Assesment of the indoor condition of a naturally ventilated nursery school in Rome

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ABSTRACT

The ventilation system in nursery buildings requires particular care to guarantee the safety of children [1,2]. When suitable outdoor conditions occur, natural ventilation can provide an appropriate indoor environment in terms of temperature, humidity and concentration of contaminants, if the design process is coherently developed taking into account the characteristics of the prevailing winds [3].
This study investigates numerically the fluid dynamic behaviour occurring in a naturally ventilated preschool building designed for the municipality of Rome. The air flow rate available is investigated for the prevailing winds with a CFD code, in order to simulate and investigate the quality of the environment where children live.
The results of the simulations show good overall behaviour of the environment-building integrated system in different seasonal conditions.
In the intermediate seasons the particular geometry of the buildings means that the breezes coming from the south west can be efficiently caught.
Classroom air change is sufficient to create good conditions in term of air quality.
In summer, the building can be efficiently cooled at night by opening all the windows and louvres to catch efficiently the cool catabatic wind. During the daytime the building is closed to reduce the thermal load..

KEY WORDS
Prevailing wind, natural ventilation, CFD, environment.

INTRODUCTION

The aim of this study consists in the assessment of the effectiveness of the natural ventilation and cooling system of a preschool building in Rome. Two different strategies are proposed respectively for mid and for summer season:

a. assessment of the internal air flow rate in mid-seasons considering the interaction with the prevailing winds;
b. assessment of the air flow rate generated by the summer breeze from north during the night hours.

The analysis are performed using a CFD code (Computational Fluid Dynamic).

BUILDING GEOMETRY

The nursery school considered is a one storey building 4 meters high, with un underground technical space. The structure is composed by concrete frames, completed by concrete block walls, with an external glass wool insulation of 6 and 8 cm, depending on the orientation. As for the vertical wall, the joists of the roof have an external insulating layer.

During the mid-seasons a cross ventilation strategy is provided. This works using the large windows above the occupies spaces in order to perform an as much as possible uniform air velocity field near the persons.
In Summer season a nocturnal cooling ventilation strategy is performed. The large window in the north face of the building is used as a catcher of the catabatic nocturnal wind, which can enter in the building to cool the thermal mass of the building.

ANALYSIS OF THE PREVAILING WIND

The analysis of the datum concerning the wind velocity and direction in Roma Urbe Airport makes possible to identify the following seasonal characteristic:

- From October to March, The Bores, coming from NE, and the Scirocco, from SSE are prevalent.
- During the warmer months, the winds from North leave their power, being substituted by the summer breezes. By night these breezes come from the North-East quadrant, but in the daytime this direction change in South-West.

MODELS GEOMETRY

Different models are considered in order to perform the seasonal ventilation strategies with the appropriate boundary conditions.

Mid-seasons

During the intermediate seasons, the physics system considered, is composed by the external environment modelled in order to suit appropriately the boundary conditions in term of wind velocity and direction. The mesh is unstructured tetrahedral with a node density of 0.1 m near the ceiling and near the children, measuring 0.3 m on the envelope of the building and 3 m on the boundary of the external environment.
The mesh uses 278.104 nodi, 2.717.145 faces and 1.297.246 cells.

Summer

The model of the summer condition has a modified external geometry in order to simulate the night breeze coming from the north.
The internal characteristics of the mesh are the same as before. The overall model uses 264.369 nodes, 2.614.819 faces and 1.249.083 cells.

BOUNDARY CONDITIONS

Two different boundary conditions, representative of the different seasonal conditions, are provided:

- mid season diurnal cross ventilation;
- summer night cooling.

In mid seasons the courts windows are opened in order to catch the air coming from the south quadrants. The air enters in the indoor spaces cooling the classrooms, the refectory and the hall. This air flow is then exhausted trough the north windows, guaranteeing an effective ventilation strategy. For the sleeping rooms a cross ventilation strategy is provided, normal or parallel to the wings of the building.

A night cooling strategy is provided for summer season. The simulation is performed in the first hours of the morning, when a north breeze generate an air airflow rate trough the internal spaces.

Wind profiles

For the mid season and summer simulations the definition of the boundary conditions for wind velocity is fundamental.

It is difficult to assign the correct wind velocity in a particular site because the lacking of the wind data for the considered place.

Frequently the nearest airport data, in this case Roma Urbe Airport, are used in order to define a suitable wind profile for the considered site. For the considered site the a logarithmic wind profile is used.

In Figure 1 three logarithmic wind velocity profiles are reported. Two of these are used to assess the fluid dynamic behaviour of the building.

Two wind profiles corresponding to a reference velocity of 1 m/s (critical ventilation condition) and of 3 m/s (discrete ventilation condition) are used at the boundary of

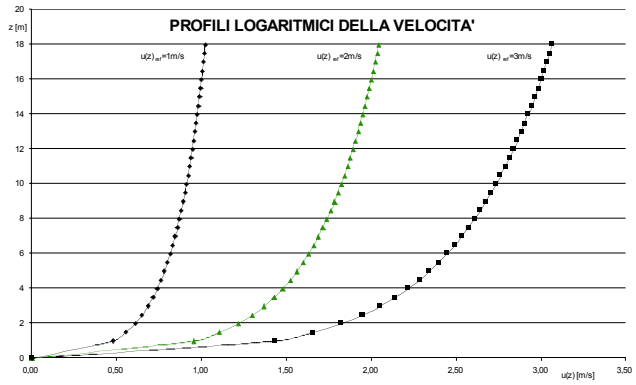


Figure 2 - Logarithmic profiles of wind velocity for different values (1, 2, 3 m/s) the reference velocity

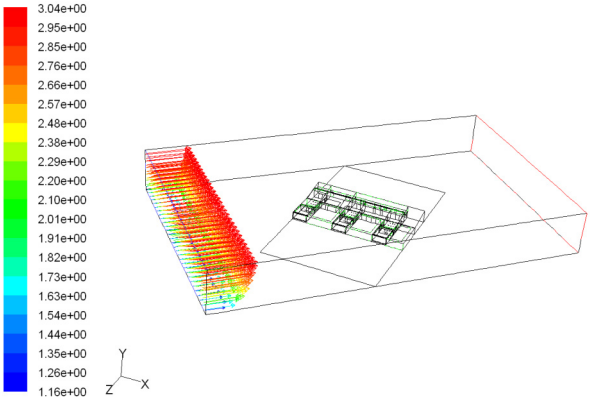


Figure 2 – Wind profile for the mid-season with discrete ventilation conditions (u_{ref} = 3 m/s)

the calculation domain which is 65 meters far from the building, with a SW direction.

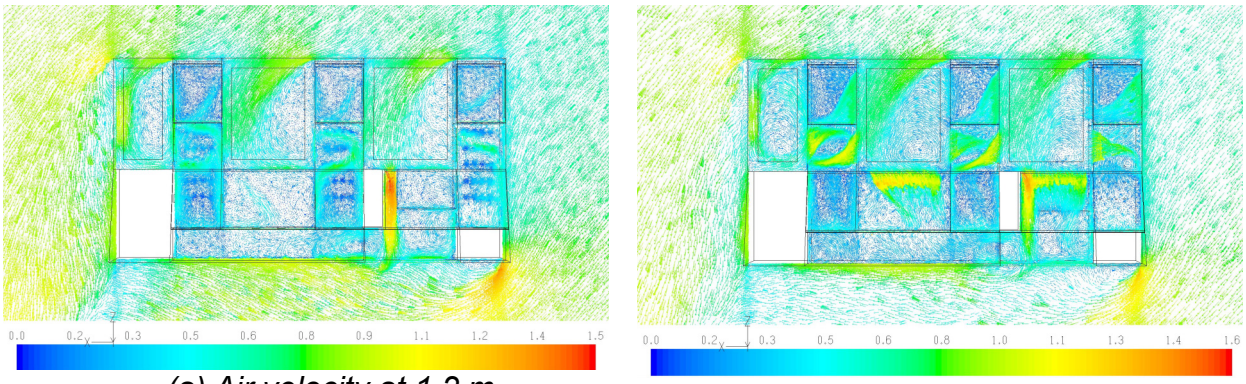
For the summer season a breeze from norh is considered with a reference velocity of 1 m/s. The corresponding log wind profile is assigned 30 m far from the north façade of the building.

RESULTS

Mid season

Critic ventilation conditions

The vectorial field of the air velocity in critic condition shows the particular effectiveness of the building to catch the air fluxes because of its particular geometry. This behaviour is shown in the air velocity distribution at 1.2 m from the floor (Figure 3,a). The air which comes from south-west impinges directly the occidental walls of the extremities of the branches, which catch the prevailing wind . The air trapped in the court generates an overpressure field. This situation makes possible the entrance of the air in the indoor spaces trough all the windows of the courts, leeward ones included. The air velocity field at 2.7 m (Figure 3,b), the height where the classroom intakes are positioned, shows the entering fluxes in the indoor spaces: The velocity



(a) Air velocity at 1.2 m *(b) Air velocity at 2.7 m*

Figure 3 – Vectorial air velocity distribution in critic conditions

of the air entering in the classrooms reches a maximum value of 1 m/s on the east and on the west side at a height sufficiently far from the children.

The entering fluxes from both the sides generates a clockwise turbulent flow which mixes the indoor air (Figure 4,a). The exhaust at the north façade is aided by the Coanda effect and by the heating of the indoor air. The sleeping rooms, direcly impinged by the prevailing winds, use a cross ventilation strategy (Figure 4,b).

Actually wind which comes from south imipinges the west openings without finding relevant obstacles to the enter. The air enters with a 0.8 m/s velocity generating an overpressure in the occupied zone going out spontanuosly from the east windows.

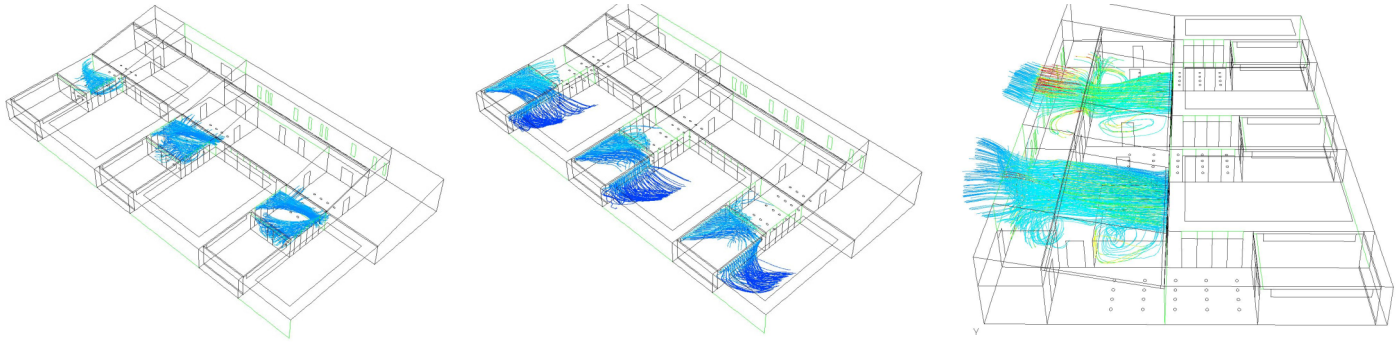
The indoor spaces displaced in the building branches are then treated by an indirect cross ventilation strategy, generated by the pressure induced by the particular shape of the building, for the classrooms, and by a direct cross ventilation, caused by the direct entry of the air without a sensible change of direction, for the sleeping room.

The position of the intake, 2.4 m from the floor, improves the global behavior of the system, cutting back the discomfort caused by the excessive air velocity near occupants.

The air path in the canteen and in the hall is similar to that of the sleeping rooms (Figure 4,c). The incoming fluxes cross the rooms at an elevated height affecting only indirectly the occupied spaces, where a more uniform and turbulent low velocity motion is performed.

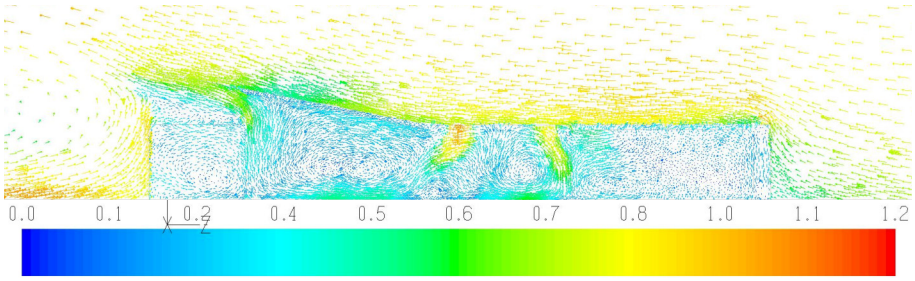
In the nearest zones to the windows of the classrooms the incoming fluxes from west on the left side and those incoming from the east on the right side are visible (Figure 5,a).

The intake air in the classrooms generate a vorticose motion which mixes the air with velocities between 0.4 and 0.6 m/s near the occupants. The zones where the

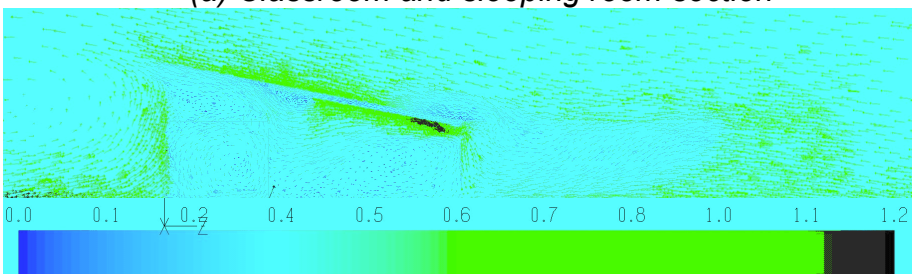


(a) Classroom intakes *(b) Sleeping room intakes* *(c) Hall and canteen intakes*

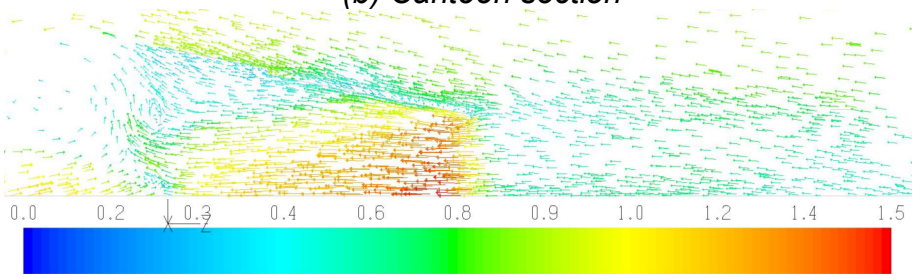
Figure 4 – Path lines of the airflow in critic conditions



(a) Classroom and sleeping room section



(b) Canteen section



(c) Hall and entrance corridor section

Figure 5- Vectorial representation of the air velocity

density of the vectorial field is higher is that where occupants stand.
The maximum air velocity in the canteen space is 1.2 m/s. This value is sufficiently far from that near the occupants, which is under 0.5 m/s (Figure 5,b).
In the meridional entrance, in the south façade, the air velocity is of 1.5 m/s, a value which can be considered undesiderable for the comport of occupants. The situation makes desiderable the closing of these opening, using only the intake vents at the top of the south wall.
This analysis considers the openings without obstacles to the propagation of the air fluxes. The presence of the window frames will generate a load loss which has to be considered in the calculus of the real performance of the natural ventilation system.
The air flow rate is 5600 m^3/h for each windows of the central and east branches classrooms. These spaces, which have two orders of windows each, have therefore a 11.200 m^3/h air flow rate, which define an ACH of about 46 Vol/h. The west classroom which has only west windows has a 20 Vol/h ACH.
The hall and the canteen are frontally impinged by a flux deviated by the branches, with a maximum outdoor air velocity of 0.6 m/s. This low velocity is sufficient to generate an important airflow rate because of the large windows facing the courts.
The air going trough the windows accelerates gaigning a velocity of 1.2m/s. The air flow rates are about 14.300 m3/h for the canteen, and 29.500 m3/h for the hall. if the volumes of these spaces is considered, it is possible to calculate respectively an ACH of 50 Vol/h and a 70 Vol/h.
As previously said, the real air flow rate might consider the presence of the opening frames which represent an obstacle for the air fluxes.

The indoor air velocities reported make acceptable higher temperatures than in the case of low air velocities, typical for the HVAC systems.

Medium ventilation conditions

The overall outdoor and indoor airflow is qualitatively coherent with the analysis for the previous critic conditons.

The behavior of the spaces of the buildings is the same of that with critic condition, considering the difference that velocities and consequently the air flow rate are increased.

Summer season

The north façade is congured in order to catch suitable air flow rate for the nocturnal mass cooling in summer season. This study case analyse the fluid-dynamic behaviour when the major part of the windows is opened making possible the entrance of the nocturnal breeze.

The air go in the classrooms with a enough high velocity crossing the indoor spaces. The east branch of the building the air velocity and the air flow rate is more reduced because of the minor surface of openings available. Nevertheless the measured average air flow rate trough the link vents between the two adjacent rooms is 3090 m^3/h, equivalent to 20 Vol/h.

During enough critic ventilation conditions (v_{ref} = 1m/s) the air flow rate trough the north intake is 52.560 m^3/h equivalent to 24 V/h.

Considering the site ventilation conditions the calculated air flow rate are suitable to perform an effective cooling nocturnal strategy.

CONCLUSIONS

The results of the simulations show an overall effective behaviour of the building-environment system in the different season conditions.

During the mid season the particolar geometry of the building make possibile to catch effectively the south west breeze generating a considerable air flow rate, able to improve the indoor comfort conditions.

The spaces used as sleeping room are also efficiently cross ventilated during the mid season, with a satisfying overall behavior of the thermal parameters. When north winds are experienced the direct cross ventilation strategy has to be abandoned being unsatisfying for this kind of wind. In order to ventilate this spaces also for north wind conditions, a number of internal vents are installed between the classrooms and the sleeping room, to generate an airpath trough these spaces.

The canteen hall is efficiently ventilated by a laminar flux which leake the covering joist, generating the mix of the air below near the occupants.

The entrance hall, as the room of the canteen, is efficiently ventilated, with a cross ventilation strategy able to undirectly cool also the office occupants without generating excessive air velocity values.

During the summer season, the building can be effectively cooled opening all the windows by night in order to catch efficiently the north breeze. This cooling strategy will be as effective as large the inlet sections will be.

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