COMFORT IN HOT SEASON IN A MEDITERRANEAN BUILDING. A ZONAL APPROACH.

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ABSTRACT

In the Mediterranean countries, where the active solutions of air-conditioning must be avoided, natural ventilation allows improvement of indoor comfort which is generally critical in hot season, and reduction of building cooling loads.
A three-dimensional zonal model for calculating temperature fields and airflow distributions inside unconditioned buildings was developed. Its coupling with a thermal comfort model allows to evaluate the thermal quality of the ambiance by the prediction of a comfort note.
This paper presents the use of this model to study the effect of the night natural cross-ventilation on the temperature field and the air velocity distribution inside an unconditioned Tunisian building, and the evaluation of the thermal sensation of its occupants.

KEYWORDS

Zonal model, Natural ventilation, Airflow distribution, Temperature field, Thermal comfort

NOMENCLATURE

A	surface of the window opening
C_d	discharge coefficient [-]
C_v	opening effectiveness [-]
g	gravitational acceleration [m/s_]
h	zone or interface height [m]
$\dot{m}_{ij}$	airflow rate between i and j [kg/s]
P	air pressure [Pa]
Q	air flow through the window opening [m^3/s]
Sij	border surface between i and j [m_]
T	zone air temperature [°C]
v	wind velocity [m/s]
ρ	air density [kg/m^3]
Subscripts	
i	relative to the zone or the surface i
j	relative to the zone or the surface j

INTRODUCTION

For the Tunisian summer climate, which is hot and fairly wet, natural ventilation is a very significant parameter of comfort. Night ventilation associated with thermal inertia play a very important role to cool the indoor air, and on the other hand, induced air motion acts directly on the thermal comfort of the occupants by increasing convective and evaporative heat transfer between them and the environment. Our context is then different from that of temperate climate countries, for which ventilation is often reduced to the only function of air change to ensure a healthy indoor air for the occupants. Besides, the recourse to natural ventilation and the very significant possibilities offered by the solar passive energy, require the simultaneous taking into account of heat exchange and air flow because of their very strong interdependence.

Several software for calculating heat transfer and heat flow in buildings have been developed these past decades: TRNSYS (1994), Esp-r (1997)… However, if most of them calculate accurately the heat transmission, they evaluate the air flow with a simplified way. Indeed, the majority of these software do not give an evaluation of the indoor stratification and the air velocity distribution inside the building. The specificity of our context leads us to develop a simulation tool of heat transfer and airflow in unconditioned buildings, based on the zonal method, which has appeared as an excellent compromise between very detailed CFD models like Fluent (1996) and very simplified models with one mean air temperature and one mean air pressure for each room like those of Roldan (1985), Caccavelli (1988) …

This software allows to determine the temperature field and the airflow pattern inside an unconditioned building. Its coupling with a thermal comfort model developed by Ghrab (1991) allows to evaluate the thermal quality of the building by the prediction of a comfort note.

This paper presents a simulation of a night cross-ventilation strategy case, to study the effect of the airflow penetrating through a window, on the temperature field and the air velocity distribution inside an unconditioned Tunisian building, and the evaluation of the thermal sensation of its occupants.

ZONAL MODEL DESCRIPTION

Modelling of the current zones

The evaluation of the natural ventilation effects upon the indoor air quality and thermal comfort requires an accurate knowledge of the temperatures and the air velocity distributions within the building.

The zonal method is based on the spatial discretization of the room or building indoor air volume into several parallelepiped homogeneous control volumes (zones) in which air temperature and density are supposed to be constant, while air pressure is supposed to vary hydrostatically. All zones achieved mass and thermal balance and are connected between them by interfaces through which circulate airflow and heat flux. The air is considered as a perfect gas.

Our model is based on the simplified method initiated by Bouia (1993). It lies in calculating the indoor pressure field by using a 'degraded' equation for the momentum conservation, for determining the mass air flow and the air temperature inside the considered building. This method is based on an important characteristic of the current zones: the uniformity and the low amplitude of the air velocities. We can then suppose that the air velocities through the interfaces are only generated by the pressure difference on both sides. This formulation expresses that the pressure differential between two adjacent low velocity zones generates a

discharging velocity flow that crosses the border between them with a discharge coefficient C_d.
The mass flow rate across a boundary between two adjacent low velocity zones i and j is based on a power-law pressure distribution as:

$$\dot{m}_{ij}=\sqrt{2\rho}\,\varepsilon_{ij}C_dS_{ij}\left|\Delta P_{ij}\right|^{\frac{1}{2}} \qquad \text{(Eqn. 1.)}$$

with:

$\Delta P_{ij}=(P_i-\frac{1}{2}\rho_i g h_i)-(P_j+\frac{1}{2}\rho_j g h_j)$ for an horizontal border

$\Delta P_{ij}=P_j-P_i$ for a vertical border

sign (ε_{ij}) = sign (ΔP_{ij}) $\quad |\varepsilon_{ij}|=1$

$\rho=\rho_j$ if $\varepsilon_{ij}=1$ and $\rho=\rho_i$ if $\varepsilon_{ij}=-1$

According to Inard and al (1996), a value of the discharge coefficient C_d equal to 0.8, obtained experimentally by airflow measurements through doors, allows to predict correctly the air movement in residential buildings, for the current zones at low air velocity.
We suppose that there is no internal heat source power, we neglect air conduction and we assume steady state conditions. Under these assumptions and by supposing that air is incompressible, we write the mass balance equation, the thermal balance, and the perfect gas law for each zone i of the room. Our zonal model does not take into account jets models, we consider that all the building zones are current zones. Furthermore, details concerning the model are presented in Gharbi (2002).

Modelling of the air flow rate through the window opening

The airflow rate through an open window depends on the natural ventilation strategy used. For a cross-ventilation strategy, where openings are situated on both sides of the room, the main driving force for natural ventilation is the wind effect. We calculate the air flow rate due to wind penetrating into the building through the window by the Ashrae Handbook (1985) formula:

$$Q = C_v . A . v \qquad \text{(Eqn. 2.)}$$

C_v is called effectiveness of openings by the Ashrae Handbook; it is analogous to a discharge coefficient which is a characteristic parameter for a specific window. Heiselberg and al (2001) show that the discharge coefficient is not constant, but depends on the type of the window, the area of the opening, and the temperature and pressure differences across the opening. However, only for large openings, they assume that a constant discharge coefficient value of 0.6 can be commonly used for sharp-edged rectangular windows or doors openings. The Ashrae Handbook (1985) assumes also a value of C_v between 0.5 and 0.6 for perpendicular winds.

Our model allows to determine the temperature fields and the air flow patterns, and consequently the air velocity distribution, into the building. Its coupling with a thermal comfort developed by Ghrab (1991) permits the evaluation of the thermal quality of the considered building, by the prediction of a comfort note. This note corresponds to the percentage of persons which will be satisfied by this environment (PPS).

DESCRIPTION OF THE SIMULATED CASES

The simulations are performed on a parallelepiped room which has an area of (5 x 3) m^2, and a height of 2.8 m. It has two large identical openings of 2 x 1.4 m^2, situated on the two opposite walls of the room. The room is divided into a 3D grid constituted of 7 zones in the x-direction, 3 in the y-direction and 5 in the z-direction. The geometric description of the room is presented in Figure 1.

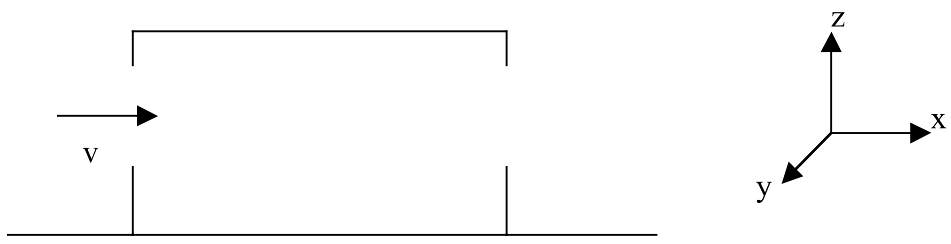

Figure 1: Geometric description

The aim of this work is to study the effects of the night natural cross-ventilation upon the temperature and the air velocity distributions inside the room, and consequently its effects on the thermal comfort. We will study two cases: one case corresponds to windows openings completely opened, and the other one corresponds to windows closed. For this case, we suppose that the windows have not perfect air-tightness, the air penetrates into the room through a crack of 3 mm width.

Regarding the heat transfer coefficients between the cell walls and the indoor air, we used the same constant values as Voeltzel (1999):
- for the floor : h_c=1.0 $Wm^{-2}K^{-1}$
- for the ceiling : h_c=5.7 $Wm^{-2}K^{-1}$
- for the walls : h_c=4.8 $Wm^{-2}K^{-}$

We consider meteorological data which are average data, typical of the climate of Tunis, during the summer nights. We suppose that the air velocity is uniform and perpendicular to the window opening, with a value of 2 m/s. The outside night air temperature is 22 °C, we suppose that the temperatures of the wall internal surfaces are homogeneous and equal to 30 °C. We consider a relative humidity of 50%.

We assume that the room is occupied by a person having a light activity (1.5 met), the thermal resistance of his clothes is 0.5 clo, which corresponds to a light summer cloth.

RESULTS AND DISCUSSION

We present the isotherms and the velocities fields in the x-z middle plane of the room corresponding to the blowing plane, in Figure 2 for case 1 (closed windows) and in Figure 3 for case 2 (open windows).

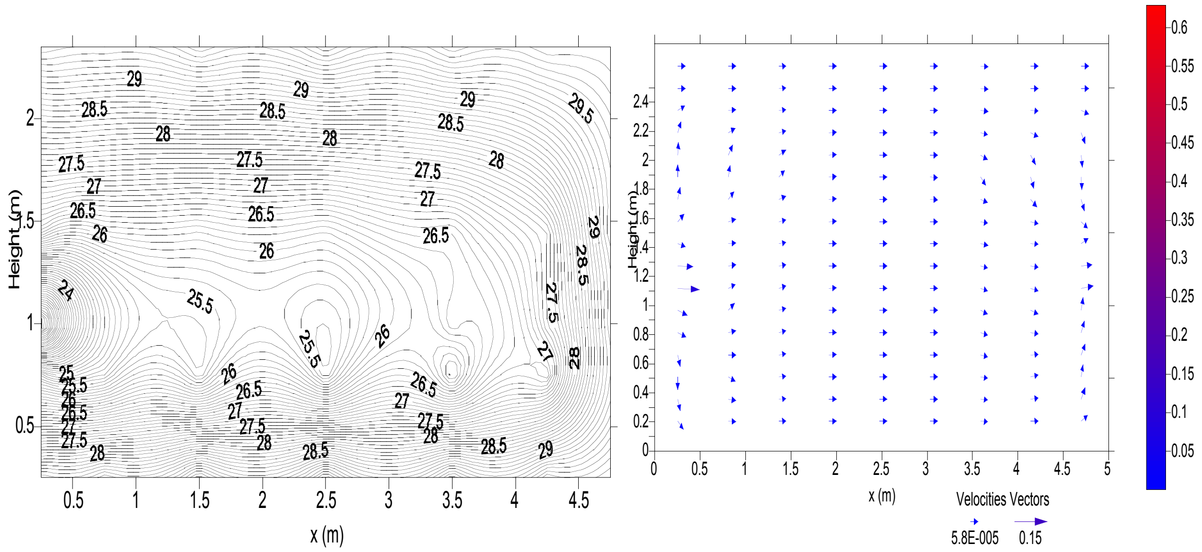

Figure 2: Isotherms and Velocities field in the x-z middle plane – Case 1

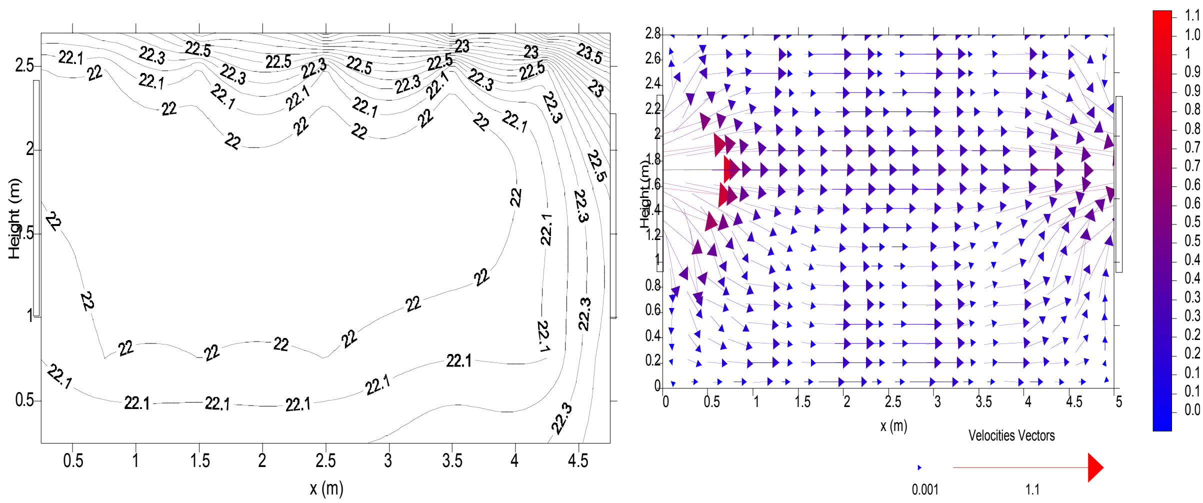

Figure 3: Isotherms and Velocities field in the x-z middle plane – Case 2

When the windows are closed (Figure 2), we remark a non homogeneous temperature distribution, which varies from 24°C to 29°C. However, when the windows are completely opened (Figure 3), the temperature field is quite homogeneous and close to the external air temperature, due to the large openings dimensions which represent 20% of the wall surfaces.
The comparison of the two figures shows that night natural cross-ventilation allows to reduce significantly the indoor air temperature. The temperature difference between the room ventilated and the room with closed windows reaches 4 °C at the room centre and 6.5°C near the walls.

As presented Figure 2, the air velocities values are very small and the air is almost stagnant, when the windows are closed.
For the second case, illustrated by the Figure 3, the air velocities are very much higher and the room is well ventilated. The air flow pattern obtained is similar to those of Regard (1996), the air flows essentially into the stream tube which joins the two openings. However, we did not detect re-circulating flow near the ceiling and the floor regions, principally because our model does not use specific laws for modelling the high velocity zones, we consider that all the zones are current zones and we did not take into account jet models.

Table 1 represents the predicted mean vote (PMV) and the comfort note at the centre of the room for an occupant in a seated (z=0.75 m) and a stand up position (z=1.70 m), for the two cases.

TABLE 1
Data and Comfort Notes of the studied cases

Height (m)	CASE 1				CASE 2			
	T(°C)	V(m/s)	PMV	Comfort Note (%)	T(°C)	V(m/s)	PMV	Comfort Note (%)
0.75	26.2	0.00108	1.15	68.08	22	0.398	$-3.42.10^{-2}$	95.15
1.70	28.5	0.00114	1.39	58.31	22	0.431	-0.13	94.96

Regarding the comfort notes presented in Table 1, natural ventilation improves significantly the thermal sensation of the occupants. When the windows are closed, only about 68% of persons in a seating position, and 58% of persons in a standing up position are satisfied by the thermal quality of the room. The PMV higher than 1 corresponds to a heat sensation.
This low comfort level is considerably improved by the effects of the night natural ventilation, as it reaches 95%. The PMV obtained when the room is largely ventilated is close to 0, which corresponds to the thermal neutrality, and consequently to a well-being sensation.

CONCLUSION

We have studied the effects of a cross-ventilation strategy upon the air temperature distribution and the airflow pattern in an unconditioned building, using the zonal 3D model that we have developed. The results obtained have shown that natural ventilation represents an efficient cooling measure by reducing overheating and improving thermal comfort in our Mediterranean context.
The work in progress is the insertion of a jet model to predict more accurately the air distribution inside unconditioned buildings.

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