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A CFD Simulation Study of Natural Ventilation with a Two-Sided Wind Catcher System.

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Abstract

The paper presents numerical CFD simulations of a two-sided wind catcher based on two previous experimental studies by Afshin et al [2] and Montazeri and Azizan [25]. K-Ɛ turbulence model was used for the study at various wind speeds to cover the range of parameters investigated in both studies. The purpose of the study is to build an initial step for future investigations of wind catcher design modifications and analysing the effect of external atmospheric turbulence on the ventilation rates. The results so far show good agreement with both studies for pressure distribution and flow rates.

Introduction

The rapid increase in energy consumption across the world is strongly implicated in the phenomenon of global warming and the problems that arise from it. Since buildings account for a 20% to 40% of the total energy consumption, it presents opportunities for mitigation of these problems through application of renewable energy substitutes and alternative technologies to achieve significant reductions in energy consumption. Natural ventilation is an alternative that has been applied to modern buildings to reduce energy consumption and provide better air quality. Wind catchers are presented as one of the most significant natural ventilation techniques; they are based on ancient architecture of the Middle East where they provided cool humid air in hot dry regions. A wind catcher is basically a tower connected to a space or a room where it receives (catches) the air and allows it to flow within the room. The wind catcher system mainly operates on two principles; climatic wind speeds and temperature difference between inlets and outlets causing air circulation due to density variations. Applying such a system to modern buildings worldwide, based on urban and architecture planning for both heating and cooling processes, can lead to a significant reduction in buildings' energy consumption.

There are several parameters that affect wind catcher operation and design. Wind catcher geometry is one of the most significant parameters that has an impact on ventilation rates through occupied spaces. Most wind catcher studies [3, 5, 7-9, 11, 13, 14, 16, 23-24, 27-28] have discussed the geometrical aspect and its effect on the system performance. Some studies compared the performance of different shapes and there was an agreement that square shaped wind catchers are better, this has been attributed to the increase in the magnitude of suction pressures surrounding the leeward side arising from flow separation past sharp edges. The formation of wakes lead to an increase in the suction rates of exhaust air. The current study simulates a square shaped wind catcher.

The performance of a wind catcher is also dependent on the climatic conditions and the surrounding built environment. Most studies were conducted in both Yazd city, Iran [2, 5, 15, 16, 28] and the UK [6, 18-21]. The studies showed the efficient performance of wind catchers as ventilation systems in both hot and dry climates and in cold and humid weather. Some of the inlet flow speeds presented in these studies are within the prevalent conditions of Auckland city, New Zealand which will be considered in future investigations.

Human comfort within occupied spaces was considered in most studies while using wind catchers [1, 3-4, 6, 10, 12, 15-16, 20, 22]. The parameters were found to be satisfying.

This paper presents CFD numerical simulations of a two-sided wind catcher based in Yazd city, Iran. ANSYS FLUENT software was used for the simulation. The wind catcher was studied twice with different scale models and at various wind tunnel speeds and orientations. However, each study took a specific single velocity and studied it with different orientation angles, while the simulations were conducted at zero orientation angle with various inlet velocities (1, 4, 7, 10, and 20 m/s) in order to cover both studies.

Modelling and Simulation

Both Montazeri and Azizan [25], and Afshin et al [2] presented a wind tunnel experimentation and a CFD simulation based on a real full scale ancient wind catcher of Kharmani's school in Iran, shown in figure 1. Montazeri and Azizan [25] scaled the building to a 1:40 scale while Afshin et al [2] was to a 1:50 scale. Both studies conducted wind tunnel experimentation at various wind speeds and orientation angles. Furthermore, smoke visualisation tests were shown to confirm the flow contours and air distribution inside the wind catcher ducts [2, 25-26].

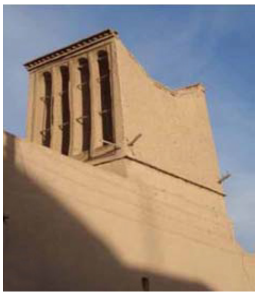

Figure 1. Ancient two-sided wind catcher of Kharmani's school in Iran [2, 25].

A 3D model based on Afshin et al [2] scale dimensions (figure 2) was created, with the building sitting below the wind tunnel, while the wind catcher tower protruded into the test section. The boundary conditions were specified (figure 3) to model the wind tunnel setup of Afshin et al [2]. The wind tunnel walls were modelled as no-slip wall boundary conditions, uniform inflow velocity was specified at the inlet, and a pressure outlet boundary condition was used for the window on the building. The investigation focused on pressure coefficients and flow rates. The pressure coefficients of the inner surface of the tower walls were obtained. Equation (1) shows the definition of the pressure coefficient.

$$C_p = \frac{p - p_s}{(\frac{1}{2})\rho V_{ref}^2} \qquad (1)$$

in which p is the surface pressure measured along the wind catcher ducts, p_s is the upstream reference pressure, ρ is the air density, and V_{ref} is the reference velocity (taken at wind catcher opening height upstream).

The flow rate was obtained from velocity sampling with the duct and performing numerical integrations as per Equation (2)

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

where Q is the flow rate inside the duct, A_i and V_i are the area and velocity for each segment respectively.

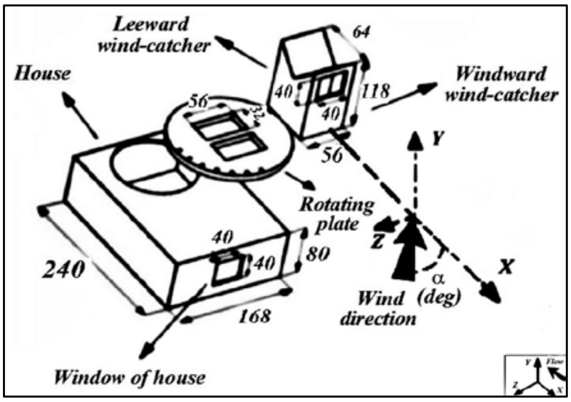

Figure 2. Afshin et al wind catcher model [2].

Figure 3 shows the velocity contours obtained for an onset velocity of 20 m/s. The air flows through the wind catcher system then circulates into the room, and the window allows the air flow to cover the whole space without any short circuiting. The velocity through the tower leeward opening is smaller than that at the windward opening as some of the flow exhausts through the window.

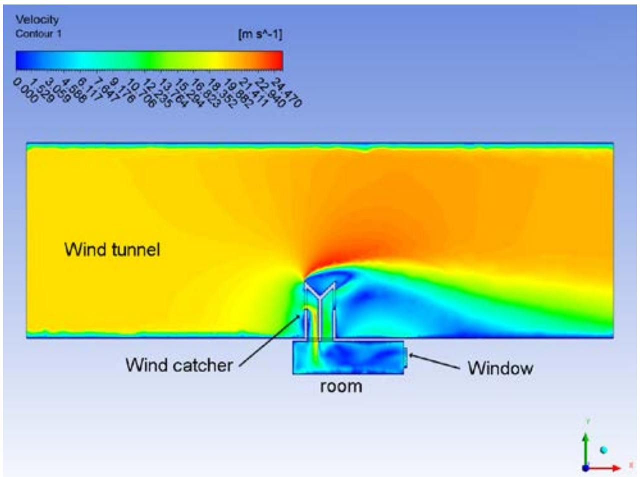

Figure 3. Velocity contours at 20 m/s.

Both velocity and pressure coefficient contours showed logical explanation of the flow.

Sampling Locations

The numerical sample locations were based on the experimental pressure tap and Pitot tube locations inside the experimental model [2, 26] so as to make direct comparisons. For the inner wall wind catcher ducts, the pressure tap locations were simulated to calculate the average pressure coefficient values as shown in figure 4.

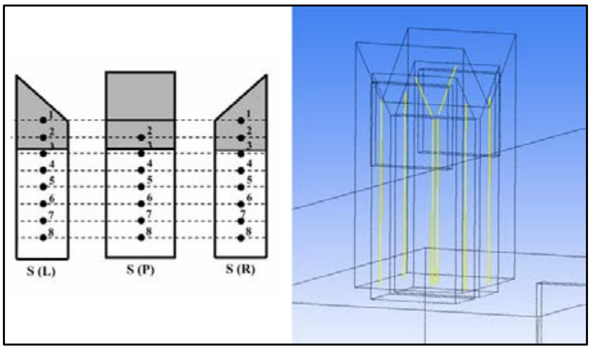

Figure 4. Montazeri and Azizan's model pressure taps [25] vs. simulation pressure line samples.

The same sampling method was conducted for the flow rates at various segments inside each duct to calculate the inlet and outlet flow rates based on Equation (2). The simulation lines were symmetrical at each level along the tower ducts.

Results and Discussions

The average pressure coefficients and flow rates at both windward and leeward sides of the wind catcher are validated for Afshin et al and Montazeri and Azizans's studies [2, 25] at an inlet velocity of 10 m/s and 20 m/s respectively. The simulations were at zero orientation angles.

Afshin et al pressure coefficients results are shown in table 1 where the average values of the windward and leeward at zero orientation are 0.55 and 0.15 respectively. On the other hand, the values from the simulation are 0.553 and 0.246 respectively. There is a slight decrease in the average pressure coefficient as the inlet velocity increases. The difference in the leeward side pressure coefficient probably arises because of the measurement methods employed in the experiments; some details were not available for this in [2]. Further investigations will be undertaken in the future wind tunnel experimentation at the University of Auckland.

The pressure coefficient was not simulated for Montazeri and Azizan's work because they focused on the flow rates and presented the pressure coefficient results along the duct wall sides without estimating the average values inside the wind catcher.

Inlet velocity 10 m/s	**Pressure coefficient**	
	Windward	**Leeward**
Current Study	0.55	0.25
Afshin et at [2]	0.55	0.15
Montazeri and Azizan [25]	N/A	N/A

Table 1. A comparison between current study and Afshin's average pressure coefficient results at 10 m/s [2]

The average flow rate values obtained by Afshin et al [2] and Montazeri and Azizan [25] at zero orientation angle for both windward and leeward ducts are shown in figures 5 and 6 respectively. The simulation results were conducted at inlet velocities of 10 and 20 m/s and were compared with both studies. At 10 m/s the flow rates are 0.00798 and 0.0044 m^3/s, while at 20 m/s the flow rates are 0.0159 and 0.0091 m^3/s for windward and leeward ducts respectively. The results matched both studies [2, 25], however, there were higher differences between the leeward values. This is possible due to the external flow variations and vortices formed at the edge of the tower.

Tables 2 and 3 show the estimated flow rate error percentage between the current study simulation results and Afshin et al [2] and Montazeri and Azizan's [25] results at 10 and 20 m/s respectively. It can be noted that the error percentage increase at higher velocities for the leeward side and decrease for the windward side.

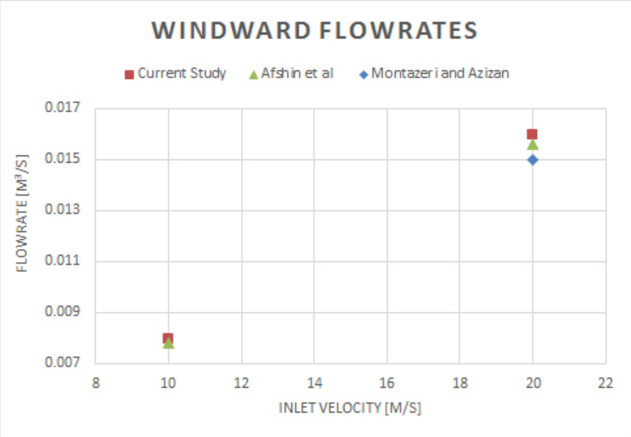

Figure 5. Comparisons between current study simulations and Afshin et al [2] and Montazeri and Azizan [25] for windward flowrates.

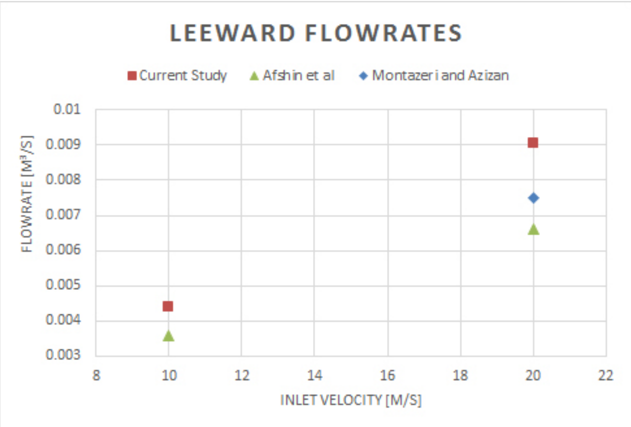

Figure 6. Comparisons between current study simulations and Afshin et al [2] and Montazeri and Azizan [25] for leeward flowrates.

Flow rate error percentage at **10 m/s**		
Location	**Afshin et al**	**Montazeri and Azizan**
Windward	2.3 %	N/A
Leeward	22 %	N/A
Window	N/A	N/A

Table 2. Estimated error percentages at 10 m/s.

Flow rate error percentage at **20 m/s**		
Location	**Afshin et al**	**Montazeri and Azizan**
Windward	1.9 %	6 %
Leeward	51.6 %	21 %
Window	N/A	5 %

Table 3. Estimated error percentages at 20 m/s.

Conclusions

The main purpose of the paper is to find an initial starting ground for future investigations related to the influence of onset turbulence on the ventilation process inside an occupied space through wind catcher systems. This was achieved by choosing two experimental studies conducted by Afshin et al [2] and Montazeri and Azizan [25] for numerical simulation and validation. Both studies presented the same wind catcher with different scale models and wind tunnel measuring techniques. The pressure coefficient and flow rate along the wind catcher windward and leeward ducts were simulated for indicating the ventilation effect relative to the outer climatic velocities. The results showed good agreement, although there were notable errors between the leeward values.

Future Considerations

- The effect of varying onset flow conditions on the wind catcher ventilation process will be studied. These will include atmospheric boundary layer simulation.
- More considerations will be focused on the flow inside the room at lower speeds which are more realistic.
- Larger scale models with blockage ratio consideration for wind tunnel experimentation to reduce the scaling errors and uncertainties.
- Both the tower and the whole building will be considered for the study. The current study is based on studies found in the literature in which the full building is not immersed in the external flow field.
- New wind catcher designs are considered for future investigations and will be compared with the current traditional ones.

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