

REALISATION AND EXPERIMENTATION OF A WIND TOWER FOR PASSIVE EVAPORATIVE COOLING IN HOT DRY AREA: HASSI MESSAOUD, ALGERIA

A. Djouima^{*}, Y. Bouchahm, F. Bourbia, A. Torkia

Laboratory A.B.E' Faculty of Architecture, University of Constantine 3, Algeria

Received: 15 July 2017 / Accepted: 29 December 2017 / Published online: 01 January 2018

ABSTRACT

The wind tower is one of the solutions to overheating issues. Using them in Algeria would be a solution in cooling hot areas and reducing energy consumption and greenhouse gas emissions. This research aims to develop a passive alternative to active cooling by exploring potentials and design parameters of wind catchers. The configuration of this built tower was based on a modified version of a model by Bouchahm (2011). The methodology used to this end consists of experimentally exploring the efficiency of wind towers through direct heat transfer induced by humidification of its built columns. Experiments on cooling efficiency were performed. The temperature and relative air humidity were monitored from May to August 2007 with and without humidification of the tower columns. The results are comparable to those of the simulated model. Lower temperatures were also recorded.

Keywords: Summer thermal comfort, passive evaporative cooling, humidified column, hot and arid climate, and wind towers.

Author Correspondence, e-mail: adjouima@yahoo.fr

doi: <http://dx.doi.org/10.4314/jfas.v10i1.25>

1. INTRODUCTION

The main functions of a wind tower is the capacity to passively and simultaneously move fresh air in and stale air out of a living room through an opening located at the roof of the



tower and oriented towards the prevailing direction of the wind. (Montazeri & Azizian) [1]. Passive evaporative cooling of wind towers is one of the oldest methods used for air conditioning in hot and dry climates. The system consists of one or several towers equipped with a water supply placed at the roof level of the tower (s). During the continuous spray of the central part of the tower, water droplets form and move downward causing inside air to become continuously moist, thus approaching saturation. Fresh air descends along the tower and leaves at its base, allowing adjacent spaces to be ventilated. In order to extend the use of wind towers for the cooling of both indoor and outdoor spaces, as well as refurbishments, a number of experiments have been carried out, particularly by Givoni [2], A. S. H. Abdallah et al [3], Erell et al [4], Amr Sayed et al [5], Mazouz et al [6], and Poshtiri et al [7].

To validate the results obtained by the simulations carried out by Bouchahm Y in 2003 [8], a wind tower, equipped with a passive evaporative system, has been designed and constructed in an office block in Hassi Messaoud, an arid and hot region in the South East of Algeria, at a latitude of $31^{\circ} 40'N$ and a longitude of $06^{\circ} 09'E$ with an altitude of 142m. One of the main objectives of these experiments is to explore ways to integrate the results simulated by Bouchahm in 2003 [9] to our work. This embodiment consists in improving the configuration of the geometry of the Wind Tower concept such as the height of the humidified column and the increase of the heat transfer surface. The humidification system, adopted, is a new design of water spray; it is added to the wind tower to improve the power of refreshing by passive evaporation of the system. The concept was taken up as one of the corrective measures that could be taken to protect the built environment from the degradation of fragile ecological zones, damage to natural resources and chemical pollution.

2. PURPOSE OF THE EXPERIMENT

During the last few decades, special attention has been paid to the use of renewable sources of energy as an alternative to using fossil fuels. One vivid example of such a development involves the use of wind towers as passive cooling systems in hot and arid climatic regions. In a wind tower, air is drawn into the tower using a sophisticated grid system that can be adjusted and oriented in the direction of maximum wind speed so that overall cooling of

indoor spaces is ensured, Bahadori [10]. The transfer of heat by evaporation of water, by contact with humidified conduits inspired by refreshing systems used in hot and arid climates using modern techniques, was based on previous theoretical studies Poshtiri et al. [6], Richard H, Tolouie S; [11] Erell et al. [4].

To improve the cooling efficiency of wind towers, a new prototype has been developed. The architectural configuration of the new wind tower integrates the results and recommendations of the simulations of the new architectural form (height optimization, section and number of ducts) of the wind tower in order to improve its potential Passive refreshing by evaporation, Bouchahm [8]. Obtained results confirm earlier works Erell [4]; Calautit et al [12]. Passive evaporative cooling systems using wind towers offer most effective, most economical solutions in hot and arid climatic zones CIBSE [13], El Mualim [14]. Therefore, the usage of wind towers in hot and arid regions in Algeria, should depend not only on clear design understanding of such towers by architects and engineers and its adoption by the populations, but also on bringing continuous improvements to the performance and testing of new prototypes, Pearlmutter et al [15], De Melo [16].

To this end, a new design of a wind tower conforming to the requirements simulated by Capcool [8] has been constructed and used to cool an office of 45.36 square metres and 2,7 m height, located in an administrative building in Hassi Messaoud. Performances of the evaporative cooling potential of the tower have been tested and results obtained proved to be very encouraging.

3. PROTOTYPE DESCRIPTIONS AND EXPERIMENTAL METHODOLOGY

According to simulation results, air temperature can be significantly reduced by optimizing the geometry and the configuration of the wind tower, namely the use of a greater height of the humidified column (h) and a reduction in the section area of air conduits. The latter is achieved by dividing the central air conduit into smaller ones using red bricks. It is at the level of the central part of the wind tower, where the compartmentalization is performed (reduction of the global section into a number of smaller ones), that the heat transfer is performed, Bouchahm [8].

The tower, which has an internal cross section of $(1 \times 1) \text{ m}^2$, was built using red brick and mortar. Forty-nine red brick partitions with a $10 \times 10 \text{ cm}^2$ section each were constructed inside the section area of the wind tower fig.2A and spread over a height of 6.5 m, as recommended by Bouchahm's [8] simulation. This design should increase the heat transfer by increasing the contact area of the incoming air inside the brick tower by a factor of five and therefore allowing a maximum drop in air temperature.

A humidification system (drip-type), as shown in Fig.2B, is installed at the upper level of the tower in order to humidify the walls of the partitions and ensure the necessary passive evaporative cooling of the studied site. This cooling system is ensured by the evaporation of water causing further heat reduction at the conduit level. A water basin is placed at the bottom of the tower collecting the excess water leaving the column, along with an overflow and a pump that guarantees the recycling of the collected water.



Fig.2. Horizontal cross-section of the wind tower $1 \times 1 \text{ m}^2$ with partitions of 10cm in section and a total number of 49 conduits (A), water spray pipes (B)

The realization of the wind tower has gone through three main phases.

As a first step, we built the lower part (Basin) over 1m height, 60cm of which was covered with earthenware Fig. 3 A and B

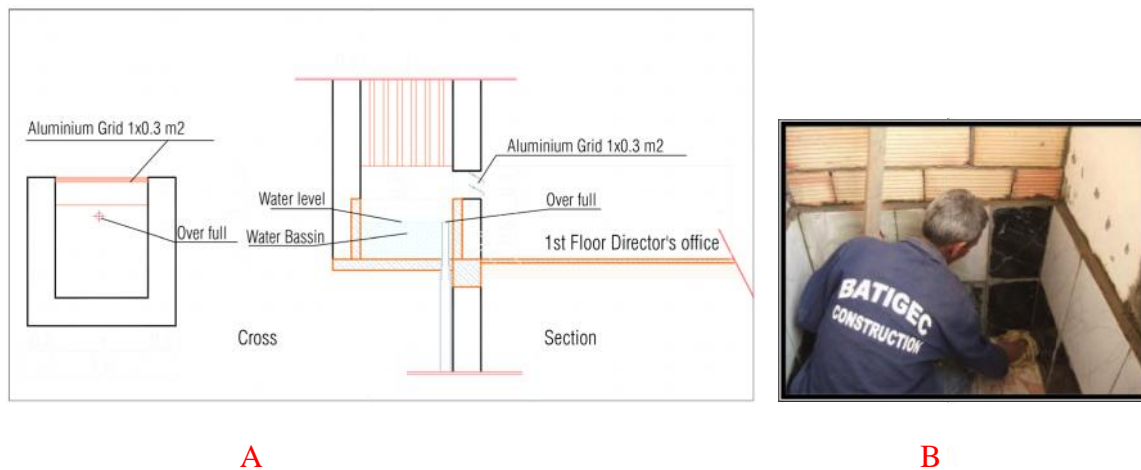


Fig.3. Realization of the lower part (A), covering of the 60 cm with earthenware

We inserted a 40cm tube to function as an over flow. We left a 0,3 x 1 m² opening to the office to allow air flow that is regulated thanks to an aluminum grid Fig.4 A, B and C.



Fig.4. Realization of the over flow A, 30 cm opening to the office B Grid C

The second phase consisted in the realization of the central part where we built three sides and left one open to allow the placing of clay partitions. IT was the most difficult part to build Fig.5.

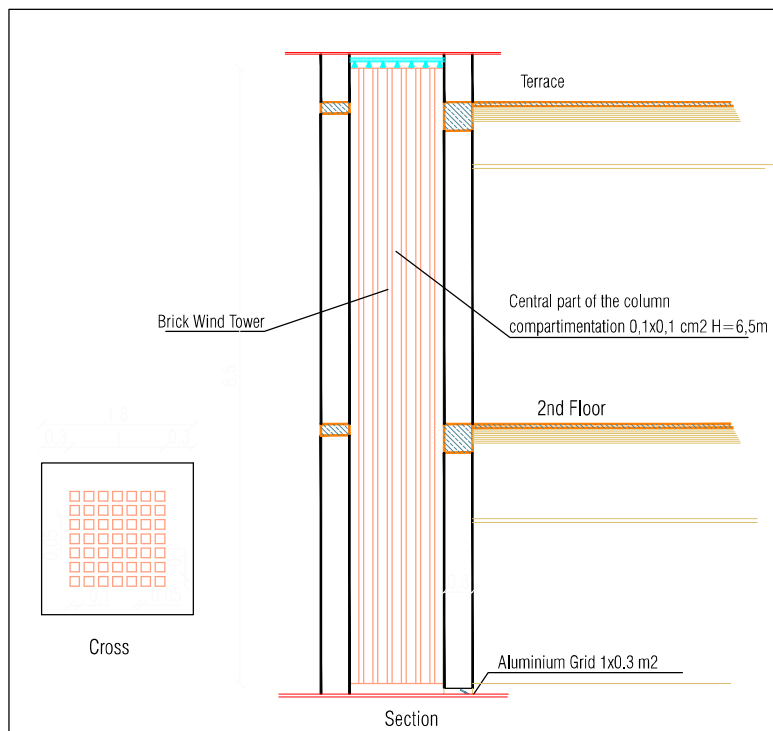


Fig.5. Realization of the central part of the wind tower

We had to fix two iron bars between two walls to sustain the clay partitions. On the other hand we placed two wooden boards over the iron bars fig.6, obtaining in this way a ceiling, which facilitated the growth of the tower in height. Once the needed height was obtained, we withdrew both the iron bars and the wooden boards and cleaned the clay partitions to allow the flow of air Fig.7.



Fig.6. Realization of the wood board ceiling



Fig.7. Towards the needed height

The third phase (realization of the wind tower head) started after the 6,5m clay partitions were built Fig.8. It consists of three open sides directed to prevailing wind. A designed and regulated humidification system was placed over the partitions inside the wind tower. It supplied water from a tank covered with galvanized sheet steel (to prevent water from heat) and placed on the terrace near the head of the wind tower Fig.9 A, B and C. The control of the humidification system is done manually.

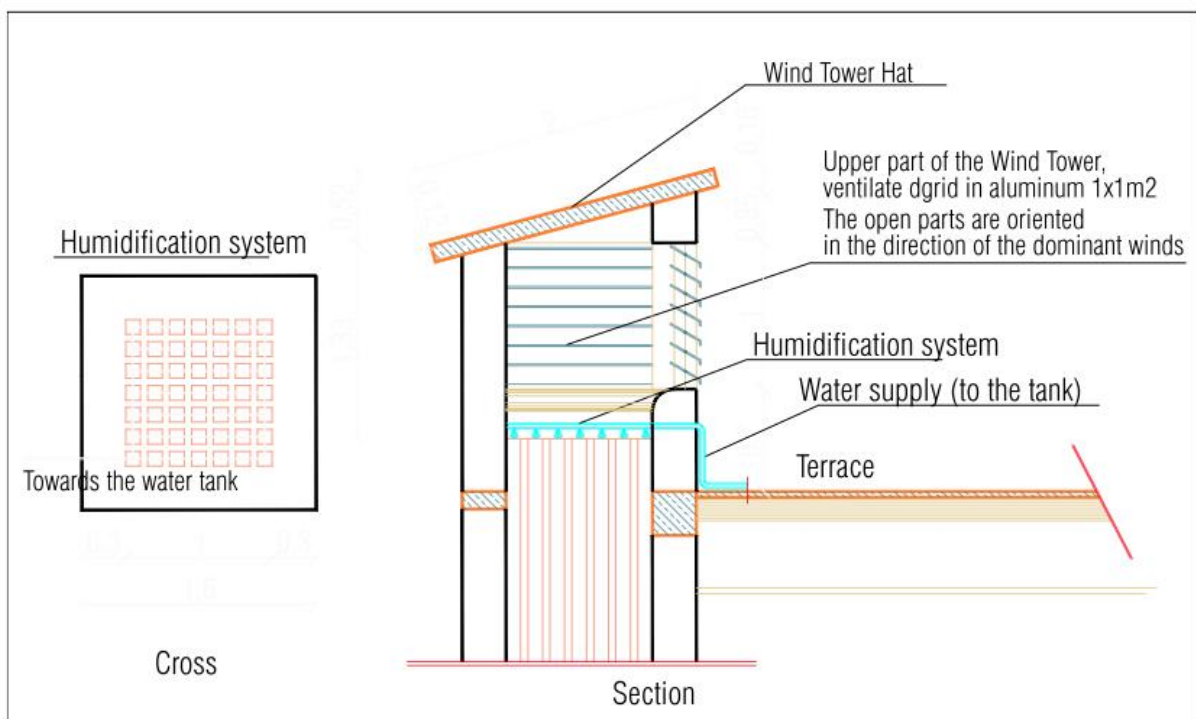


Fig.8. The wind tower head

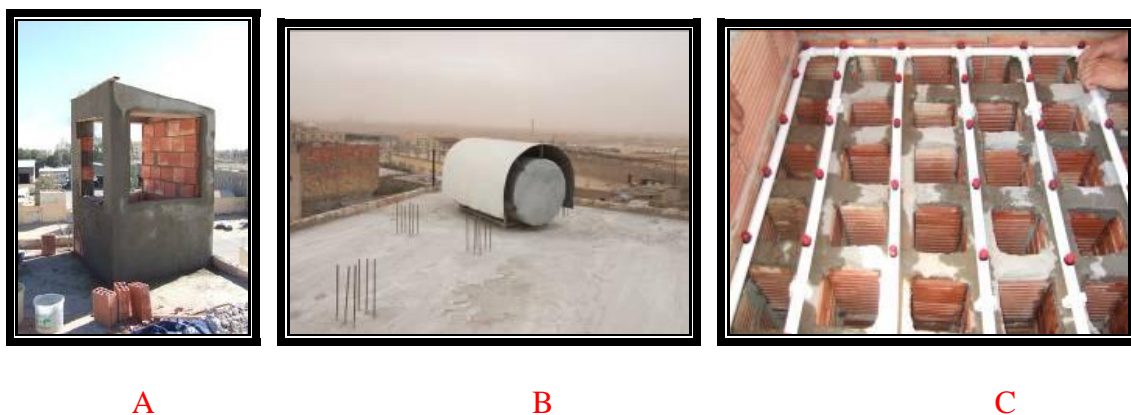


Fig.9. The head openings A, the water tank B, the humidification system C

4. INVESTIGATIONS AND MONITORING

The temperature and relative humidity of the air were collected using a *wireless weather station, with PC software model WMR928NX equipped with several sensors –probes- and accuracy of ± 0.1* , as shown in Fig.10



Fig.10. Wireless weather station with PC software model WMR928NX

The performed tests involved the monitoring of climatic factors that have a direct impact on thermal comfort. The recorded results were compared with those obtained from the newly improved simulation model by (Bouchahm .Y, 2003) [9]. In order to achieve this, we used to measure at different levels of the tower. A series of measurements were collected from three stations. The first station was placed at the outside top level of the tower with the assurance that the sensors were protected from the sun Fig.11 A and 11 B. The second station was placed at the deliverance of the air coming from the tower to the office room with the assurance that

the sensors were also protected from droplets of the humidification system. The measurements were performed in summer from May until August 2007, representing the hottest period. The weather station of the town of Hassi Messaoud namely, station 3, provided us with hourly weather data during the same monitoring period.

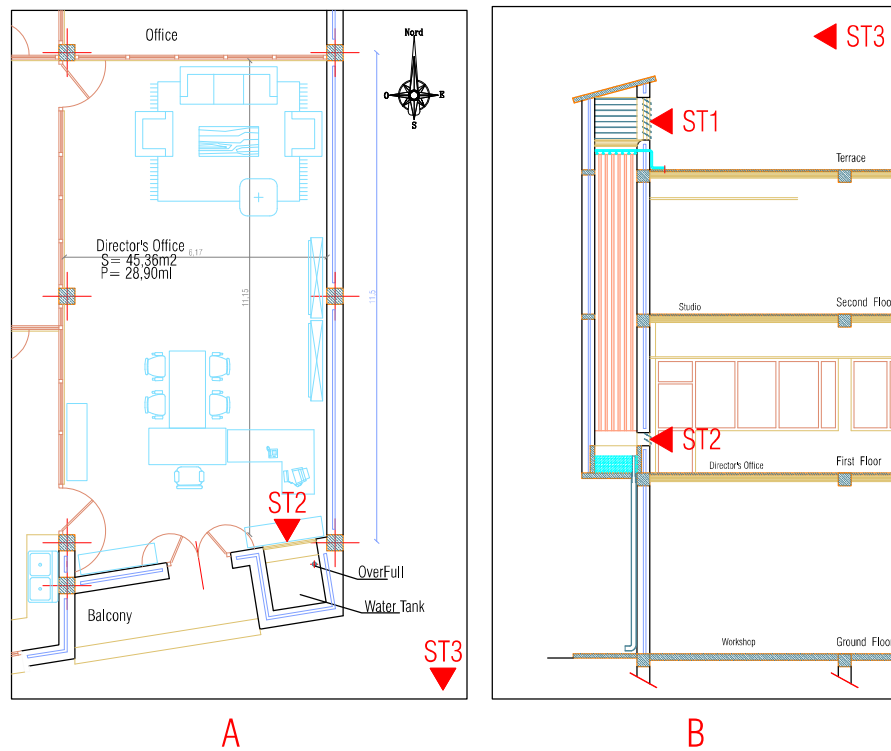


Fig.11. Position of measurement stations (A) plan section (B) longitudinal section

Early results from the period of May 22 to 25, 2007 were very encouraging. The performance tests were limited to the operation of water spraying system in purely wind-driven mode of operation.

Two series of experiments were carried out, specifically with and without humidification. The purpose of these tests was first to verify the thermal performance and cooling potential by direct heat transfer between the air and the walls of the columns, and second to achieve refreshing or cooling by evaporation through the humidification of the walls conduits. Measured air temperature and relative humidity at the inlet and at the outlet of the wind tower were recorded and compared respectively.

After installing the humidification system and opening the blow out at the office where the air is blown, the first test of the wind tower is carried out. Two phenomena chimney effect and

stack effect are observed as shown in Fig.12 A and B.

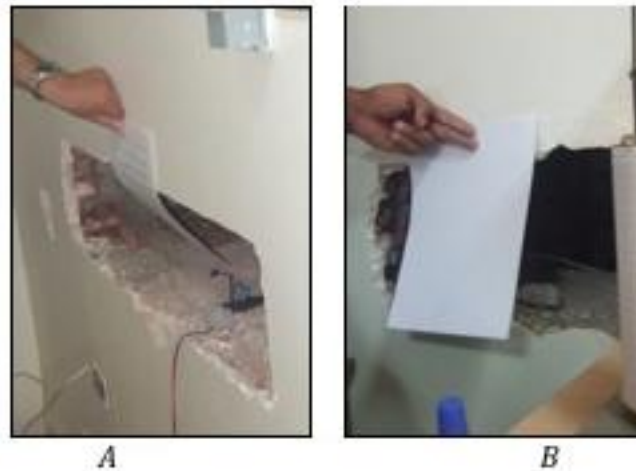


Fig.12. Chimney and stack Effects in the wind tower when the outlet in the office is opened

The experiment was done with and without humidification. The aim was to check the thermal performance and the cooling capacity by:

- Direct heat transfer between air and clay partitions,
- The humidification of the partitions and the presence of the water basin in the lower part of the wind tower

Temperatures and humidity are measured inside and outside are compared in both cases.

The measurements are made as follows:

May 2007

Early results from the period of May 22 to 25, 2007 only with humidification were very encouraging. The first measurements accomplished on May 5th (first day where the wind tower was operated) showed that at 04.02 p.m. a difference of 8.5 ° C is obtained. While the outdoor temperature was 37 ° C, the indoor temperature was 28.5 ° C.

After nearly one hour (04.54 p.m.) a considerable difference of 15 ° C is recorded, when the outside temperature (at head of the tower) is 41 ° C and the temperature inside (blowing outlet to the office room) is only 26 ° C.

Results show that improving the performance and efficiency of the passive evaporative cooling effect could be achieved by improving the geometric design of the built wind tower Fig.13.

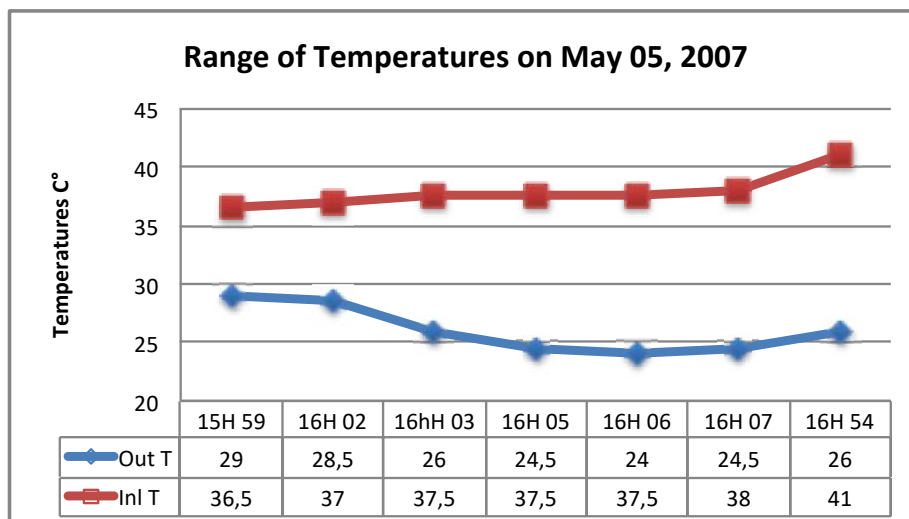


Fig.13. First results from measurements in May 2007.

June 2007:

Measurements were made without humidification from June 11 to 17, 2007 and with humidification from June 18 to 24, 2007. The humidification system was full time active 24/7 days. This resulted in high humidity scores.

July 2007

The measurements without humidification were made from 18 to 24 July 2007, and the measurements with humidification were made from 25 to 31 July 2007.

Since the measurements with humidification accomplished in June 2007 have shown high humidity scores, we opted for an alternated scheme of humidification $\frac{1}{2}$ day and the results were very satisfactory at blow.

August 2007

The measurements followed the same pattern as that of July. Those without humidification were made from 08 to 14 August 2007 and those with humidification were made from 01 to 07 August 2007.

The month of July was chosen to perform the tests as it is considered the hottest month of the year in this region, moreover the results obtained could be compared to those found by the simulation (in previous work) [9].

5. DISCUSSION

New advances in wind towers conception, design and construction have led to significant

efficiency improvements in passive evaporative cooling systems. For instance, evaporative cooling could reach 85 to 90% of humid temperature, thus producing an air temperature of 2 to 3°C below the ambient humid temperature [10], [11].

Our research will use a newly configured wind tower with a modified geometry [8] to study passive evaporative cooling effects in the hot and dry regions of Algeria. This will be illustrated by the evaluation of the difference between the air temperature measured at the inlet openings at the top level of the tower and that measured at the outlet air supply in the office.

The month of July was chosen to perform the tests as it is considered the hottest month of the year in this region, moreover the results obtained could be compared to those found by the simulation model *Capcool* [8].

Indeed, as the humidification of the brick columns continued, the difference between the air temperature at the entrance and at the exit of the tower increased. The performance of the tower reached its maximum potential after all forty-nine columns were fully humidified through the 6.5m Height.

Outside Temperature is measured at the top level of the tower and Inside Temperature is measured at the office opening where the air exits.

5.1 Measurements Without Humidification Of The Columns

Measurements without humidification of the columns were performed from the 18th to the 24th of July 2007. During this period of testing, the inside air temperature was relatively stable and showed a variation of up to 2°C, whereas the outside air temperature changed periodically and displayed variations of up to 14.1°C. This wide gap between inside and outside air temperatures caused negative and positive temperature gradients over the testing period as shown in Fig.14 A.

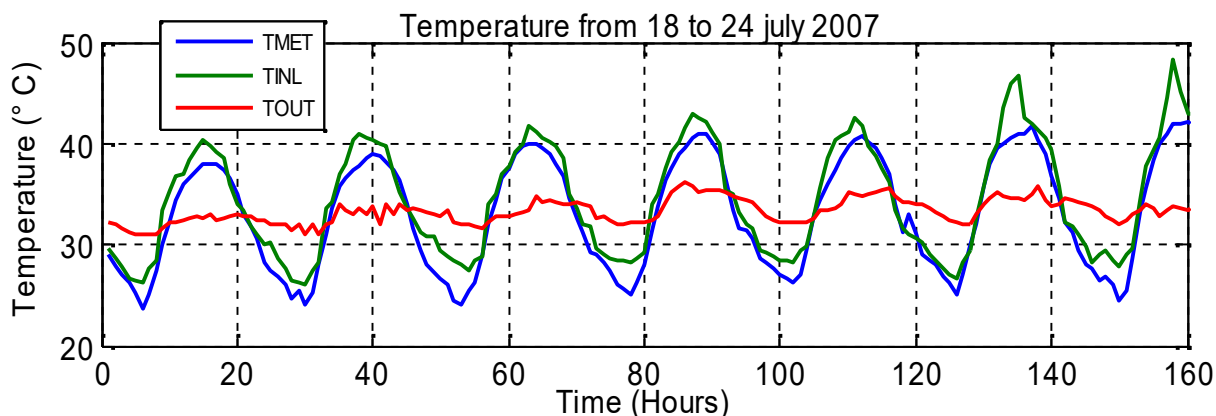


Fig.14 A. Tests without humidification; Air temperatures comparison (Tmet from the weather station; Tinl at the top inlet of the wind tower; Tout at the bottom outlet of the tower)

The wind tower had a cooling effect by direct heat transfer from 8 a.m. until 9 p.m. This cooling effect increases when the outside air temperature is rising. The highest performance of the wind tower is reached between the hours of 12 p.m. and 7 p.m. where the temperature drop was between 5.8°C and 14.5°C. This drop in temperature is the driving force of the stack effect in the wind tower where the wetting process was inactivated as shown in Fig.14 B. The maximum temperature variation was recorded at 2 p.m. on July 24th as shown in Fig.14 B.

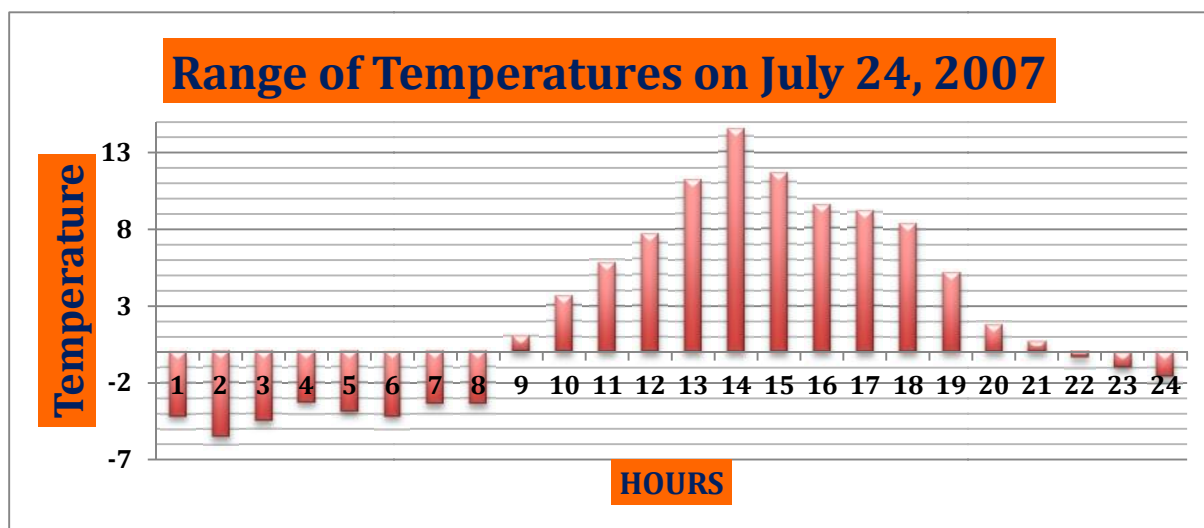


Fig.14 B. Tests without humidification- variation on July 24

At this peak time, the usage of artificial air conditioning in this region of Hassi Messaoud in Algeria was significantly high.

At night, the outside air temperature decreases but the air temperature recorded at the opening

in the office remains practically stable, the thermal mass of the tower, as well as that of the internal walls of shafts absorbed an important amount of heat during day. The heat accumulated by radiation will be restored to the contact of the fresh air at night (chimney effect) [8].

The relative humidity recorded at the exit in the office was 17.40 % in July 24th, 2007. This rate is higher than the one measured at the entrance of the air at the top level of the wind tower (10.46 %), thus the temperature is very high and the relative humidity is very low Fig.14C.

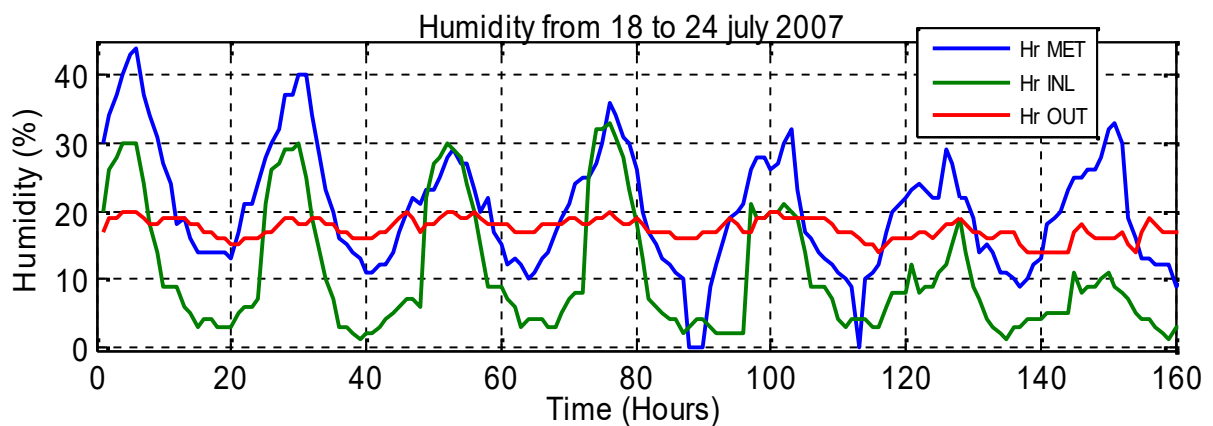


Fig. 14 C. Tests without humidification; air Relative humidity comparison (Rh met from the weather station; Rh inl at the top inlet of the wind tower; Rh out at the bottom outlet of the tower)

While the relative humidity, as provided by the meteorological station on the 24th of July, was 12%, it was only 2% at the top level of the tower and 17% at the office exit. These values indicate that the overall reigning climate was very dry given that the humidity was lower than limit comfort (30%) as shown in Fig.14 D.

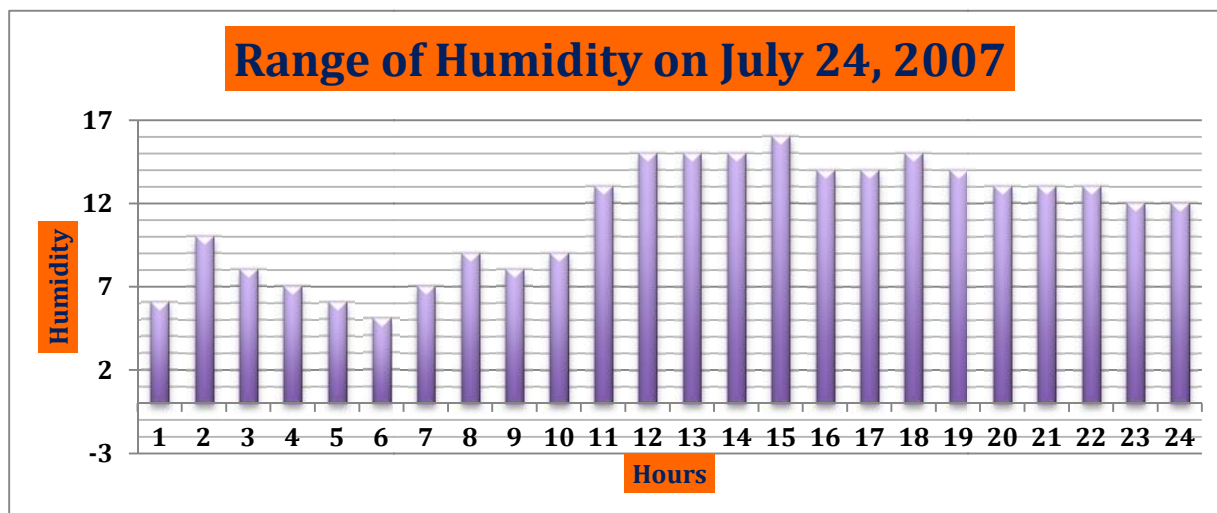


Fig.14 D. Tests without humidification- Variation in air relative humidity on July 24
(Rh inl at the top inlet of the wind tower; Rh out at the bottom outlet the tower)

The results from the measurements of air temperatures and relative humidity at the level of the air supply didn't attain a standard level of thermal comfort. Therefore a humidification system of the columns inside the wind tower is an important and necessary step to take in order to improve the cooling capacity of the tower.

5.2 Measurements With Humidification Of The Columns

Evaporative cooling started to take place as soon as water was introduced into the system and all columns were evenly humidified. As outside hot air moved inside the humidified columns, water started to evaporate and moisture content in the air increased, therefore causing air coming inside the office to become fresher and more humid.

During the monitoring period from the 22nd to the 25th of May, the humidification system was used 24 hours a day. Results of the relative humidity at the outlet were found to be slightly elevated, therefore it was decided to operate the humidification system on alternate days for the rest of the measurements period, namely for the months of June, July and August.

During the period from the 25th to the 31st of July, we noticed that the effect of passive evaporative cooling increased day by day and that the drop of the air temperatures at the outlet increased as shown in Fig.15 A.

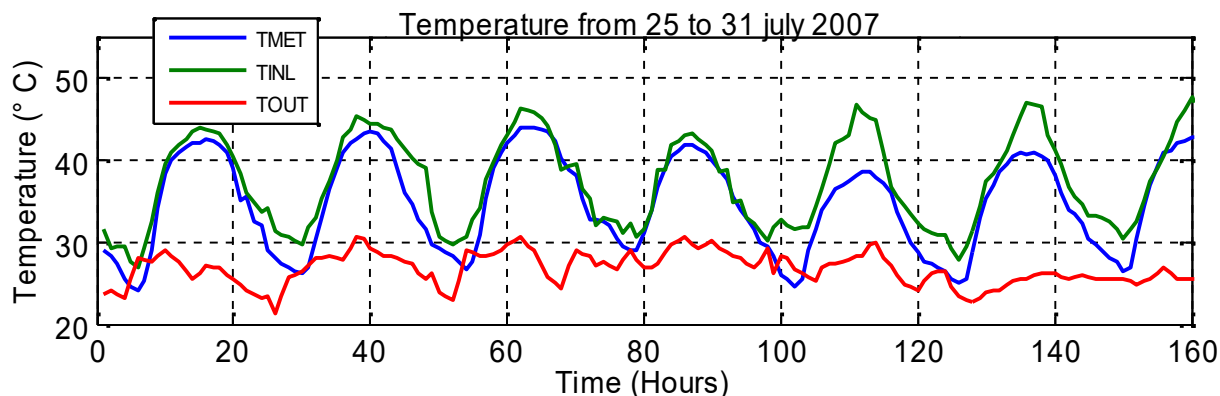


Fig.15 A. Tests with humidification of the columns- Air temperatures comparison (Tmet from the weather station; Tinl at the top inlet of the wind tower; Tout at the bottom outlet of the tower)

This drop reached a maximum of 22.1°C on the 31st of July at 4 p.m., which is higher than the 18°C obtained from the previous simulation results [8]. The wind tower performed at its best between 10 a.m. and 9 p.m. achieving a decrease in temperature that ranged from 11.6°C to 22.1°C as shown in Fig.15 B, and therefore offering an alternative passive evaporative cooling solution to the use of artificial air conditioning during this extremely hot period.

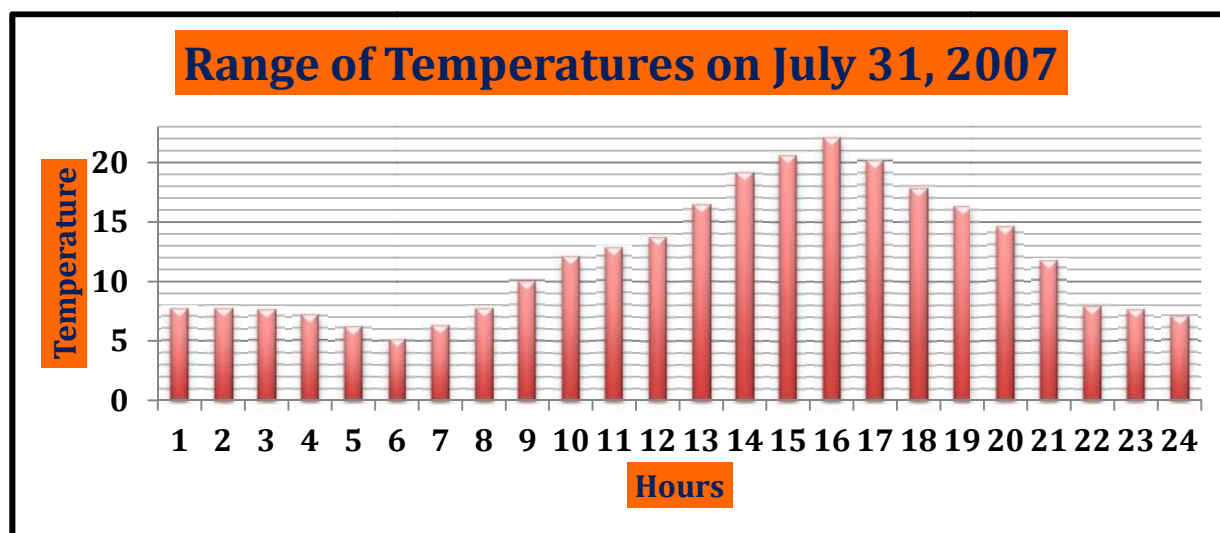


Fig.15 B. Tests with humidification of the columns- Variation in air temperature (Tinl at the top inlet of the wind tower; Tout at the bottom outlet of the tower)

At night, the temperature differences between the inside and the outside of the tower became less significant as compared to the drop recorded during the day from 10 a.m. and 9 p.m. The

air temperature recorded at the outlet remained relatively low and ranged between 25.4°C and 29.7°C. The humidification of the columns yielded significant improvements to the performance of the tower achieving an extra 7.6° C gain in temperature difference as compared to the tests performed without humidification and realizing better results than those obtained by simulation (18°C) Bouchahm [8].

The relative humidity of the air at the office vent was not consistent given that the humidification of the columns happened on alternate days. From the 25th to the 31st of July, the average relative humidity of the air as measured at the outlet in the office was 46.26%, a value falling within the range of comfort of 30% to 70% as shown in Fig.15 C. This value was also greater than the one measured at the inlet of the wind tower (8.18%).

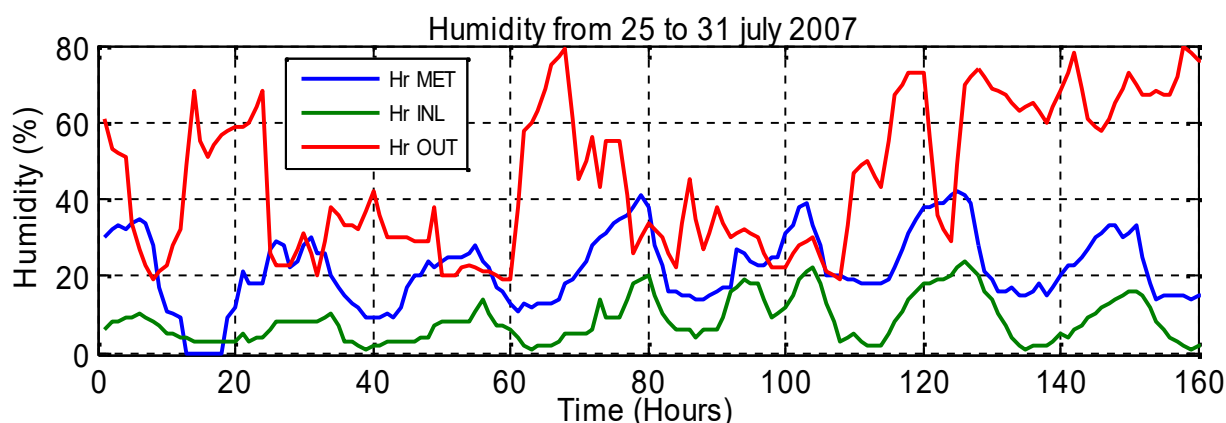


Fig.15 C. Tests with humidification of the columns- Comparison of relative air humidity (Hrmet from the weather station; Hrinl at the top inlet of wind tower; HROUT at the bottom outlet of the tower)

While the relative humidity, as provided by the meteorological station on the 31st of July, was 15%, it was only 2% at the inlet of the wind tower and 76% at the outlet in the office as shown in Fig.15 D. The humidification of the columns played a significant role in increasing the content of moisture in the air at the outlet in the office.

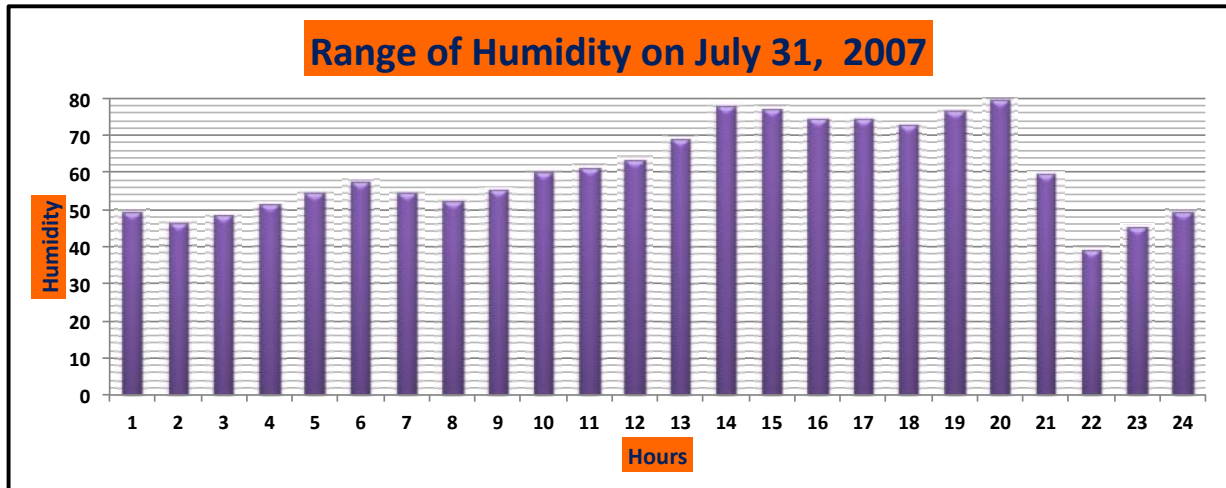


Fig.15 D. Tests with humidification of the columns- Variation in relative humidity (Hr inl at the top inlet of the wind tower; Hr out at the bottom outlet of the tower)

6. CONCLUSION

The efficiency of passive evaporative cooling of a wind tower is determined by its capacity to reduce temperature and increase humidity of the air. Experiments performed, using a new wind tower design, have shown that significant reduction in temperature and a substantial increase in humidity can be achieved by an adequate system of water spray of brick columns, where the transfer of heat between the air and the mass occurs.

Obtained results not only validated the new simulated (18°C) design but also exceeded expectations in terms of temperature and average relative humidity output (22°C / 46,26%). The integration of humidification is an added value since it still allows a reduction of temperature by a value of 7.6 ° C. It was also concluded that the performance of the wind tower depended greatly on the physical properties of both the outside hot and dry air and the fresh and humid inside air of the wind tower.

These performance achievements of the wind tower are a result of a well-adapted interior geometrical structure and an optimal water spray system. The performance of the system is very impressive. It is highly recommended to use wind towers instead of artificial air conditioning as a cooling means for both existing and new buildings. In Algeria and particularly in hot and arid zones, Wind Towers can decrease or replace Active air-cooling which uses large amounts of energy, costs lots of money to run and is responsible for the

deterioration of the environment through air pollution, Ozone layer depletion, release of greenhouse gases, formation of urban heat islands and contribution to global warming. It is expected that further studies could investigate energy consumption reduction possibilities through passive evaporative cooling systems and lead to the optimization of the realized model within similar climate conditions. Besides, future research works are expected to determine the optimal Wind Tower's dimensions in other climatic conditions in Algeria.

6. REFERENCES

- [1] Montazeri H, Azizian R. *Building and Environment*, 2008, 2193-2202, doi: 10.1016/j.buildenv.2008.01.005
- [2] Givoni B, *Passive and low energy cooling of buildings*. John Wiley & Sons, Library of Congress Cataloging-in-Publication Data; 1994.
- [3] Abdallah A S H, Hiroshi Y, Goto T, Enteria N, Radwan M M, Eid M A. *Energy Environ eng*, 2014, 5, 92-100, doi : 10.1007/s40095-014-0092-6
- [4] Erell E, Etzion Y, Pearlmutter D, Guetta R, Pecornik D, Krutzler F, A novel multi-stage evaporative cool tower for space cooling. Part 1: Aerodynamic design. In: Santamouris, M. (Ed.), *Passive and Low Energy Cooling for the Built Environment*, Santorini, Greece, 2005, 19–21
- [5] Amr Sayed H., Yoshino Hiroshi, M. Abdelsamei Eid, and Magdy M. Radwan, *Indoor Natural Ventilation Using Evaporating Cooling Strategies in the Egyptian Housing, A Review and New Approach*. *IACSIT International Journal of Engineering and Technology*, 2012, 3.4, 229-233
- [6] Mazouz S, Torkia A. *Natural ventilation and passive cooling in a hot and arid area of southern Algeria: a case of Ouled Djellal in Algeria*. *Journal of architecture and planning*, Riyadh, 2014, 26.2, 65-75
- [7] Poshtiri A.H., Mohabbati S.M., *Journal of Cleaner Production*, 2017, 148, 452-466, doi: 10.1016/j.clepro.2017.01.160
- [8] Bouchahm, Y., Bourbia, F., Belhamri, A., *Renewable Energy*, 2011, 36, 898-906, doi: 10.1016/j.renene.2010.08.030

-
- [9] Y. Bouchahm, A. Djouima, The experimentation of improved evaporative cooling wind tower in real office building, PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, Dublin, 22nd to 24th October 2008
- [10] Bahadoria M. N, Mazidi M, Dehghani A. R., *Renewable energy*, 2008, 33.10, 2273-2281, doi: 10.1016/j.renene.2007.12.018
- [11] Richard H, Tolouie S, *Les Tours des vents: aux origines du bio climatisme*, Habitat Naturel, 2006, 7, 52-56
- [12] Calautit J. K, Hughes B. R., *HVAC&R Research*, 2014, 20.7, 722-730, doi: 10.1080/10789669.2014.936795
- [13] CIBSE, *Natural Ventilation in Non-Domestic buildings, applications Manual 10*, London, CIBSE 2005, pp.70
- [14] El Mualim A, *Energy and buildings*, 2006, 38.8, 939-948, doi: 10.1016/j.enbuild.2005.11.004
- [15] Pearlmutter D, Erell E, Etzion Y, A multi-stage down-draft evaporative cool tower for semi-enclosed spaces: Experiments with a water spraying system. *Solar energy*, 2008, 82.5, 430-440
- [16] De Mélo A, Martins C, Guedes M. C., *Passive Draught Evaporative Cooling Applied On Existing Fabric: Using Traditional Chimney As Case Study In Portugal*, In The Conference On Passive And Low Energy Architecture, 6th to 8th September, Geneva, Switzerland, 2006.

How to cite this article:

Djouima A, Bouchahm Y, Bourbia F, Torkia A. Realisation and experimentation of a wind tower for passive evaporative cooling in hot dry area: hassi messaoud, Algeria. *J. Fundam. Appl. Sci.*, 2018, 10(1), 344-364.