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Numerical study of Trombe wall as a passive ventilation system: The case of Moroccan climate

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Abstract

Nowadays, as building's energy consumption has become of outstanding importance, passive solar design strategies such as Trombe Walls have received extensive attention from researchers all over the world. In this context, the present work is intended to contribute to a better understanding of the feasibility of using the Trombe wall as an effective natural ventilation technology in order to achieve potential energy savings as well as acceptable thermal comfort conditions. To that aim, a mathematical model describing the thermal performance of the studied wall system was used, and then by means of COMSOL Multiphysics software, a parametric study of a single room with four different wall configurations that differ only in the inlet and outlet air vent position was carried out under six Moroccan climate zones during both winter and summer seasons. Temperature and velocity fields in the test room incorporating the Trombe wall were analyzed. From the simulation results, some useful conclusions were derived.

Materials & Methods

Meteorological data

In order to obtain a wide range of climate conditions, the study was carried out for six Moroccan climates: Agadir (Zone I), Tangier (Zone II), Fez (Zone III), Ifrane (Zone IV), Marrakech (Zone V) and Er-rachidia (Zone VI). Meteorological data of particular interest were hourly ambient air temperatures (Fig.1,2) and global solar radiation (Fig.3,4). Typical winter (i.e., January 1st and 2nd) and summer (i.e., August 1st and 2nd) periods have been chosen to run the simulation under relevant winter and summertime weather conditions.

Fig. 1. Summer ambient temperature

Fig. 2. Winter ambient temperature

Fig. 3. Summer solar radiation

Fig. 4. Winter solar radiation

Materials & Methods cont.

Cell description

For optimum control of the study, as shown in Fig.5-a, a virtual model of a 1.261 m x 1.112 m x 1.112 m test cell with south facing Trombe wall was developed. This wall consists from the inner to the outer side of a 0.1 m thick concrete wall, an air gap of 0.1 m and a 0.005 m thick glass cover. As for the other walls, the roof, and the floor, they are made of 0.018 m thick plywood with expanded polystyrene insulation (0.02 m thick) placed between the two sheets.

Fig. 5. Description of the studied cell: (a) 3D view, (b) floor plan

A cross sectional view A-A (Fig.5-b) of the configurations design details is illustrated in Fig.6.

Fig. 6. Cross-section of the studied Trombe wall configurations:

CFD model

COMSOL Multiphysics model was used in which heat transfer and fluid flow physics were coupled through the Nonisothermal Flow Multiphysics feature. The Fluid Flow module is based on the Navier-Stokes equations governing conservation of mass, momentum, and energy, which may be written as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0, \quad (1)$$

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho (\mathbf{u} \cdot \nabla) \mathbf{u} = \nabla \cdot [-p \mathbf{I} + \mu (\nabla \mathbf{u} + (\nabla \mathbf{u})^T) - \frac{2}{3} \mu (\nabla \cdot \mathbf{u}) \mathbf{I}] + (\rho - \rho_{ref}) \mathbf{g}, \quad (2)$$

As for heat transfer, the governing equation is given by:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = Q, \quad (3)$$

$$\mathbf{q} = -k \nabla T, \quad (4)$$

For heat transport turbulence model Kays-Crawford was chosen, in which Prandtl number is given by:

$$Pr_T = \left(\frac{1}{2 Pr_{T\infty}} + \frac{0.3}{\sqrt{Pr_{T\infty}}} \frac{C_p \mu_T}{k} - (0.3 \frac{C_p \mu_T}{k})^2 (1 - e^{-k/(0.3 C_p \mu_T \sqrt{Pr_{T\infty}})}) \right)^{-1}, \quad (5)$$

ρ is the density (kg/m³)
 $\mathbf{u}$ is the velocity vector (m/s)
 p is pressure (Pa)
 μ is the dynamic viscosity (Pa·s)
 T is the absolute temperature (K)

C_p is the specific heat capacity at constant pressure (J/(kg·K))
 $\mathbf{q}$ is the heat flux vector (W/m²)
 Q contains the heat sources (W/m³)
 k is the Thermal conductivity (W/(m·K))
 $Pr_{T\infty}$ is the Prandtl number at infinity (0.85)

Results & Discussion

Air temperature and velocity distribution in the upper air vent (for In-In and Out-In configurations) and the lower opening (for In-Out configuration) during both winter and summer seasons are illustrated for each location in Fig. 7, 8, 9, and 10.

Fig. 7. Winter temperature and velocity distribution in Agadir

Fig. 8. Summer temperature and velocity distribution in Agadir

Fig. 9. Winter temperature and velocity distribution in Er-rachidia

Fig. 10. Summer temperature and velocity distribution in Er-rachidia

As can be seen in Fig.7 (Agadir case), During winter, the three studied configurations exhibited temperatures that exceeded the ambient in the nighttime, this temperature difference caused a free cooling, leading to higher speeds reaching values of up to 0.294, 0.27 and 0.17 m/s respectively, for In-In, In-Out and Out-In configurations.

As regards summer season, Fig.10 clearly shows that in Er-rachidia case, daytime temperatures decreased below ambient, and the stack effect due to solar radiation caused a rise in air velocities which attained 0.23, 0.20 and 0.15 m/s respectively, for In-In, In-Out and Out-In configurations. Fig. 11 shows the flow pattern and air velocity distribution in Ifrane during winter (Fig.11-a,b) in addition to Marrakech during a summer day at (Fig.11-c,d).

Fig. 11. Velocity field distribution: Winter in Ifrane (a,b) & Summer in Marrakech (c,d)

Conclusion

For the study, a numerical simulation was carried out for different Trombe wall configurations in order to assess their efficiency as a passive ventilation technique under various Moroccan climate zones during both winter and summer seasons. Simulation results revealed that during the winter season, In-In configuration was found to be the most suitable solution; meanwhile In-Out configuration has proven most effective in the summer season.

Trombe wall may be considered as an effective natural ventilation technique; however, its integration into the building envelope requires more research on the parameters influencing its performance, such as air gap thickness and the glazing type.

Future Work

The Trombe wall could ensure better thermal comfort conditions when coupled with other passive technologies and proper protection technique during the summer season.

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