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Thermal and dynamic analyses of the Siraf city's wind tower: Construction of a half-scale model at Lyon university, France

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ABSTRACT: A wind tower (Badgir in Persian) captures wind from any direction and guides it to the occupant's zones. Built on the roof, the wind tower has been used for many centuries, employed at different heights, ranging from 1 m to 33 m. These towers are a zero carbon cooling technology. This paper describes four steps: climate search in Iran; various specific tests with small-scale models at the wind tunnel to visualize the pressure drop in different conduits; construction of a half-scale model of Badgir with our students; and numerical analysis with "Fluent software".

1 INTRODUCTION

1.1 *History*

It is certainly the originality of this wind tower that caught our attention and led us to perform multiple analyses. The city of Siraf is an ancient port located in the central district of Kangan, province of Bu-shehr. During the Sassanid Dynasty, Siraf was a port on the north shore of the Persian Gulf. Siraf was used as a route between the Arabian Peninsula and India.

1.2 *The local measurements in Siraf*

Nasuri's house is located in the city of Siraf, at the foot of the mountain, at about 50 meters of the seaside. The first day of analysis on this tower was carried out on April 17th, 2013 between 8 a.m. and 8 p.m. The second analysis commenced on April 18th, 2013 at 9 p.m. and was completed on April 19th at 7 a.m. To obtain more precision, we recorded the data for three successive days. This tower is 14.83 m high. The room located under Badgir is 12.24 m long and 2.80 m wide, with a surface area of 34.27 m^2 and a height under ceiling of 3.84 m. The room has a door and two small windows giving onto other rooms. The measurements are given in Table 1.

Table 1 highlights the difference between the inside and outside temperatures. The gain freshness is most notable between 3 p.m. and 4 p.m.

Figure 1. Wind tower of Nasuri's house in Siraf city.

Table 1. Measurements performed in Siraf.

	Outside air		Inside air		
Hours	Velocity (m/s)	T (°C)	Velocity (m/s)	T (°C)	ΔT
9 a.m.	2.5	33.2	1.5	27.8	5.4
10 a.m.	2.1	34.6	1.2	27.2	7.4
11 a.m.	2.6	34.9	1.5	27.1	7.8
12 a.m.	2.6	35.1	1.4	28.8	6.3
1 p.m.	2.5	35.8	1.8	28.5	7.3
2 p.m.	3.2	35.9	2.1	28.2	7.7
3 p.m.	3.1	36.2	2.1	28.2	8
4 p.m.	3.9	35.7	1.3	27.6	8.1
5 p.m.	3.8	35.1	1.2	27.3	7.8
6 p.m.	3.6	34.2	1.4	26.9	7.3

2 CONSTRUCTION OF A HALF-SCALE MODEL AT LYON UNIVERSITY

We conducted a workshop with third-year students at the University of Lyon (L'Isle-d'Abeau) over a period of 5 days, from 20 to 24 April 2015. We built a half-scale tower (6 m in height). Students learned to design the successive steps of the construction, followed by observing the use of Bernoulli's theorem and Navier-Stokes equations. To build the tower, we used lime and brick similar to the materials used in Siraf (original Badgir).

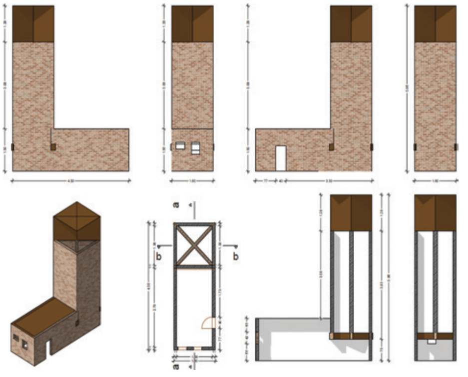

Figure 2. Plan and section of the tower.

Figure 3. Lime (clay, straw and water) and bricks (solid and hollow).

Figure 4. The process of construction of a Badgir.

Figure 5. The interior of the half-scale model.

Figure 6. Original Badgir (left) and the half-scale Badgir (right).

Figure 7. The interior of Nasuri's house (original wind tower).

3 CONDITION OF THE EXPERIMENT IN THE WIND TUNNEL

In this experiment, we used a subsonic Prandtl wind tunnel located in the laboratory of Ville d'Avray. This wind tunnel has the following characteristics:

The square test section (side length 450 mm) has a longitudinal length equal to 750 mm; the maximum velocity is 40 m/s; the rate of turbulence is between 1% and 2%.

We made a model to perform tests and analyses in the wind tunnel.

We installed the model in the wind tunnel. As shown in the figure, we found the data by changing the direction of the wind at different angles: 0°, 15°, 30° and 45°.

On the other side, at $\alpha = 45°$, the pressure in A and C tunnels is almost the same. The pressure in C and D tunnels is also the same. In this case, two tunnels are operated by sucking (A and B) and the two others by blowing (C and D). Everything occurs as if the building has only two tunnels A–B and C–D.

3.1 *Results and analysis of wind tunnel tests*

Wind tunnel tests show that when the angle $\alpha = 0°$ to 15°, there is a total lack of dynamism in the ducts, but when $\alpha = 30°$ and 45°, the four conduits support the wind and the tower begins to expel the air.

The case at $\alpha = 30°$ is an intermediate configuration: tunnels A and B are operated by suction and tunnel C by blowing. In comparison with the case $\alpha = 45°$, the contribution of tunnel B for suction is more weak.

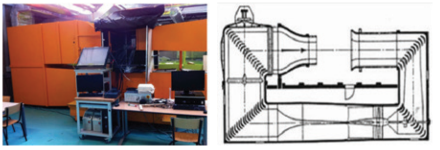

Figure 8. View of the wind tunnel.

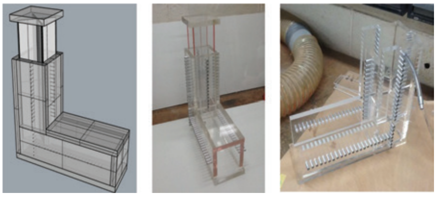

Figure 9. View of the model.

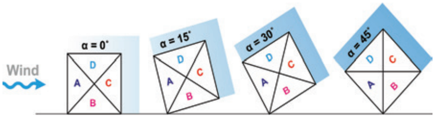

Figure 10. Evaluations at different wind angles.

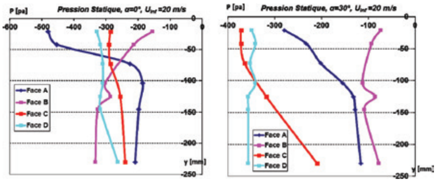

Figure 11. Static pressure, α = 0° and α = 30° U inf = 20 m/s.

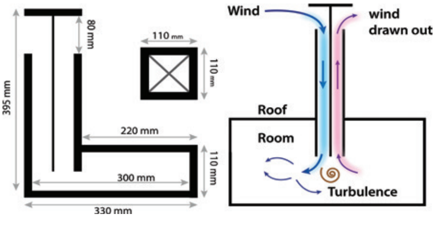

Figure 12. Plan and section (left); a turbulent air back to the top of the tower (right).

To verify the accuracy and validity of the results, we compared the data obtained in parallel with the numerical calculations with Fluent.

4 FLUENT MODELING

The geometry of a Badgir is shown in the following figure. A 3D geometry was generated according to

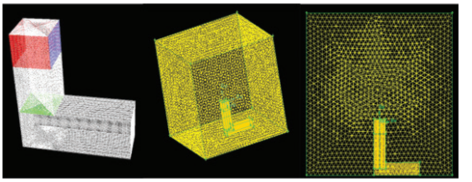

Figure 13. The 3D and the generated grid.

an experimental prototype that has been used in a wind tunnel.

The numerical simulations were carried out at a wind (air) speed of 20 m/s, and four different angles for wind were considered: 0º, 15º, 30º and 45º.

To observe the Fluent results, two different quadric surfaces are defined in Fluent, z = zmean and x = xmean-tower = zmean (since the tower cross section is square, so xmean-tower = zmean). The results and contours are drawn on these two surfaces. With the help of these planes, we can determine whether the part of the tower is exhaling or inhaling the air flow.

4.1 *0° Wind angle*

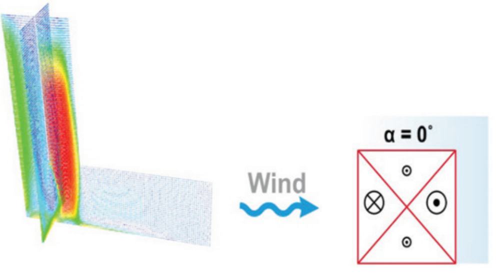

Figure 14. The pressure is negative in canals B, C and D Maximal velocity in canal A.

4.2 *15° Wind angle*

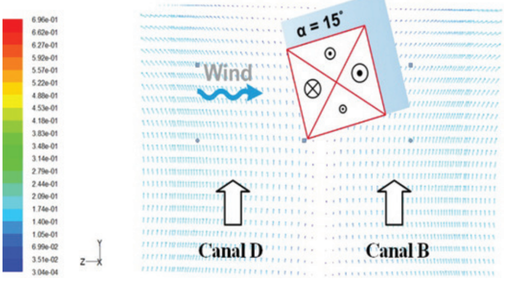

Figure 15. The canals D and B exhale.

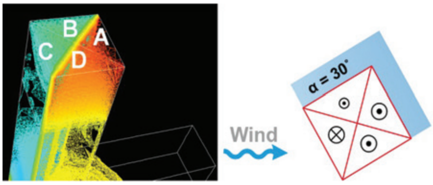

Figure 16. 30º Wind angle.

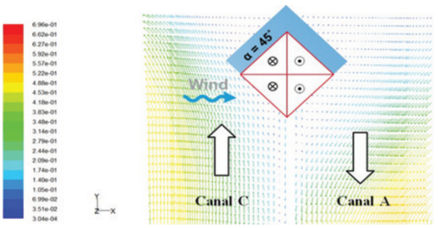

Figure 17. 45º wind angle.

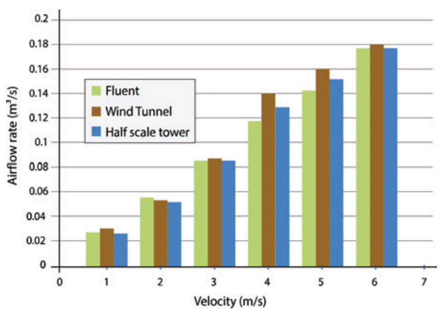

Figure 18. Comparison of Fluent, wind tunnel and the half-scale model at Lyon University.

4.3 *30° Wind angle*

As compared with the two previous cases, it seems that for 30° wind angle, the velocity vectors are smoother in canals B and D. Moreover, the velocity vectors in these two canals are to some extent identical with canal C. Therefore, it can be deduced for this condition that the wind enters canal A and then smoothly and uniformly exits from the three remaining canals.

4.4 *45° wind angle*

The air flow through canals B and D for 45° wind angle is the same with the 15° wind angle case. This result is predictable because of geometric symmetry of a Badgir. It is obvious that the geometry has a mirror symmetry with respect to the quadratic plane z = zmean. Hence there is no difference between the results of the internal air flow for 15° and 45° wind angle cases.

In summary, the smoother flow with one canal as an inhale part and three other canals as exhale parts of the Badgir tower occurs at the 30° wind angle. Since at this condition, three exhaling canals have identical velocity vector distributions. That means each of these three canals bears the same portion of air conducted to the outside.

5 FACTORS CONSIDERED IN THESE CALCULATIONS

1. Different wind speeds; 2. Different temperatures; 3. Different wind incident angles; 4. Humidity; 5. Building materials (clay soil); 6. Thickness of the walls; 7. Full and empty fountain; 8. Location openings; 9. Different surfaces.

6 CONCLUSIONS

The CFD simulations are validated with detailed wind tunnel experiments. Results show that a four-sided wind tower has great potential.

An angle of 32° remains the optimum angle for this Badgir experience.

At 32° angle, one air duct blows air into the room and three ducts expel the room air.

The air undergoes a temperature loss of 2°C upon entering the room.

When the fountain is full, we achieve 4°C in terms of cooling (the temperature drop).

The more the windows are placed in the bottom area, the more speed the output receives.

We can calculate the same parameters for adjacent rooms.

We can choose the ideal location for Badgirs in buildings with large dimensions.

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