

Passive natural cooling techniques for wooden buildings in warm climate: case study

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ABSTRACT

The consequences of the global climate change are perceptible even in Italy, where in the last 15 years the mean temperature values increased of 0.4 °C in the northern part of the country and of 0.7°C in the southern one. It is besides well known that the 44% of the total energy consumption in Italy is due to the building sector, and the situation is unfortunately not improving yet. It is therefore of primary importance to outline guidelines for designers in order to realize low energy buildings with high performances not only in wintertime but even in warmer periods in order to reduce the energy demand for cooling. This paper deals with a research activity carried out by the University of Trento together with the Polytechnic of Bari concerning the analysis of a bioclimatic building with a prevalent wooden structure placed in Mezzane di Sotto (Verona – Italy), provided with a wind tower for passive cooling and a sun space for passive heating. In particular, two main aspects have been investigated: the behaviour of the building during real life conditions by means of a survey of the main inner thermal and air distribution characteristics; the theoretical behaviour of the natural ventilation system by means of the Computational Fluid Dynamics (CFD) numerical simulation. While the model reflects the behaviour as it should be, the on site continuous survey gives the possibility to assess the model outputs and to understand the users influence on the real building performance.

In this way, some simple rules can be given concerning the design of sustainable buildings with passive cooling techniques in Northern Italy.

1. METHODS

The aim of the research is to provide tools for designers to support the design of bioclimatic buildings (for new constructions as well as for retrofitting actions) in order to improve the energy efficiency in winter and summertime using adequate passive solar devices and natural materi-

als with a low impact in terms of LCA (especially timber).

The research is organized into five steps:

- modelling and simulating the thermal behaviour of one pilot building during winter and summertime using specific software (Ecotect, EnergyPlus, DesignBuilder and CFD analysis), with particular attention to the natural ventilation strategies in order to decrease the inner temperature during the hottest periods of a typical Italian summer;
- testing the performances of the pilot building by monitoring the inner microclimate parameters and the energy behaviour on site during real life conditions for one year and comparison with computer simulations;
- critical calibration of the model taking into account the real performance of the building so to have a “perfect virtual copy” of the house;
- suggesting changes of the building design (by a formal, technical, constructive and material point of view) in order to improve the efficiency and the inner comfort conditions and testing the results on the virtual model;
- determining a practice code to support choices towards a correct design of bioclimatic buildings in Northern Italy, with particular attention to the passive cooling techniques.

The research presented in this paper is still on going, so the first two steps will be described and discussed.

2. THE OBJECT BUILDING

The building intervention analysed during the research consists of four terraced houses placed in Mezzane di Sotto (122 metres asl) near Verona in Northern Italy. It is interesting because both natural materials and passive bioclimatic strategies have been used and experimented in order to increase the users comfort conditions and to diminish both the summer and the winter total energy consumption. First of all, particular attention has been put to the morphology of the site, positioned on an hill on a steep slope mainly oriented to South-East. For this reason,

the building units have been designed focusing on their transversal sections and then joint together on the NE and SW direction. In this way, it is possible to cross the hanging garden and to enter the sunspace, the sitting room and then the sleeping area following a SE-NW direction (Fig. 1).



Fig 1. The south-east façade where the hanging garden and the sunspace are exposed

By a structural point of view, the building has a concrete basement while the main body is a bearing wooden panel construction with 8 cm of external insulation of pressed natural fibres and an internal finishing of gypsum board.

For what concerns the climate, the site is characterized by hot summer and cold winter periods, no fog banks (usually typical of the

Padana Valley) and prevailing winds going up and down the slope during the day and the night respectively. Therefore, the first idea of the designer was to realize a natural ventilation system for the summer cooling by the sequence massive basement – staircase – wind tower (hereafter specified) and to provide a sunspace for winter heating that could be completely opened during the summer becoming a kind of porch, taking advantage from the good orientation and the lack of foggy days.

In particular, during winter sunny days the solar heating coming from the sunspace and the large windows in the living room (Fig. 1) is stored in the concrete floor that acts as a huge thermal mass, and this should balance the “light” behaviour of the walls wooden structure. Moreover, the sunspace is like a buffer area that prevents the decrease of the temperature in the living room during the night (the minimum sunspace inner temperature is supposed to be 5°C when the outside temperature is 5°C below zero).

During summer the situation is just the opposite. A rough calculus have been made in order to position the sitting room windows avoiding direct solar irradiation through an appropriate overhang. Moreover, an opaque removable curtain has been put over the sunspace roof

in order to prevent overheating during the day and the windows can be completely opened allowing a complete ventilation of the sunspace.



Fig 2. The north façade protected by the hill and with the wind tower for the natural ventilation strategies.

The daily summer ventilation (prevailing wind from south) should allow the expulsion of the air entering the windows in the basement from the wind tower (Fig. 2). The basement acts as a thermal inertial mass that allows the air to cool down a bit before going through the house using the staircase. During the night (prevailing wind from north) the fresh air comes down from the hill and pass through the house going across the bedrooms. The monitoring of the building began in January 2007 and it is still on going.

3. THE THERMAL SURVEY

The thermal analysis and the monitoring of the building is strictly related to the evaluation of the behaviour of the natural ventilation system concerning users' comfort conditions during the summer period. So, in the early stage of the research probes for the recording of the temporal courses of air temperature, relative humidity, air velocity, globe temperature and walls surface temperature have been positioned in some rooms chosen to be representative of different indoor conditions, levels and exposure. In this way, it is possible:

- to analyse the performance of the sunspace for the winter heating as well as the functionality of the shading devices in order to avoid overheating during the warmest period of the year;
- to evaluate the performance of the light wooden walls and of the heavy concrete slab in order to highlight the different behaviour of building elements with different specific weight, and to investigate the possibility to built light structures in warm Italian climate when appropriate heavy elements are added so to guarantee the thermal inertia of the building

system;

- to record and analyse the changing of the air temperature values entering the building and most of all to check the possibility to use the natural ventilation system even when the outside air temperature is higher than the inner one by means of a convective cooling system (the passage in the basement);
- to use anemometers inside the building in order to record the real capacity and direction of the air flows in the indoor environment.

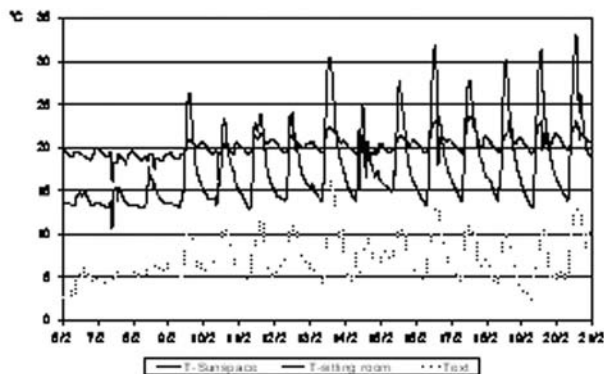


Fig 3. Trend of the temperature values in the sunspace and in the sitting room – February 2007.

Even if in this paper particular relevance is given to the testing of the effectiveness of the natural ventilation design by means of a CFD analysis, it seems important to briefly show the most important results coming out from the first 5 months of monitoring (January-May 2007), that seem to confirm the validity of the design choices.

3.1 The sunspace

During February, when the minimum average values of the outside temperature were of 4-5°C, the temperature in the sunspace never drop under 13°C, while during the day, with the maximum average values of the outside temperature of 13°C, the temperature in the sunspace raised till 30°C without the shading devices (Fig. 3). On one side, the warm sunspace guarantees temperature values in the sitting room between 19 and 22°C with a minimum intervention of the heating system (optimum comfort conditions); on the other side, it is a first warning about possible overheating phenomena during the warmest period of the year. In fact, during April the maximum temperature in the sunspace raised up to 38-44°C with a relatively low outside temperature (22-24°C), and this cause a consequent overheating of the adjacent sitting room. The introduction of shading devices (opaque movable curtains) on the sunspace roof allows to decrease the maximum temperature of the sunspace to 28°C and of the sitting room to 24.5 °C, even if the outside temperature was slowly increasing (Fig. 4).

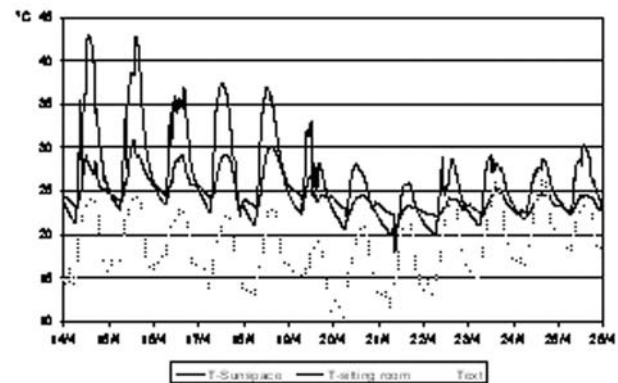


Fig 4. Trend of the temperature values in the sunspace and in the sitting room – April 2007.

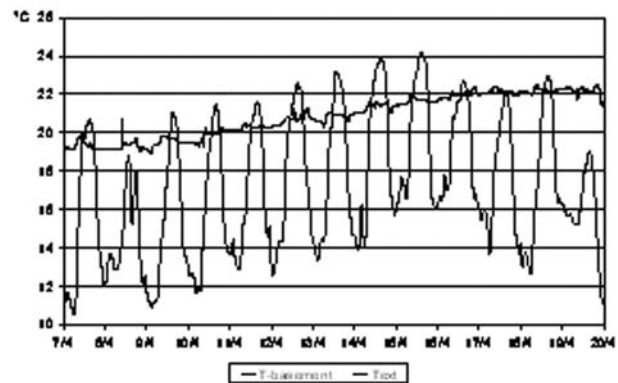


Fig 5. Trend of the temperature values in the basement – April 2007.

3.2 The basement

The temperature values in the basement has a little daily swing (Fig. 5), and the maximum value is lower than the outside temperature one. This fact is positive concerning the future behaviour during the summertime concerning a first cooling of the warm air entering the building from the basement openings and used for the natural ventilation cooling.

4. NATURAL VENTILATION SIMULATIONS

The natural ventilation system has been verified by means of Computational Fluid Dynamics (CFD) simulations in order to evaluate the performances and to plan the field investigations.

The details of the calculation models have been set in order to capture the main behaviour of air flow (inside and outside the monitored building) due to the wind. So, the model is composed of (Fig. 6):

- the monitored building including external openings (windows characterized by variable degree of opening), internal partitions and doors (totally opened or closed);
- the other buildings of the complex (modelled as

- blocks without openings);
- the ground and the main external obstacles (external walls, etc.).



Fig 6. CAD model used for CFD simulation.

The climatic data highlight that wind flows mainly from SSE and NNW (Fig. 7). The collected data show that the wind has a periodic behaviour: during the night time cold winds blow down slope hill from the north side, while during the day time, convective currents rise from the south side. This behaviour may be related to thermal effects and to the ground morphology. The collected data are limited to the winter period and further data are necessary to investigate the prevailing winds on other seasons. The numerical simulations presented in this paper concern the effects of the prevailing wind, that is basically perpendicular to the façade of the pilot building.

The buoyancy effects has been ignored and will be evaluated in future works.

The openings has been simulated as sloping planes (basement level, wind tower at the top) or plane resistances (main room and bedrooms). Different combinations of openings have been tested. Here the “base case” is presented: windows at the basement and at the top level open, doors of the main room totally open.

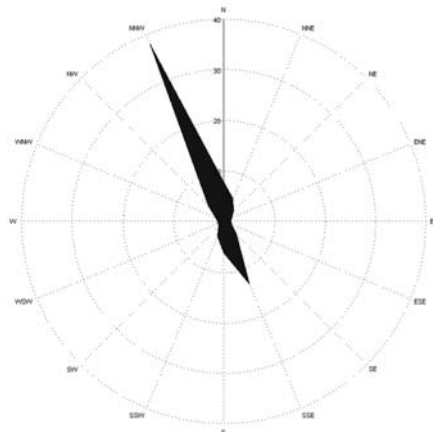


Fig 7. Windrose about the period January-April 2007.

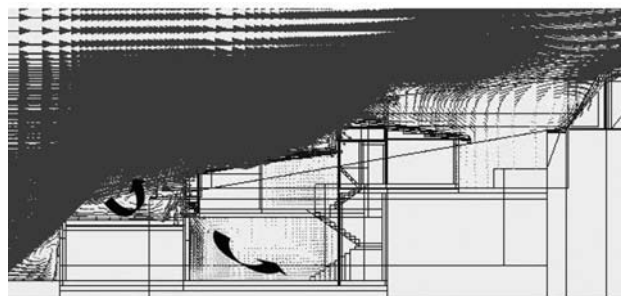


Fig 8. Wind from south: global transversal section.

4.1 The results

The first set of CFD simulations concerned the study of the behaviour of the natural ventilation system with prevailing wind from the south side. The air should enter the building at the basement level, get cool near the ground and been extracted from the wind tower. The simulations highlight that:

- near the inlets at the bottom level (upwind) and near the outlets at the top (downwind) the airflow re-circulates (Fig. 8); the main behaviour of the external flow is related to the sloped morphology of the building-ground complex;
- the openings at the basement level are partially shielded from the external wall (Fig. 8, 9);

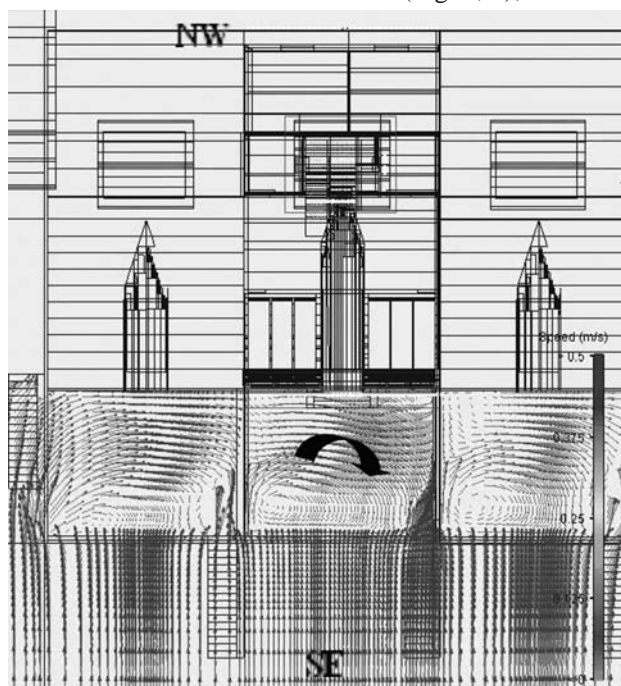


Fig 9. Wind from south: plan near the basement openings.

- not all the openings at the basement level are inlets, so the external air circulates inside the room at the basement and is extracted outside without cooling the building; this behaviour may be due to the non-symmetrical flow caused from the stairs at the east

side and from the building at the west side of the complex (Fig. 9, 10);

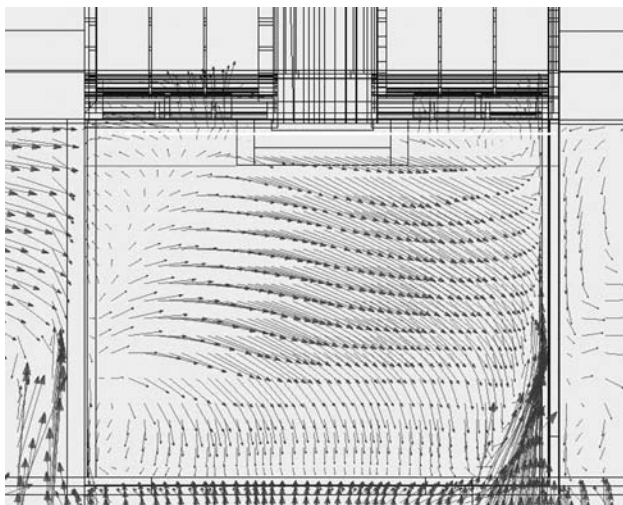


Fig 10. Wind from south: plan near the basement openings (detail of the inlets).

- the air cooled at the basement level flows mainly along the staircase with poor circulation inside the main room (Fig. 11, the bedrooms doors are hypothesized closed);
- the airflow rates flowing from the openings at the west and east side of the wind tower are different; this is due to the wind deviation at the top of the building (see details of Fig. Fig. 12).

The CFD simulations highlight that the main behaviour is as expected during the design phase, but the details can have a fundamental role in the design of natural ventilation system.

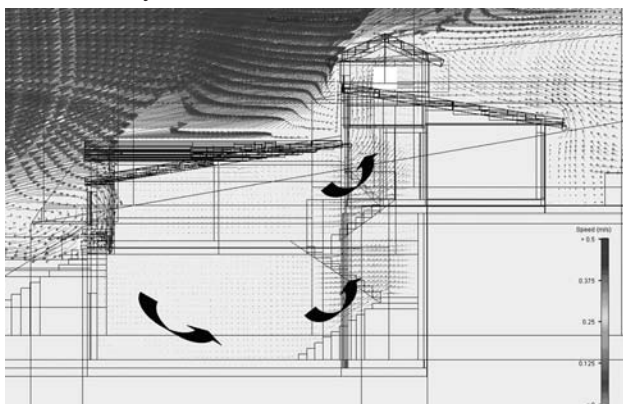


Fig 11. Wind from south: transversal section near the staircase (detail).

For example, the shielding effects of the external wall in the hanging garden has been ignored and the aerodynamic of the inlets at the basement level has not been optimized. The inlet airflow is not directed to the cold surfaces (floor), so the cooling effect of the ground may be less than expected.

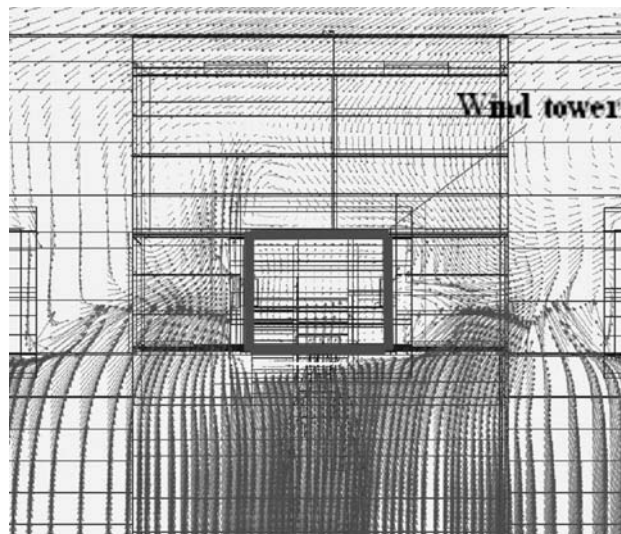


Fig 12. Wind from south: plan section near the wind tower (detail of the outlets).

Another possible lack of performance is due to the poor air circulation in the sitting room: it seems that colder air rises in the staircase without circulate in the main room and with no suction effect. However, this behaviour needs further numerical simulations that will evaluate the thermal effects, as well appropriate in field monitoring. Future simulations will evaluate the behaviour of the natural ventilation system without the cooling of the basement (windows of the sitting room opened). This ventilation strategy may be effective in intermediate seasons to avoid overheating of the sunspace. Numerical simulations and monitoring of thermal behaviour of the building will suggest the airflow rates adequate for passive cooling and the controls of the system.

5. CONCLUSIONS

The classical design principles based on the natural ventilation strategies, seem to be applicable even in Northern Italy in order to guarantee appropriate users comfort conditions in warm climates without mechanical systems using fossil fuels. In particular, the CFD simulations suggest that the presence of a large basement underground with low daily temperature swing and maximum values lower than the outer ones plus a wind tower over the staircase (directly connected with the basement), allows a certain fresh air circulation in the house. Both the air cooling during the day and the structure cooling during the night are assured. The monitoring of the main thermal parameters inside the building during the first 5 months of the year supports the model analysis. However, even if the whole building design is appropriate, the introduction of some optimized details (both outside and inside) should allow

a better behaviour of the natural ventilation strategies, most of all for what concerns the amount of air flows involved in the rooms and the efficiency of the pre-cooling effect of the basement.

The further step of the research will be the complete monitoring during the rest of the year (with particular attention to the inside air circulation) and the suggestions of some changes in the building shape (verified on the CFD model) so to improve its performance as well as the users comfort conditions, and to evaluate even the impact of some changes occurred to the original design during the building construction.

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