

# Sustainable Design of Wind-catcher of an Earth-to-Air Heat Exchanger in Hot Dry Areas

Jamal Abed Al Wahid Jassim

**Abstract**— The study provides a new design for passive cooling system using Wind-catcher of an earth-to-air heat exchanger (WEAHE). Increase space Wind-catcher and supply Natural lighting, Performs part of Wind-catcher into the earth. To take advantage of underground water to moisten the air movement paths in the walls, pipes and Air moves into indoor air column depending on pressure. After we found that Wind-catcher which has been used in traditional architecture for long periods has disappeared in modern housing after the emergence of mechanical ventilation and because the amount of air provided are few that do not meet the limits of thermal comfort requirements of the modern man. The studies are aimed at evaluating the performance of wind-catcher of an earth-to-air heat exchanger in improving the internal environment and reduce energy consumption in the hot dry areas, including the city of Baghdad. The study was conducted in the summer of 2014 the month of July, August, September For three days and two stages. First: To conduct field measurements housing in the city of Baghdad has a Wind-catcher optimizer deport  $2.5 * 1.8$  m. Second: constructing a model represents the first development of the model by adding vertical and horizontal corridors deeply 3m to move the antenna in the ground and a computer simulation using a numerical simulation program (CFD). Results showed during the summer to increase Wind-catcher clip offset by increased air flow and temperature has dropped about  $18^{\circ}\text{C}$  was outside temperature  $45.3^{\circ}\text{C}$  and improvement in the relative humidity to 23%, The coefficient of performance (COP) of WEAHE system in this paper difference 3.43-5.24 with the increase in air speed 1.5-3.5 m/s. This makes the new design WEAHE a means for self-cooling and sustainable source of Illumination day and reduces the consumption of energy in the hot dry countries such as Iraq.

**Index Terms**— Courtyard, Environmental design, Hot dry climate, Natural lighting, Passive cooling, Sustainable, Wind-catcher,

## 1 INTRODUCTION

NATURAL ventilation of the basics of design low-energy wings through Wind-catcher design is capable of pulling the air air and expels [1]. Wind-catcher used for long periods to provide natural ventilation and passive cooling in the building through the air entry of Wind-catcher confrontation movement wind hole and move to the spaces of the building because of the negative wind pressure difference [2]. But Wind-catcher has disappeared from contemporary housing after the emergence of artificial ventilation because the air intake is appropriate to achieve thermal comfort requirements of the modern man. Mechanical devices have affected the environment to pay the hot air of outer space and the noise caused by As well as the air is dry when using air conditioners and loaded with moisture when using evaporative air coolers In both cases, the effect of increasing Ion Positive in the air that cause drowsiness and depressions to users of artificial organs [3]. A traditional house was accompanied by the presence of the courtyard, which is considered one of the most recognizable shapes in traditional residential architecture in different climates including hot climate. Researchers have tried to integrate different techniques to cool the Wind-catcher to improve its ventilation and thermal performance including modern techniques as tools to improve the quality of fresh air equipped and efficiently through the design of advanced cold tower within smart buildings techniques [4]. That need very high-tech as well as the maintenance and sustainability costs. These attempts were to take a specific aspect remains the integration of traditional design concepts in contemporary forms process represents a challenge for many architects and designers. Which made us think about contemporary applications constitute

the development of historical models within an innovative approach and at the lowest costs, And the adoption of natural ventilation ground single Wind-catcher and increase the size of the development Wind-catcher that will increase the amount of air moving to be suitable for the limits of thermal comfort, And the replacement of the air moving through walls corridors larger area and then into the ground through vertical and horizontal corridors Which means wetting the walls of the vertical and horizontal Wind-catcher through groundwater to the earth, which can reduce the temperature of the air, It is through the inner courtyard are the removal of warm air spaces of the process to replace him cold air normal and healthy. So research aims to verify the impact and effectiveness of the heat exchange the earth-to-air and supply Wind-catcher natural ventilation existence of the inner courtyard to improve the internal environment and reduce energy consumption in the dry tropics. The study was conducted in two phases. First: To conduct field measurements of residence in the city of Baghdad has a Wind-catcher deported  $2.5 * 1.8$  m. Second: constructing a model represents the first development of the model by adding vertical and horizontal corridors deeply 3m to move the antenna in the ground and a computer simulation using a numerical simulation program (CFD).

## 2 BACKGROUND TO THE STUDY

Wind-catcher towers are connected to the building is used for cooling a building above the port to pull cold air down through the passage of the wall to enter the interior spaces of the building, Air traffic generated depending on the pressure. Researchers have partnered to develop those individual to find different techniques to Wind-catcher traditional wind to improve their ventilation and thermal comfort, Bahadori. *et al* (2008) [5] experimentally studied the thermal performance of two different wind towers. One pole moisturizer made from curtains hung in the tower and the other was equipped

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with evaporative cooling pads on internal surfaces. The results showed that the temperature of the air inside is much lower than the air temperature of the traditional wind tower space and wind tower with a wet column was more effective during high wind while the tower equipped with wet surfaces was more effective during low wind. Either Safari & Hosseinnia (2009) [6] were used analytical approach based on computational fluid dynamics CFD. The researchers recommended that wet columns rise 10m able to reduce the temperature inside the buildings up to 12 °C and increasing the relative humidity of the air by 22%. Either study Kalantar (2009) [7] this study provides air flow inside the Tower of the Winds pattern analysis within evaporative cooling systems with the help of numerical simulation specimen CFD. Either Da Silva (2005) [8] The study indicated that the performance of passive evaporative cooling system is mainly influenced by the cooling efficiency of the evaporator and the number of hours of cooling degree and it is not effective in the summer to improve the internal thermal comfort and needs a mechanical aid. The study Abdel-moniem El-Shorbagy (2010) [9] This study shows the value of the Wind-catcher and its importance in the modern alternative to natural ventilation cooling system and referred to the attempts in the design of wind holder within smart buildings and the use of modern tools such as metal sheets of light aluminum and plastic slave few heights above the ceiling. The study Mahmud Dehnavi *et al* (2012) [10] Describe the performance of the Wind-catcher box section the most efficient in reducing the internal temperature. And it's initial steps towards providing the most comprehensive guide to the wind tower in passive cooling design. The study Al-Ajmi *et al.* (2006) [11] provided a theoretical model (EAHE) developed to predict the degree outside air temperature in the hot climate and showed that there is a reduction in the temperature limits 2.8 °C. Elsewhere Sehli *et al.* (2012) [12] A proposal for a one-dimensional numerical form flow EAHEs put different depths underground, Note the that the increase in the depth and shape of installation reduces the temperature of air, concluded that the system EAHE unit is not enough to improve the thermal comfort but it can be used to reduce energy demand in the building. Elsewhere Sodha (1993) [13] Presented analytical model the effect of the length of the pipe underground and verification of Qatar and the air mass flow rate and the ability to apply cooling accounts in warm dry climates. A similar study by Bansal *et al.* (2010) [14] Ahead the development of the system cooling buildings in the summer (EPAHE), which consists of an earth-to-air heat exchanger connected to tower wind, They noted that the speed of the air inside the buried pipes are the most important of the tube material and which affect the thermal performance. The study Goswami *et al.* (1993) [15] developed system EPAHE and used a plastic tube crispy diameter of 12 Lang and a length of 100 feet and a depth of 9 feet with a fan to push air through the tube conducted research at the University of Florida. The researchers found that the system can reduce the temperature of 90 °F to 80-83 °F. Elsewhere M. Benhammou *et al.* (2015) [16] Presented a model to predict the speed of air inside the tube and buried depth best suited 2m and the results showed that the dimensions of the wind tower (high cross-section) does not have a significant impact compared to the length and diameter of the tube, The cooling effect of the system is the best compared to the traditional passive cooling tower wind surfaces wet system. Different models where mechanical techniques used to help improve their ventilation studies have shown no mention to increase Wind-catcher section and performs part of Wind-catcher in the ground, So paper presents a new design based on Wind-catcher Ground and air cooling to the ground through vertical and horizontal, and with the help of the inner court-

yard corridors until the process of moving the antenna ground smoothly for the cool fresh air within the normal levels of thermal comfort and reduce energy consumption.

### 3 CLIMATE PROPERTIES

Study area is located in Baghdad- Iraq, at a latitude 33°30'N and longitude 44°40'E. The rise of 34.1m above sea level and are classified as warm regions. The advantage of being a climate desert climate or semi-desert strongly solar radiation and drought caused by the high rate of evaporation, The sky is clear in the case of most of the times of the year, leading to the arrival of large amounts of direct solar radiation to the ground during the day, The average hours brightness 12.30 hour brightness / day in summer and 6.30 hours Brightness / winter day, Air temperature reaches about 48 °C in late July and the highest daily variation of 8.18°C during the month of September, While the highest quarterly contrast to the 33.5°C between the months of January and July, relative humidity (RH) between 22% in June and 71% in December. Most of the wind may carry with them a local dust and sand. Annual rainfall 50-200 mm, The warm and temperate period is eight months and longer in control of the balance of the sun's rays as one group and the basis of style climate deal is to try almost complete protection from direct solar radiation and control of the air currents in the case of porous building to achieve comfort in this climate.

### 4 DESCRIBED THE CONCEPT OF THE DESIGN OF THE COOLING SYSTEM AND NATURAL VENTILATION

Concept of the design is based on the natural air intake through the Wind-catcher higher housing through an open corridor surrounded by four walls of the housing authorities built of light concrete block with high thermal insulation and smooth surfaces blocks to help the movement of air, Sectional area (2m<sup>2</sup>) Upper Wind-catcher directed toward the north-west, where the movement of the prevailing winds in the study area, Rises from the ground surface level 1.50 m north and west of the wall. The southern and eastern wall rises 3.00 m. And continue the underground level of depth 15:00 contain puller air to increase air movement when periods of silence protected air cover, Paths and horizontal underground pipe is manufactured from polypropylene or high density polyethylene material of pottery processor chemicals weatherproof composition of microbes Paths and horizontal underground pipe is manufactured from polypropylene high density polyethylene or material of pottery processor chemicals weatherproof composition of microbes Bear the high pressures diameter of 50 cm to ensure the quality of heat exchange where low soil temperature and reach 10-15°C Depends on the soil type and depth and heat exchange process between the hot air within the walls of the corridors and cold wet pipe, which reduces the temperature of the air, Corridors ends to vertical pipe through the wall inside the building spaces to be provided with natural ventilation cool up 1m on the ground level Can be controlled by conquest or sealed with a clip protection, contains Neighboring blanks for internal courtyard puller air placed in the top of the wall to pull the hot air from the upper layers of the spaces addressed to the inner courtyard of the house. The principle of the exchange of air between the air pressure depending Wind-catcher internal courtyard helps to remove heat accumulation of inside the residence. The Air received the amount of Wind-catcher in very few traditional houses and a small difference in temperature as a pass through the wall of the building and sectional area does not exceed 0.2m<sup>2</sup>. This made us think about

the importance of adopting a model Wind-catcher natural ventilation air and develop up sectional area of an earth-to-air heat exchanger With the help of the courtyard are the removal of thermal over-crowding and provide space cool and healthy air.

### 5 RESEARCH METHODOLOGY

The study was conducted in the summer 2014 for months of June, July, and August. For three days under the climatic conditions of the city of Baghdad as part of the hot dry climate. For the purpose of verification of the effectiveness and impact of moving natural air Ground proposed search through Wind-catcher presence in the inner courtyard improve the efficiency of the thermal performance of the home study took place in two phases:

- Phase I: A field measurement to model the study, which represents housing unit's courtyard, has Wind-catcher in the city of Baghdad using the device (Temperature data-logger ).

- Phase II: constructing a model Default represents the development of the first model by adding lanes corridor to move the antenna in the ground and a computer simulation using a numerical simulation program. (CFD)

#### 5.1 model study

Represents Model study two storey house a central courtyard, House area of 288 m<sup>2</sup> oriental facade, Courtyard 20 m<sup>2</sup>, thick walls 25 cm built by Bechtel light concrete block thermal isolation 0.2(twice isolate ordinary construction materials), Has Wind-catcher area 2m<sup>2</sup> slot heading to the northwest rises from the ground level of the surface of 1.50 m north and west of the wall. The southern and eastern wall rises 3.00 m. development of the model study the basis for the Wind-catcher adding vertical corridor same dimensional underground level of depth 3m<sup>2</sup> Provider Puller air put ground level to increase the antenna to move when the stillness air. The horizontal pipe diameter of 50 cm and air ports of exit in the housing spaces, Rising air column 13.90m, Fig. 1 • Fig. 2 •Table 1.

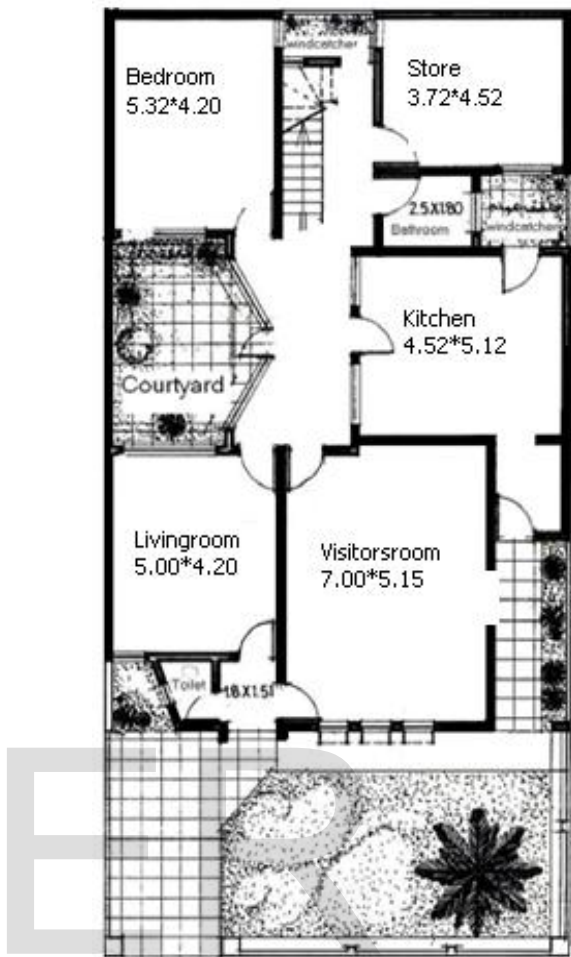


Fig. 2, Ground Floor Planner model of Ground Floor Iraq-Baghdad



Fig. 1, The interface study model Iraq-Baghdad for the first phase

TABLE 1  
PHYSICAL AND THERMAL PARAMETERS USED IN SIMULATION.

Material	Density (kg/m <sup>3</sup> )	Specific heat Capacity (J/kg K)	Thermal conductivity (W/mK)
Air	1.225	1006	0.0242
Soil	2050	1840	0.52
Potterytherapist	1600	1436	0.405

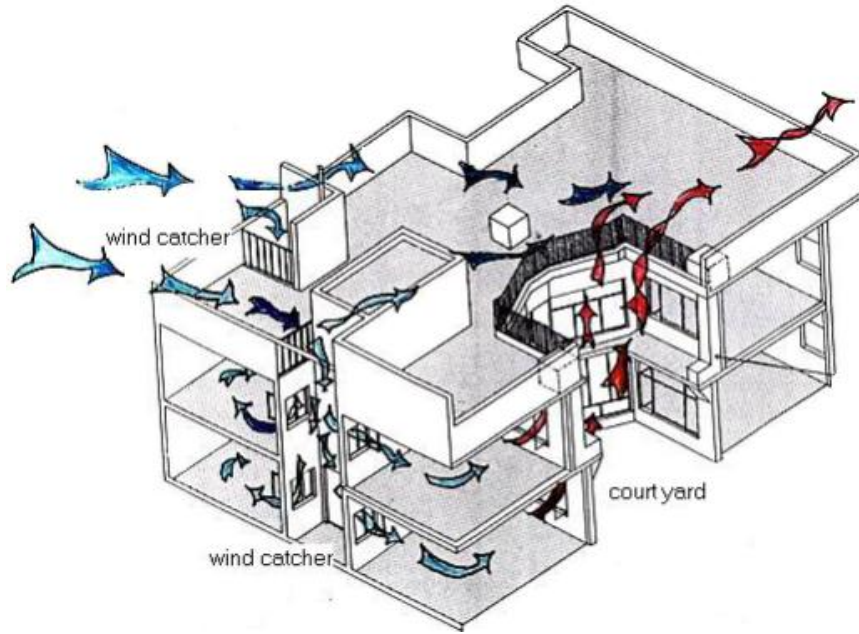


Fig. 3. Air distribution using wind catchers make the best increase the space

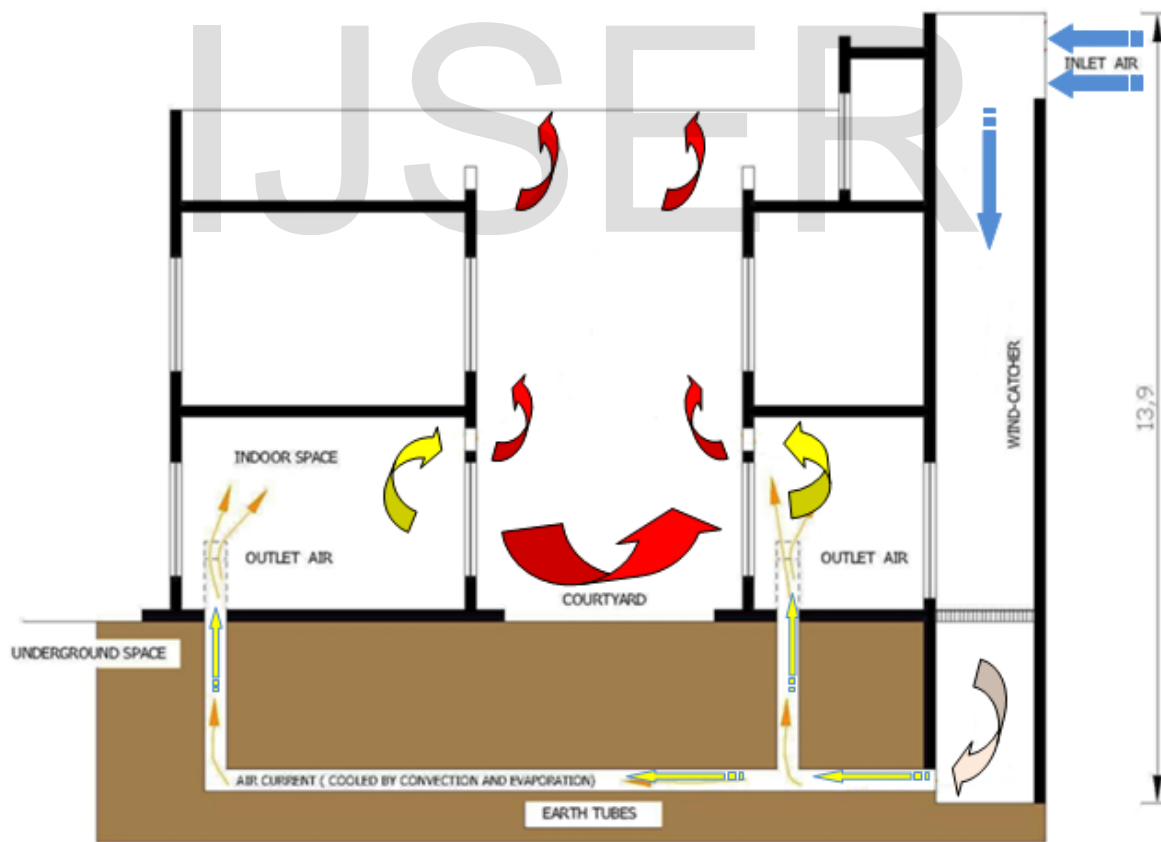


Fig. 4. Wind-catcher of an earth-to-air heat exchanger

## 5.2 Performance analysis CFD and experimental verification

Be validated CFD (computational fluid dynamics) modeling WEAHE conduct experimental calculations separately for daily testing in the June 20 to 21 for the summer of 2014 and repeated for the month of July and August, both in experiments and simulations. The flow of air through the air Wind-catcher passing through the earth across pipes of pottery items total hourly cooling has been calculated for flow velocities 1.5, 2.5, 3.5 m/s by the following equation:

$$Q_c = 3600 \dot{m} C_d c_p (T_{inlet} - T_{outlet}) \quad (1)$$

Where:  $\dot{m}$  = mass flow rate of air through the pipe.

$C_d$  = coefficient of discharge of the pipe = 0.6.

$C_p$  = specific heat capacity at constant pressure (KJ/ Kg °C).

$T_{inlet}$  = inlet temperature (°C)

$T_{outlet}$  = outlet temperature (°C)

Coefficient of performance of the system (COP) can be evaluated by the following equation:

$$COP = \frac{\dot{m} C_d c_p (T_{inlet} - T_{outlet})}{Q_c} \quad (2)$$

The volumetric rate was calculated from:

$$V = Vel (\pi d^2 / 4) \times 10^{-4} \quad (3)$$

Where:

Vel = Air velocity (ms<sup>-1</sup>)

d = pipe diameter (cm)

## 6 RESULTS AND ANALYSIS

### 6.1 Soil temperature system

Soil temperature system depends on the soil type and the level of groundwater in the study area. Found depth 2-3m stable system of temperature and the temperature was deeply 2.5-3.0 m ranging from 25.30 °C to 28.20 °C during the test period. These results support the Sharan and Jadhav [17] in the tropics. These depths can be used as a source of cooling in the summer.

### 6.2 Different of outdoor and indoor temperatures

#### 6.2.1 Field measurements existence Wind-catcher improved

Before designing WEAHE model study. Field measurements were conducted. Table.2 shows temperatures in outdoor temperatures indoor living room and bedroom during the test period in the summer months of June, July, August, during the three days of every month 20-21-22. From 12:00 am to 15:00 respectively, was taking readings rate for hours testing. The results indicated that the temperature indoor higher volatility during the month of July compared with other months, In spite of the difference between ocean temperatures and grades within the space of closed places. The bedroom has recorded a difference of 9.4 to 10.8, the lowest compared with the living room.

TABLE 2

AVERAGE MONTHLY DIFFERENCE BETWEEN THE TEMPERATURE OF THE AIR IN ENCLOSED AND OUTDOOR A HOME IN THE CITY OF BAGHDAD IN THE SUMMER DURING THE STUDY PERIOD IN 2014.

Month	Location	Average air temperature for the day 20		Average air temperature for the day 21		Average air temperature for the day 22	
		External temperature	Internal temperature	External temperature	Internal temperature	External temperature	Internal temperature
June	livingroom	43.7	33.2	43.4	32.3	43.1	32.1
	Bedroom	42.6	31.8	43.4	31.4	43.1	31.1
July	livingroom	45.3	32.6	44.9	32.1	44.2	32.1
	Bedroom	45.2	34.2	44.9	33.9	44.2	33.1
August	livingroom	45.7	33.5	45.9	33.8	45.2	32.3
	Bedroom	45.7	33.1	45.9	32.8	45.2	32.1

#### 6.2.2 Wind-catcher of an earth-to-air heat exchanger

Table, 3, shows the outdoor air temperatures and average degrees and experimental simulation of indoor living room, Relative humidity during the test period for the three days of the months June, July, August 2014, By three hours from 12:00 to 15:00 every day. The results signal a higher fluctuate in temperature during the month of August, And that there is a clear difference between the scores of the external and internal temperature, Decreased in June from 27.4 to 27.9 in July from 27.1. to 27.6 and the month of August from 27.1 to 27.9. When the outside temperature ranged from 42.6 to 45.9, The difference increases with increasing air velocity. Relative humidity 22% to 24% when the relative humidity in the outside 16% to 17%. The material walls and contributed to the pipe-

line in the air humidified reduces the air temperature.

Table, 4, shows the average readings experimental and simulation temperatures in outdoor temperatures indoor bedroom, Within months the study, Noted the system there is a clear difference has decreased during the month of June from 28.6 to 28.9 in July, 28.5 to 29.1 and 28.5 to 29.1 the month of August. When the outside temperature ranging from 42.6-45.9%. The difference increases with increasing air velocity. And scored relative humidity inside the blanks from 22% to 23%.The results show a difference in temperature inside the closed spaces. Recorded Living room the highest of Bedroom, This means that increasing the length of the tube reduction in air temperature .At the same time the relative humidity recorded the lowest in the room Livingroom .A positive relationship between the internal temperature and the length of the



tube and the relationship between the reflectivity of the relative humidity of the spaces with the length of the tube, Fig .5, Shows the difference in internal temperatures during the study period and the difference between the highest have been achieved in the month

August, The values that were obtained during the day were within the limits of thermal comfort, the system can conclude that WEAHE alone is enough to provide thermal comfort during the hot period without relying on assistant devices.

TABLE 3

COMPARISON BETWEEN THE DEGREE OF EXPERIMENTAL AND SIMULATION TEMPERATURE AND RELATIVE HUMIDITY FOR THE LIVINGROOM IN THE SUMMER 20/07/2014.

Month	Location	Air flow velocity = 1.5 m/s			Air flow velocity = 2.5 m/s			Air flow velocity = 3.5 m/s		
		Exp. temp.	Sim. temp.	RH	Exp. temp.	Sim. temp.	RH	Exp. temp.	Sim. temp.	RH
June	T inlet	42.6	42.6	17%	43.9	43.9	18%	43.1	43.1	17%
	T outlet	27.4	26.2	22%	27.6	26.2	24%	27.9	26.8	26%
	T courtyard	30.4	29.4	20%	30.9	28.0	19%	31.2	27.9	20%
July	T inlet	45.3	45.3	16%	44.9	44.9	17%	44.2	44.2	16%
	T outlet	27.5	26.3	23%	27.8	26.6	25%	28.3	27.1	26%
	T courtyard	32.1	31.0	19%	32.5	29.5	20%	32.3	28.9	19%
August	T inlet	45.7	45.7	17%	45.9	45.9	17%	45.2	45.2	16%
	T outlet	27.9	26.8	23%	28.1	27.1	25%	28.4	27.1	27%
	T courtyard	30.1	29.8	20%	30.7	27.8	19%	32.6	29.2	20%

TABLE 4

COMPARISON BETWEEN THE DEGREE OF EXPERIMENTAL AND SIMULATION TEMPERATURE AND RELATIVE HUMIDITY FOR THE BEDROOM IN THE SUMMER 20/07/2014.

Month	Location	Air flow velocity = 1.5 m/s			Air flow velocity = 2.5 m/s			Air flow velocity = 3.5 m/s		
		Exp. temp.	Sim. temp.	RH	Exp. temp.	Sim. temp.	RH	Exp. temp.	Sim. temp.	RH
June	T inlet	43.9	43.9	17%	43.4	43.4	18%	43.1	43.1	17%
	T outlet	28.6	27.3	23%	28.8	27.7	25%	28.9	27.8	26%
	T courtyard	30.4	29.4	20%	30.9	28.0	19%	31.2	27.9	20%
July	T inlet	45.3	45.3	16%	44.9	44.9	17%	44.2	44.2	16%
	T outlet	28.9	27.5	23%	29.1	28.1	27%	29.9	28.5	27%
	T courtyard	32.1	31.0	19%	32.5	29.5	20%	32.3	28.9	19%
August	T inlet	45.7	45.7	17%	45.9	45.9	17%	45.2	45.2	16%
	T outlet	28.6	27.9	24%	29.5	28.2	24%	29.3	28.1	27%
	T courtyard	30.1	29.8	20%	30.7	27.8	19%	32.6	29.2	20%

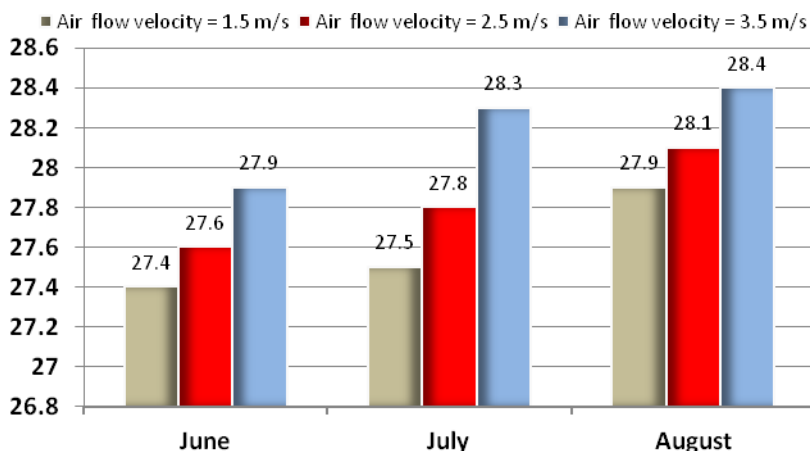


Fig. 5, The air temperature in the indoor (living rooms) air speed of 1.5 m / s for the day 20/07/2014

### 6.2.1 Comparison between results and thermal Comfort limits

In summer, July 20/07/2014, the mean air temperature measured by dry air bulb thermometer inside the guest house hall was 28.3°C. The mean relative humidity was about 22%. The air temperature found for wet bulb thermometer was 17.1 [18].

The rate of air movement inside the hall was around 1.5 m/s. Therefore, the temperature felt by human wearing normal clothes of (1 Clo.), as shown in Fig. 6, would be as 22.2°C, which is within the limits of thermal comfort [19].

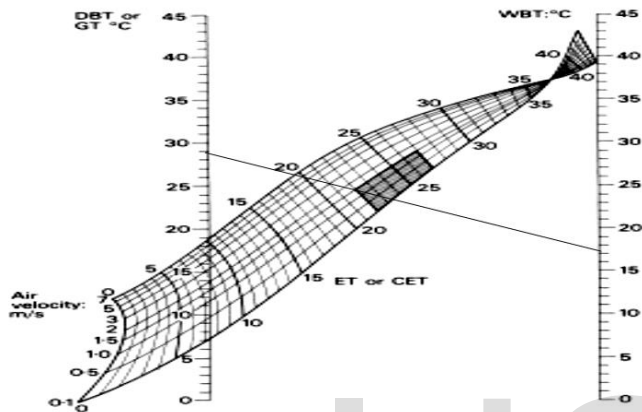


Fig. ,6. Effective temperature nomogram for thermal comfort limits for people wearing normal clothes, represented by relationship between air temperature, humidity and air velocity

## 7 CONCLUSION

Increase Wind-catcher space in the first stage did not achieve an acceptable level of thermal comfort during the day due to solar radiation and high temperature of the air. The second phase, the system wind-catcher of an earth-to-air heat exchanger WEAHE Has contributed to the reduction of air temperature 18°C which is about 37% of the external air temperature. Which is directly proportional to the air flow speed and the length of the track is buried underground, Improvement in the relative humidity, which confirms the use of material pottery pipes because of capillary action. You can control the amount of air in enclosed places, according to the season and increasing the antenna to move in the inactivity of air. Has achieved a coefficient of performance (COP) of WEAHE system in this paper difference 3.43-5.24 with the increase in air speed 1.5 - 3.5 m/s, When the thermal comfort equivalent between effective and the temperature at which it is achieved at the limits of the required comfort when the air speed is 1.5 m / s to reach 22 °C. This makes the new design and a means for self-cooling and a sustainable source of day-lighting and reduces the consumption of energy in the hot dry countries such as Iraq.

## References

- [1] A. Mochida, et al., "Methods for controlling airflow in and around a building under cross ventilation to improve indoor thermal comfort," *Journal of Wind Engineering and Industrial Aerodynamics* 93, pp. 437–449. 2005.
- [2] P.S. Ghaemmaghami, M. Mahmoudi, *Wind tower a natural cooling system in Iranian traditional architecture*, in: *International Conference "Passive and Low Energy Cooling for the Built Environment"*, May, Santorini, Greece, pp. 71–76, 2005.
- [3] Alsahrawardy, Ibtisam and Al-Jawadi, Miqdad, "Healthy Architecture", *Proceedings of the Third Architecture Conference*, pp. 326-347, Department of Architecture, University of Technology, Baghdad, Iraq, November, 2010.
- [4] Su. Yuehong, et al., "Experimental and CFD study of ventilation flow rate of a Monodraught™ wind catcher", *Journal of Energy and Buildings* 40, pp. 1110–1116. 2008.
- [5] Bahadori M, Mazidi M, "Dehghani. Experimental investigation of new designs of wind towers". *Renew Energy*, 33:pp.2273–81. 2008.
- [6] Saffari H, Hosseinnia S. "Two-phase Euler–Lagrange CFD simulation of evaporative cooling in a wind tower". *Energy Build*; 41: pp. 991–1000. 2009.
- [7] Kalantar V. "Numerical simulation of cooling performance of wind tower (Baud-Geer) in hot and arid region", *Renew Energy*; 34: pp. 246–54. 2009.
- [8] Silva CD. *Passive windcatcher evaporative cooling applied to an auditorium*. In: *Proceeding conference: passive and low energy cooling for the built environment, Santorini, Greece*; p. 555–560 May, 2005.
- [9] Abdel-moniem El-Shorbagy, "Design with Nature: Windcatcher as a Paradigm of Natural Ventilation Device in Buildings", *International Journal of Civil & Environmental Engineering IJCEE-IJENS* vol: 10 no.03, pp. 21-26. 2010.
- [10] Mahmud Dehnavi & other, "Study of Wind Catchers with square plan: Influence of physical parameters", *International Journal of Modern Engineering Research IJMER*. Vol:2 no: 01: pp. 559-564. 2012.
- [11] F. Al-Ajmi, D. L. Loveday, and V. I. Hanby, "The cooling potential of earth-air heat exchangers for domestic buildings in a desert climate," *Building and Environment*, vol. 41: no. 3: pp.235–244, 2006.
- [12] A. Sehli, A. Hasni, and M. Tamali, "The potential of earth-air heat exchangers for low energy cooling of buildings in South Algeria," *Energy Procedia*, vol. 18, pp. 496–506, 2012.
- [13] Sodha MS, Buddhi D, Sawhney RL. Optimization of pipe parameters of an underground air pipe cooling system, *Energy Convers Manage*; 34(6):465–70. 1993.
- [14] Bansal V, Misra R, Agrawal GD, Mathur J. Performance analysis of earth–pipe–air heat exchanger for summer cooling. *Energy Build*; 42:645–8. 2010.
- [15] D.Y. Goswami, K.M. Biseli, "Use of Underground Air Pipes for Heating and Cooling Agricultural and Residential Buildings" Fact Sheet EES 78, a series of the Florida Energy Extension Service, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, 1993.
- [16] M. Benhammou, B. Draoui, M. Zerrouki, Y. Marif. "Performance analysis of an earth-to-air heat exchanger assisted by a wind tower for passive cooling of buildings in arid and hot climate", *Energy Conversion and Management*, vol. 91 pp. 1–11. February 2015.
- [17] Sharan, G. and R. Jadhav. Performance of single pass earth-tube heat exchanger: An experimental study, Indian Institute of Management, Ahmedabad, 2004.
- [18] Roland Stull, "Wet-Bulb Temperature from Relative Humidity and Air Temperature," *Journal of Applied Meteorology and Climatology*, volume 50, issue 11, pp.2267-2269, November 2011.
- [19] Ogunsole, O.O. & Prucnal Ogunsole, B, "Comfort Limits for the Effective Temperature Index in the Tropics," *Architectural Science Review*, Vol.45, issue 3, Sydney, Australia, pp.125-132, 2002.