Research Article

Numerical Approach of the Natural Ventilation of a Space by a Wind Tower Using a Porous Medium

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Abstract: The techniques of natural ventilation are among the best solutions which serve both to ensure the thermal comfort of the occupants and to reduce the energy bill. In an arid region like southwest of Algeria, which also sees a significant source of wind, the use of wind towers in the design of the building allow us to provide passive cooling. This work aims to evaluate the effect of the natural ventilation of a habitat by a wind tower using a porous media saturated with water and to determine the effect of the tower length on energy efficiency. This objective is possible thanks to the study of the flow by the method of Lattice Boltzmann D2Q9, using a numerical code (LBM - FORTRAN). The results of this work proved that as the length of the tower increases the temperature decreases and the speed increases at the exit of the channel. Also the surface of the porous medium influences the climate at the exit of the tower.

Keywords: Natural Ventilation - Wind Tower - Porous Media - Arid Region - Lattice Boltzmann.

1Introduction

The building sector is the world's largest consumer of energy, accounting for 45% of total energy consumption and emitting almost 25% of greenhouse gases. Its main function is to maintain occupant in comfort conditions [1].

One of the main economic concerns is the energy problem. It is important that building science continues to develop real and sustainable solutions to the challenges we face in terms of energy and the environment. The design of a "responsible building" must offer a balance between its thermal performance (building envelope, heating, air conditioning and lighting system) and the quality of the interior environment in terms of thermal comfort and occupant health [2].

Wind towers have existed in various forms for centuries as a means of ventilation, the very high price of energy and climate change programmes have pushed researchers to focus on passive or low-carbon emission systems.To provide thermal comfort without the use of electrical energy, wind towers can be integrated into the modern architecture of new buildings [3].

Our work is based on a simulation of natural ventilation by a wind tower under the effect of a porous environment saturated by water based on the Lattice Boltzmann method, in the town of Béchar which is located to the southwest. of Algeria and which belongs to arid zones (hot and dry), one of the regions which presents an important source of winds, where the assurance of comfort is possible by a well-designed natural ventilation.

2Climate data of the city of Bechar (southwest of Algeria):

Algeria is quite a windy country because of its geographical location. Wind speeds exceed 3 m/s in 78% of its surface area, and they exceed 5 m/s in 40%. According to the wind maps (Figure 1), the wind speeds in the south of the country are the highest. The south-west region has great potential with speeds exceeding 4 m/s for the city of Béchar [4]. With a temperature that exceeds 40 ° C in the summer period.

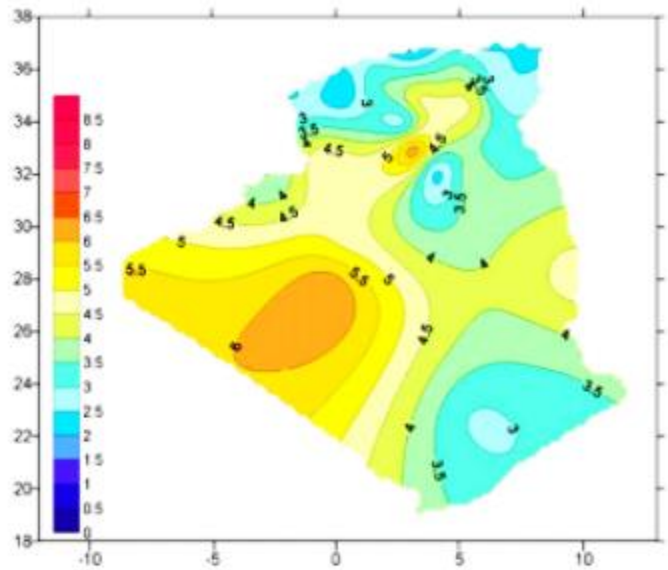

Figure 1 Annual map of the wind speed in Algeria at 10m altitude

Variation of wind speed as a function of altitude [5]:

$$\frac{V_1}{V_2} = \left(\frac{h_1}{h_2}\right)^{\alpha} \quad (1)$$

V1 and V2: horizontal wind speeds (in m/s) at the respective heights h_1 and h_2 (in m). The exponent α is the shear coefficient. Its value, calculated on the basis of the average speed, is of the order of 0,343.

3Lattice Boltzmann Method:

3.1 Dynamic model

The Lattice Boltzmann method [6, 7] is a new numerical approach. This method is derived from the kinetic theory of gases of Ludwig Boltzmann. Its principle is to imagine that fluids are made up of a large number of small particles which have random movements. Heat and hydrodynamic exchange is achieved by the flow and collision of billiard-like particles. We can model these transformations by the Boltzmann transport model:

$$\partial f_i\ (x,t) + e_i \nabla f_i (x,t) = \Omega_i(f) \quad (2)$$

The collision is modelled by the correlation (BGK) which leads the particle to an equilibrium, by integrating a relaxation time before the propagation for the following time step, such as:

$$\Omega_i(f) = \frac{1}{\tau}\ (f_i^{eq}(x,t) - f_i(x,t)) \quad (3)$$

The time τ which puts the distribution function in terms of speed to return to its equilibrium state $f_i^{eq}(x,t)$ is called the relaxation time. It depends on the viscosity of the fluid. To arrive at the Lattice equation BGK, we will introduce the collision operator in Eq. (1).

$$\partial f_i (x,t) + e_i \nabla f_i (x,t) = \frac{1}{\tau}\ (f_i^{eq}(x,t) - f_i(x,t)) \quad (4)$$

To have a simplified form of Lattice Boltzmann, we will integrate the equation (5) with respect to time.

$$\partial f_i(x + e_i\Delta t, t + \Delta t) + e_i\nabla f_i(x, t) = f_i(x, t) + \frac{\Delta t}{\tau}\left(f_i^{eq}(x, t) - f_i(x, t)\right) \quad (5)$$

In the model D2Q9, we associate a discrete distribution function $f_i(\vec{x}, \vec{e}_i, t)$ for each particle of the lattice.

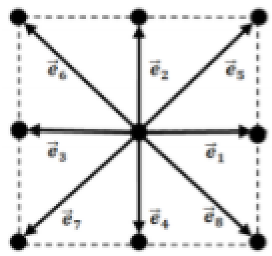

Figure 2 Lattice structure inside thefluid (D2Q9)

For an isothermal and incompressible flow, the discretization of the equilibrium function developed to the second order, becomes:

$$f_i^{eq} = \omega_i \rho\left[1 + 3\frac{e_i u}{c^2} + \frac{9}{2}\frac{(e_i u)^2}{c^4} - \frac{3}{2}\frac{uu}{c^2}\right] \quad (6)$$

We can calculate the macroscopic quantities using the preceding distribution functions such as:

$$\rho(x, t) = \sum_i f_i(x, t) \quad (7)$$

$$\rho u(x, t) = \sum_i e_i f_i(x, t) \quad (8)$$

Using the Chapman-Enskog procedure we can recover the Navier-Stokes model, by the following formula:

$$\nu = \left(\tau_v - \frac{1}{2}\right) c_s^2 \delta t \quad (10)$$

3.2 Temperature field

The calculation of the temperature field requires the introduction of a second distribution function similar to the function f. Indeed, only five directions are necessary for the temperature calculation.

$$g_i(x + e_i, t + \Delta t) = g_i(x, t) + \frac{1}{\tau_k}\left(g_i(x, t) - g_i^{eq}(x, t)\right) \quad (11)$$

The relaxation time τ_h distribution function g_i used for the calculation of the temperature is related to the thermal diffusivity of the fluid. The macroscopic temperature is calculated by:

$$T_i = \sum_i g \quad (12)$$

The relationship between the thermal diffusivity α of the fluid and the relaxation time τ_T is given by:

$$\alpha = \frac{1}{2}\left(\tau_T - \frac{1}{2}\right) c^2 \delta t \quad (13)$$

4 Code validation

The most important point is to check the reliability of the calculation code To this end, the adopted model has been validated by performing calculations for the case of a square cavity with two vertical walls, one hot and the other cold, and two adiabatic horizontal walls (De Vahl Davis1983). The results were found to be in good agreement with the corresponding results as shown in (Table 1). the error does not override the 0,6%.

Table 1: Raleigh values and Nusselt number of the hot wall

	Our Work	De Vahl Davis	Error %
$Ra=10^3$	1,116	1,122	0.535
$Ra=10^4$	2.242	2.247	0.223
$Ra=10^5$	4.523	4.540	0.374

5Physical problem and governing equations:

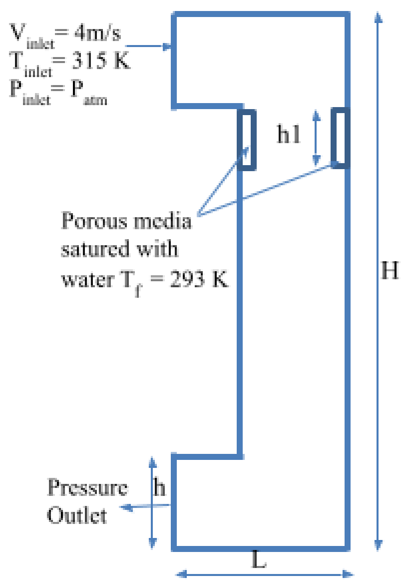

Figure 3 Geometry and boundary conditions

It is about a wind tower with height H and width L. the boundary coditions are gathered in the following table.

Table 2 Boundary Conditions

Geometry	Solid
Fluid	Air
Fluid of porous media	Water
Velocity inlet	4 m/s
Pressure Outlet	Atmospheric
Temperature Inlet	315 k
Water Temperature	293 k
H	10 m

L	2.3 m
H	1.1 m
h1	0.4 m

6 Results and discussion

6.1 Effect of the porous media height (h1)

Figure 4a shows the velocity contour inside the tower at high wind (H = 10m)with a porous media height (h1=40cm). The air absorbs water which saturates the porous medium and becomes heavier (denser) which causes an increase in its speed.In Figure 4b. we observe a slight increase in velocity due to the widening of the contact surface with the porous medium (h1=0.7m).

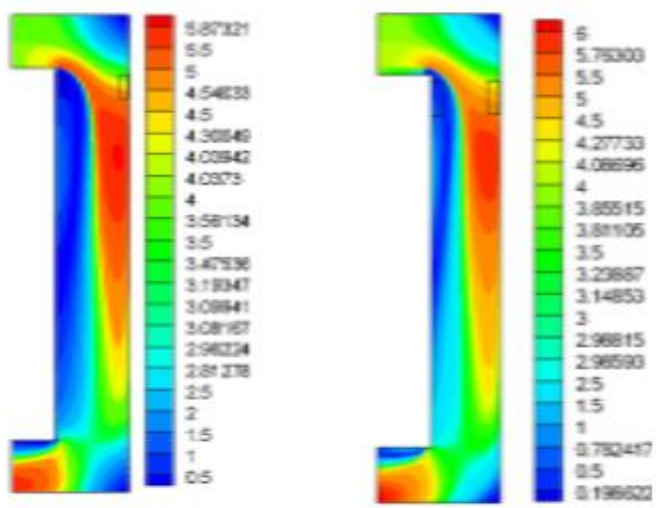

Figure 4 Velocity contour lines: (a) for h1= 0,4m, (b) for h1=0,7m

In figure 5a. which represents the temperature contours lines inside the channel, we notice that there is a strong decrease in the air temperature. It reaches 300k at the outlet for a height of h1 = 0.4m of the porous medium, this reduction is due to the presence of water which saturates the porous medium. For h1 = 0.7m the temperature becomes less because of the elongation of the contact surface between the air and the porous medium (figure 5b).

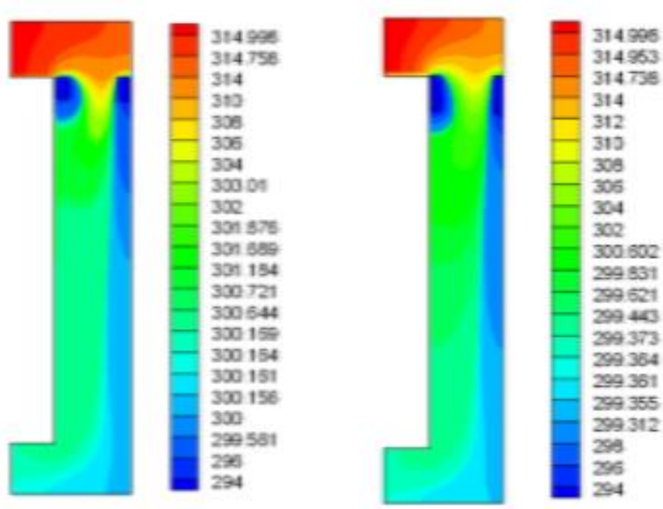

Figure 5 Temperature contour lines: (a) for h1= 0,4m, (b) for h1=0,7m

The observations made previously can be confirmed from (figure 6) where we have plotted the temperature profiles from the inlet to the outlet of the wind tower. We notice that they look the same, the temperature values decrease in the first three meters afterwards they become constant until the exit, with favorable results for the enlarged contact surfaces (h1=0,7m).

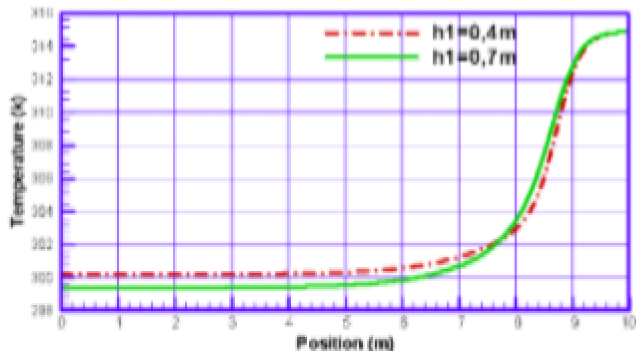

Figure 6 Theairflow temperature variation from wind tower inlet to outlet for different value of h1

In (figure 7), we notice an increase in velocity in the upper part after it relapses up to 3 m / s, and it starts again the growth or it reaches 6 m/sat the exit.

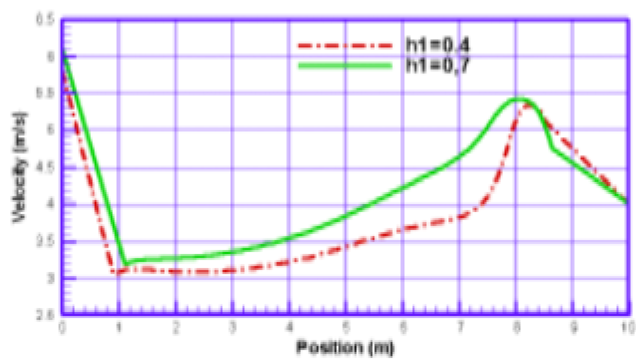

Figure 7the airflow velocity variation from wind tower inlet to outlet for different value of h1

6.2 Wind tower height effect (H)

Figures (8 -9) show that the wind tower height has an effect on the air flow. For a height H = 6m the temperature at the outlet of the channel was 303k and the speed of 5,5 m / s, but for a height of h=12,5m the temperature at the outlet decreased to 299.5k and the speed exceeded 6,5 m/s.

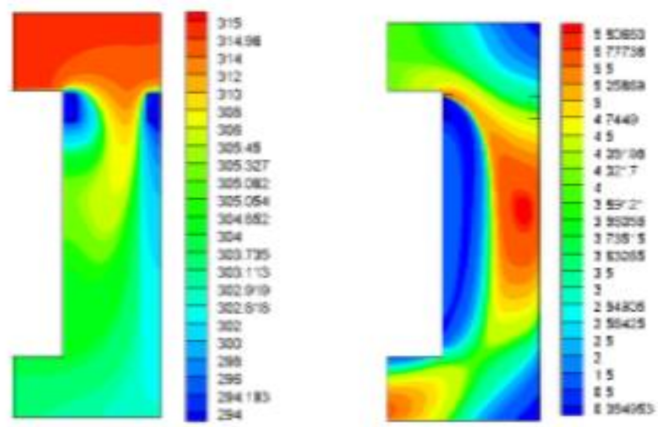

Figure 8 Temperature and Velocity contour lines for wind tower height H=6m

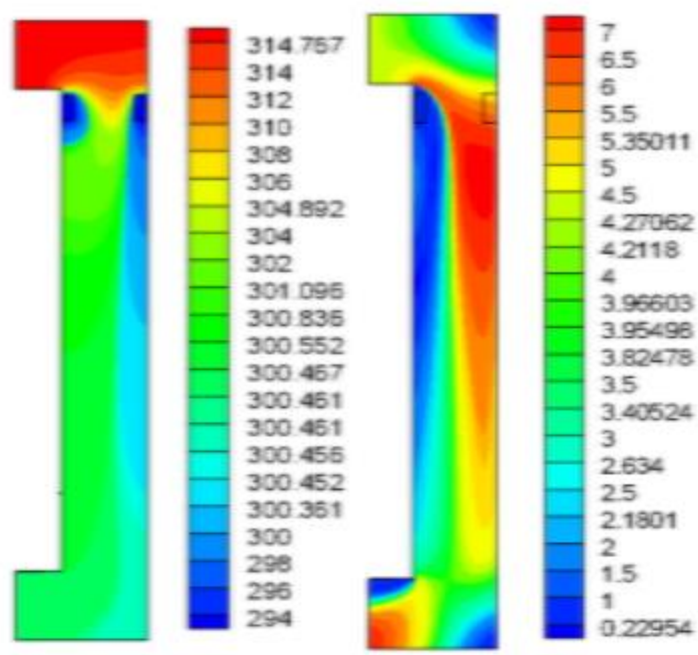

Figure 9 Temperature and Velocity contour lines for wind tower height H= 12,5m

the figures (10 -11) shows the effect of height (H) on the thermal and dynamic behaviors of a wind tower. It is noted that the temperature at the outlet decreases when the height of the tower is increased, on the other hand the value of the speed increases.

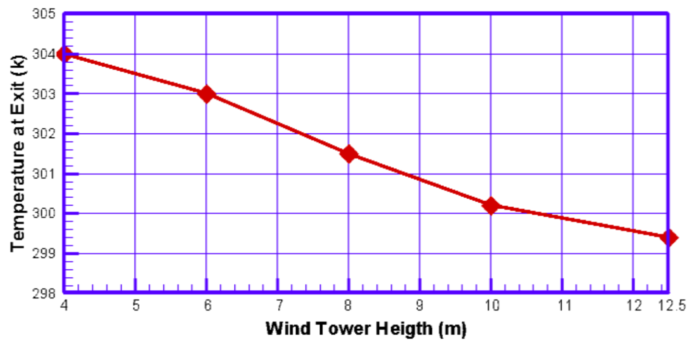

Figure 10 Effect of the height of the wind tower (H) on the outlet temperature

Figure 11 Effect of the height of the wind tower (H) on the outlet Velocity

7 Conclusion

The present work aims to prove the effectiveness of the utilization of wind towers for natural ventilation for the improvement of thermal comfort in arid windy areas such as the town of Bechar. The exploitation of the Lattice Boltzmann LBM Method programmed in Fortran has facilitated the calculation of speeds and temperature. porous media saturated with water gave satisfactory results in terms of cooling. Wind towers can have different heights depending on the region or operation.

A comparison between wind towers with different heights which vary from 6 to 12,5m shows that the wind tower with 10 m height is more suitable for the climatic conditions of the city of Bechar. the temperature variation beyond 10m becomes slight.

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Nomenclature

e_i	Speed of the particle in the lattice
f_i	Dynamic distribution function
f_i^{eq}	Dynamic equilibrium distribution functions
gi	Energy distribution function
g_i^{eq}	Energy equilibrium distribution functions
H	Height of wind tower
h1	Height of porous media
T	Temperature (K)
wi	Lattice Weights
α	Thermal diffusivity (m^2/S)
ρ	Density (Kg/m3)
τ	Density relaxation times
τ_T	Energy relaxation times
Ω_i	Rate of change of a particle after a collision.
ν	Kinematic viscosity (m^2/S)

Biographies

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