Experimental and Numerical Simulation of Two Iranian Badgirs in the Persian Gulf, City of Kong and Laft

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Abstract—**Iranian wind towers “Badgir” works thanks to natural driving forces, such as differences in temperature between a building and its environment. By evaporation, convection and natural air currents, we can manage the internal thermal comfort of the local interior environment. The air movement is carried out by the process of pressure and extraction. This paper focuses on sustainable structure, Badgir and the computer simulation, experimentation and reconstruction of a wind towers in the city of Kong located in the Persian Gulf. The construction material of this Badgir is stone and adobe (earth clay, straw and water). This natural material has high heat storage capacity and help to evacuate hot air. The aerodynamic aspects are examined numerically by using CFD (Computation Fluid Dynamics). The calculated velocity and pressure fields are compared to measurements taken on the model installed in a wind tunnel.**

Keywords: Natural ventilation, CFD simulation, Iranian wind tower, Badgir, Kong, Laft, Persian Gulf, sustainable buildings

I. Introduction

Iranian wind towers are designed to introduce cool outside air, driven by relatively high wind pressure. The internal partition allows the low pressure on the lee side of the tower to suck air from inside the building. These wind towers have generally four faces, but some of them are hexagon or octagon. The next pictures show the city of Laft.

Figure 1. The wind towers of the city of Laft

Figure 2. The wind towers of the city of Kong - The angle of Badgirs is inclined a few degrees to the prevailing wind

Through the narrow alleys, we can observe a Badgir refreshed with wet palm leaf. We also note the use of mechanical air conditioner under the Badgirs. The heart of the discussion is right here. Should we search a hybrid solution?

Figure 3. Narrow alleys are decorated with some mechanical air conditioners

Badgirs are directly related to a piece, called “Badgir’s room”. This piece plays a very important role in the right functioning of the tower. The lengths, widths and heights are carefully determined by the builders.

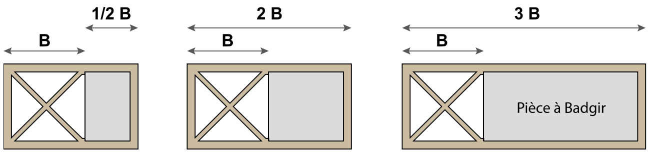

Figure 4. Proportion of towers

Given the weak wind in some areas of the Persian Gulf, many towers are built on the same plot. Sometimes, there is five Badgirs in the same house.

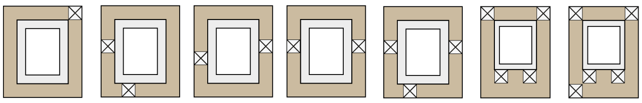

Figure 5. Location of Badgirs in different parts of the house

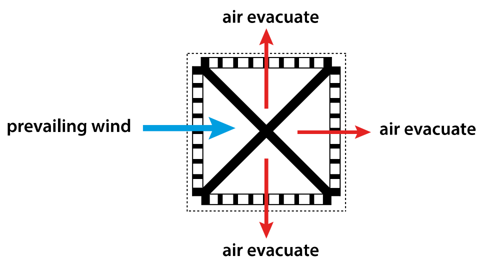

Figure 6. Operation of Badgir

In fact, one duct receives and the others evacuate air, but it depends on the angle of arrival prevailing wind.

A. *Badgir operation*

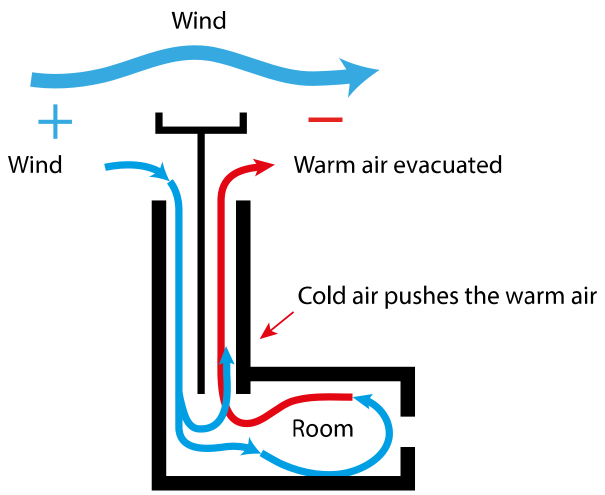

Figure 7. How the Badgir works

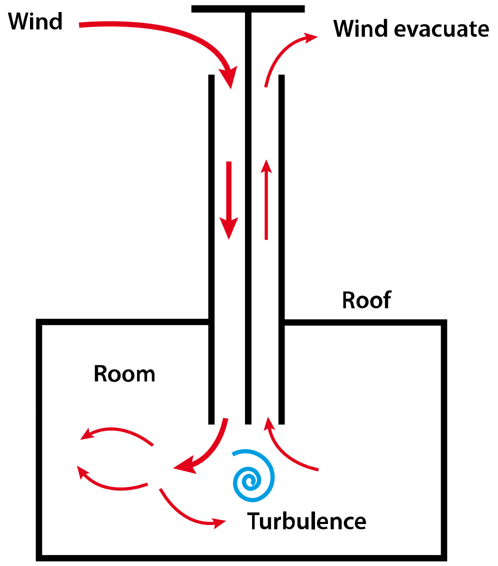

Figure 8. How the hot air is evacuated

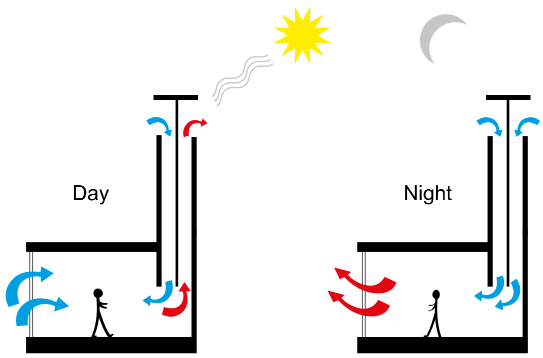

Figure 9. Badgir operation during the day and the night

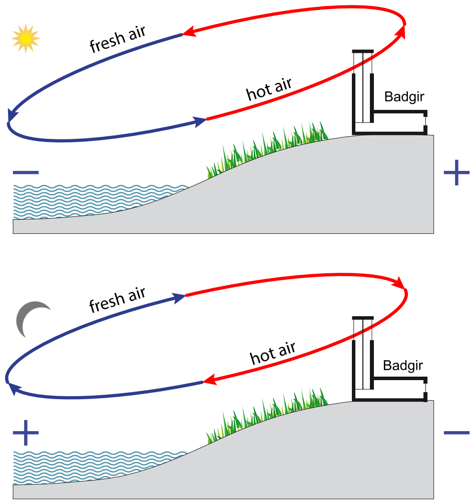

Figure 10. The behavior of the sea wind during the day and the night

II. THE FIRST BADGIR WE EXAMINED IN KONG

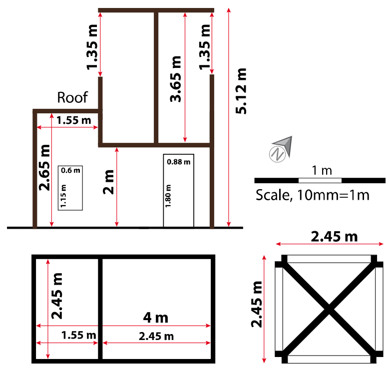

Figure 11. Section and plan of the Badgir of Kong

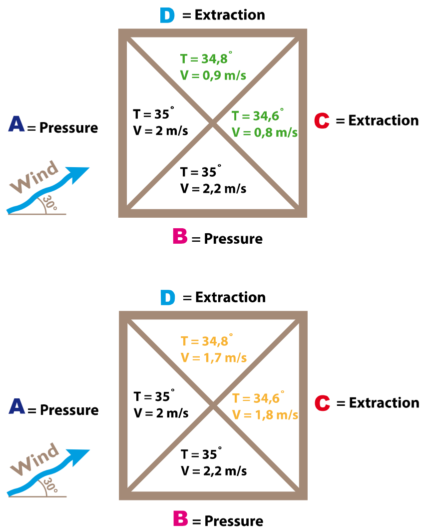

Figure 12. Measurements under the badgir, in the room and on the top of the duct (the outlet velocity in D and C is higher).

For the above measurements, the temperature in the shade was 36º C, and wind speed of outside was between 1.2 and 2.2 m/s.

III. THE SECOND BADGIR WE EXAMINED IN LAFT

Figure 13. The Badgir and one of the ducts receiving winds

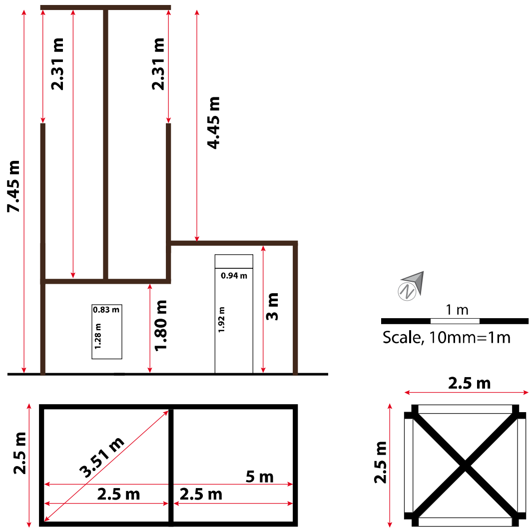

Figure 14. Section and plan of the Badgir of Laft

The main room has a door and a window. The upper part of the door is made of perforated plaster. One of the ducts is under pressure while the opposite one is on extraction procedure. The piece of red paper is sucked to outside when the duct is in extraction mode; otherwise the paper is pushed to inside the room. In some cases the piece of paper is attracted to neighboring ducts. It demonstrates the existence of immediate extraction before the air enters in the room.

Figure 15. The main room with a four sided Badgir

A. The perforations

Figure 16. The perforations are used in various locations in the buildings

B. Construction materials

The construction materials used are: Earth clay, sea coral stone, palm leaves, wooden beam and rope.

Figure 17. The materials used for the construction of a house with Badgir

IV. LOCAL MEASUREMENTS

TABLE I. MEASUREMENTS PERFORMED IN KONG ON AUGUST 2015

Time	Outside air		Inside air		
Hours	*Velocity m/s*	*T°C*	*Velocity m/s*	*T°C*	*ΔT*
7h	3,2	38,1	2,5	32,5	5,6
8h	3,5	38,2	2,2	32,7	5,5
9h	3	39	2,5	32,9	6,1
10h	4,1	39,5	2,4	33,1	6,4
11h	4	42	2,9	33,3	8,7
12h	3,8	43,6	2,5	34,2	9,4
13h	3,5	44,2	2,5	34,6	9,6
14h	3	44	2,3	33,2	10,8
15h	3,1	41,3	2,4	32,8	8,5
16h	3,2	39,2	2,4	32,2	7
17h	3,2	38,2	2,4	32,2	6

V. EXPERIMENTS IN WIND TUNNEL

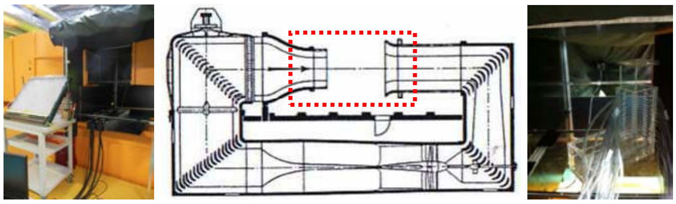

Figure 18. The Wind Tunnel of Paris-Ouest University, Ville d'Avray

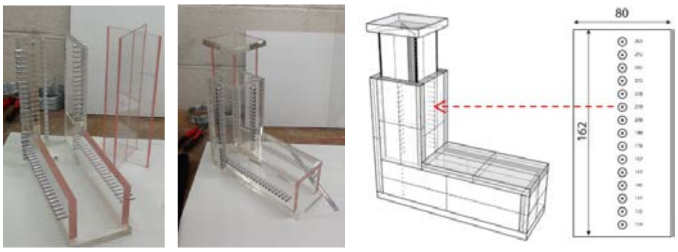

Figure 19. The model used in the wind tunnel with breakthrough wall for pressures analyzes

A. Four different angles are measured

The velocity in wind tunnel is 20 m/s. As in the city of Kong, we observed an important inclination of Badgir in front of the prevailing wind, we test four different angles: 0°, 15°, 30° and 45° to show the efficiency of the tower. The next figure show how we proceed.

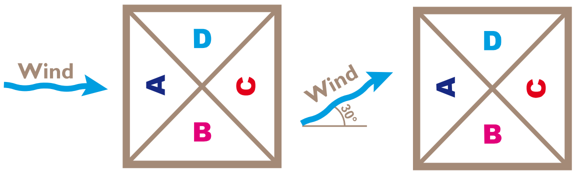

Figure 20. Different angles of the model in front of the prevailing wind

VI. EXPERIMENTAL RESULTS

A. *Interpretation:*

When α=0°, the pressure drop is higher in B, C and D than in A. The ventilation of the first model is carried out by all conduits. The A is working by sucking air from outside while the B, C and D are blowing air.

When α=30° the A and B are working by suction while C and D by blowing.

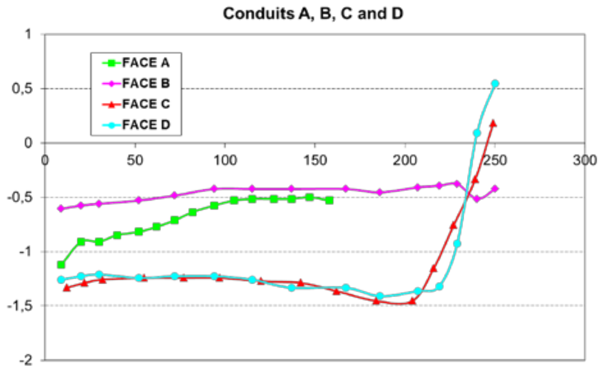

Figure 21. α=30°

VII. FLUENT MODELING

The 3D drawing has been drawn after the model used for wind tunnel.

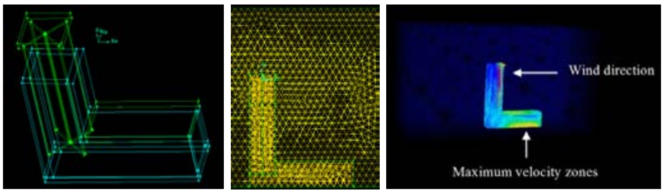

Figure 22. 3D drawing and the domain of the wind tower

The wind speed for this experimentation on four different angles is 20m/s.

A. *0° Wind Angle*

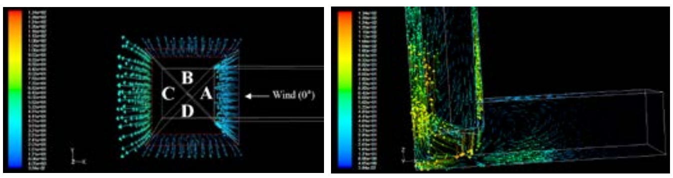

Figure 23. The velocity at B and D are very low

B. *30° Wind Angle*

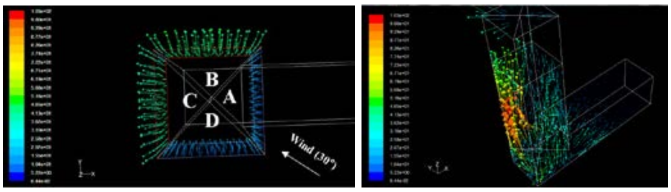

Figure 24. At 30°, the velocity in A and D is lower

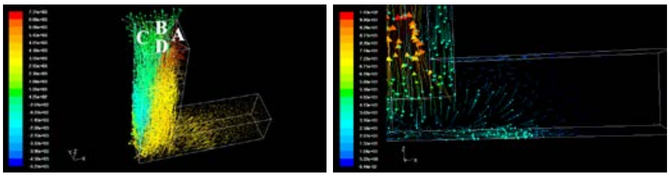

Figure 25. At 30°, the velocity is superior in B and C. The A and D receive, but B and C evacuate air

We observe that for 30° wind angle, the velocity vectors are smoother in B and D.

C. *45° Wind Angle*

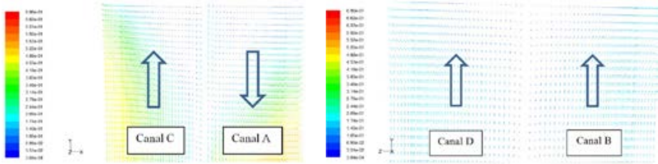

Figure 26. 45° wind angle

In fact, at 30°, one duct inhale and three other ducts of the Badgir exhale. That means three ducts allows the same portion of air evacuated to the outside. And we can conclude that the hot air is evacuated permanently at 30°.

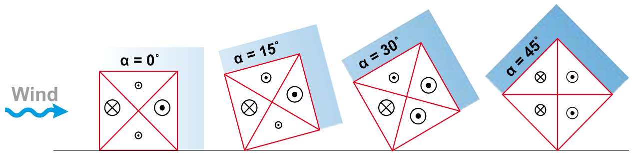

Figure 27. The behavior of air in the ducts

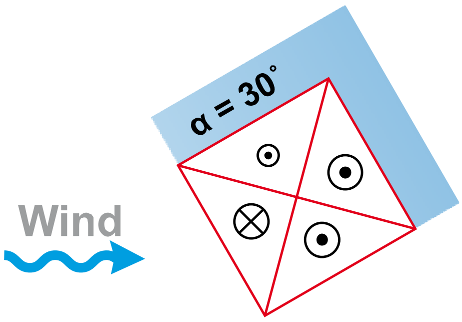

Figure 28. At 30°, one duct inhale and three other ducts exhale

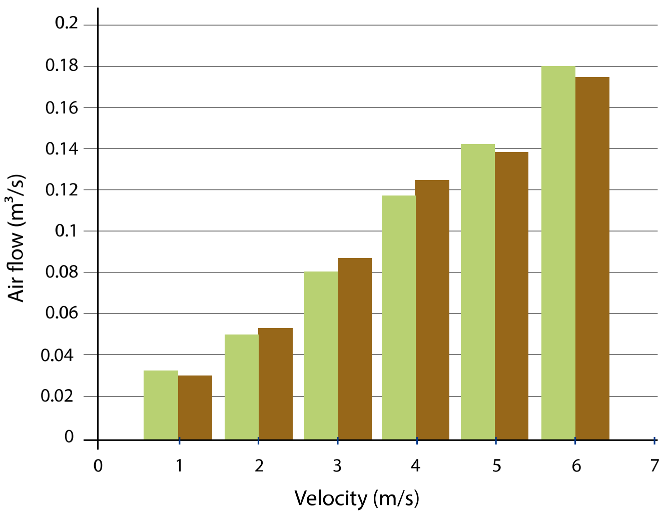

Figure 29. Comparison of Fluent and wind tunnel

VIII. ASSUMPTIONS

This part determines the air flow in a building equipped with a Badgir where wind incident angle is 30º and the effects of finite temperature vary between inside walls and ceiling. Once the flow equation is solved, airflow rates and flow distributions are calculated. The numerical method employed in this study is based on 3D finite volume method. The flow field is analyzed by a simple algorithm. Algebra equation system will be solved by a line to line TDMA (Tri Diagonal Matrix Algorithm) method until convergence. The k-ε RNG model for viscosity is recommended for good results and also good simulation stability. Steady state conditions are assumed.

In this study, the effect of door and window locations on airflow distribution into the room, and air mass flow rate of doors and windows, has been investigated. The changes were recorded by displacing the door location from left to right (vice-versa) and the windows from up to down (vice-versa).

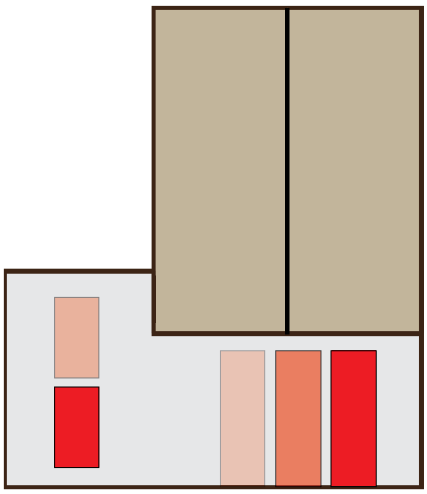

Figure 30. Impact of different places of the openings

TABLE II. DOOR AND WINDOW LOCATIONS FOR 9 STATES

Windows location	Door location	State	Num.
Main place	Moved to the left of the main place Equal to door width	1	1-1
Main place	Main place	2	1-2
Upper than the main place	Moved to the left of the main place Equal to door width	4	2-1
Upper than the main place	Main place	5	2-2
Lower than the main place	Moved to the left of the main place Equal to door width	7	3-1

TABLE III. MASS FLOW RATE RATIO OF DOOR AND WINDOWS ON WINDWARD FOR 9 STATES

NUM.	STATE	D/B %	W/B %	SUM %
1-1	1	14.53	19.6	34.13
1-2	2	20.7	19.6	40.3
2-1	4	14.09	20.66	34.75
2-2	5	22.33	19.9	**42.23**
3-1	7	14.68	18.5	**33.18**

As shown in the figure in bold letters, during this experience we found that, more windows are placed in the bottom area; the more speed there is at the output.

IX. CONCLUSIONS

The aerodynamic aspects are examined numerically by using CFD (Computational Fluid Dynamics). The calculated velocity and pressure fields are compared to measurements taken on the model installed in a wind tunnel. We measured important factors in these calculations as different wind speeds, temperatures or wind incident angles. We considered the humidity, building materials (earth clay), thickness of the walls and location openings. Following various tests, in Iran, then the wind tunnel tests, and then with Fluent, an angle of 32° remains the optimum angle for this Badgir experience. We observe that at 32° angle, one duct is blowing while three other ducts are evacuating air. Other important conclusion is that more windows are placed in the bottom, more speed there is at the point of evacuation.

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