Modeling and Measurements in Natural Ventilation of Massive Buildings: A Case Study

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Abstract

Numerical simulations are widely used to evaluate the thermal comfort and energy savings in the retrofit of historic buildings. In most cases, however, no detailed data are available on the materials and stratigraphy of the building envelopes, and on-site measurements can be expensive and time consuming.

The present work uses as a case study a university building characterized by a high thermal capacity in the city of Rome to verify whether the use of natural ventilation can be a practice of use in order to guarantee energy saving and natural comfort.

To this end, in the summer of 2020, an experimental campaign was carried out aimed at acquiring thermofluximetric measurements through the vertical walls, the air temperature inside and outside the analyzed environment and the air velocity. Measurements were conducted under three different usage protocols, including night ventilation and 24-hour continuous ventilation.

These measurements made it possible to identify the thermophysical characteristics of a wall considered "equivalent" to the real wall, allowing the realization of thermofluidodynamic computational models. In particular, in the study, 3 different stratigraphies were considered and compared, corresponding in the first case to the equivalent wall, in the second to that available from the Comsol software library, and, finally, in the third and last case, from literature data (Tabula project) for the building typology analyzed.

From the analysis, it emerged that the 3 groups of parameters do not have a significant impact in terms of variation of internal comfort, confirming the reliability of the use of the literature values for these types of modeling.

1. Introduction

Several findings in the literature highlight the significance of the aspects related to the indoor climatic control and the energy efficiency of historical buildings (Bay et al., 2016).

Natural ventilation of buildings is a good practice for the air quality of living and working environments and the well-being of the occupants. One of the significant effects of an adequate air change is the contribution given to the reduction of gas levels in buildings. The systems that are usually applied in heritage buildings are forced air coils and radiators based on hot water, since the initial investment is quite low compared with other solutions, and they have a short response time to cool/heat large volumes of indoor air. These two plant typologies adapt very well to the specific occupancy patterns and can be employed either discontinuously, targeting occupant thermal comfort satisfaction for a brief period of time, or uninterruptedly, to maintain constant hygrothermal conditions benefitting from the building's thermal mass (Bay et al. 2016; Bencs et al., 2007; Bratasz et al., 2007).

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In buildings which are not designed to guarantee an adequate number of air changes, the ventilation obtained through the opening of windows does not allow high indoor thermal comfort level to be maintained, which inevitably returns within a few hours to levels similar to those present before ventilation.

An alternative to the ventilation obtained by simply opening windows can be obtained by equipping the building with an active ventilation system, obtained by means of ducts and aspirators that ensure an exchange of air between the external and internal environment.

This system guarantees greater continuity in the ventilation of the environment, not being linked to manual intervention, and can be carried out uninterrupted or cadenced over 24 hours, limiting the inconvenience of not being able to be used in the presence of wind. However, it should be emphasized that the use of active ventilation must be suitably sized, in order to avoid possible negative effects of a different nature.

In the presence of natural ventilation and high thermal masses, the use of passive and hybrid strategies based on natural ventilation and nocturnal thermal mass precooling can be crucial in terms of internal comfort and energy saving.

The aim of this work, taking as a case study a university building characterized by a high thermal capacity in the city of Rome, is to show the potential of CFD numerical models for quantifying the cooling effects and internal thermal comfort, analyzing different sets of thermophysical parameters assigned to the high thermal mass walls.

2. Material And Methods

This work presents a 2D model of Pavilion 2B (Fig. 1) of the *Ex-Mattatoio* (former abattoir) (Ersoch, 1891) in Rome, built using Computational Fluid Dynamics (CFD) software based on the finite element method (FEM). The transient simulations, as explained in a previous work (Vitale & Salerno, 2017), take the temporal variations and the interactions between internal and external thermal conditions into account, with the aim of evaluating different usage profiles and estimating the effects of passive cooling in the presence of natural ventilation and high thermal masses.

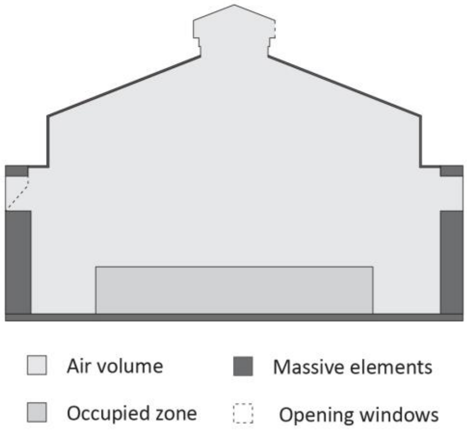

Fig. 1 – Cross section of the Pavilion 2B

The simulations were set up according to the following criteria:

- considering the variations in external conditions (temperature and solar radiation);
- without the use of HVAC systems;
- without occupancy load.

All simulations were carried out in three different usage profiles:

- with nocturnal and diurnal ventilation (24hV);
- with only nocturnal ventilation (10hV);
- without natural ventilation (Nov).

In addition to the three usage profiles, a parametric study was conducted using in each simulation three different sets of thermophysical parameters assigned for the wall (Table 1), determined as follows:

- COM: values from COMSOL Multiphysics library and literature (old simulations);
- SOS: values calculated with measured data and equivalent wall model;
- TAB: values from Tabula library, a report on Italian Building Typology realized by Turin Polytechnic as part of a European project and including the thermophysical characteristics of the most common building types in Italy from the 20th century onwards (Tabula project).

Table 1 – Thermophysical properties of the walls used for the simulations

Set	Thermal conductivity λ	Heat capacity c	Density ϱ
Unit	[W/(m·K)]	[J/(kg·K)]	[kg/m³]
COM	0,81	1512	1800
SOS	0,68	1200	2200
TAB	0,64	840	1681

In particular, Figs. 2 and 3 illustrate the plan of the pavilion selected for the experimentation (Fig. 2) and the measurement scheme of the instruments used for the acquisition of experimental data in the study room (Fig. 3) (Insula Architettura e Ingegneria), respectively.

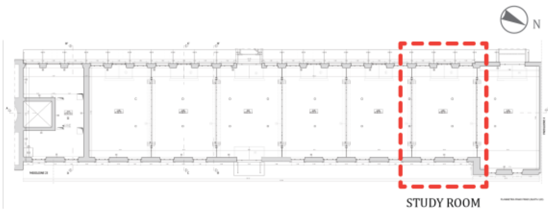

Fig. 2 – Plan of the pavilion analyzed with the delimitation of the study room

The experimental campaign took place in summer, in the period from 28 July 2020 to 7 September 2020, with the aim of acquiring data on the surface temperatures inside and outside the study wall, the heat flow through the wall, the temperatures of the air both inside and outside the study room, at the speed of the internal air (by placing a microclimatic control unit in the central position of the study room), and finally the surface temperature of the floor in the area near the microclimatic control unit. The uncertainty related to the measurement performed on the case study is equal to ±10 % (Evangelisti et al., 2022).

The data recorded allowed the study room to be characterized from a thermal point of view and made it possible to evaluate the equivalent thermal properties of the multilayer wall under study by coupling the simulations conducted with COMSOL Multiphysics software (COMSOL) on the experimental measurements (Evangelisti et al., 2022). By assimilating the multilayer wall to an "equivalent homogeneous wall" (Evangelisti et al., 2018.), thanks to a methodology already applied in several literature studies, its "equivalent thermophysical properties" were determined, thus obtaining a further set of data called "SOS" (Evangelisti et al., 2018; Gori et al., 2016).

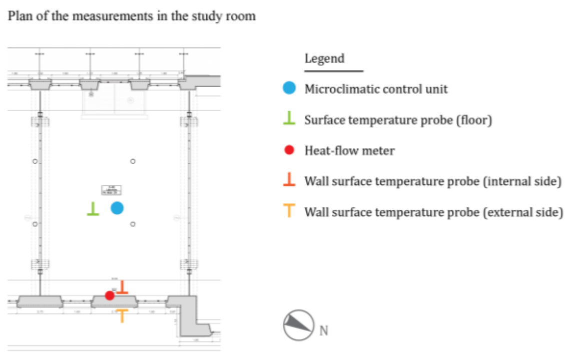

Fig. 3 – Plan of the study room with the measurement scheme of the instruments used in the experimental campaign

The main objective of this work is to show the potential of CFD numerical models for quantifying the incidence of different thermophysical characteristics on internal thermal comfort conditions in buildings with high inertia wall in different natural ventilation scenarios.

Figs. 4 and 5 show the air temperature trend (considering the average in the potentially occupied zone), the mean radiant temperature and the operative temperature for the three thermophysical sets with nocturnal and diurnal ventilation (24hV).

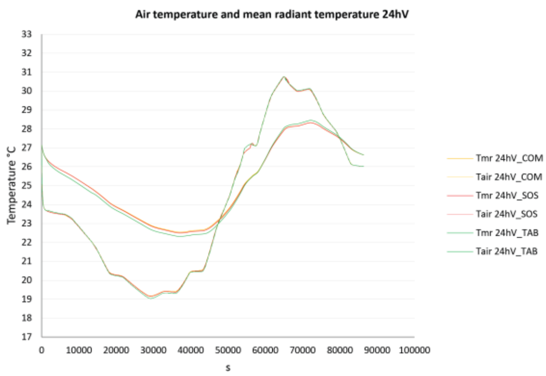

Fig. 4 – Air temperature and mean radiant temperature with diurnal and nocturnal ventilation (24hV)

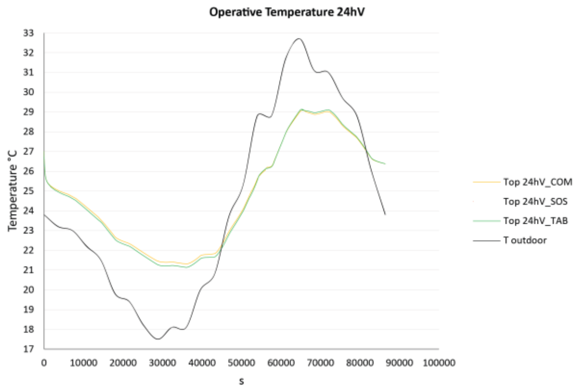

Fig. 5 – Operative temperature with diurnal and nocturnal ventilation (24hV)

In Figs. 6 and 7, the results for the three thermophysical sets with only nocturnal ventilation (10hV) are shown.

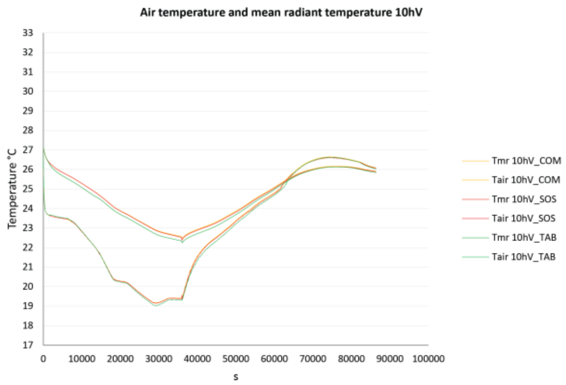

Fig. 6 – Air temperature and mean radiant temperature with only nocturnal ventilation (10hV)

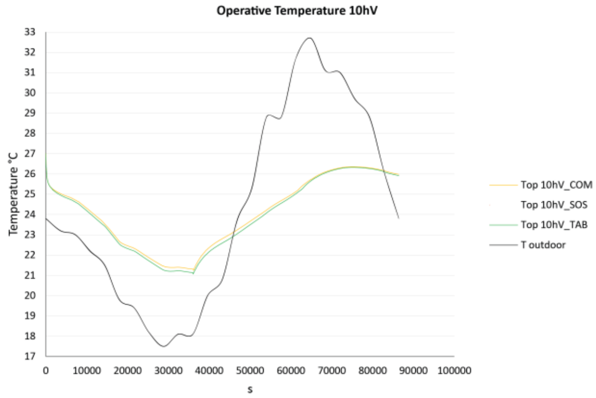

Fig. 7 – Operative temperature with only nocturnal ventilation (10hV)

In Figs. 8 and 9, the results for the three thermophysical sets without ventilation (NoV) are shown.

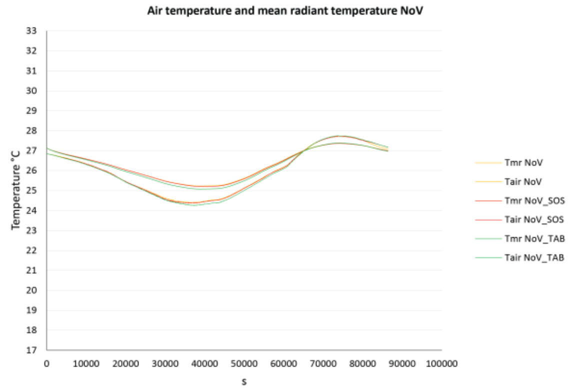

Fig. 8 – Air temperature and mean radiant temperature without ventilation (NoV)

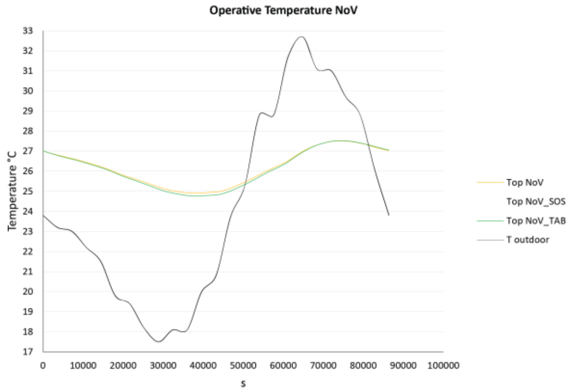

Fig. 9 – Operative temperature without ventilation (NoV)

Finally, Figs. 10, 11 and 12 show, for each ventilation scenario, the differences found between the results of the simulations, using the three sets of thermophysical parameters. The figures show the maximum, minimum and average difference of the mean radiant temperature (Tmr), the air temperature in the potentially occupied zone (Tair), and the operative temperature (Top).

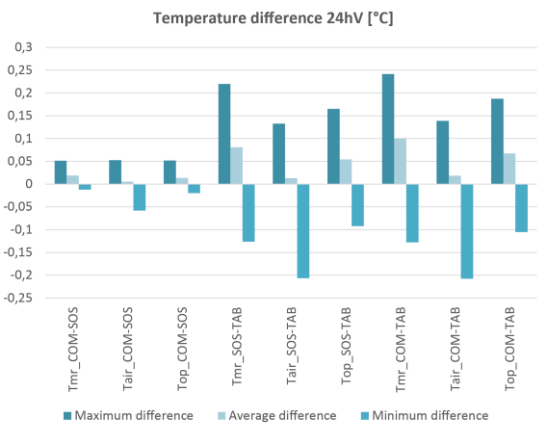

Fig. 10 – Temperature difference between thermophysical parameters sets with diurnal and nocturnal ventilation (24hV)

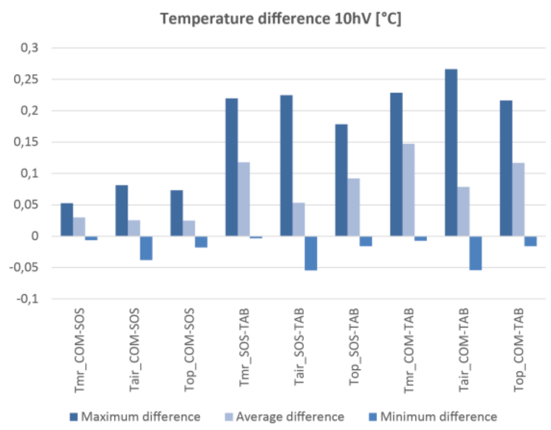

Fig. 11 – Temperature difference with only nocturnal ventilation (10hV)

By comparing temperature differences, we deduce that, in the three cases, although the parameter sets are different, their impact on internal condition is not so incisive.

It is interesting to note that the COM and SOS sets have more similar trends than the TAB set. Since the COM and SOS sets have more similar values of heat capacity while the SOS and TAB sets have more similar values of conductivity, it can be deduced that, in buildings with high thermal inertia under natural ventilation scenarios, the heat capacity value of the walls has a greater impact, in terms of internal comfort, than the thermal conductivity.

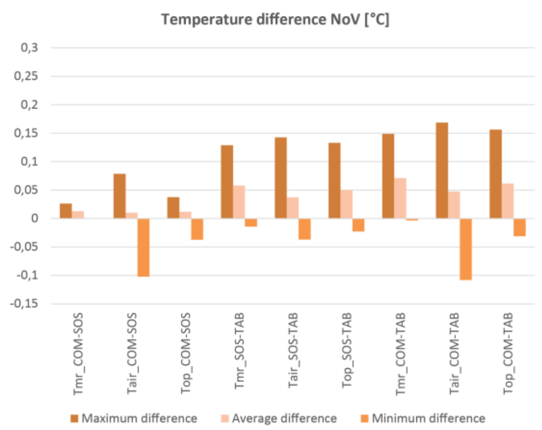

Fig. 12 – Temperature difference without ventilation (NoV)

This concept is reinforced by the fact that the NoV profile (without ventilation) is the one that reports the lowest differences between the three sets of thermophysical parameters.

3. Conclusions

In buildings characterized by high thermal masses, employing passive and hybrid strategies based on natural ventilation and nocturnal thermal mass precooling can be a critical issue for internal comfort and energy saving. With the aim of verifying whether the use of natural ventilation can be a practice of use to achieve energy saving and natural comfort, this work took a university building (in the city of Rome) characterized by high thermal capacity as a case study.

Different CFD numerical models were carried out to quantify the cooling effects and internal thermal comfort of different thermophysical parameters assigned to the walls and different natural ventilation scenarios (both nocturnal and diurnal).

It is worth noting that, when comparing the temperature differences among the three cases analyzed, although they have different thermophysical parameters, their impact on internal condition is not significant. Starting from the characteristics of the parameters sets considered, it can be observed that the internal comfort of buildings characterized by high thermal inertia, under natural ventilation conditions, are more influenced by the heat capacity value than by the thermal conductivity.

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