Application of new design of wind tower configuration to existing building for passive cooling

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ABSTRACT

In hot and arid climates, evaporative cooling appears to have significant potential to provide thermal comfort and reduce the energy loads of summer season. These regions used wind towers as means to reduce energy consumption of air conditioning systems.
However, the cooling potential of wind towers technique was investigated in real exiting building in Ouargla city of Algeria (hot and arid climate); Measurements have been performed under two conditions "with and without evaporative potential".
A mathematical model of wind tower has been developed and validated using the measured data. For a more effective evaporative cooling, a number of improvements on wind tower design was proposed and calculated. Hence, results showed better performance with the improvements.
However the new design of the wind tower are constructed in another building under the same climatic condition, the results of monitoring the performance of the building incorporating the new design are discussed in this study.

1. INTRODUCTION

Wind catchers, or wind towers have been used extensively in traditional architecture throughout the hot arid countries of the Middle East. They are known variously as a malqaf in Egypt or as the badger in Iraq and Iran, and are found as far as east as Pakistan and Afghanistan. Recently they are introduced in arid region of Algeria, imported by the Egyptian designers to cool passive houses in Ouargla, southern town. Renewed interest in passive cooling in 1980s led the development of a number of cool towers, in which air was drawn into the tower through gravity-shut dampers designed to prevent air escaping on the lee side (Bahadori,1985) or through wetted pads similar to those used in desert coolers (Cunningham and Thompson, 1986; Chalfoun,2000) based on these theoretical considerations.
An evaporative wind tower was developed and constructed as an improvement to an existing one. The new wind tower incorporates the results of experiments conducted to establish the performance of wind tower found in Ouargla houses as well as guide lines of better new design computed to improve the evaporative cooling potential of the wind tower (Bouchahm, 2005)
As it was found by (Erell, 2005; Guetta, 1993),
the evaporative cooling is the only economically viable solution for cooling in arid climate. Hence, their widespread adoption depends not only on their acceptance by Algerian designers and the public, but also on improvements in performance and the installation of demonstration projects.
In this purpose the new design of wind tower has been constructed to cool an office building where its evaporative cooling potential has been improved

2. PREVIOUS RESULTS FROM EXPERIMENT AND SIMULATION

2.1 Experiments results

The measurements were conducted in two kinds of houses. The first one (H1), is a house with operational wind tower, the second one (H2) is a house with a wind tower closed by the residents because unaware of the importance of this cooling system.
The studied cases consist of a wind tower used for cooling purpose of a living room at a semi detached houses, with an area of (4.00 x 4.00 m²) and 3.00m height, having two kind of windows: a large one (1.40-1.20m²), oriented North and two smaller ones (1.20 – 0.50 m²). All are equipped with shutters overhangs and fines for protection from the intense sun radiation. The 6.5m wind tower is built with hollow concrete block and covered with rough mortar. Its interior cross section is (0.70 – 0.75m²). The head opening which is used as inlet of the air is on an accessible terrace. It is unidirectional wind tower facing north, in order to catch the prevailing wind. The adjacent wall is ventilated, to minimize heat gain from intense solar radiation. At the bottom of the tower is a pool filled up with water.
It can be noted from measurement that inside air temperature in H1 is lower than in H2 from 9.00 a.m. till 8.00 p.m. with a peak difference ranging between 2.5°C and 4°C. This result confirms clearly that the wind tower has a direct effect on reducing indoor temperature, which helps cooling the room much better than when leaving it closed. Between 9.00p.m and 8.00a.m the inside temperature is high compared to the outside, which

is decreased rapidly in the nighttimes. It is due to the effect of the thermal inertia of the house envelope. This was supposed to be evacuated by a good night ventilation strategies. Unfortunately, this cannot occur as windows are left closed causing stagnant heat inside, which leads to high temperatures.

Humidity reaches its minimum (9%) at 3.00 p.m. while the temperature recorded by the weather service at that time is at its maximum (48°C). The opposite occurs at 6.00 a.m. when the temperature reaches its minimum value (33°C) and humidity its maximum one (35%).
Hence, these results confirm that the potential of evaporative cooling is not exploited since no watering has been used.
To exploit the potential of evaporative cooling, it seems to be judicious to add a humidification process. The pool is filled of water and the wind tower interior surfaces are wetted twice a day. Monitoring the airflow inside the wind tower and measurements of the air temperature and humidity are carried out at inlet (top of the tower) and outlet (at living space).

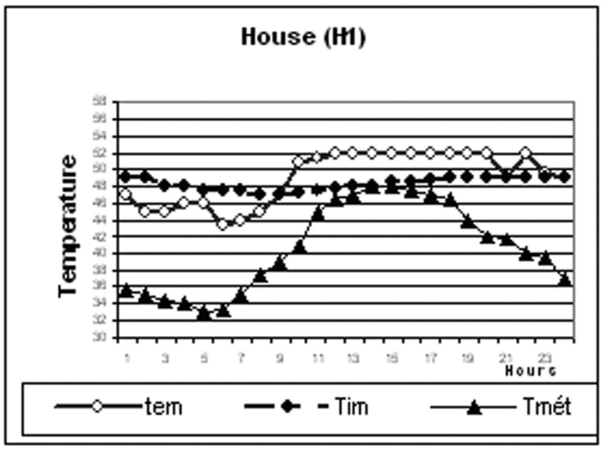


Figure 1: Interior and exterior measured air temperature

Results show clearly that, with this approach, a better improvement is occurring (figure 1). The air temperature measured reduces by 6°C at 9.00 a.m., while the reduction from 6.00 a.m. till 10.00 p.m. is ranging between (2.5°C and 5.5°C). It can be noted that while the external temperature amplitude are very large, the internal one remains low. The air temperature increases slowly in proportion to the condition of the wind tower wall (whether the surface wall is dried with heat evaporation or not). The humidity is directly affected by evaporative process (figure 2). An increase of humidity (φext measured: 16%, φint measured: 31%) at 6.00a.m., occurs when the walls are wetted. Thus as, internal surfaces of wind towers' begins to dry (4.00 p.m. – 7.00 p.m.) a drop of humidity is measured reaching (2% - 3.5%). As the surface (inside wind tower walls) is wetted again, a 10% increase on humidity is recorded.

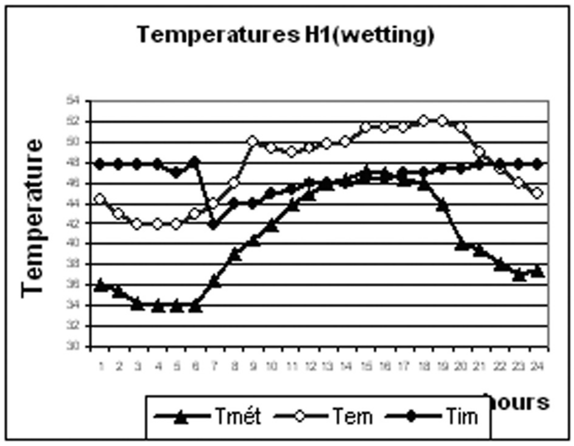


Figure 2: improvement occurred with the wetting system

In this case, further reduction of temperature and increase of humidity are obtained by humidification procedure. Wind towers can promote natural ventilation significantly and offer an acceptable level of indoor comfort regardless of the harsh outdoor conditions.

2.2 Simulation results
As the objective of the present work is to investigate the efficiency of the wind tower and its evaporative cooling potential , a series of simulation tests are carried out, using a micro computer program ''CAPCOOL'' developed by the authors, with respect to the climatic data of Ouargla. The passive cooling, with evaporative strategies are the most recommended for this type of climate (hot and dry). Important improvements for better performance of wind tower are made, for its design and use, which are inspired mainly from the Bahadori's (1985) work, such as:
1-Watering the interior walls of the tower at the top, using a small pump, which would operate in intermittence;
2-The surface of heat and mass transfer can be increased considerably, by introducing several conduits of small section in the shaft of the tower;
3 -The using of hygroscopic porous materials for the internal surface of conduits (clay for example);

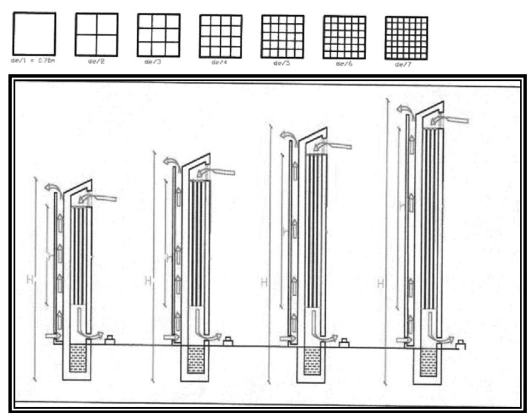


Figure 3: Different configuration on wind tower Various partitions and lengths (de/h)

4 - The roughness of internal surfaces enhances heat and mass transfer, but causes pressure losses for the airflow. So a compromise can be found to maintain high airflow rates with significant transfers.

Mathematical model, which consists to predict the evolution of the air parameters in the conduit can be found with details in an extensive presentation (Bouchahm, 2005). These investigations show the results for different combinations of height (h) and the equivalent diameter (d_e). July is considered the hottest month with a temperature of 42.7°C and humidity as low as 14.1% Hence the variation on 'd_e' gives a higher drop of temperature (ΔT=18.6°C). But, a drop of 7.2°C is obtained only with the extension of the wetted tower. These results confirm the conclusion drawn previously which is that with small sized partitions (by increasing their number) better efficiency is reached than with a higher wetted column of the cooling tower. Indeed, the results show that the air temperature going in the living room is nearly half that which occurs at the top of the tower.

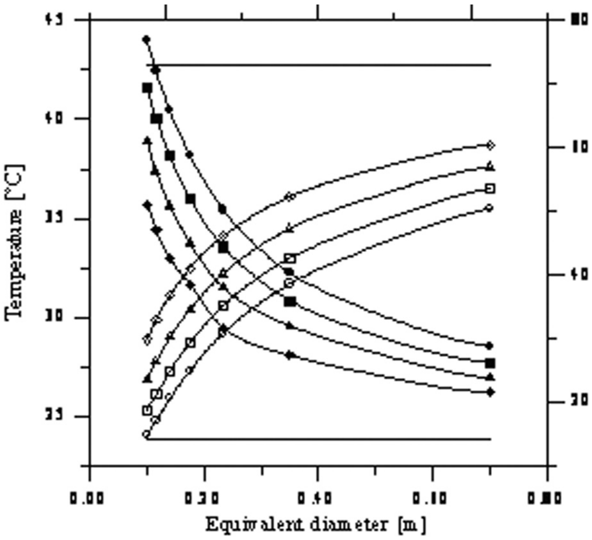


Figure 4: Results with variation on (d_e and h) for July (the hottest month)

The same conclusion can be drawn for the humidity case. The highest value is obtained when the partitions are the narrowest in diameter rather than when the wetted column is the highest in length. Humidity increases in the second case to 62.6%, $\Delta\varphi$ =37%.

3. EXPERIMENT

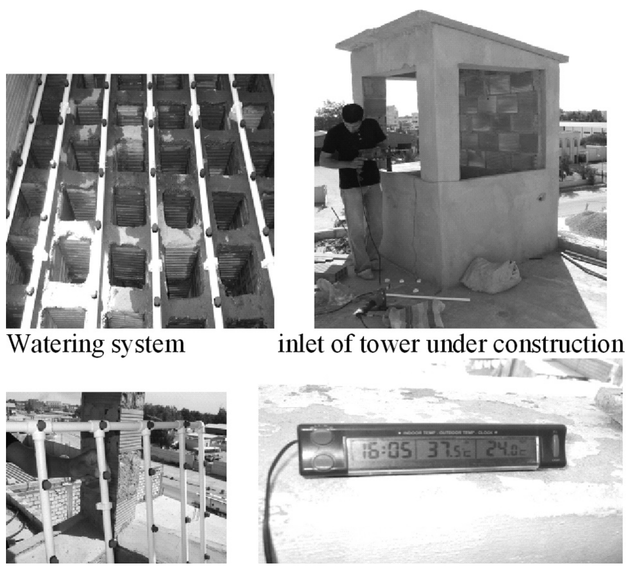
Air temperature can be significantly reduced by only improving the two determinant factors of the wind tower configuration: a higher height of wetted column (h) and a smaller size of the conduits partition inside the tower (by increasing their number). The number of the clay partition introduced inside the shaft is responsible for the increase of surface heat and mass transfer.

According to these results, a prototype improved wind tower is constructed at Hassi Messaoud, Algeria for passive evaporative cooling of an office building under the same climatic condition as Ouargla, hot and dry, as shown in figure 5.

A 6.50m multidirectional wind tower is built with red brick and covered with rough mortar. Its interior cross section is 0.70 – 0.70m². A 40 clay partition introduced inside the shaft with a diameter of 10cm as recommended by the above results in order to increase heat and mass transfer which achieve better temperature reduction. Watering the interior walls and clay partitions inside the tower at the top by a system shown in figure 6. The water spraying system designed for the preliminary experiment on the prototype tower draws water from the main operational reservoir. It is protected from intense sun radiation by a double envelope sheet and thus keeps the water as cool as possible. At the bottom of the tower is a pool collecting excess of droplet of water which can be recirculated by a simple pump.

Reservoir with double skin

Figure 5: The new wind tower built on an existing office



Watering system inlet of tower under construction

Figure 6: Watering the 40 clay partitions inside the tower (Tat inlet is 37.5°C / T at outlet is 24°C at 16.05pm) these results are recorded after 2 hours of the beginning of watering.

3.1 Results and Discussion

The following section presents results of preliminary series measurements carried out over a short period only (May 2007). The performance tests were limited to the operation of water spraying system in purely wind-driven mode of operation.

Air temperature and humidity are measured in specially designed screens to protect the sensors from contact with water spray or sun radiation (at inlet); a thermo hygrograph with a thermograph are used to measure them at the outlet of the tower. The air temperature and relative humidity (at both outlet and inlet) are hourly recorded for a period of three days.

Figure 7a shows the evolution of the air temperature at inlet and outlet of the tower. They are measured during which the spraying system was active.

At the beginning of the watering the clay partitions and the wall surfaces inside the wind tower only small drop is recorded, as far as the total height of the clay column is watered a significant decrease on air temperature is measured. On the second day (23 May 2007) at 13.00pm as the inside clay partitions are well wetted and when the outdoor temperature (at the inlet) reaches a maximum of 42°c the tower exit air temperature is only 21°c. This is mean that better efficiency is reached by the improved wind tower constructed to cool the office building as 21°C reduction is recorded, while the reduction predicted temperature by CAPCOOL Program was only 18°C. Hence, the prototype wind tower built is more efficient than the model simulated by a difference of 3°C and may be more for other days. The temperatures are reduced from 9.00am till 21.00 pm ranging between 20°C and 23°C and then they begin to increase slowly to reach its maximum (28°C) at 1.00 am.

Humidity is reaching its minimum of 10% at 13.00pm at inlet while 85% is recorded at outlet.

The experiment results obtained show a drop of temperature with an increase of humidity of the air going into the office; when the wetted column is extended, the number of partitions is increased and their sizes are reduced. The experiment concludes that the exit air temperature from the tower and the humidity rate are controlled almost exclusively by the temperature difference between the cooler and wetted air inside and the hotter dry air outside the tower. They seem to be proportional to watering system and to the design details of the wind tower. The performance of the system is very impressive.

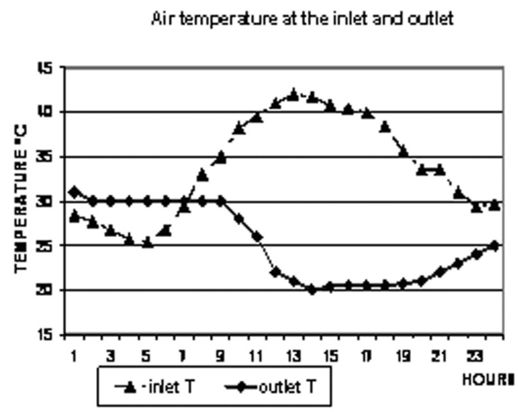


Figure: 7 a the air temperature measured at inlet and outlet of the wind tower.

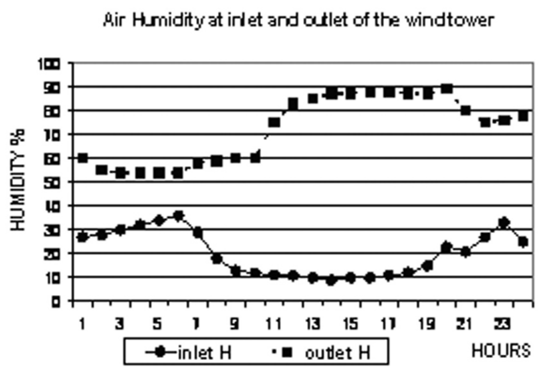


Figure: 7 b The air Humidity measured at inlet and outlet of the wind tower.

4. CONCLUSIONS

The results reported upon in this paper are based on preliminary measurement carried out over a short period only (21, 22, 23 May 2007).

A series of measurements are planned for summer season from June till September to provide a sufficiently large database for better evaluation of the effects of both geometric configuration of the more performed wind tower and its best spraying water. Hence the widespread adoption of these evaporative cooling towers may be a practical means of providing summer comfort with low-cost, low maintenance cooling, for this kind of climate dry and arid.

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