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EXPERIMENTAL STUDY ON PERFOMANCE OF WIND CATCHER IN TROPICAL CLIMATE

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ABSTRACT

Today, the knowledge of using natural ventilation in buildings with consideration of traditional architecture of different areas, has become an important factor to consider in the buildings. The focus is on increasing the quality of space regarding to climate and environmental parameters. Iran is a country with vast and different types of climate and each one has come with it's own harmonic way and response in architecture. In these study conventional traditional buildings exposed to the hot and humid weather in the northern coast of Persian Gulf and Oman Sea is considered. The wind catcher is widely applied in these areas to enhance the natural ventilation in buildings. Studying the regional measures of the local expert architects can contribute to a suitable building design for such a climate. This paper aims to study how the wind catcher works by the wind-tunnel testing and CFD simulations. The main objective of this research is to discover how a wind catcher works by considering climate situations of a tropical region. The results show that increasing the height optimizes a wind catcher's performance by taking other appropriate variables. Furthermore, this study shows that the proposed system, even at relatively low speed outdoor wind, is able to create ventilation in a residential unit. According to the results of the wind-tunnel test and CFD simulations, the wind catcher can be used in hot and humid tropical areas to help create thermal comfort in green buildings by increasing the natural ventilation.

Keywords: wind catcher, natural ventilation, green building and tropical climate.

INTRODUCTION

Increasing the use of energy has always been a fundamental and important matter in human life, and trying to use renewable energy sources has been the historic wish of human being [1]. Since mechanical cooling systems in buildings exposed to hot and humid air are both main fossil-energy consumers and greenhouse gas (GHG) producers, natural ventilation is an effective strategy to solve this problem. This occurs by allowing natural air flow through the building and as a result, improving indoor air quality that reduces the consumption of non-renewable energies and fossil fuels [2]. In other words, natural ventilation brings the fresh air to indoors and gradually reduces the concentration of air pollution at buildings [3]. Allard [4] believes that natural ventilation system is highly cost-effective, considering the operating costs and maintenance of mechanical central systems [5]. To increase the use of natural ventilation, researchers have studied different methods to extract this idea for buildings. For example, some characteristics which improve indoor air by including the central courtyard [6], atrium and wing walls [7], side walls [8] and dome roofs [9]. In this case, one of the traditional methods for the use of natural ventilation in Iran is a wind catcher system; however, there is little evidence of any research into their design, calculation, and operation. In addition, because of little familiarity of designers and researchers from other countries with this concept, only a few architects and practitioners have executed the plan. Several research projects related to the optimization of energy consumption have recently been conducting in industrialized countries. Other studies also aim to analyse the wind catchers' cost-effectiveness. Incidentally, this system has been employed in central cities of Iran with hot, dry climate and also in hot, humid areas of southern Iran (Figure-1).

Figure-1. Wind catcher in the northern coast of Persian Gulf (Iran, Laft).

One of the important and effective variables on the performance of the wind catcher is its height since, according to Bemoulli's principle [10], the height increase allows access to higher wind speed which, in turn, improves the catcher's performance. In fact, this idea encouraged the present study of natural ventilation application, with the aid of wind catcher, in hot and humid regions.

LITERATURE REVIEW

For providing natural ventilation, wind tower is one of the old passive cooling methods that have been used in the Middle East over three thousand years in building designing [11].

The effect of the wind and the basic rule of passive stack and wind effect were studied to find out the stack plan. Li and Mak[11] investigated how a wind

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catcher system works, and in their analysis, they employed computational fluid dynamic (CFD) and wind tunnel testing. During the test, they set different wind velocities and directions inside the tunnel and then compared the experimental and numerical outcomes. The results showed that the external velocity and the wind direction remarkably control the catcher's performance. Moreover, as the external wind velocity is increased, the flow rate of the wind inside rises as well. Their results also revealed that the incidence angle of the wind decreases the flow rate in case the wind velocity is less than 3 m/s.

Hughes and Ghani [12] conducted a study in order to find out the total feasibility of sustainable improvement, while lowering the present costs of buildings. They applied a passive ventilation instrument (windvent) in numerical fluid dynamics with numerical analysis of wind velocities ranging between 1 and 5 m/s. The findings showed that the windvent can give the desired rate of fresh air supply inside the building, even at low velocities; therefore, the instrument is appropriate for sustainable ventilation systems.

Montazeri and colleagues conducted a study on the wind catchers of Yazd city, where they studied the influence of the number of opening wind catchers on performance [13]. They used CFD simulation, experimental wind tunnel and smoke visualization test. The airflow rate was measured at each opening. Velocities were 10, 20 and 25 m/s and the angle of attack 0◦ and 45◦. The results showed that the efficiency decreases as the number of openings increase. There is also a relationship between the wind angle and resulting airflow pace in the wind catcher, in such a way that a two-sided wind catcher at an angle of zero degrees has greater efficiency. The findings also showed that wind angle effect is decreased by increasing the number of openings and, moreover, the wind catcher in the rectangular shape absorbs airflow more efficiently [13], [14]. In another case, Asfour *et al* (2006), using CFD simulation, showed that arched roof of wind catcher increases its efficiency and improves the internal air distribution in the wind catcher [15].

Finally, Saadatian and colleagues, after reviewing the previous studies on the effects of wind catcher, recommended further studies on the height effects [16].

METHOD

In this study two series of wind tunnel studies on the performance of wind catcher in tropical weather in Aeronautic Laboratory of University Technology Malaysia (UTM) were performed (Figure-2). An Industrial open circuit, a fan driven wind tunnel (Suction tunnel) was used for this study. It must be mentioned wind tunnel included a flow straightener to make the stream lines of flow in straight lines, a big test section with low speed range (5-7 m/s) and a contraction section which is designed to connect the flow straightener with big section area to test section with small section area, a test section and driven fan. This wind tunnel can reach the maximum speed of 60 m/s velocity.

First series of experiment were done using made models by Plexiglas in different dimensions at height and in area which included a house (The typical layout of unit of the basic simplified configuration of single buildings in high- rise low- cost residential building) and the wind catcher.

Figure-2. Wind tunnel in aeronautic laboratory of University Technology Malaysia (UTM)

At this stage only a part of the model was set up in the test section up and the rest of the model was located outside the wind tunnel (Figure-3) in order for the airflow to only affect the small body part of the wind catcher inside the test section. In this case, according to the mechanical principles, Bemoulli's, while a part of model is located inside the test section and the rest outside the test section, the flow around the wind catcher inside the test section makes the suction flow taking the air inside the model, leading a flow from lower levels to upper levels. In this case, the objective was to find out the behaviour of flow and examine the results of CFD simulation and Compare them with data recorded (pressure coefficients on the inner sides of model were measured) from experiment which inside the small test section.

Figure-3. Wind tunnel test (small test section).

Second series of experiment were done in the big test section (Figure-4) with low speed range, but this time

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all the model (the same as previous test) was located inside the test section to check the performance of wind catcher.

Moreover, the pressure coefficient, air velocity at the Centerior of the wind catcher inlet and Centerior of the wind catcher outlet (connection of wind catcher and house) were measured to have good comparison with CFD results.

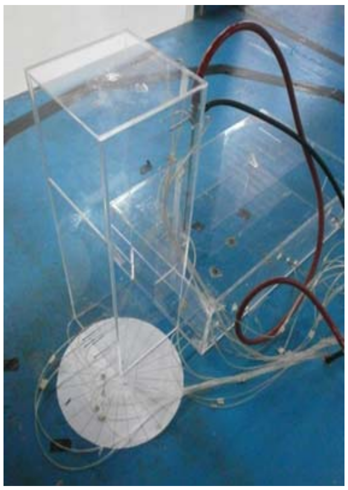

Figure-4. Wind tunnel test (big test section).

RECORDING OF PRESSURE (Pa)

To calculate the value of pressure coefficient (Cp) for all velocities, this study needed to record 1 tare file only in zero angle of attack (AOA). Then all raw data for pressure was being recorded at maintained speed (i.e.: V=20 m/s) and the test was started from the lowest AOA. The raw file was recorded for each AOA; consequently, there is one tare file relating to each run.

The pressure transducer had 30 inputs, from which only one was used to connect the free stream pressure sensor installed inside the tunnel (Figure-5). Tap number 18 was not been connected to the pressure transducer because of the sensor limitation.

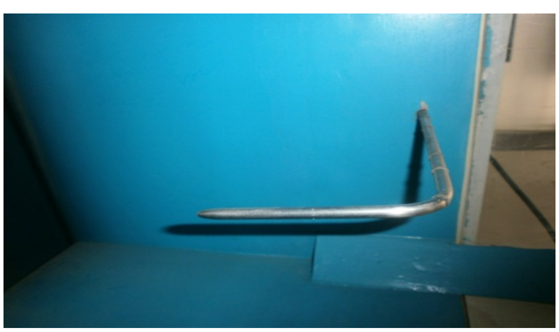

Figure-5. Free stream pressure sensor installed inside the wind tunnel.

After recording a tare file and all raw data, it necessitated calculating the average value of pressure in each tap. All recorded data, either in tare file or in raw files, were arranged (Table-1 shows the sample). Each column indicates the pressure value of each tap. Researchers just needed to calculate the average value of each column at the end of that column. Then the average value of each tap in tare file was subtracted from raw data for the same tap.

For example if average value ($P\infty$) of tap 2 in tare file was - 0.8469 and the same tap in raw data of velocity V=20m⁄s was equal to Pi = - 99.03 pa then according data of test:

For 20 m ⁄ s → $P_i - P_\infty$= - 99.03 - (- 0.8469)
= - 98.1831 pa (1)

Table-1. Tare files and raw data are arranged in presented way (unit of the value is Pa)

DP12	DP13	DP14	DP15	DP16	DP17	DP18	----
-186.201	-122.2813	-101.7782	-59.57397	-5.994038	74.281424	45.958984	......
-185.5907	-122.897	-85.32308	-60.18624	-5.382401	76.12769	50.27149	......
-188.0319	-119.8184	-93.24594	-60.79851	-0.489309	71.819737	44.72684	......
-183.7598	-121.0499	-93.24594	-61.41078	-1.712582	71.204315	51.503634	......
-184.9804	-123.5127	-94.46484	-58.9617	-2.935855	74.896846	42.878623	......
-187.4216	-118.587	-93.24594	-64.47213	-0.489309	69.358049	43.494696	......

Now according to the pressure coefficient equation which is shown below:

$$\mathrm{Cp} = \frac{P_i - P_\infty}{\frac{1}{2}\rho u^2} = \frac{P_i - P_\infty}{q} \tag{2}$$

This indicates the average value of both a tap in raw data and the same tap in the tare file. The q represents the fluid dynamic pressure.

$$\mathrm{Cp} = \frac{P_i - P_\infty}{\frac{1}{2}\rho u^2} = \frac{P_i - P_\infty}{q} = \frac{-98.1831}{295.30} = 0.3324 \tag{3}$$

So at velocity 20 m/s pressure coefficient was equal to Cp= - 0.3324. Same procedures were done for all taps and for all velocities in any angle of attack. After finding the sum of all taps at desired velocity, the value of Cps versus X (position of each tap) is plotted for each series of pressure taps.

CFD simulation

For each series of experiments were a number of simulations. First, in order to discover the proper mesh quantity, the grid independence test was done for each set. Upon finding the correct number, their precise solution was evaluated. To do so, all possible running conditions for different boundary conditions; different solution methods; discretization methods; and different turbulence models were studied to find the exact solution method for this project.

Grid independency

As mentioned before, both series of experiments grid independence studies were done as this is a way to find an optimum grid size for a particular simulated problem any larger grid size has no bearing on the solution.

For the first experiment in small test section, seven series of mesh with different quantities such as 70000, 1000000, 1500000, 2000000, 3500000, 4900000 and 6800000 meshes were generated by using the ICEM software included in Ansys package. All results monitored (same monitoring points) from all meshes were plotted and finally the mesh with 3500000 grids has been selected as a proper mesh which is accurate enough to capture the result.

For the second experiment in big test section, the same again, seven series of mesh with different quantities such as 700000, 1400000, 2800000, 4200000, 5600000, 8400000 and 11200000 meshes were developed by using ICEM software were generated which the mesh with 5600000 grids has finally been selected for the simulation. It should be mentioned that in this case both meshes with 700000 and 1400000 grids even failed to finish the simulation and gave divergent error which means unity solution for these meshes could not be found. With refinement of meshes, all other meshes could get convergence which means solution of all related equation in CFD packages obtained unity solution. It is important that all CFD users follow these rolls to ensure that they are reporting accurate simulation results.

Validation

For the first series of experiments several CFD simulations were performed and the entire data collected from all different conditions in CFD were compared and the most accurate results with the lowest error was selected for the validation stage.

For the second series of experiment, the grid independence study was carried out and according to the quantity of meshes (5600000 meshes) which takes a long time to complete the process of simulation. It should be mentioned since there were 9 different models for wind catcher (3 different heights at 40, 80 and 120 cm and 3 different section areas with 4*4 cm, 8*8 cm and 12*12 cm).

RESULTS AND DISCUSSIONS

Wind catchers have many applications in natural ventilation that they have been used for many years in different countries. Designing basics and performance of this technique can be diagnosed and will be compiled in the existing buildings. Not enough effort in innovation and updating is one the factors limiting the extensive use of wind catcher technology. There is no doubt that if contemporary architecture takes advantage of the wind catchers in the construction, it will lead to wider public attention and the traditional- architecture technique will create the new architecture dimensions in the 21st century architecture.

In this test, a model of one-way wind catcher (scale: 1/25) connected to an atmosphere with appropriate dimensions of a residential unit was tested. The desired model which was placed in the wind tunnel in test section was validated with CFD simulation results. The results obtained from the experimental validation showed good agreement and convergence with the results of wind tunnel. The authors of the study also compared different CFD turbulence models for this test. CFD results of wind catcher system were compared with the data obtained from the wind tunnel tests. A moderately strong correlation was observed between the different methods of analysis that raises the influence of height dimensions factor on the performance of air movement by passive ventilation wind catcher device.

CONCLUSIONS

The findings showed that the increase in height by considering other variables is a factor that increases the performance of the wind catcher. In addition, this study suggests that the proposed system, even exposed to relatively low-speed outside winds, is also able to create ventilation in residential buildings. The results of the model which tested showed the efficiency of wind catcher in a hot and humid climate. In the absence of modern air conditioning systems or air-mechanical ventilation equipment, the wind catchers can take the charge of getting the wind and leading it to home or the residents of the house. In the future work, the researcher should investigate performance of wind catcher in hot and humid countries such as Malaysia.

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