APPLYING COMPUTATIONAL FLUID DYNAMICS TO ANALYZE NATURAL VENTILATION & HUMAN COMFORT IN BUILDINGS

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ABSTRACT

Computational fluid dynamics (CFD) is a relatively new tool in the field of architecture, and its potential for modeling natural ventilation & human comfort has not been explored fully. This paper is a study that looks at modeling human comfort within a naturally ventilated environment, weighing in factors like mean radiant temperature (MRT), comfort temperature, and humidity level. The study examines the performance of a traditional Iranian wind tower (*Badgir*), feeding a room adjacent to a courtyard under varying conditions of wind speed and evaporative cooling.

1. INTRODUCTION

In the heart of the Iranian Desert is the Ancient city of Yazd. Its wealth was built on trade, owing to the fact that it existed along the silk route. The architecture of the city reflects this wealth, with its domes & vaults. Above all, the skyline is dominated by fantastic mud brick towers, giving the city an incredible urban aesthetic. This architectural language repeats itself through most of the ancient cities of the Middle East.
These towers serve 3 main Functions

1. To ventilate basements.
2. Provide convective cooling
3. Cool the interior mass of the house.

Traditionally, Iranian wind towers are either rectangular or octagonal, with openings facing all directions, to catch wind coming from any direction. The center of the tower has a baffle wall that directs the wind downwards, preventing it from blowing right across the tower. In conventional wind towers, this baffle wall works to a certain degree, but there is a considerable loss of wind through the openings in the leeward side of the tower, partly because of the positive pressure of the windward side of the tower, but also because of the negative pressure on the leeward side of the tower sucking air out of the tower. This paper analyzes this phenomenon using CFD, and looks at the performance of the tower under 4 different conditions – with a strong wind, with a weak breeze, when there is a strong wind and evaporation is introduced at the top of the tower, and when there is a weak breeze and evaporation is introduced at the top of the tower.

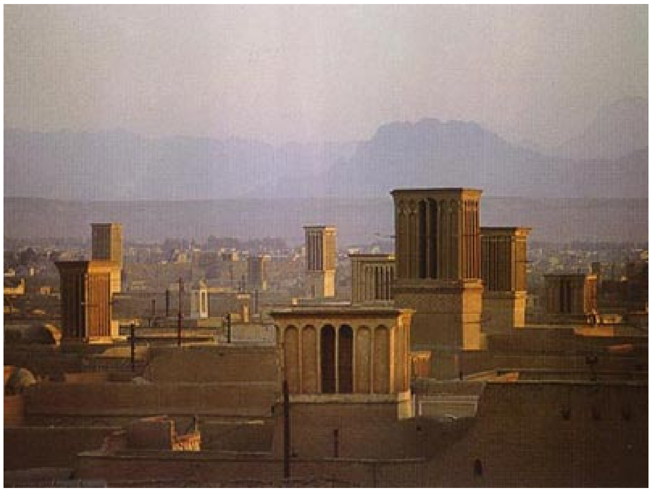


Fig 1 Yazd Skyline http://www.irses.org/gallery.htm

2. EXPERIMENTAL SETUP

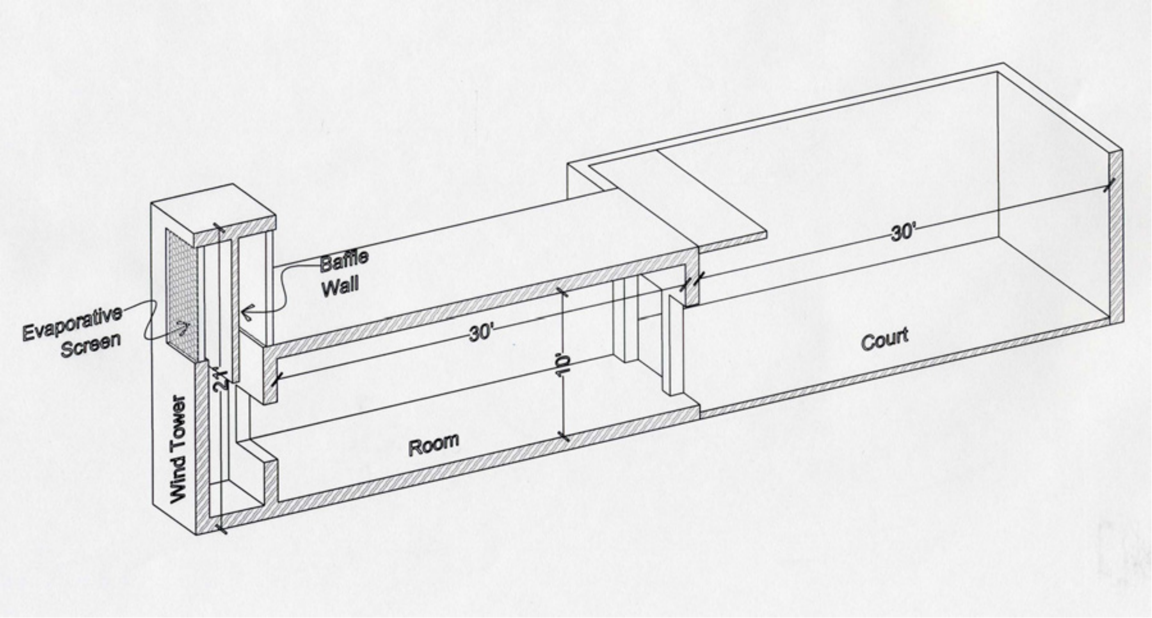


Fig 2.1 Isometric long section through experimental model

2.1 The Physical Model

The basic structure is a rectangular brick tower feeding a room attached to a courtyard. The tower has a baffle wall that runs halfway down its height. In the first analysis, the tower has no evaporative cooling means, but in the second case, an evaporative screen is added to the windward side of the tower.

2.2 The Mathematical Model

The model is a Revised Ke model for analyzing turbulent airflow. It is set to a 6-hour transient period from July 20th 11am – 5pm. In the 1st two studies, the boundary wind condition is a steady 16 km/h blowing from the east. In the 2nd two studies the wind condition is a steady 7 km/h also blowing from the east.

To increase the speed of the simulations, the grid used for the model is a non-uniform grid, getting denser at the actual points of reference, and sparser near the solution domain boundaries.

In the second study in both cases (transient runs 2 & 4), evaporation is introduced into the tower openings. This is done by a combination of a "coolth" source – a negative energy source depending on the airflow & relative humidity, and an introduction of vapor impurities as a concentration (again based on relative humidity & airflow). Table 2.2 shows the calculations performed for the "coolth" source as well as the vapor source. The calculations are based on a 60% efficiency of the evaporative pads on the wind tower. A flow resistance of 10 is also placed across the openings, resulting in a drop of pressure across the evaporative pads of 0.05 inches of water – equivalent to a 4" evaporative screen.

2.3 Ambient Conditions

Due to lack of weather information in Iran, the model is analyzed in weather conditions similar to that of the Iranian desert, taken from Phoenix TMY2 weather data. The model is analyzed on a July day in the afternoon period between 11:00 am & 5 pm.
The system ambient temperature is taken from the dry bulb temp. (table 2.2)

TABLE 2.2 – CALCULATIONS FOR EVAPORATIVE COOLING AND VAPOR DISCHARGE FROM PADS

hour	dry bulb	wet bulb	wind direction	Avg w/s kmh	Speed across pad (ft/min)	(W) Evap Energy	Vapor Discharge Kgs/sec
11	97	72	E	16.00	450.00	130720	0.05332
13	102	73	E	16.00	450.00	151635	0.06185
15	104	73	E	16.00	450.00	162093	0.06612
17	104	73	E	16.00	450.00	162093	0.06612
11	97	72	E	7.00	200.00	58098	0.02370
13	102	73	E	7.00	200.00	67393	0.02749
15	104	73	E	7.00	200.00	72041	0.02939
17	104	73	E	7.00	200.00	72041	0.02939

3. SANITY CHECKING THE MODEL

As a sanity check for the modeling method, a cool tower evaporative model was compared under 2 separate conditions with a model set up in *Cool T* – a program developed at the University of Arizona by Nader Chalfoun and Martin Yoklic. Figure 3.1 shows the *Cool T* model in section.

The conditions picked for analysis were a July day with a DBT of 97°F & a WBT of 73°F. The simulations were run for a 20ft tower & a 30 ft tower. Table 3.2 shows the comparative results from *Cool T* & the *Flovent* model.

The *Cool T* models in both cases show a higher air velocity at the outlet as well as in the tower. This could be because the Flovent simulations are taking solar radiation into account, resulting in some upward movement of air into the tower. A point of concern was the increase of disparity in the readings with an increase in the height of the tower. On the matter of temperatures within the tower however, both simulations were relatively close.

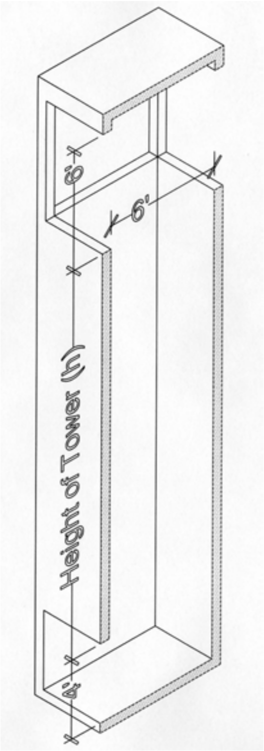


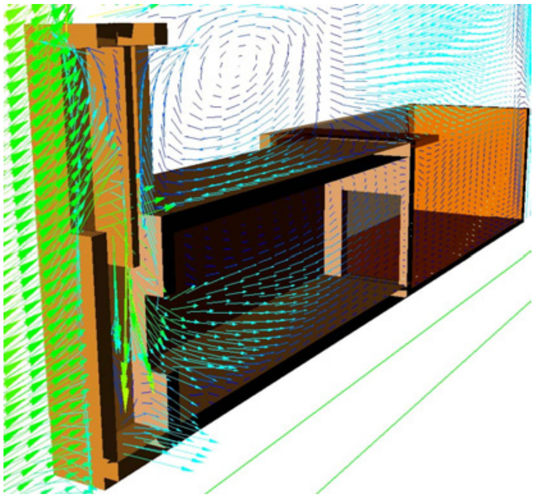
Fig 3.1 Isometric Section through the Cool Tower model

TABLE 3.2 SHOWS COMPARATIVE RESULTS FROM COOLT & FLOVENT SIMULATIONS

	Tower Ht h (ft)	DBT	WBT	Temp Inside Tower	Tower fpm	Air Vel at Outlet fpm
Cool T	20ft	97	73	77.1	177	266
FloVent		97	73	74	124	214
Cool T	30ft	97	73	78.1	253	285
FloVent		97	73	76	155	223

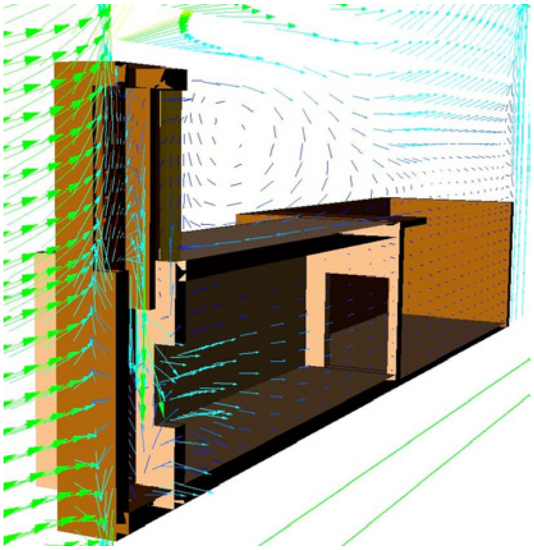
4. ANALYZING THE RESULTS

4.1 Simulating 16km/h Eastern wind



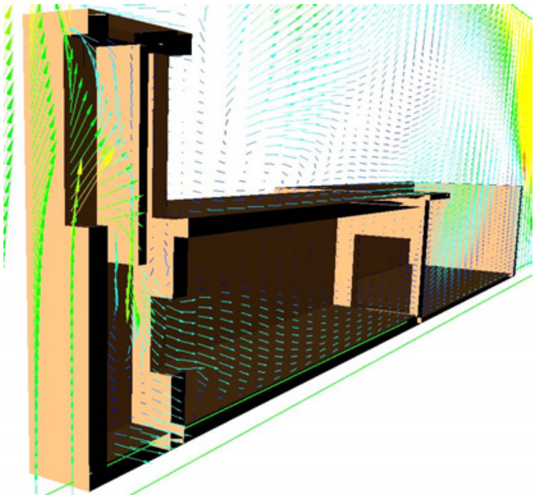
The negative pressure on the leeward side of the tower causes the tower to short circuit itself. The air distribution through the room however is not too adversely affected since the courtyard is also a negative pressure zone sucking air out of the building.

4.2 Simulating 16km/h Eastern wind and evaporative pads



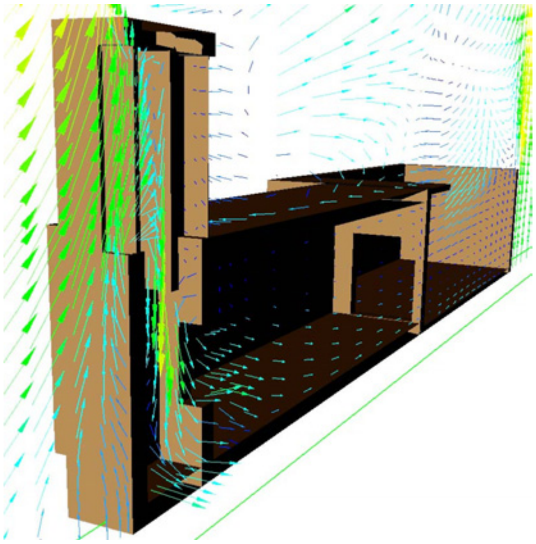
The evaporative cooling reduces the short-circuiting of the tower. This is partly because the air becomes heavier with saturation and drops, and partly because the flow resistance presented by the evaporative screens presents a barrier to the negative air pressure on the leeward side of the tower.

4.3 Simulating 7km/h Eastern wind



With a reduction in the wind pressure, the short-circuiting is reduced considerably. This is mainly because the pressure difference between the inside of the tower and the leeward side of the tower is not that high. The problem is that there is very little airflow to the room.

4.4 Simulating 7km/h Eastern wind and evaporative pads



Reducing the wind speed and introducing evaporative cooling means that the dynamics of the airflow are now governed mostly by gravity with the heavier air dropping with saturation. The wind tower works more like a Cool Tower than a wind catcher. It also reduces short-circuiting on the leeward side of the tower.

TABLE 4.5 SHOWS VARYING CONDITIONS IN THE ROOM.

	East wind16 km/h, no evaporation			**East wind16 km/h, evaporation**		
	11am-1pm	1pm-3pm	3pm-5pm	11am-1pm	1pm-3pm	3pm-5pm
Outside DBT	97	102	104	97	102	104
Outside WBT	72	73	73	72	73	73
Air Temp (Room)	93	98.5	100.5	75	78	76
Comfort Temp	88	94	97	74	75	77
Mean Radiant temp	79	86	91	72	77	80
Wind Speed (ft/min)	85	115	118	86	90	89

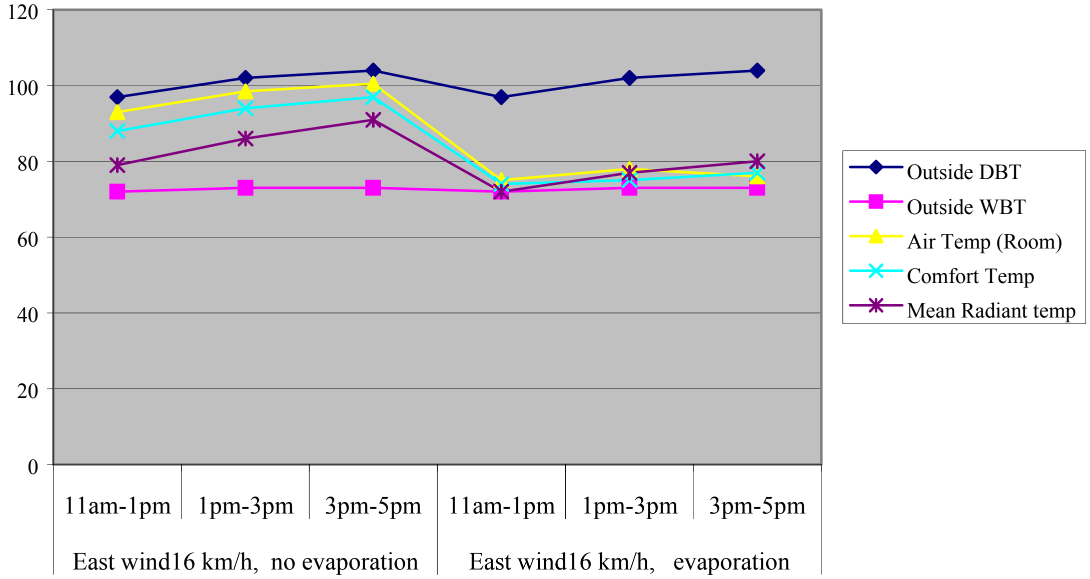


Chart 4.6 Showing Conditions within the room

5. CONCLUSIONS

The analysis of the wind towers clearly shows that as far as delivering comfort to the interior space, the option of introducing evaporative pads to the top of the tower proves very attractive. It also ensures that there is a steady airflow even in times when the ambient wind conditions are negligible. Introducing the evaporative pads however, provides a flow resistance, and do reduce the airflow to the tower, but that is offset by the fact that they also reduce the short-circuiting of the tower.
Though there are still some issues to be explored with the model, I feel that using CFD for analyses like this provides designers with the option of predicting human comfort within space for naturally ventilated and cooled spaces.

6. REFERENCES

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