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Numerical Modeling on the Performance of the Wind Tower Integrated into the Storied Building for Reducing Electrical Energy Consumption for Spaces Cooling

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Abstracts: Natural convection in integrated wind tower into a high storied building is numerically investigated by solving natural convection equations with the Boussinesq approximation. The present investigation deals with velocity and temperature distribution in a wind tower integrated into a high building divided into three stories; in which the upper horizontal heated wall is vented by a fresh air jet entranced by the wind tower and hot waste air exits from different outlet openings. The purpose of this study is to evaluate the Performance of integrated wind tower into the storied building, thus providing a wind and buoyancy factors for induced natural ventilation to drive air flow through the floors. Numerical solutions of the Navier Stokes equations and energy equation have been solved by the Thomas' algorithm. Solutions are presented for various geometrical aspect ratios and for different values of Grashof and Reynolds numbers. The results are presented in terms of streamlines, isotherms, velocity, and heat transfer intensity versus the governing control parameters in detail.

Keywords: Wind tower, Storied building, Natural ventilation, Thermal comfort, Greenhouse gas emissions

1. INTRODUCTION

Optimizations of energy consumption and thermal comfort for occupants are important factors in designing buildings, especially in hot and dry climates. It is estimated that over 40 per cent of the total energy consumed in the world is employed in buildings [1,2], and approximately more than 60 percent of this involves heating, ventilation, and air conditioning (HVAC) systems [1,3]. According to reports by Gong et al. [4] and Wang et al. [5], it is predicted that energy consumption in buildings will increase in the future owing to the variations of lifestyles and technology along with increased economic prosperity, so homes will take a larger share of total energy consumption. Robert and Kummert [6] reported that one-third of GHG emissions are created because of energy consumption in buildings. Therefore, passive ventilation systems, such as wind towers, can not only play a significant role in reducing energy consumption in buildings, but also diminish Greenhouse Gas (GHG) emissions [7].

Increasing awareness of the need for energy efficient and environmentally friendly approach for building design has renewed emphasis on the integration of natural ventilation devices in buildings. Heating, Ventilation and Air Conditioning (HVAC) accounts for a substantial amount of the energy use in building and represents a significant opportunity for energy savings. Ventilative methods which do not use mechanical intervention and thus energy free are termed natural ventilation. Sustainable ventilation technologies have been proposed to reduce the buildings energy consumption and carbon footprint.

An example of one such innovative ventilation device is the wind tower. Montazeri and Azizian [8] defined the wind tower as a device which facilitates the effective use of natural ventilation in a wide range of buildings in order to increase the ventilation rates. Wind towers have been used in the hot and arid regions of the Middle East for many centuries to provide passive cooling and achieve thermal comfort. Bahadori [9–18] is a pioneer in wind tower research and has carried out extensive studies on passive cooling systems in hot and dry regions over the last four decades. He suggested two modern wind tower designs to improve their performance: "wind towers with wetted columns" and "wind towers with wetted surfaces" [9,13,16]. Bahadori et al. [9,13,16,18,19] have theoretically and empirically investigated the operation of both new designs and compared their performance with conventional wind towers. They concluded that the modern wind towers had a better thermal performance compared to the conventional wind towers at a lower temperature and a higher relative humidity. In addition, the efficiency of wind towers with wetted columns is greater than other wind towers in the regions where the velocity of wind is high enough. Conventional and modern wind towers are increasingly being used in modern buildings to minimize the consumption of nonrenewable energy. Modern design of wind towers combines the ventilation principles and passive stack in one design. Wind tower architecture can be integrated into the designs of new buildings, to replace or assist mechanical ventilation systems. However before adapting new technologies, it is necessary to research into the function and design parameters of traditional and modern wind catchers and to demonstrate how it can be applied and improved in order to provide a simple and effective means of natural ventilation.

Dehghani-Sanij et al. [20–29] have conducted several studies on passive cooling and natural ventilation systems, such as wind towers, domed roofs, and cisterns in hot and dry climates. Their investigations illustrated that these systems were appropriate solutions to make pleasant cool air in buildings and provide cold drinkable water to people throughout the warm months.

An example of one such low carbon ventilation system is the wind tower. Elmualim [30] stated that naturally ventilating buildings by means of wind towers provided increased control and reliability compared to cross-flow ventilation. Natural ventilation plays a significant role in providing optimum indoor air quality and maintaining acceptable thermal comfort without the aid of mechanical systems, thus enables fresh air delivery to occupants using sustainable and energy efficient methods [31]. Allard [32] defined optimum air quality as air free of contaminants or harmful materials that can present a health risk to the occupants, potentially causing irritation and discomfort. It is known that the pollution level decreases exponentially with the airflow rate. Hence, optimizing the supply of air is essential to ensure adequate indoor air quality while maintaining the ventilation rates within a certain range [32].

Natural ventilation is dependent on three climatic factors: wind velocity, wind direction and temperature difference. The speed and direction of the wind over a structure generates a pressure field around the building. This study aims to innovate and contribute toward a more sustainable society through developing alternative ventilation technologies as the modification of existing wind towers to improve their aerodynamics and consequently, the natural ventilation of the buildings that have them. Thus, the present work focuses on improving the traditional wind tower design in terms of aerodynamics and aims to enhance natural ventilation technologies for reducing simultaneously the load of energy consumption and carbon emission.

2. MATHEMATICAL FORMULATION

2.1. Physical Model and Governing Equations

The configuration under study with the system of coordinates is sketched in Fig. 1. It consists a vertical rectangular structure with a wind tower integrated into a high building divided into three stories heated by a uniform heat flux from its upper horizontal wall while the remaining walls are considered perfectly insulated. In the upper part, the channel is oriented in the direction of the prevailing the winds to facilitate the external fresh air capture. Once the fresh air is captured, it flows through the channel duct, increases its speed, and is then channeled and mixed with indoor air. The exhausted air is currently discharged through the stories, providing comfort to occupants without need of electromechanical air conditioners. The third dimension of the high building (direction perpendicular to the plane of the diagram) is assumed to be large enough so that fluid motion can be considered two-dimensional.

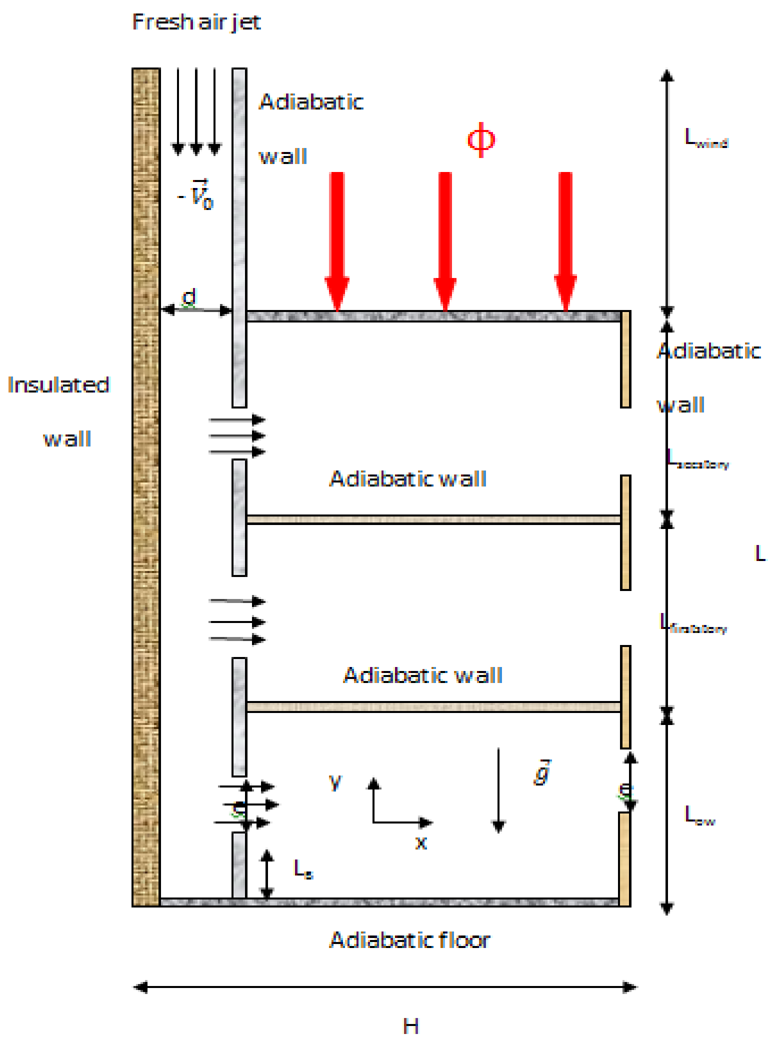


Figure 1. Physical Model.

Flow regimes inside and around the wind tower and the storied building are considered fully laminar and incompressible with negligible viscous dissipation. All the thermophysical properties of the coolant fluid are assumed constant except density that gives rise to the buoyancy forces (Boussinesq approximation). The wind direction angle was assumed to be constant at each fixed wind speed. Radiation and infiltration are neglected in this study. Taking into account the above-mentioned assumptions, the non-dimensional governing equations, written in vorticity – streamlines (**ω**-ψ) formulation, in Cartesian coordinates are as follows:

2.2. Mathematical Formulation

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \quad (1)$$

$$\frac{\partial \omega}{\partial \tau}+U\frac{\partial \omega}{\partial X}+V\frac{\partial \omega}{\partial Y}=Ri\frac{\partial \theta}{\partial X}+\frac{1}{Re}\left(\frac{\partial^2 \omega}{\partial X^2}+\frac{\partial^2 \omega}{\partial Y^2}\right) \quad (2)$$

$$\frac{\partial \theta}{\partial \tau}+U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{1}{RePr}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right) \quad (3)$$

$$\omega=-\left(\frac{\partial^2 \Psi}{\partial X^2}+\frac{\partial^2 \Psi}{\partial Y^2}\right) \quad (4)$$

2.3. Boundary Conditions

- Initial conditions: at $\tau=0$

$$\theta=\omega=U=V=\psi=0$$

- at $\tau > 0$

The boundary conditions associated with the problem are found below.

At the left, right, top and bottom walls of the wind tower channel and the building:

$$X = D \; and \; 0 < Y < B; U = V = \psi = 0; \; \omega = -\left.\frac{\partial^2\psi}{\partial x^2}\right|_{X=D}; \left.\frac{\partial\theta}{\partial X}\right|_{X=D} = 0$$

$$X = D \; and \; B < Y < BE; U = 0; \; \psi = 0; \; V = \omega = \theta = 0$$

$$X = D \; and \; BE < Y < 1; U = V = \psi = 0; \; \omega = -\left.\frac{\partial^2\psi}{\partial x^2}\right|_{X=D}; \left.\frac{\partial\theta}{\partial X}\right|_{X=D} = 0 \quad (5)$$

$$Y = 0 \; and \; D < X < S; U = V = \psi = 0; \; \omega = -\left.\frac{\partial^2\psi}{\partial Y^2}\right|_{Y=0}; \left.\frac{\partial\theta}{\partial Y}\right|_{Y=0} = 0$$

$$X = S \; and \; 0 < Y < B; U = V = \psi = 0; \; \omega = -\left.\frac{\partial^2\psi}{\partial x^2}\right|_{X=S}; \left.\frac{\partial\theta}{\partial X}\right|_{X=S} = 0$$

$$X = S \; and \; B < Y < BE; \left.\frac{\partial U}{\partial X}\right|_{X=S} = \left.\frac{\partial V}{\partial X}\right|_{X=S} = \left.\frac{\partial\psi}{\partial X}\right|_{X=S} = \left.\frac{\partial\omega}{\partial X}\right|_{X=S} = \left.\frac{\partial\theta}{\partial X}\right|_{X=S} = 0$$

$$X = S \; and \; BE < Y < 1; U = V = \psi = 0; \; \omega = -\left.\frac{\partial^2\psi}{\partial X^2}\right|_{X=S}; \left.\frac{\partial\theta}{\partial X}\right|_{X=S} = 0$$

$$Y = 1 \; and \; D < X < S; U = V = \psi = 0; \; \omega = -\left.\frac{\partial^2\psi}{\partial Y^2}\right|_{Y=1}; \left.\frac{\partial\theta}{\partial Y}\right|_{Y=1} = 0 \quad (6)$$

$$X = 0 \; and \; 0 < Y < A; U = V = \psi = 0; \; \omega = -\left.\frac{\partial^2\psi}{\partial X^2}\right|_{X=0}; \left.\frac{\partial\theta}{\partial X}\right|_{X=0} = 0$$

$$Y = 0 \; and \; 0 < X < D; U = V = \psi = 0; \; \omega = -\left.\frac{\partial^2\psi}{\partial Y^2}\right|_{Y=0}; \left.\frac{\partial\theta}{\partial Y}\right|_{Y=0} = 0$$

$$Y = A \; and \; 0 < X < D; \; V = -1; \psi = X - D; \; U = 0; \omega = 0; \theta = 0$$

$$Y = LW \; and \; D < X < S; U = V = \psi = 0; \; \omega = -\left.\frac{\partial^2\psi}{\partial Y^2}\right|_{Y=LW}; \left.\frac{\partial\theta}{\partial Y}\right|_{Y=LW} = 1$$

The same boundary conditions are written for the second and the third stories of wind tower integrated building. No slip and impermeability boundary conditions have been used on all walls except at inlet and outlet openings.

Stream function and vorticity are related to the velocity components by the following expressions:

$U = \frac{\partial\psi}{\partial Y}$, $V = -\frac{\partial\psi}{\partial X}$ and $\omega = \left(\frac{\partial V}{\partial X} - \frac{\partial U}{\partial Y}\right)$

2.4. Evaluation of Heat Transfer Intensity

The heat transfer through the upper horizontal heated wall is better represented by the Nusselt number, which is a measure of the ratio of the heat transfer by conduction to the flux convected by the cooling fluid. The local Nusselt number on the upper horizontal heated wall is given by: the relation

$$Nu_w = \frac{\emptyset \, L_{ow}}{\lambda(T_W - T_a)} = \frac{1}{\theta_W} \quad (8)$$

2.5. Numerical Procedure

2.5.1. Method of Solution

The nonlinear partial differential governing equations, (1-3), were discretized using a finite difference technique. The first and second derivatives of the diffusive terms were approached by central differences while a second order upwind scheme was used for the convective terms to avoid possible instabilities frequently encountered in mixed convection problems. The integration of the algebraic equations (2) and (3) was assured by the Thomas' algorithm. At each time step, the Poisson equation, Eq. (4), was treated using the Point Successive Under-Relaxation method (PSUR) with an optimum under-relaxation coefficient equal to 0.8 for the grid (121×121) adopted in the present study. Convergence of iteration for stream function solution is obtained at each time step. The following criterion is employed to check for steady-state solution. Convergence of solutions is assumed when the relative error for each variable between consecutive iterations is below the convergence criterion ε such that $\sum\left|\left(\emptyset_{i,j}^{n+1}-\emptyset_{i,j}^{n}\right)/\emptyset_{i,j}^{n+1}\right|<10^{-5}$ where ϕ stands for ψ, Θ, ω, n refers to time and *i* and *j* refer to space coordinates. The time step used in the computations is $\Delta\tau=10^{-5}$. In order to reduce the influence of the mesh on simulation accuracy, mesh independency solutions are assured by comparing different grid meshes for the highest Grashof and Reynolds numbers used in this work (Gr =10^5 and Re = 100).

It was found that the differences between meshes of 121 x 121 and 141x141 were not significant for all variables. The results obtained with these grids were comparable to those obtained with others uniforms grid size of 81x81, 101 x101, 161x161. Thus, a uniform mesh of 121 x121 was selected. The vorticity computational formula of Woods [33] for approximating the wall vorticity was used: $\omega_P=\frac{1}{2}\omega_{P+1}-\frac{3}{\Delta\eta^2}(\psi_{P+1}-\psi_P)$, where ψ_P and ψ_{P+1} are stream function values at the points adjacent to the boundary wall; n the normal abscise on the boundary wall.

Table 1. Grid Independency.

Stage	Ψ_{max}	Change (%)	Θ_{max}	Change (%)	Nus_{max}	Change (%)
81x81	0.096439558	-	0.4784585304	-	2.21223664	-
101x101	0.099315211	2.98	0.4864555569	1.64	2.15442773	2.68
121x121	0.098922980	0.39	0.4894582819	0.61	2.12172789	1.51
141x141	0.097577829	1.36	0.4886724631	0.16	2.12202531	0.01
161x161	0.0969874615	0.64	0.4890068332	0.06	2.11512450	0.3

3. RESULT AND DISCUSSION

3.1. Validation

In order to test the computer code developed for this study, the natural convection problem has been verified by performing the simulation in an enclosed air filled rectangular enclosure with an isoflux flush mounted single heater, Ar = 5, S/L = 0.5, l/L = 0.133 and Gr = 5.16 x 10^5 [34].

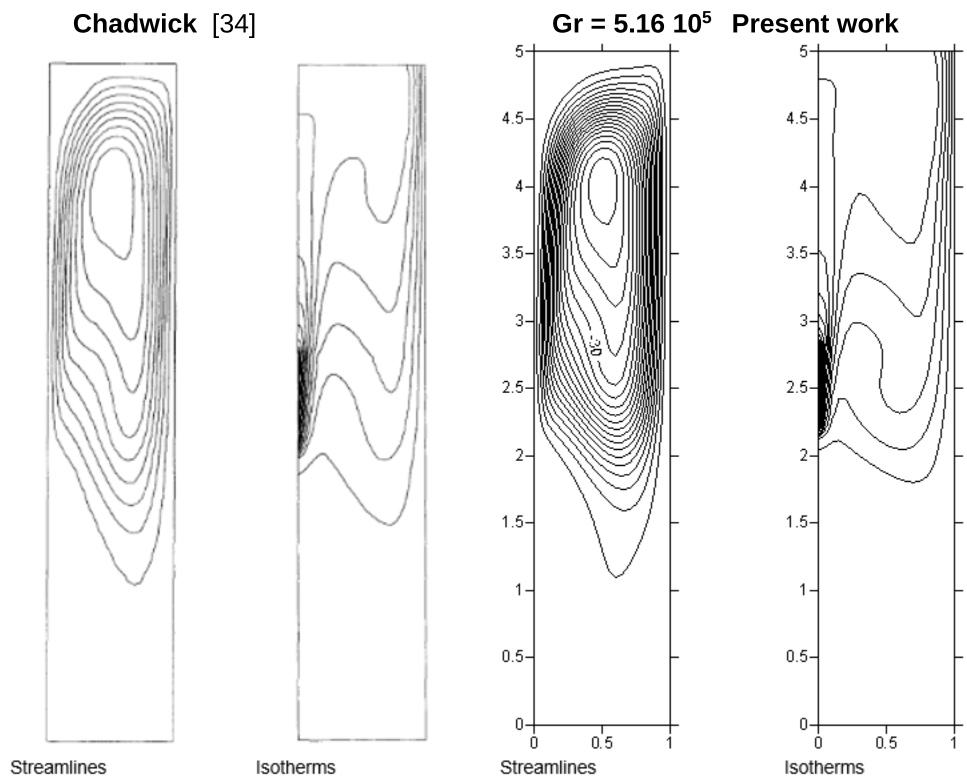


Figure 2. Validation of Streamlines an Isotherms.

The present isotherms and streamlines are perfectly in good agreement with those obtained by SIMPLER algorithm [34] as seen in figure 2.

3.2. Flow and Thermal Visualization

In the following, the effects of the Grashof number ($0 \le Gr \le 10^6$) and the Reynolds number ($5 \le Re \le 200$) on fluid flow topology and temperature distribution are illustrated.

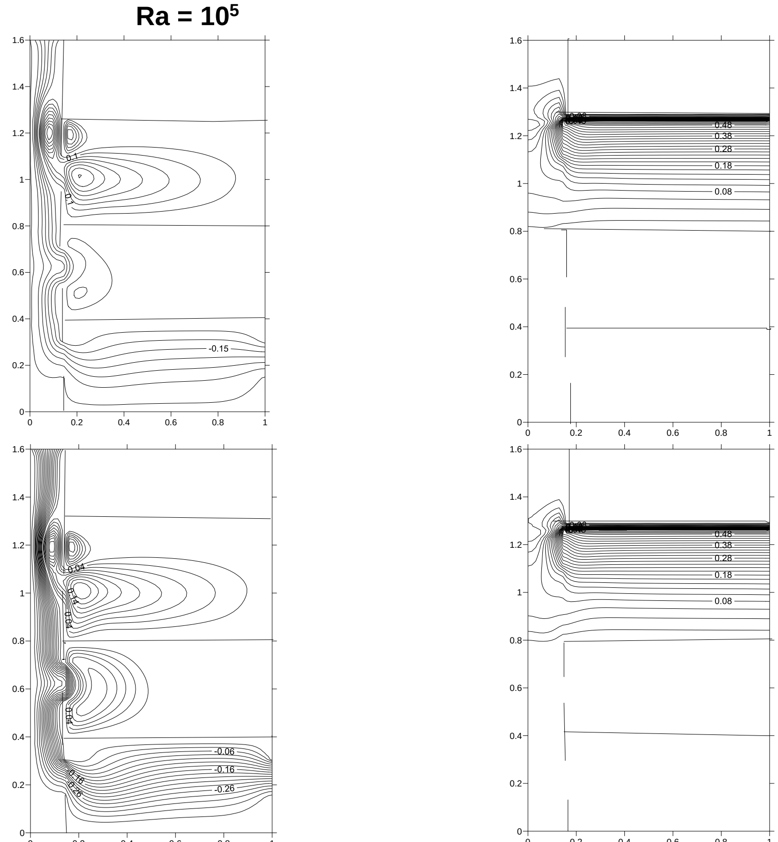
The investigations were conducted by considering air as a working cooling fluid (Pr = 0.72). The geometrical aspects ratio, A = L/H, D = d/H and the relative height of the inside or outside openings for each story, E = e/L, are maintained constant at 1.7,1/4, 1/20 respectively.

The effect of the Reynolds number on the flow structure and temperature distribution is shown in Figure 3 (a–d). The streamlines and the isotherms are presented for steady state flows obtained for $Gr = 10^5$ and different values of the Reynolds number ranging between 5 and 50. For the weak Reynolds numbers, the analysis of the streamlines in Figure 3(a-d) reveals a complex structure in the integrated wind tower into the storied building. It reveals that there is a mixed convection on the stories of the building, while the presence of the natural convective flow is respectively observed on the second and third floors.

Ra = 10^5

(a) Re = 5

(b) Re = 10



(C) Re =20

(d) Re = 50

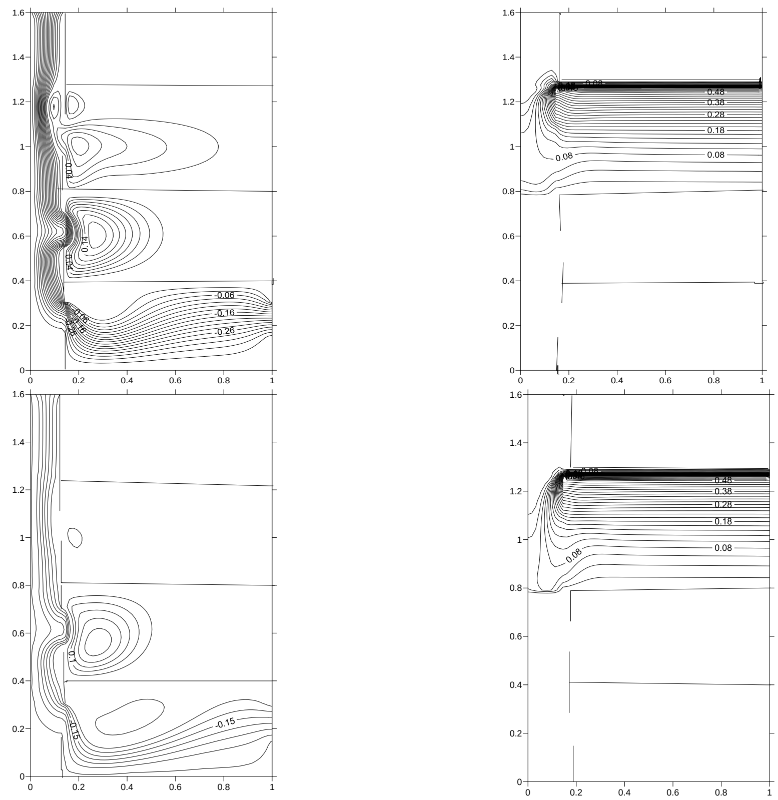
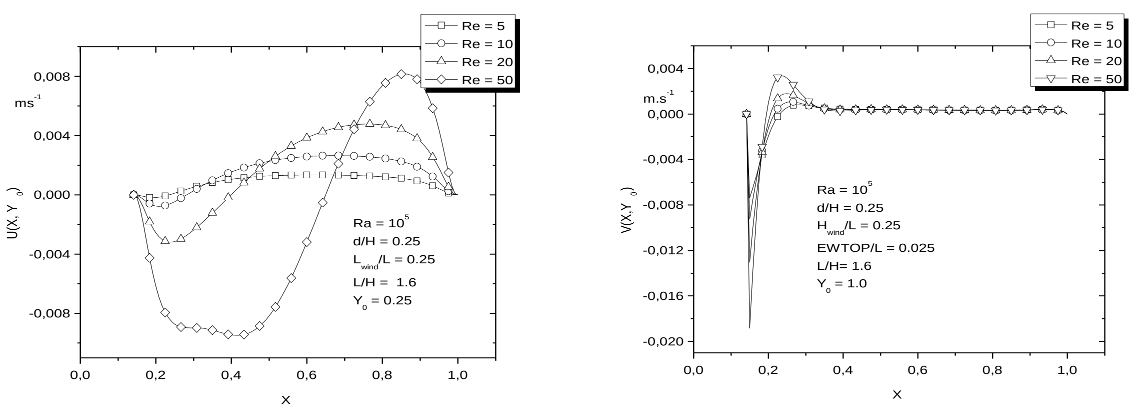


Figure 3. Streamlines and isotherms obtained for Gr =10^6 and different values of Re: (a) Re=5 (b) Re = 10; (c) Re = 20, (d) Re = 50.

By increasing the Reynolds number, the closed cells and the open lines appear simultaneously in the wind tower duct and the storied building. This situation indicates that the real manifestation of the mixed convection in the integrated wind tower into the building, Figure 3 (b-c). The heated upper horizontal wall, located above the inlet channel of the wind tower, impose a clockwise circulation on the stories. The lower closed cells will play an increasingly important role by increasing Re since the more intense is the forced flow, the greater its negative (positive) effect on the natural convection flow in the upper (lower) part of the storied building.

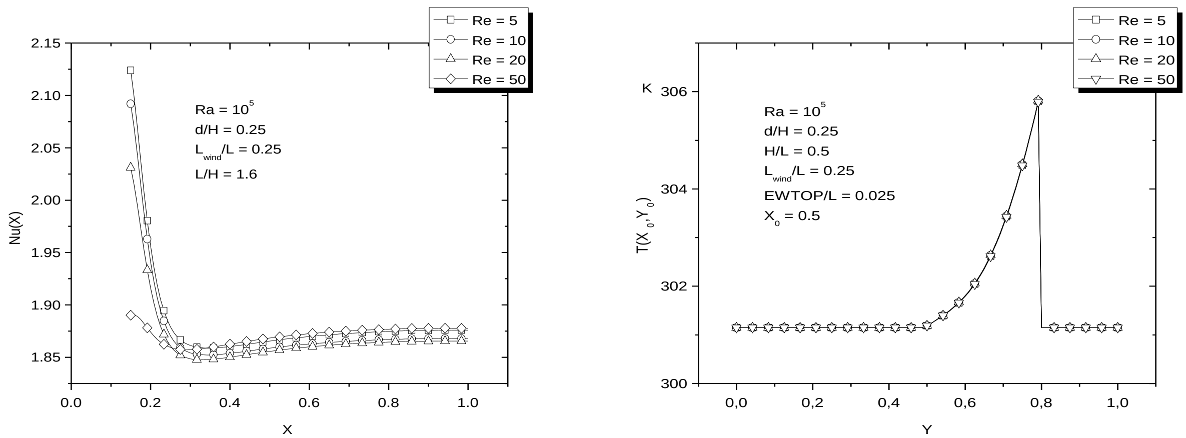


(a) Horizontal component

(b) Vertical component

Figure 4. Variation of the Components of the Velocity versus Reynolds Number.

In the figure 4(a-b), one can observe that near the inlet opening of the stories, the velocity components decrease to attain the negative minimum value before increasing to reach the maximum positive value The maximum value of the horizontal component is obtained near the vicinity of the outlet opening located at the right wall whereas the variation of the vertical component of the velocity attains its maximum near the right wall of the wind tower before decreasing to attain the minimum value along the next right wall of the building These variations of the velocity components indicate that the no slipping condition is respected along the walls in the physical studied model. Hence the variation of the curves in figure 4 (a-b) indicates that the velocity components are the increasing function of the Reynolds number.



(a) Local Nusselt number (b) Dimensional Temperature

Figure 5. Variation of local Nusselt Number and Dimensional Temperature Versus Reynolds Number.

Figure 5(b) presents the predicted indoor temperature for various external fresh air speed interring the wind tower (Reynolds number). One can observe, along the first and second stories, the indoor temperature is close to the ambient temperature, due to the performance of the wetted integrated wind tower. into the building. The pick observed in the third story indicates the manifestation of complex flows or recirculation near the upper heated horizontal wall of the building. The indoor temperature variation along the vertical axis is mainly due to the heat gains from the upper heated horizontal wall and the reduction of ventilation heat load The variation of the indoor temperature in the stories is the proof of the temperature stratification in the vented stories. The thermal comfort obtained in the floors show clearly that the wind tower integrated into the building plays a key role for the passive air conditioning of the building. In the fig.5(a), the variation of local Nusselt number indicates that it deceases from the high value near the left adiabatic wind tower wall to the upper horizontal heated wall. The local Nusselt number along the upper horizontal heated wall is an increasing function of the inlet fresh air speed (Reynolds number).

3.3. Rayleigh Number Effect

The effect of Grashof number ($0 \leq Gr \leq 10^6$) for a fixed Reynolds number (Re =10) is presented. Increasing Gr to 10^4, Figure 7(a) shows a big change in the flow structure; the enclosed cells appear in the stories. The importance of the forced flow is visibly affected in Figure 7(c), corresponding to $Gr = 10^6$. A further increase of Gr leads to more important deformation of the open lines and recirculation cells in the channel of the wind tower causing a visible tightening of these lines and showing a net domination of the natural convection effect, due to the heating of the upper horizontal wall.

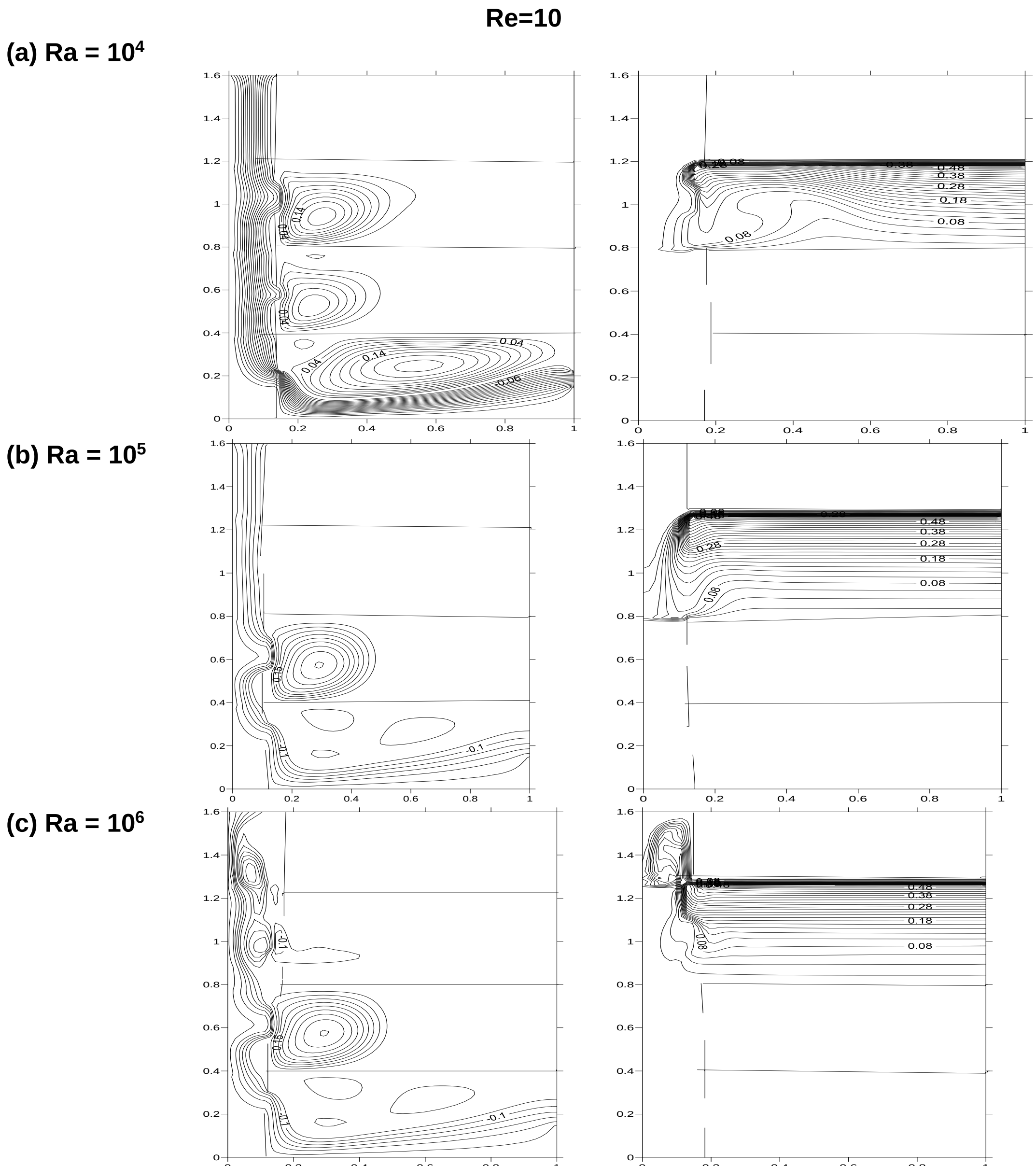
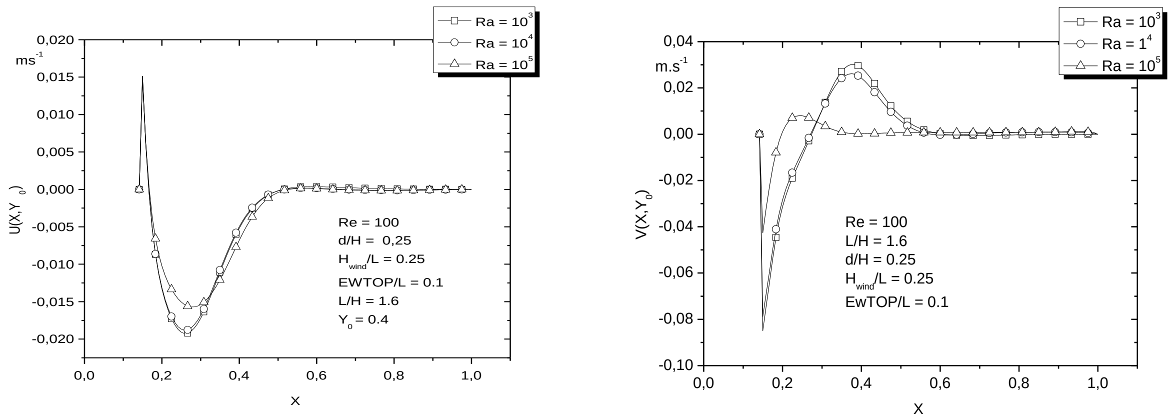


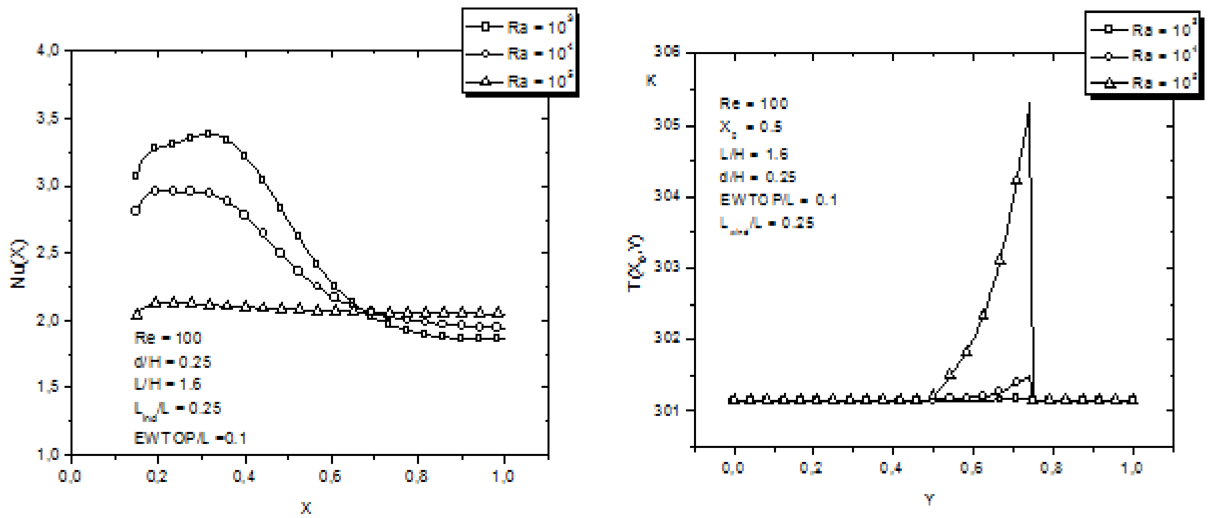
Figure 7. Streamlines and Isotherms Obtained for Re=10 and Different Values of Ra:(a) Ra =10^4; (b) Ra =10^5; (c) Ra =10^6.

Moreover, this increase of Gr contributes to the homogenization of temperature within the building by reducing the dimension of the cold zone, as shown by the isotherms. These aspects are shown in Figure 7 (c), plotted for Gr = 10^6, the Raleigh Bernard natural convective cells and the open lines, appear simultaneously in the stories. One can observe that this situation is a manifestation of the mixed convective heat and mass transfers in the building. Hence, the local Nusselt number along the heated wall is an increasing function of the Grashof number as shown in figure 9 (a-c). This variation of the local Nusselt number proves that the local Nussselt number is inversely proportional to the heated flux which is correlated with Grashof number. By increasing Grashof number, the dimensionless temperature decreases, consequently the local Nusselt number increases.



(a) Horizontal component (b) Vertical component

Figure 8. Variation of the Components of the Velocity Versus Rayleigh Number.



(a) Local Nusselt number (b) Dimensional temperature

Figure 9. Variation of Local Nusselt and Dimensional Temperature for Various Rayleigh Number.

In the natural convection of a wind tower the flow and temperature distributions are influenced by many geometrical factors, such as the channel size, the inlet or the outlet opening size in this section, the effect of these factors will be assessed.

3.4. Wind tower Duct Effect

Figure 10 (a-c) shows the streamlines and the temperature fields of the cooling air integrated wind towers with different widths. Seen from the temperature contours, the heating effect of the heat flux on the internal air mainly occurs in the adjacent regions of the sidewalls of the wind tower. The maximal temperature is attained near the horizontal heated wall for all these integrated wind towers. When the aspect ratio d/H exceeds 0.25, there is still a large vented part in the internal area of the floors. The larger the width, the bigger the cooling living space is. in the stories of the building.

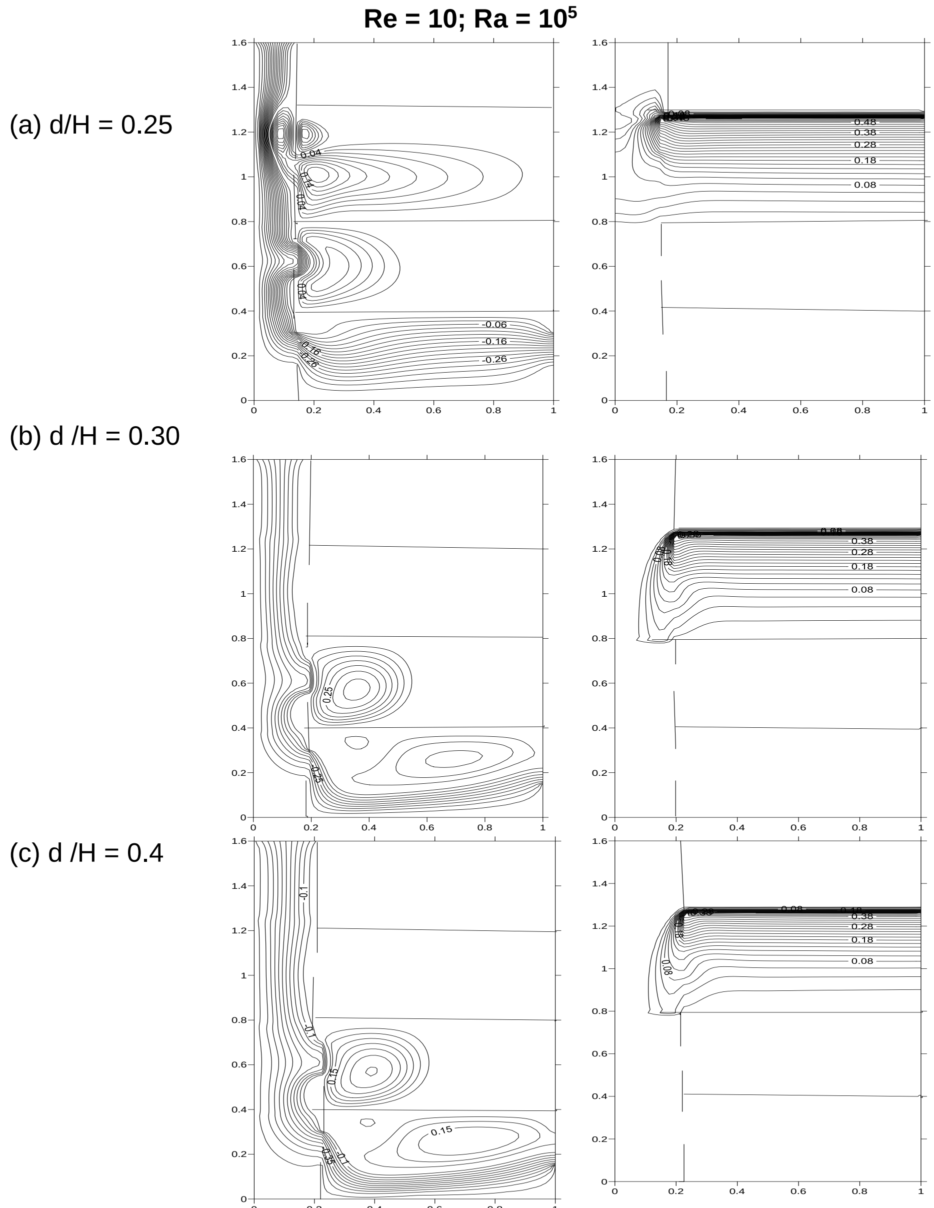
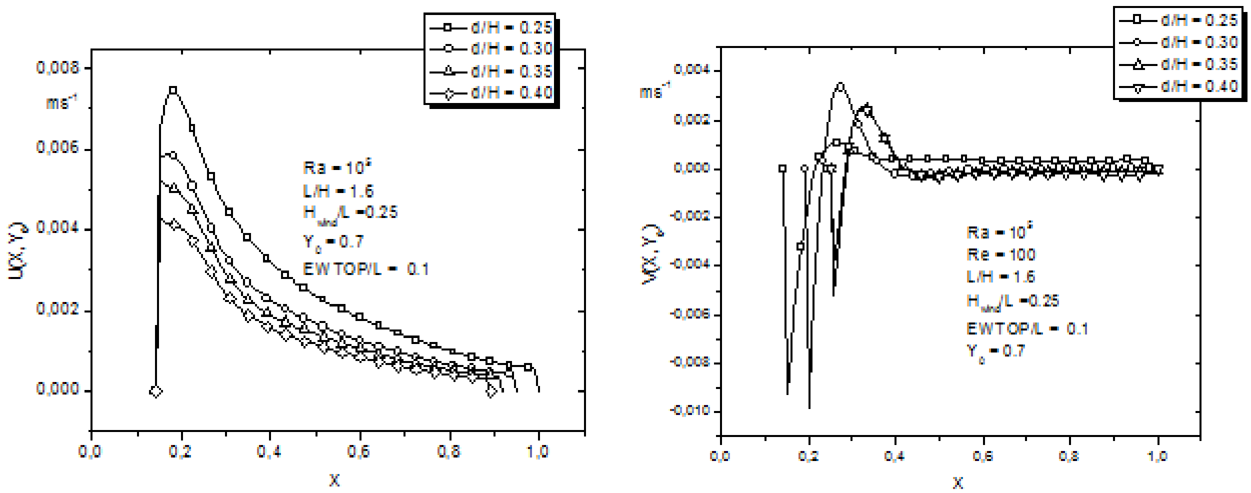


Figure 10. Streamlines and Isotherms Obtained for Re =10, Ra = $10^5$and Different Wind tower Width (a) d/H = 0.25; (b) d/H = 0.30; (c) d/H = 0.4.

Figure 11(a-b) presents the velocity components profiles along the horizontal axis of the building

At the middle and exit cross-sections, the velocity components generally decrease when the wind tower width increases. One can observe that the horizontal velocity component increases to attain the maximal value before decreasing to reach the minimal value at the right wall of the building. The vertical component velocity distribution indicates that the advection phenomenon in the first time near the left wall of the wind tower before it involves to attain the maximum value in the middle of the floor and decreases along the remaining horizontal axis.



(a) Horizontal component (b) Vertical component

Figure 11. Variation of Velocity Components Versus the Width of the Wind Tower.

Figure 12 illustrates that the local Nusselt along the upper horizontal heated wall, is an increasing function of the wind tower width. Larger is the width; higher is the local Nusselt number. This variation of the local Nusselt number indicates that the size of the wind tower plays an important role for passive cooling in the floors of the building. Hence the size of integrated wind tower into the building contributes for its performance for the thermal comfort in the different floors for the storied building

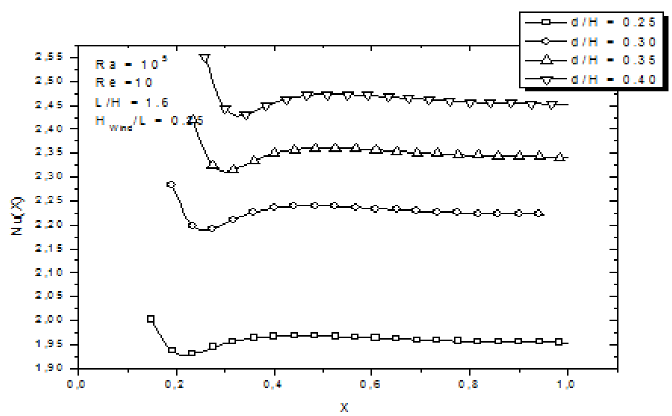


Figure 12. Variation of Local NUsselt Number Versus the Width of the Wind Tower.

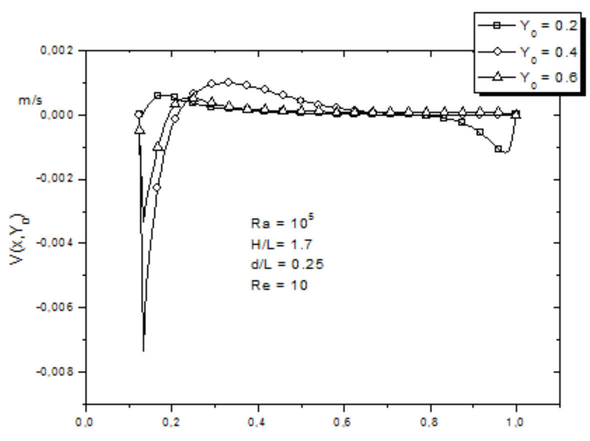
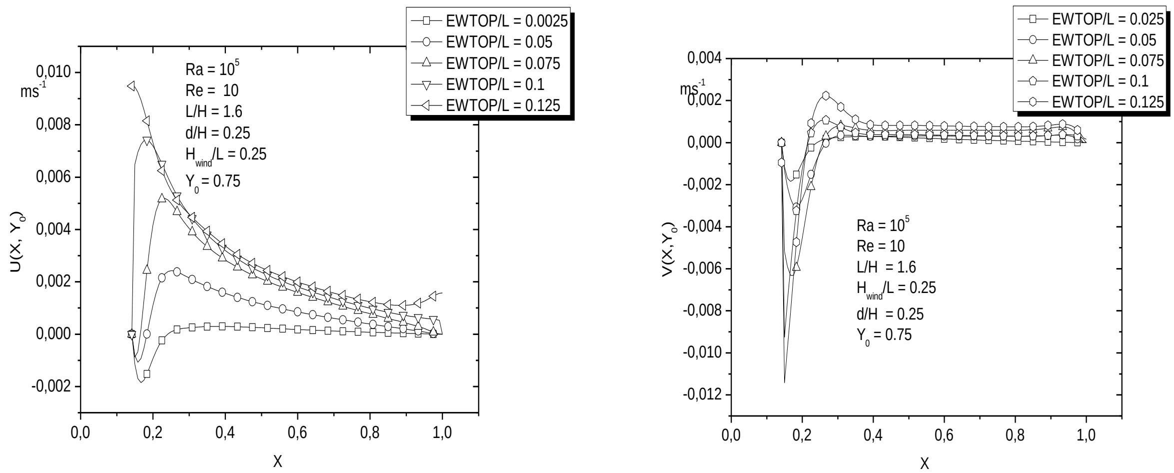


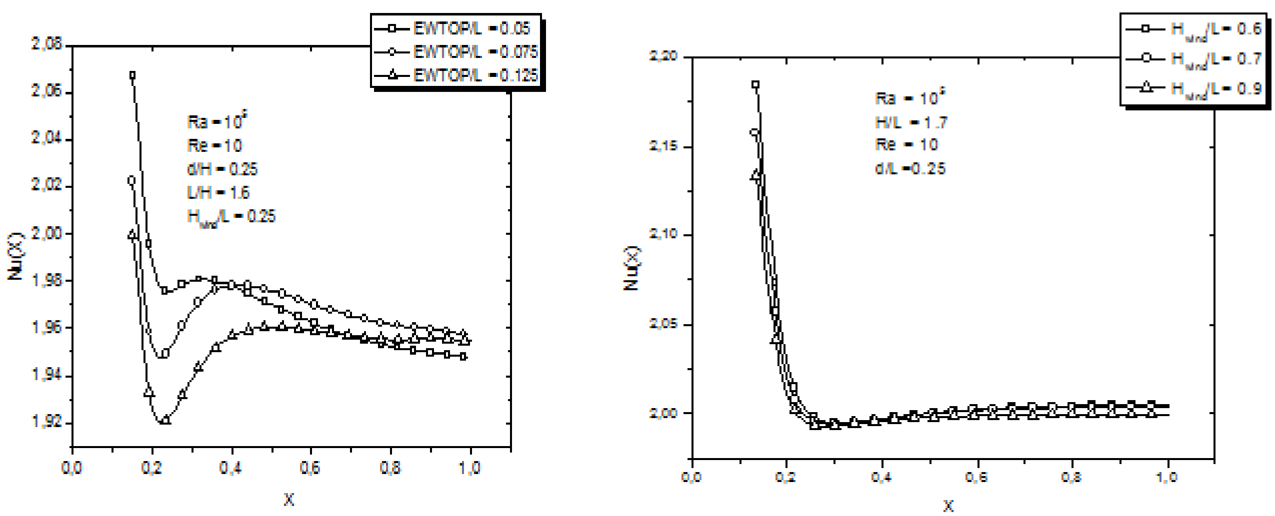
Figure 13. Variation of Vertical Velocity Component in the Floors.

In Figure 13 the variation of the vertical component of velocity, shows sufficiently that the advection phenomenon is manifested in the rooms of the multi-storey building. Moreover, the no- slip condition is respected on all the solid walls of the rooms of the building.



(a) Horizontal component (b) Vertical component

Figure 14. Variation of Velocity Components for Different Top Inlet Size.



(a) Variation of local Nusselt number versus inlet opening of the third floor (b) Variation of local Nusselt number versus the height of the wind tower

Figure 15. Variation of Local Nusselt Number along the Horizontal Upper Heated Wall.

Figure 15 shows the variation of the local Nusselt number due to the effects of the wind tower height and the upper fresh wind inlet opening for obtaining thermal comfort in the multi-storey building. These two geometrical parameters as well as the width of the wind tower play an important role for the performance of the wind tower for passive cooling in multi-storey buildings. On the other hand, the width of the wind tower and the top opening of the fresh air inlet to the rooms have a significant influence on the variation of the local Nusselt number along the active top wall. The higher the Nusselt number, the more excess heat is removed from the rooms and consequently the thermal comfort is achieved in the living spaces on each level of the multi-storey building.

Table 2. Geometrical Parameters of the Building and the Wind Tower.

Parameters	Value
Width of the wind tower d	0.03 (m)
Length of the building, L	1.0 (m)
height of the wind tower, H_2	0.50 (m)
Outlet opening size E	0.05 (m)
Height of the building, H_1	0.5 (m)
Inlet opening size E	0.05(m)

4. CONCLUSION

The present study has sufficiently demonstrated that the integration of naturally ventilated wind towers as an energy efficient alternative to the ventilation and air conditioning systems can improve the thermal comfort in the living spaces for the occupants, the indoor air quality and reduce energy consumption and greenhouse gas emissions. A non-exhaustive literature review on the progress of Computational Fluid Dynamics (CFD) in wind tower development tools was presented. This study concluded that the control of the supply air temperature by a low energy process is still incomplete. Therefore, the study of the performance of a wind tower integrated in the multi-storey building for passive room air conditioning and low-energy internal air temperature control is ongoing. CFD modelling and numerical scale wind tunnel were used to evaluate the performance of the wind tower device. The numerical results obtained were generally in good agreement with the experimental or numerical results of other authors in the literature who have worked on the integration of wind towers into buildings. A significant temperature reduction was observed at lower wind speeds (1-2 m/s), up to 9.5-12 K reduction. In terms of results, the performance of the wind tower is achieved by optimizing geometric parameters such as the width, height, of the wind tower and the dimensions of the fresh air inlet openings into the rooms.

Within the investigated parameter ranges, the following conclusions can be drawn:

Flow analysis in the wind tower integrated into the high divided building has given several possibilities to reduce the energy charge for air conditioning and provide passive cooling on the stories. Coolant fluid temperature is an increasing function of the geometrical aspect ratio while the local Nusselt number is a decreasing function.

- Openings size give the possibility to decrease conventional electrical energy consumption load for air conditioning in a divided multi-storied high building.
- Wind tower provides passive venting and thermal comfort by natural convection on the floors in the storied building.
- For the lowest values of Grashof and Reynolds numbers, thermal comfort is attained in a high building divided into three stories.

Nomenclature

C_P	Specific heat (J. kg^{-1}. K^{-1})
H	Building Length (m)
L	Building height (m)
L_{ow}	First story height (m)
L_B	Height of the building before the first inlet opening
e	Inlet /outlet opening (m)
A	Geometrical aspect ratio of the building (A = L/H)
D	Geometrical aspect ratio of the duct of the wind tower ($D = d/L_{ow}$)
S	Aspect ratio of the building ($S = H/L_{ow}$)
E	Inlet/outlet opening aspect ratio ($E = e/L_{ow}$)
g	Gravitational acceleration ($m.s^{-2}$)
n	Coordinate in normal direction
B	dimensionless Height of the building before the first inlet opening $B = \frac{L_B}{L_{ow}}$

BE	dimensionless Height of the building after the first inlet opening $BE = \frac{(e+L_B)}{L_{ow}}$
LW	dimensionless Height of the building $LW = \frac{L-L_{wind}}{L_{ow}}$
t	Time (s)
T	Temperature(K)
T_a	Ambient air temperature (K)
u, v	Velocity component in x and y directions ($m.s^{-1}$)
U, V	Dimensionless velocity component in X and Y directions; $U= u/v_0$, $V = v/v_0$
u_0	Air inlet velocity ($m.s^{-1}$)
x,y	Coordinates defined in fig. 1 (m)
X,Y	Dimensionless spatial coordinates; $X = x/L_{ow}$ $Y = y/L_{ow}$
Re	Reynolds number: $Re = \frac{\rho v_0 (2d)}{\mu}$
Pr	Prandlt number: $Pr = \mu Cp/\lambda$
Nu	Nusselt number: $Nu = \frac{\emptyset L_{ow}}{\lambda(T-T_a)} = \frac{1}{\theta}$
Gr	Grashof number $Gr = \frac{g\beta\emptyset L_{ow}^4}{\lambda V^2}$
Ri	Thermal Richardson number ($Ri = Gr / \mathrm{Re}^2$)

Greek symbols

θ	Dimensionless temperature $\theta = \frac{\lambda(T-T_a)}{\emptyset L_{ow}}$
τ	Dimensionless time $\tau = \frac{u_{0t}}{L_{ow}}$
Ψ	Dimensionless stream function: $\Psi = \frac{\psi}{L_{ow} v_0}$
ω	Dimensionless vorticity: $\omega = \frac{\Omega L_{ow}}{v_0}$
Ω	Vorticity(s^{-1})
ψ	Stream function ($m.s^{-2}$)
β	Thermal expansion coefficient (K^{-1})
ρ	Density of the air ($kg.m^{-3}$)
λ	Thermal diffusivity of the air ($W.m^{-1}. K^{-1}$)
μ	Dynamic viscosity of the air ($kg .m^{-1}. s^{-1}$)
ϕ	Solar radiation ($W.m^{-2}$)
ν	Cinematic viscosity ($m^2.s^{-1}$)

subscripts

F	Fluid (air)
W	Wall

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