THE EFFECT OF PLAN SIZE IN WIND CATCHER ON ITS VENTILATION RATE

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Abstract- Wind catchers/towers systems were employed in buildings in the Middle East for many centuries and they are known by different names in different parts of the region. Their application in the hot arid region of the Middle East is to provide for natural ventilation/passive cooling and hence thermal comfort, exploiting, particularly, night-time ventilation strategy. They can be beautiful objects, feasible architectural feature additions to buildings and are inherently durable. This paper aims to find out the best plan geometry and plan size in order to increase the ventilation rate by 3-D computational fluid dynamics (CFD) simulations with comparing volume flow rate in different four-sided wind catcher with different geometry and plan size.

Keywords- Wind Catcher, Wind Catcher Geometry, Wind Catcher's Plan Size, CFX Software, Ansys.

I. INTRODUCTION

In last few decades, people feel to have a remarkable and real anxiety concerning the shrink of natural resources as well as global warming and the rise in fossil-fuel prices. It is well admitted that the building section occupies over 40% of the total world's energy consumption. Moreover, the energy consumed in our buildings for various purposes such as cooling, heating, and ventilation systems takes over 60% of total building energy utilization. As the result of these, the notion of "Natural Ventilation" has been increasingly considered by the stakeholders in building investment as to lessen the energy consumption; meanwhile, a newfangled field of study referred to as the "Low Energy Architecture" has been emerged, as well. In order to improve the mass effect as ventilation driving forces, then the green architectural features would be notable, including the appropriate building designs, wind catchers, the solar chimney, well lighting, alongside the atria.Wind catchers are always used as traditional structures for ventilation which can be seen in the Middle East with different names and forms. Although wind catchers are designed in a variety of forms, they have the same function which is capture prevailing wind and drive it to indoor spaces to ventilate and cool the interior spaces due to pressure difference between windward and leeward channels.

Fig. 1 Traditional wind catchers in Iran

Wind catchers in Middle East are come in five categories including wind catchers with rectangular, square, octagonal, hexagonal and circular base with different blades positions according to their plan form. Among these types of wind catchers the frequency of rectangular is more than others with various blades form comprising of H blade, K blade, plus blade, I blade and X blade form.

They can also categorize based on their number of sides to catch the wind including one-sided, two-sided four-sided six-sided and eight-sided wind catchers. Nowadays, wind catcher has been employed in modern architecture, such as in the visitor center at Zion National Park, Utah, where it operates as a regulate temperature device without the addition of mechanical systems.

Fig. 2 modern wind catcher in Zion National Park

II. PREVIOUS WORKS

Karakatsanis et al. determined wind pressure coefficients at various openings of a square wind catcher by testing a scale model of the building in a boundary layer wind tunnel. The tests were conducted on an isolated tower, the tower and the adjoining house, and the tower and the house surrounded by a courtyard. Using measured pressure coefficients natural ventilation through the building was estimated analytically. Elmualim and Awbi carried out experimental investigations and computational fluid dynamics (CFD) simulations to evaluate the performance of square and circular section wind catchers. The achieved results showed that the efficiency of the four-sided wind catcher is much higher than that of the circular one for the same wind speed. They claimed that these results had arisen from the fact that the sharp edges of the square wind catcher create a large region of flow separation and a higher pressure difference across the device. Montazeri and Azizian evaluated the performance of a one-sided wind catcher using experimental wind tunnel and smoke visualization testing. The induced airflow rate into the test room and the pressure coefficients around all surfaces of its channel were measured for different values of approaching air incident angles. Neglecting the dependence of discharge coefficient on the flow direction, natural ventilation performance of one-sided wind catcher was estimated using a non-dimensional analytical model. Liu and Mak used CFD technique to examine the performance of a 500 mm square section wind catcher which demonstrated good agreement with Elmualim and Awbi's data, although this is limited to overall ventilation rates. Elmualim studied a similar wind catcher device, including dampers, diffuser, and a heat source to assess the ventilation capabilities of the device. The results yielded a good correlation between the numerical simulation and experimental measurements. Hughes and Ghani used CFD to calculate net flow rates through a 1000 mm square wind catcher. They concluded that the CFD results show good correlation, and the grid adoption technique is a well-recognized practice for achieving reliable result.

III. METHOLOGY

In this study, computation of the wind flow properties was undertaken by employing the commercial computer code ANSYS CFX R14. The software was indeed based on the finite volume method developed into numerous components such as the pre-processor, the solver, and the post-processor.

In details, the computational model is configured in the pre-processor with regard to the solution domain geometry as well as the dividing the domain into the finite control volumes for the solution procedure. Furthermore, the boundary conditions, like the wind velocities and wall boundaries, are adjusted in the pre-processor.

The solver is used to assimilate the governing equations of the fluid flow as well as solving the algebraic expressions generated by the numerical approximations of such equations with the purpose of yielding a solution to the fluid flow problem. Finally, the post-processor is employed for visualizing the resultant fluid flow with reference to the velocities, pressure, as well as other flow variables.

A. Wind catcher model

Rectangular base plan wind catchers are investigated in this study. For the pattern of partitions, four types of rectangular wind catchers blades are investigated in this study including K, H, +, and X blades form. Reference cases are presented in Fig. 3.

Each type of selected wind catchers consisted of five wind catchers with different cross section dimension and same length to width ratio (Fig. 4) including 1m by 1.5m (1.5m^2), 1.25 m by 1.875 m (2.34375 m2), 1.5 m by 2.25 m (3.375m^2), 1.75 m by 2.625 (4.59375 m^2) and 2 m by 3 m (6 m^2). Totally there are 20 models in order to investigate the effect of plan size on ventilation rate. Perpendicular wind direction of 0° is selected for this study.

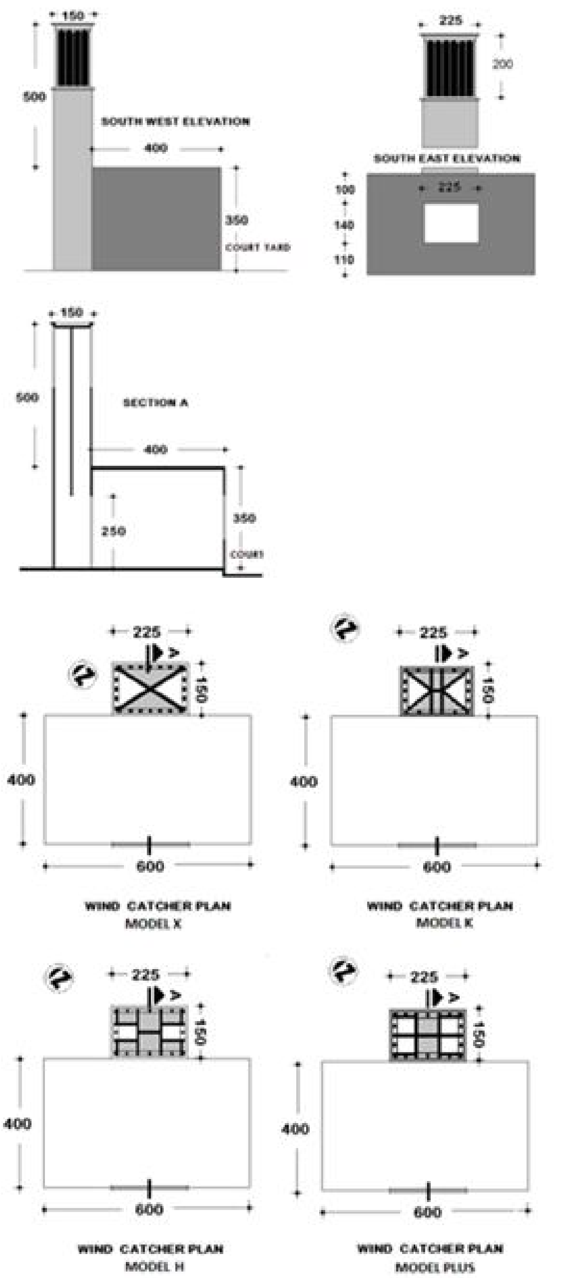

Fig. 3 Selected wind catcher models for simulation

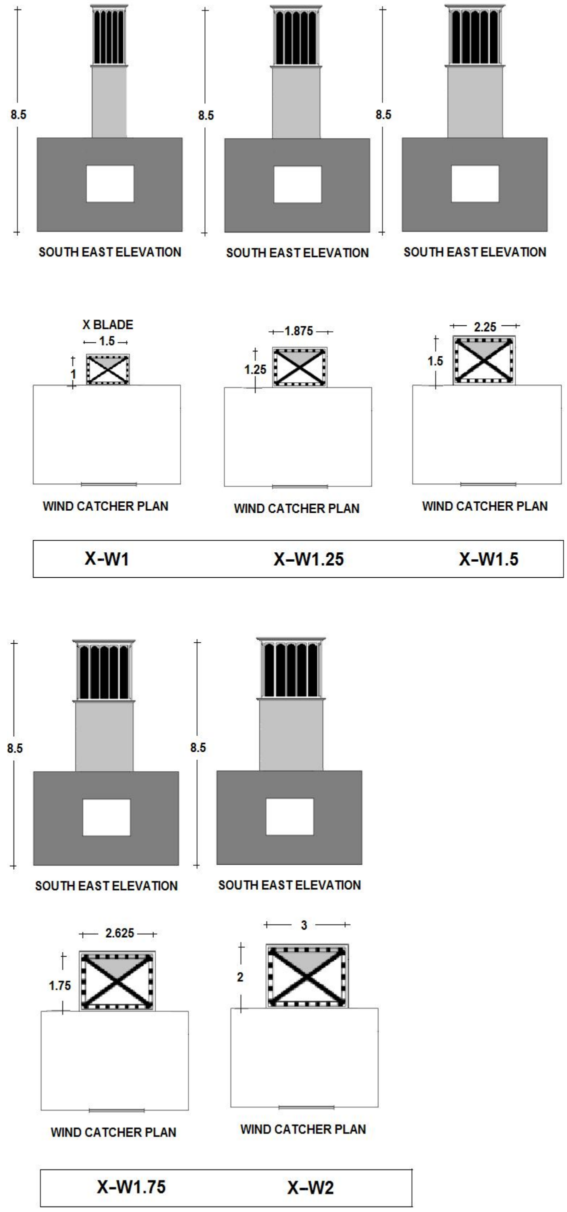

Fig.4 Different plan sizes of model X

B. Computational Domain and Grid

According to accomplished sensitivity study by M. Hossein Ghadiri et al. and best practice guidelines, a distance of one building height (8.5m) was used between inlet and the windward face of the building (upstream), five building heights (42.5m) between the sides of the domain and the sides of the building (lateral), and between building roof and the top of the domain, and a distance of ten building heights (85m) between the leeward face of the building and the domain exit (downstream).

Therefore, the height, length and width of the computational domain were set at 51m, 99m and 91m respectively with the blockage ratio of 0.7%. Computational flow domain is discredited into structured hexahedral and prism meshes of 1,747,200 elements for perpendicular angle of 0° for half geometry (see Fig. 5 and 6).

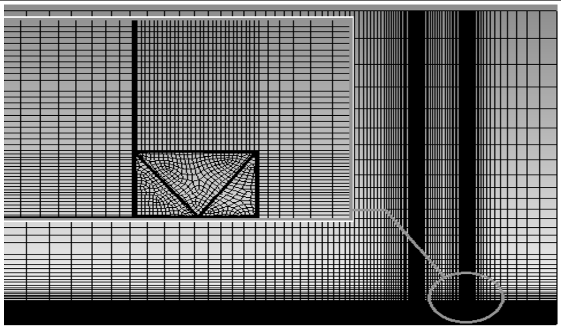

Fig. 5 Top view of hexahedral and prism mesh in X blade wind catcher in wind angle of 0° for half geometry

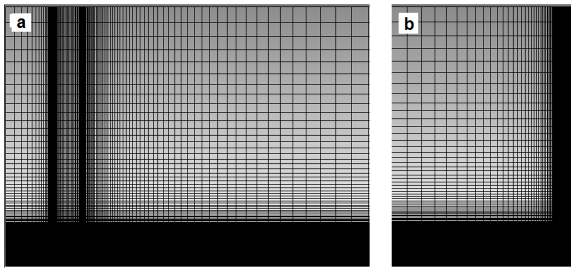

Fig. 6 hexahedral and prism mesh in X blade wind catcher in wind angle of 0° for half geometry (a) Front view (b) Side view

C. Boundary Conditions

To develop a theoretical velocity profile the power law equation presented in (1) with the recommended values suitable for this study is applied.

$$V_h/V_H=(h/H)^9 \quad (1)$$

Where V_h is the mean wind velocity at heights h (point of interest) and V_H (5m/s) is the selected wind speed at height H (10m) while β is the power law index, β =0.28, which is recommended value for suburban area. The calibrated power law equations of the velocity component U (5 m/s at reference) and the turbulence intensity I (5%) are applied at the inlet, with the other wind velocity components V and W at the inlet being zero. At the outlet, the static pressure difference (SPD) is set equal to zero, because wind structures had been fully developed and captured in the flow domain.

D. Solver settings

Standard k-ε model is applied with the 2nd order upwind discretisation scheme. The convergence criterion is that the root-mean-square (RMS) of the normalized residual for all variables is less than 10^{-5}. Table I shows the summary of CFD prediction.

Table I Summary of CFD prediction

CFD setup	
Computational grid resolution	1,594,385 tetrahedral and prism (30°-135°) 1,747,200 – hexahedral (0° and 180° half geometry)
Turbulence model	Standard k-ε
Turbulence intensity	5%
Discretization scheme	2nd order upwind
Boundary	Inlet – power law

condition	(U=5m/s, V=0, W=0) Outlet– SPD = 0
Convergence target	10^{-5}
Algorithm	Steady states

Three monitor points including the average air velocity at the bottom of the windward channel, top of the leeward channels and window, are utilized in all simulations. The airflow rate passed through these surfaces was calculated as follows:

$$Q = \sum_{i=1}^{n} A_i V_i \quad (2)$$

Where Q is the flow rate through the channel of the wind catcher and A_i and V_i Are the area and velocity of the portion i, respectively. As an example, windward surface of wind catcher with H blades form, consisted of 3 portions in 0° wind angle.

IV. RESULTS AND ANALYSIS

Volume flow rate versus the wind catcher width for wind angle of 0 is indicated in Fig. 7. Through the chart, among all models, the highest ventilation performance provides by wind catchers with H blades form followed by K leaving plus forms to have the minimum performance. The highest performance of the plus blade form is 70% that of wind catcher with H blade form at width of 2m. The predicted air flow rate of air entering the room through wind catcher increases sharply as wind catcher width increases and represents about 313%, 373%, 270%, and 495% improvement from wind catcher width of 1m to 2m in wind catcher with for wind catcher with X (see Fig. 5), K, H and plus blade form. Therefore it could be concluded that huge wind catchers increased the value of air flow considerably.

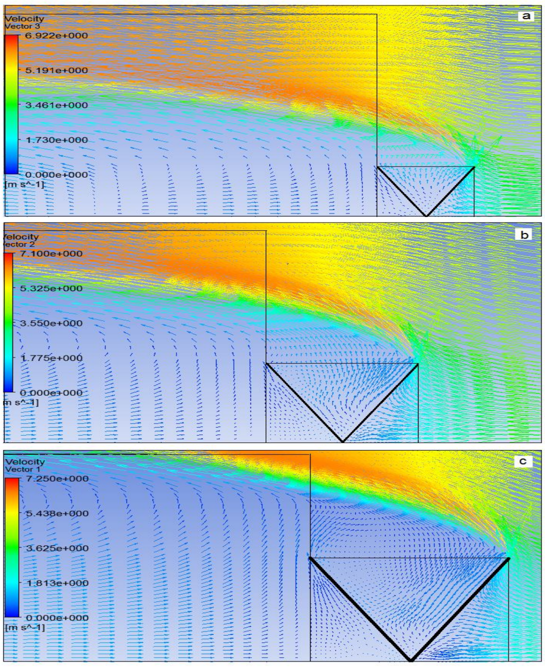

Fig. 7 the velocity vector of X blade wind catcher model with plan dimension of (a) 1m×1.5m (b) 1.5m×2.25m and (c) 2m×3m

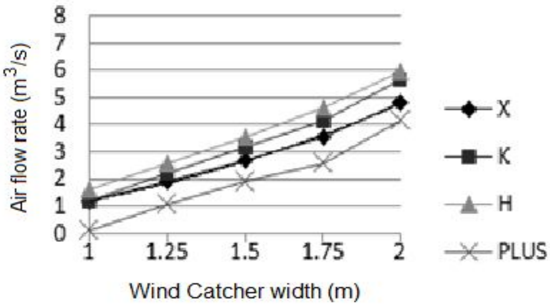

Fig. 8 Ventilation rate versus wind catcher width in wind angle of 0°

CONCLUSION

The wind catcher is an intelligent exploitation of wind energy which makes possible thermal comfort in hot region. The major advantage of the wind towers is that they are passive systems, requiring no energy for their operation ventilation rate of 20 form of wind catchers with different plan size and geometry are investigated and it could be concluded that the air flow rate and wind velocity increases considerably by increasing the area of wind catcher cross section from 1.5 m^2 to 6 m^2. The air flow rate in wind catcher with cross section of 6m^2 improved almost four times greater than wind catcher with 1.5 m^2.

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