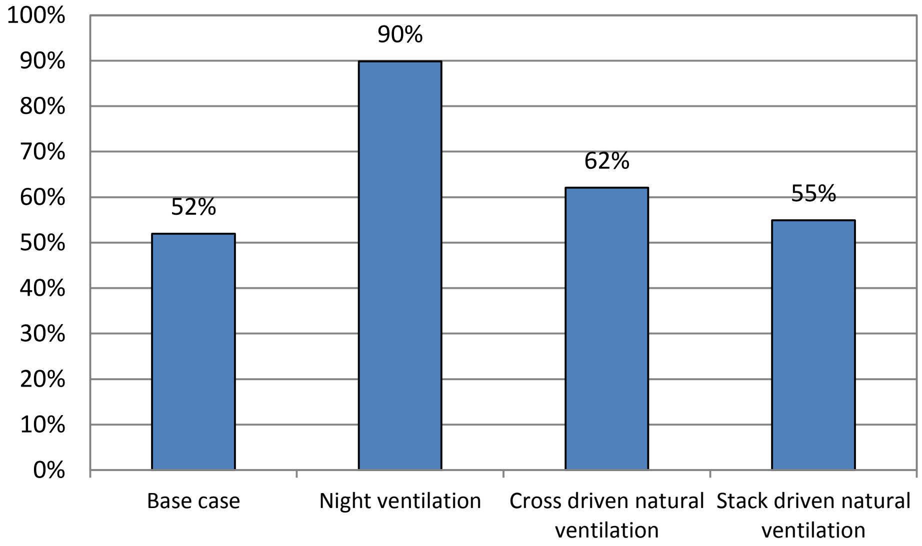

Figure 10. Mean percentage of heat (due to solar and internal loads) rejected by ventilation during the cooling season.

CONCLUSIONS

Natural ventilation seems to be a promising technique to improve thermal comfort in school buildings during the cooling season. In this work the potential of natural ventilation strategies in an existing school building has been studied.

The climate analysis showed how typical wind scenarios can be found by analysing data from a local weather station. The wind conditions at the building site are proven to rely on the dynamics of valley winds.

Three feasible natural ventilation strategies have been proposed on the basis of the climate analysis and the existing natural ventilation design guidelines: night ventilation, wind driven cross ventilation and stack driven cross ventilation.

The strategies effects on thermal comfort have been compared by means of coupled heat and airflow dynamic simulation models. The thermal comfort in classrooms has been evaluated according to the standard UNI EN 15251. Assuming a standard occupant behaviour, discomfort situations occur in the 34% of occupational period hours during the spring-summer season due to overheating. The night ventilation strategy proposed allows reducing this value to 5% and also allows increasing the percentage of hours when operative temperatures are within the first comfort category boundaries. The study was completed by a survey on existing technologies, available on the market, to evaluate the practical fesibility of the proposed solutions.

It has been demonstrated that natural ventilation is an interesting low cost solution to control indoor temperatures and avoid mechanical cooling systems installation.

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