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A NEW DESIGN OF THE MINARET AS A TWO - SIDES WIND CATCHER INTEGRATED WITH THE WING WALL FOR PASSIVE EVAPORATIVE COOLING IN HOT CLIMATES

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Abstract

Recent studies awareness of reducing fossil energy consumption that result searching for Natural energy resources and renewable. One environmental solution is the application of natural ventilation systems. However, there is a reluctance to use them due to low wind speed. This paper aims to provide a new design of the minaret, which employs as a two- sides wind catcher that integrated with the wing wall to improve the performance of natural ventilation and a heat exchange between the earth to air MWETHE. Part of the minaret and a pipe inside the soil and the lining of the minaret provides a water spray system. Air moves due to differing air column pressure. This research used two methods of investigation; the experimental test represents the wind tunnel and the other test, simulate the dynamics of computational fluids (CFD). Two-sided wind catcher models have been tested. It has been observed that the values of the angles of the 15-25 wing wall represent the optimum angles for an increase of cold airflow within the space of up to 2.5 m/s. The verification showed a good convergence between the two tests. The present study shows that the design of the minaret wind catcher within the evaporative cooling system, which is effective in achieving thermal comfort in hot, dry climates. The results have shown that increased airflow speed leads to a reduction in air temperature; the air temperature has dropped to 18 °C and improved humidity of 24% in summer, Increase in temperature 6 °C in winter. It can be inferred that the system reduces the dependence on energy. Finally, it was found that the new design is as close to the indicators ASHRAE 62.1. An efficient system can be improved by expanding the pipe network and enhancing the wind force.

Keywords: Earth-air tube, Environmental design, Heat exchanger, Hot day, Minarets, Passive ventilation, Wind tower.

1. Introduction

Suffer buildings not to approach the limits of thermal comfort offset by an increase in demand for energy consumption. As well as rising prices, while at the same time there is a power supply crisis. Public and residential buildings are represented in approximately 30-40 m of energy consumption, which is responsible for carbon emissions [1]. In general, large-scale efforts focused on the adoption of an environmentally friendly building design approach that reveals the growing interest of researchers in this area, the need to reduce energy use within efficient systems but without compromising a comfortable and healthy internal environment [2]. Use wind catcher in the Middle Eastern countries for centuries and uses of different means of natural ventilation and passive cooling of buildings to reduce the consumption of non-renewable energy and the reduction of harmful emissions in enclosed places [3]. Wind catcher is a building that rises from the roof of the building level contains openings facing the wind driving the wind to the interior spaces of the building because of the column of air pressure differentials [4]. However, this element of architecture has disappeared from the contemporary architectural practice after the emergence of artificial ventilation, due to the lack of adequate knowledge of the basic principles in the work of air intake and because the amount of air provided does not meet the requirements of the thermal comfort of modern man.

With the emergence of evaporative cooling that uses large quantities of water while operating, at the same time a crisis in the water and high prices, or the use of air conditioners that work with the pressure of cooling steam and causing emissions polluting the environment. In both cases, there is an effect of the increase of positive ions in the air that causes depression and drowsiness for users of synthetic devices [5]. In this approach, there are promises that have received great attention through the integration of natural resources, including natural ventilation [6]. Which made us think of the clean power supply depends on the self-cooling.

There have been widespread efforts to use natural ventilation techniques such as wind tower equipment in new buildings to increase fresh air and reduce energy consumption. For example, Bahadori et al. [7] experimental comparison of thermal performance in two-wind catcher designs within the concept of evaporative cooling with the traditional wind catcher. The wetted column, consisting of wet curtains hanging in the shaft of the tower and the other with wetted surfaces, shows that the wind catcher with the wetted column has achieved better thermal performance at high wind speeds while the performance of the tower with wet surfaces is better with low wind speed. Safari and Hosseinnia [8] presented the numerical study of the new designing of the wind catcher was examined under various environmental conditions. Consisting of wet curtains hanging in the tower column with pumping drops of water with low speed. The effect of water droplets was examined. The effect of wind velocity and the rise of wetted columns and their effect on evaporative cooling were studied.

The arithmetic results showed that increasing the diameter of the water drop and temperature drop diameter led to the increased air temperature outside the wetted columns. The 10 m height of wetted columns increases 22% relative humidity and reduces 12 K of indoor air temperature. Montazeri et al. [9] presented the experimental, analytical and numerical modelling to the investigation of two-sided wind catcher performance and pattern of airflow around and across the wind catcher. Investigations showed the results of good analytical and numerical modelling and agreement with experimental results and the potential of the wind catcher from two sides to enhance the naturalist ventilation to the buildings. Based on studies by Dehghani-sanij et al. [10], it is the development of the design of two-sided wind towers.

Based on a study of the new design, wind towers, which were installed over the proposed building, rotated by itself in the direction of wind speed. A solar chimney can be installed to improve system efficiency or a single wind tower in the opposite direction. With the proposed design, transparent materials can be used to enter natural light into the building. Wind towers, which do not need the power to run, are passive systems. Furthermore, Nejat et al. [11] studied the performance evaluation of a two-sided wind catcher, which integrated with the wall and compare with the traditional wind catcher.

Firstly, the assessment showed the impact of the wing wall with different angles on ventilation performance. The second performance compares to this new design with traditional winds. Experimental evaluation and simulate the dynamics of CFD were used. He confirmed that the new design is within the limits of ASHRAE 62.1. Hughes and Ghani [12] conducted a study to assess the potential for wind and ventilation rates in classrooms and compare them with ventilation within British standards. The study confirmed that the ventilation system could provide pure air supply required even at low wind speed. Bansal et al. [13] presented the development of a heat exchanger model of the earth-pipe-air inside the simulation, ‘computational fluid dynamics‘ program within the realization experimental of land and pipes.

Investigations have shown that parameters are effective (air velocity and pipe material) and have an impact on heat exchange systems. The speed of the air through the pipes has highly influenced the performance of the system compared with the pipe material. Hatraf et al. [14] assess the performance of pipes in the design of the heat exchanger from earth to air through modelling and experimental realization of buildings cooling with minimal energy. It turned out that there are many parameters that affect the earth's performance to the air exchange such the depth and quality of the earth and pipe diameter. According to Calautit et al. [15], it is the integrating the wind tower into heat transfer devices. The CFD program, pressure coefficients and simulation of the airflow pattern are used to improve the numerical exemplar of a new wind tower design in order to meet the standards of internal comfort. The proposed system can reduce temperatures to 15 k.

From the review of previous studies, it can be concluded that Al Walid Jassim [16] conducted a pilot test of CFD techniques during the hot period in Baghdad. The results show that an integrated wind trap with EAHE can reduce air temperature and that the proposed design has greatly contributed to improving internal thermal comfort and reducing energy consumption in hot periods in hot dry climates. That there is no study to investigate the possibility of employing a wind catcher minaret that integrates with the wing wall and part of the minaret is under the soil. Therefore, the aim of this research is to close the gap of studies by evaluating the performance of a new design of the minaret wind catcher for heat exchangers from ground to air, heat exchange with the wall of the minaret and the pipe underground. Moreover, the wing wall angle effect is analysed to move air and achieve passive evaporative cooling. Research Methodology This research adopted two methods of numerical investigation using computational fluid dynamics (CFD) and experimental wind tunnel testing.

The aim of this paper is to explore a new design of the minaret that can be used as a two- sides wind catcher integrated with the wing wall and achieve heat exchange Earth -to- Air with minaret walls and underground pipes. The natural air moves from the top of the minaret because of the pressure of the air column to the lining of the minaret and the touch of the minaret lining of the wet-scrubbed brick with the water spray system and then into the pipes under wet soil due to underground water and then to the prayer hall. Take advantage of the air move through the development of wind turbines in the air intake outlet, to generate electricity to pump water. The structure of the research: The first part includes the introduction to the proposed new system and the second section analyses the performance of the heat exchanger and passive evaporative cooling. The new system can reduce power consumption. The system can be used in the design of towers within the new residential complexes.

1.1. Concept of minarets and achieve natural ventilation

The primary function of the design of the minarets is connected to the call to prayer, minarets are the connection between the earth and heaven. A form of minarets has evolved over the history of the square shape and cylindrical and conical and multiple ribs and this depends on two main factors as shown in Fig. 1.

Fig. 1. Different forms of the minaret.

The first factor is the period of construction of the mosque and the other regional worker and the location of the building. Over time, it became an Islamic landmark linked to Islam. The development of acoustics technology leads to the need of a smaller ladder minaret. Hence, it can replace the huge ladder structure of the minaret staircase to a lighter than aluminium material, fixed on the inner walls of the minaret, which can be used for the maintenance of the speakers. The possibility of converting the antenna to air intake without losing its basic function and achieve air movement through them depending on the air pressure difference, taking into account other climatic factors of wind speed and direction and temperatures between the outside and inside. The direction and speed of the wind generate a negative and positive pressure field for air movement. Wind speed in the upper is always greater than that near the ground. The difference in the height of the neighbouring buildings affects the speed of the wind.

1.2. Wind catcher forms and proposed design

It can be classified wind catcher normal and traditional to five general types: as shown in the Fig. 2.

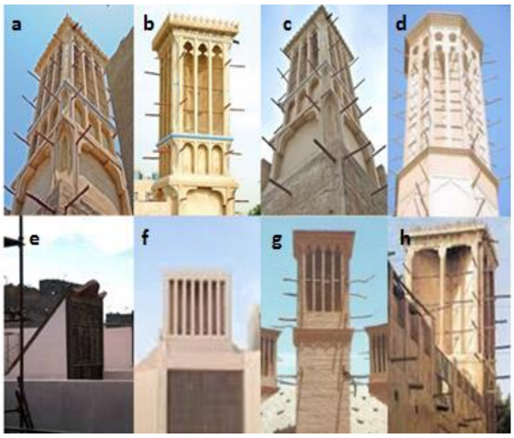


Fig. 2. Different wind catcher openings in traditional architecture: (a)-(c) Four-sided wind catcher with flat roof, (d) Octahedral-sided wind catcher, (e) and (f) One-sided wind catcher, (g) Two-sided wind catcher, (h) One-sided wind catcher [9].

1.2.1. One-sided wind catcher

The air inlets in this type of wind catcher are open only in the direction of the prevailing winds in the area. No openings in other directions.

1.2.2. Two-sided wind catcher

The air inlets in this type of wind catcher are two-way and according to prevailing winds. From an architectural point of view, this type is small and simple compared to a one-sided but has a better and more efficient performance for airflow.

1.2.3. Four-sided wind catcher

The air intake openings are four sides, the structure of the picker is larger and taller than the previous two types.

1.2.4. Multi-sided wind catcher

Air vents enter multiple depends on the design of the structure wind catcher and the climate of the region.

1.2.5. Cylindrical wind catcher

The cylindrical frame structure is the most advanced of the other wind catcher with better performance than the other types of wind catcher, which have already been described. The main objective of this paper is to explore a new design of the Minaret Wind-catcher to create natural ventilation in the mosque and to achieve thermal comfort for people in the hot areas.

2. Climate Characteristics and House Typology

Baghdad is the metropolis of Iraq. Founded in AD762 its original name (City of Peace), the study area is located in Baghdad, located at latitude 44°40'E and Latitude 33°30 N. Rising 34.1 meters over sea level, Baghdad's climate is dry and hot in summer and cold and humid winter. Autumn and spring are short, climate advantage is desert or semi-desert climate, the average daily maximum temperature is 40 °C and the height may reach 50 °C in the middle of the day in July and August. The temperature drop by 17 °C at night or more, Relative Humidity (RH) between 23% in June and 72% in December)[17]. Most winds might carry it with dust. Figure 3 and Table 1 show wind characteristics of the study site. That cold period length is four months and eight months temperate warm.

The houses of Baghdad are characterized by a few relatively small openings in the external interface, with the existence of the internal courtyard. Is a garden and a home activity centre: all the spaces are opened on it, a fountain is put in the middle courtyard, helping to moisten the air and several backyard trees are planted where adding shade and life to this area. These give an image of the type of air conditioning needed in the area. Heating in the winter is not confusing, while the summer cooling is desirable. Therefore, a large demand for electricity, which requires the development of energy alternatives, including improved natural ventilation and utilization of soil and groundwater.

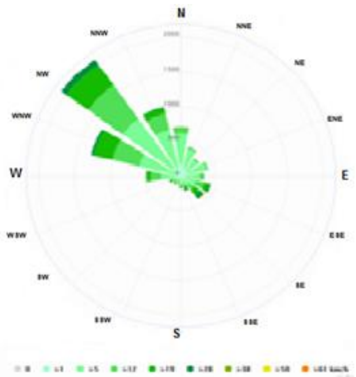


Fig. 3. The wind rose diagram shows the direction of the wind in the Baghdad study area [17].

Table 1. Wind characteristics of the study site (Baghdad) [17].

Monthly and annual rates of wind speed (m/s) in area study													
Baghdad	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual rates**
	2.8	3.2	3.6	3.4	3.6	4.3	4.6	4.1	3.1	2.7	2.5	2.6	3.4

Wind direction (percentage)								
	North	**Northeast**	**East**	**Southeast**	**South**	**Southwest**	**West**	**Northwest**
Jan	7.7	2.6	6.1	14.8	4.9	4.6	13.8	21.0
Jul	9.0	0.9	0.6	0.8	1.0	2.3	28.3	47.1

3. Description Minarets Wind-Catcher System Negative Ventilation

Wind catcher is a one natural air ventilation system in buildings in the hot dry regions. A structure of the hollow rises above the building ends with an opening or several openings to face the prevailing winds in order to enter the air free of dust and cooler to the inside of the building. Designed with different heights to provide wind movement and with high minarets in mosques that symbolize Islamic architecture and with increasing numbers, has made us think of the new design of the minarets to play an additional role as well as its fundamental role of symbolism and aesthetic function. Description of the new design of the minaret:

- The structure of the minaret consists of two parts, one above the ground level at 25.00 m, it has two- sides wind catcher and the other part continue inside the soil at a depth of 4 m. As shown in Fig. 4.
- The base of the minaret is connected to a series of pipes made of polyethylene or clay-treated clay with chemicals to treat microbes that can grow on the surface of the pipes, high density, high pressure and resistance to soil factors to ensure heat exchange, pipe lengths, the first group 75 m and the second 99 m, pipe end with holes inside the prayer hall.
- Air entrances to the prayer hall are four regularly distributed and at a height of 2 m from the floor level of the hall, equipped with fans to increase the movement of air inside the hall, with the possibility of controlling the opening and creation of air outlets.
- The minaret lining is made of brick pierced yellow, brick colour material with high poetic properties (pottery at a temperature of 800-1150 °C) in which, the poetic property is integrated. It is noted that it is not recommended to use the mud-brick, reddish and low porosity, in which, should the water entered, it causes the fragmentation of the brick in the future. Brick starts from the base of the minaret and continues above the level of the ground at a height of 4.5 m to be a total lining height 8.5 m.
- Preparation of a sprinkler system with perforated pipes (for the purpose of moisturizing). Prove on the upper wall of perforated bricks, composed of armed plastic pipe diameter 50 mm containing holes diameter of 4 mm per 10 cm connected water tank system provider to control the amount of water comes down.
- The windows at the base of the dome are connected to a system that controls its work, helping to get out the warm air accumulated on the roof of the Prayer Hall and increase air movement.
- The placement of a fan in the minaret cavity at the ground level contributes to moving the air in times of quiet wind.
- An aluminium ladder is installed on the interior walls of the minaret for maintenance purposes. Place the water plunger at the base of the minaret to draw water back into the water tank.

The study adopted homogeneity of soil properties, high and low soil temperature of 10-18 °C depending on the depth and type of soil. Soil depth 3.5-4.0 m is homogeneous at a temperature as shown in Fig. 5 [18], a differing column of air pressure between the outside and inside and the speed of external wind has to do with the speed of wind-generated inside the minaret. The air inside the cavity of the minaret is larger than the amount realized from the traditional wind catcher, which are a sectional area of up to 0.25 m^2 amounts. The minaret will be the largest area. The air inside has a cleaner purity than the upper layers and with an air purifier filter. Moisture the lining of the minaret by water spray, the tubes inside the soil moistened by groundwater, evaporative cooling occurs, cold air moves into the prayer hall and air flow are increased with the help of air fans. These combined air-cooled air to equal air humidity in dry hot areas. The minaret cavity and its height and its potential development, provide a new design for wind catcher, to achieve negative natural ventilation and increase heat exchange between wet walls and wet underground pipes.

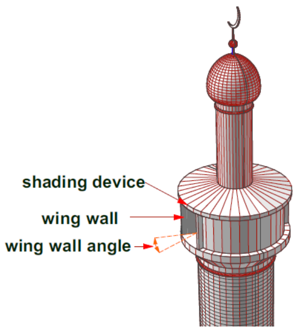


Fig. 4. Model of the minaret as a two-side wind catcher including minaret structure, wing wall and wing wall angle.

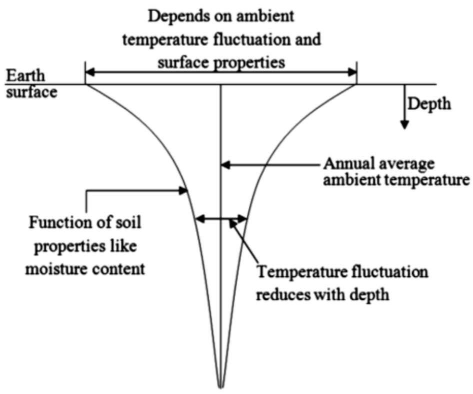


Fig. 5. Earth temperature varies with depth [18].

4. Research Methodology

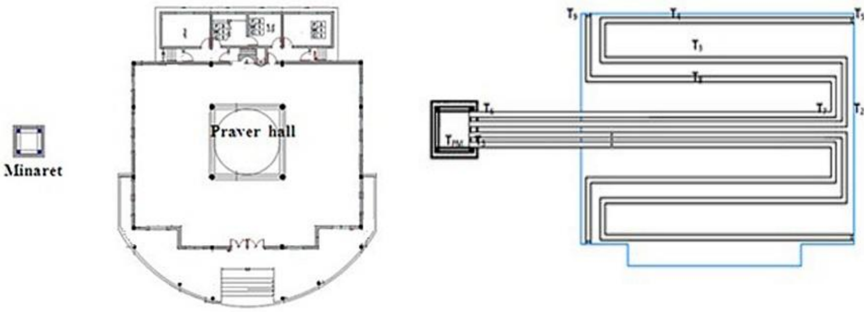
This research adopted two methods of investigation: Numerically using Computational Fluid Dynamics (CFD) and Experimental wind tunnel testing. Precedent studies have shown that these methods in assessing the performance of wind ventilation have produced reliable results [18]. The wind tunnel test has been selected because it is a controllable environment to study various wind speeds and low cost. However, it is necessary to achieve a similar geometric model [19]. The model was reduced by 1:10 made of glass. The Minaret is a wind catcher of a two-sided integrated wall with wings. The wind input consists of two channels separated by a wall; airspeed data logger OMEGA®HHF-SD1 accuracy of 0.01 m/s accuracy and accuracy 5% of reading. The mathematical investigation in this study is the "Computational Fluid Dynamic"' (CFD). Franke et al. [20] presented the arithmetic field size and location of the model for the principle of cost action 732, simulation of CFD, which consists of three stages and the study of the effect of a different angle wing wall.

4.1. CFD application

The dynamics of computational fluid (CFD), has achieved in recent years a better understanding of airflow simulation and more accurate results Through 3D models, many researchers applied and studied different CFD models, including Franke et al. [21] and Li [22], who introduced a new experimental model for airflow calculation, widely investigated in vertical noises, but little is known about flow in horizontal apertures, air flow rates and air flow pattern are predicted and compared to full scale. Guohui [23] introduced the arithmetic domain, which is used in simulating natural buoyancy. Ventilation in a vertical tunnel has a larger physical volume than multi-story ventilation objects will give a more accurate ventilation rate inside the tunnel. Another study by D'Agostino and Congedo [24] is to investigate the adequacy of natural ventilation in the historic building. The goal was to find an approach that could be able to do so in providing a suitable local climate in maintaining the building.

4.2. Description of the building

The study model represents the building of a mosque in the city of Baghdad has a prayer hall with internal measurements length 25.70 m and width 20.10 m and a height of 5.60 m, with an area of 516.57 m^2. The outer walls are built of bricks of 24 cm, enveloped from the outside with the Sino stone and the interior finish of the walls with plaster. The windows are made of aluminium with double glass, the roof of reinforced concrete, in the middle contains a dome with a base on the side windows. The minaret is 10 m from the prayer hall. Its base is 9 m^2 and its height is 25 m. Part of the minaret is in the soil at a depth of 4 m. The minaret contains a vertical ladder of aluminium. The air intakes at the top of the minaret are 21.00 meters high as shown in Figs. 6 and 7.



(a) Underground floor plan. **Ground Floor plan.**

Fig. 6. A study model diagram mosque containing minaret with group of pipes under soil.

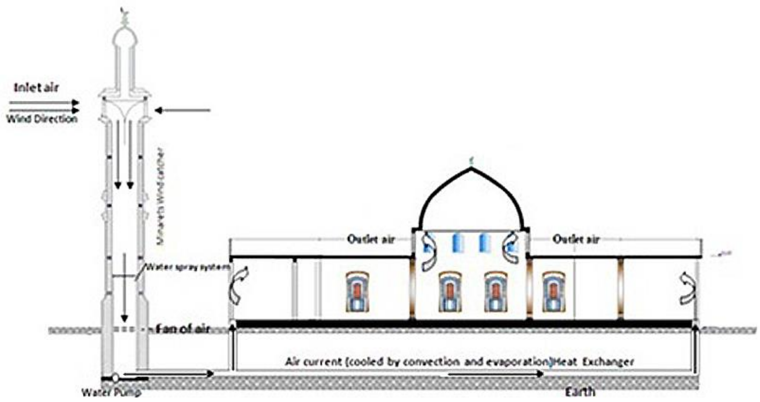


Fig. 7. The model of the study contains a minaret of a mosque in the city of Baghdad.

4.3. Description of evaporative cooling system

A heat exchanger was made in the form of two stages, the first stage of the minaret built through the lining of the pierced yellow brick 12 cm thick and equipped with a water spray system. Part of the lining below the ground level and the part above the level of the ground with a total height of 8.5 m. The second phase of the pipes of the pottery pipe diameter of 50 cm and the thickness of 3 cm, which is moist because of the groundwater in the soil. At the same time, the temperature is low, as shown in Table 2, which is placed at a depth of 4 m under the surface of the soil horizontally. The inclination angle in the direction of the base of the minaret is to prevent condensation of water in the pipes. The air exit in the prayer hall at 1.8 m above the floor of the hall is equipped with an air fan.

The minaret is provided on the ground floor of the mosque with a fan protected by a metal cap that can be operated when the wind is low speed. The presence of a water diver at the base of the minaret to draw the collected water and return it to the water tank on the roof of the mosque, which provides the water “spraying system”. The air enters from the top outlet because the movement of air outside the top of the wind catcher and with the openings in the dome on the roof of the mosque creates pressure teams that help to pull air from the outside through the wind catcher and thus, ensures a constant renewal of the air of the building. The airspeed within the minaret depends on the speed of the external wind and the height of the air pressure column. The air moves in the lining of the minaret and pipes, leading to air-cooled humidity. Consequently, the cool air moves into the prayer room, removing hot air in the ceiling of the hall. The air movement helps to move the air turbine to power the batteries running on the plunger as shown in Fig. 7.

Table 2. Physical and thermal parameters used in simulation.

Material	Density (kg/m^3)	Thermal conductivity (W/m K)	Specific heat capacity (J/kg K)
Soil	2050	0.52	1840
Air	1.225	0.0242	1006
PVC	1380	1.16	900
Pottery therapist	1600	0.405	1436

4.4. Data collection

To verify the performance of the minaret design with a two-sided wind catcher and the effect of natural air movement within the evaporative cooling system and heat exchanger, the system was run in 2016. The performance of the system was tested during June, July, August of 2016, in January, February, March and winter in 2016, among the climatic variables of the city of Baghdad, which is classified within the province of hot and dry. It operates two hours per day as shown in Tables 3 and 5. The readings were conducted at 3 p.m. and 3 a.m. Recorded data included air temperature in the air intake outlet and temperature in the prayer room, relative humidity and airspeed. Data was recorded by OMEGA®HHF-SD1. Ashrae Handbook Committee [25] developed a formula, which is adopted in calculating the Coefficient of Performance (COP) and the calculation of airflow and cooling temperature for hours and input power with several equations:

$$Q_{out} = \dot{m} c_p (T_o - T_i) \tag{1}$$

$$COP = Q_{out} / W_{in} \tag{2}$$

$$\dot{m} = V / v \tag{3}$$

$$ACR = 3600Q / v \tag{4}$$

where $\dot{m} = \rho \times vel \times \pi d^2 / 4$ and $V = vel \times \pi d^2 / 4 \times 10^{-4}$ [4], ρ is the air density.

5. Results and Discussion

5.1. Soil Temperature System

Soil temperature changes with time and soil depth. The homogeneity of physical soil properties and the level and quantity of groundwater in that area, the annual fluctuation in temperature are affected daily, mainly, by changes in solar radiation and air temperature. The annual variation in average soil temperature with different soil depths, depending on soil surface temperature and average water level in each layer. The bare soil differs from the shaded soil in which, the soil content and the thermal capacity of the soil, soil temperature is necessary for many construction projects because of the soil energy storage. With the increasing need for energy conservation, the soil at a depth of 3.5-4.0 m has a stable system ranging from 23.0 °C to 25.5 °C during the testing period. This depth can be used as a source of cooling in the summer season.

5.2. Experimental readings from the minarets of wind-catcher

Table 3 shows the temperature in the prayer hall and outdoor temperatures during the test period in the summer of 2016 for June, July, August and 2016 winter for months of January to March and three days of each month 3rd to 5th day and at 3 am and 3 pm respectively. A reading rate was taken for the test hour, including air temperature of the air outlet and temperature in the prayer room. The results indicate that indoor temperature fluctuations between morning and evening readings occur within three days of each month and during the months as well. The difference between internal and external temperatures was 16.9 °C in summer during the month of August and 6.4 °C in the winter during February.

Table 3. Experimental temperature during month of winter and summer 2016.

Month		Average daily air temperature for day 3		Average daily air temperature for day 4		Average daily air temperature for day 5	
		Outside temperature	Inside temperature	Outside temperature	Inside temperature	Outside temperature	Outside temperature
January	3 am	10.6	17.1	10.8	17.3	10.3	17.0
	3 pm	5.8	12.1	5.9	11.9	5.6	12.6
February	3 am	10.9	17.3	10.2	17.8	10.8	17.3
	3 pm	7.4	12.9	7.7	12.9	7.7	12.1
March	3 am	12.9	19.0	13.2	20.9	13.3	20.8
	3 pm	9.8	14.3	10.5	16.7	10.9	16.9
June	3 am	45.4	28.4	46.1	27.9	45.7	28.9
	3 pm	30.0	20.3	31.0	20.9	29.9	19.7
July	3 am	47.2	29.2	47.6	29.6	47.3	29.1
	3 pm	31.6	20.6	31.1	20.3	30.9	20.7
August	3 am	46.2	28.8	46.3	29.1	46.7	28.9
	3 pm	38.1	20.1	30.4	20.5	30.3	20.1

5.3. Readings of simulation and experimental heat exchange

Table 4 shows the average internal temperature of the prayer hall and external outdoor temperatures during the third day of the test months for the hot and cold period 2016. At three in the morning and three in the afternoon respectively, the hourly reading rate was taken. The temperature included the air intake outlet, the area at the minaret base and the air exit outlet inside the hall. The results indicated that there were clear differences between the internal and external degrees, decreased in June by 17.3 °C when the external temperature 45.4 and the internal temperature at 48.1 and in July, from 47.2 to 28.5. The internal temperature during the cold season in January was 6.2°C when the external temperature was 10.6 and the internal temperature was 16.5. When testing the different angles of the wing wall to the air intake outlet in Fig. 8, it shows the results of CFD in the performance of air movement with different wing wall angles (5° - 70°) to increase the flow of air inside Minarets Wind-catcher. When the 5° angle was recorded by 2.651 m/s and gradually increasing access to the value of 2.691 m/s in 30° and then show that if the increase in the angle reaches a minimum value of 2.564 m/s, which is 4.7% lower when the angle 30°, angles represent the optimal values of 10-30 angles to achieve higher air flow inside wind-catcher and this increases the flow of cold air inside the space.

Table 3 shows the average of computer simulation and experimental readings of open temperatures and temperatures at the base of the minaret (wet). Built of penetrating bricks and temperatures when air enters the prayer hall within the different airspeed 1.5-3.0-5.0 m/s during the testing period. There is a clear difference in temperature when the airspeeds of 1.5 m/s during the month of June up to 17.4 °C and to 17.6 °C in July and up to 18 °C in August. When the airspeed reaches 5 m/s, there is a temperature difference is 17.1 °C. Figure 9 shows temperature distribution of points in the air motion path at 1.5 m/s during wind catcher and pipe and outlet air. This means that the increase in air velocity does not mean that there are significant differences in air temperature dissipation in summer and can make a difference in temperature in the movement of medium air and near the limits of thermal comfort within the space. There is also convergence in the limits of thermal comfort in the winter and can be deduced that the system is able to provide the requirements of thermal comfort limits in a warm period without the need for artificial assistance, either the cold period, which is relatively low in Baghdad, we need a little artificial aid. This system is possible, therefore, be applied easily in the tropics.

Table 4. Simulation and experimental temperature and relative humidity in the winter and summer for day 3 in 2016.

(a) Air flow velocity 1.5 m/s.

	Month	Location	Experimental temperature	Simulated temperature	Relative humidity
Winter	January	T outside	10.6	10.6	65%
		T bm	15.6	13.6	67%
		T pl	15.8	14.8	69%
		T inside	15.8	14.8	69%
	February	T outside	10.9	10.9	66%
		T bm	14.9	14.2	69%
		T pl	15.8	15.9	70%
		T inside	17.3	16.9	71%
	March	T outside	13.9	13.9	66%
		T bm	17.4	16.2	67%
		T pl	15.8	17.6	68%
		T inside	20.0	19.6	69%
Summer	June	T outside	45.4	45.4	20%
		T bm	35.7	34.9	27%
		T pl	32.6	31.5	29%
		T inside	28.4	28.1	34%

	July	T outside	47.2	47.2	19%
		T bm	33.1	35.2	26%
		T pl	31.2	31.3	29%
		T inside	29.2	28.5	33%
	August	T outside	46.2	46.2	20%
		T bm	35.9	35.1	26%
		T pl	32.0	31.2	28%
		T inside	28.8	28.2	33%

(b) Air flow velocity 3 m/s

	Month	**Location**	**Experimental temperature**	**Simulated temperature**	**Relative humidity**
Winter	January	T outside	10.6	10.6	65%
		T bm	15.1	14.0	67%
		T pl	16.3	15.1	68%
		T inside	16.3	15.1	69%
	February	T outside	10.9	10.9	66%
		T bm	15.2	14.7	68%
		T pl	15.7	15.0	69%
		T inside	17.1	16.8	70%
	March	T outside	13.9	13.9	65%
		T bm	17.9	17.6	67%
		T pl	18.4	18.1	69%
		T inside	20.1	19.0	71%
Summer	June	T outside	45.4	45.4	20%
		T bm	35.1	34.6	27%
		T pl	32.4	31.1	30%
		T inside	28.6	28.2	33%
	July	T outside	47.2	47.2	19%
		T bm	32.1	32.6	26%
		T pl	30.9	30.1	29%
		T inside	29.3	28.8	32%
	August	T outside	46.2	46.2	20%
		T bm	35.2	34.6	27%
		T pl	33.1	32.5	29%
		T inside	29.4	29.4	31%

(c) Air flow velocity 5 m/s

	Month	**Location**	**Experimental temperature**	**Simulated temperature**	**Relative humidity**
Winter	January	T outside	10.6	10.6	65%
		T bm	15.2	14.4	68%
		T pl	16.3	15.2	69%
		T inside	17.4	16.8	70%
	February	T outside	10.9	10.9	69%
		T bm	15.6	15.2	70%
		T pl	16.8	15.8	70%
		T inside	17.7	17.2	71%
	March	T outside	13.9	13.9	67%
		T bm	17.4	16.1	68%
		T pl	18.6	17.8	69%
		T inside	20.4	19.7	70%
Summer	June	T outside	45.4	45.4	20%
		T bm	35.6	34.0	26%
		T pl	32.3	32.0	30%
		T inside	28.1	27.7	33%
	July	T outside	47.2	47.2	19%
		T bm	32.6	31.9	25%
		T pl	31.2	30.3	30%
		T inside	29.2	29.0	33%
	August	T outside	46.2	46.2	20%
		T bm	34.6	30.1	27%
		T pl	32.5	31.1	30%
		T inside	29.4%	28.7	31%

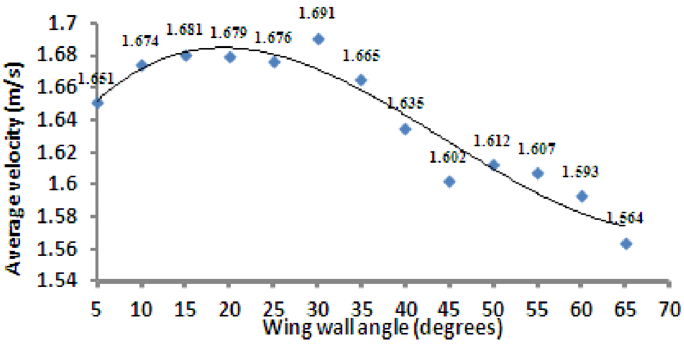
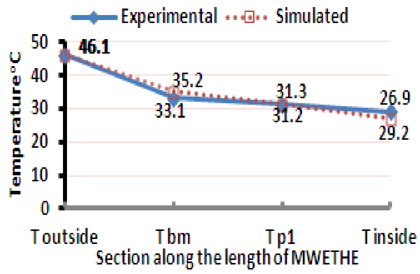
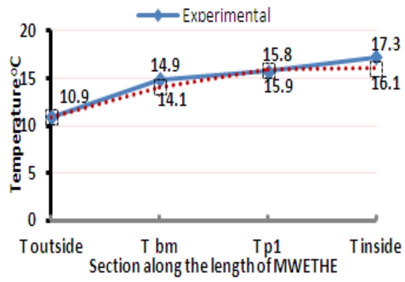


Fig. 8. Different air velocity with a wing wall angle for wind catcher.



(a) Temperature during Summer 2016.



(b) Temperature during Winter 2016.

Fig. 9. Distribution of temperature in the path of air movement during the minaret and pipes at wind speed 1.5 m/s during the summer and winter 2016.

5.4. Effect of variation in pipe length

The presence of four outlets to exit the air into the prayer space represent two paths of pipes similar to a depth of 4 m. The first group T1- T5 and the second T9- T6. The difference in pipe length with the velocity parameters of airflow affect the measurement of air temperatures inside the tube at those points as shown in Table 5. It shows that a drop in air temperature along the path of the pipe varies from the inlet through the base of the minaret and then into the pipes. The air temperature at the air outlet was 45.4 at airspeed 3.0 m/s and 5.0 m/s. Low in the air temperature at the base of the minaret up 10.3 was observed rapidly, wind at 3.0 m/s in the experimental data. At T4, the air temperature is 29.8 and T8 is 28.9 at 3.0 m/s. There was a difference in the air exit outlets, the first port recorded 28.6 and the second port 27.2 within the speed of 3.0 m/s and recorded air temperature of 28.1 at airspeed 5.0 m/s, when validating experimental data with simulation, as shown in Table 5, found a percentage line up to 4.9%.

Table 5. Compare the experimental temperature and the simulator with the variation along of MWETHE pipe for different speeds.

Section	Air velocity 3.0 m/s			Air velocity 5.0 m/s		
	Experimental temperature	Simulated temperature	% difference	Experimental temperature	Simulated temperature	% difference
***T* outside**	45.4	45.4	0.0	45.4	45.4	0.0
***T* bm**	35.1	34.6	1.4	35.0	34.0	2.9
T_1	32.4	31.1	4.3	32..3	31.8	1.5
T_2	31.6	30.4	3.8	31.5	31.1	1.3
T_3	30.9	29.3	5.1	30.5	29.0	4.9
T_4	29.8	29.1	2.3	29.4	28.8	2.0
T_5 **inside**	28.6	28.2	1.5	28.1	27.7	1.4
T_6	32.1	31.3	2.5	31.9	31.1	2.5
T_7	31.3	30.2	3.5	29.8	28.6	4.0
T_8	28.9	28.3	2.1	28.2	27.1	3.9
T_9 **inside**	27.2	26.8	1.5	26.3	25.6	2.7

5.5. Arbitrage between the results and thermal comfort limits requirements

In the summer, July 03/07/2016, the average air temperature inside the chapel hall measured by thermometer dry air bulb at 29.2. The average relative humidity up to 20%. The wet scale thermometer for the bulb was found at 17.9 [26]. When the speed of the air inside the prayer space up to 1.5 m/ s. This means when you wear regular clothes (1 Clo.) The temperature felt by a human, as shown in Fig. 10 will be about 22.2 degrees celsius, which is within the limits of thermal comfort [27].

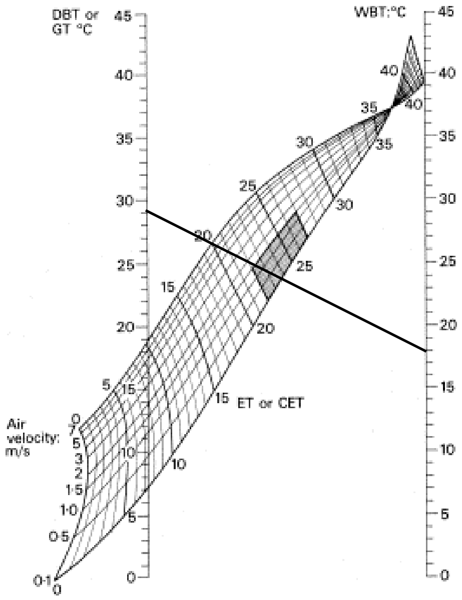


Fig. 10. Scheme of the limits of thermal comfort and effective (1 Clo.), represented by the relationship between air speed, air temperature and relative humidity.

6. Conclusions

Wind catcher is one of the traditional architectural vocabulary, has a long history, but there is a reluctance to use it at present because of the speed of low winds. This study suggested the employ the minaret wind catcher increase the area of its section Increase in air pressure column to improve wind speed performance. And evaluating the integration of a two-side wind catcher with the wing wall. This study proposed the design of the new minaret if part of it is submerged below the ground level at a depth of 4m. The soil temperature at 4 m depth is low and constant at 18°C, with a set of pipes buried in the same depth to maintain the survival of the walls of the minaret and pipes moist because of groundwater. The air-to-earth heat exchanger system with a wet minaret lining with the water spray system and wet buried pipes achieves the concept of passive evaporative cooling with an increase in relative humidity. There is a positive relationship between the velocity of the air flow and the length of the pipe path and the inverse relationship between air velocity and relative humidity.

The use of an experimental test of wind tunnel and simulation of Computational Fluid Dynamics (CFD). Based on the speed air of 1.5-5 m/s, a comparative comparison was observed between wind tunnel results and a simulation of computational fluid dynamics. The angles of the wing wall were examined at angles of 5-70 with the wind to investigate the performance of wind movement of the two-side wind catcher in the low-wind tunnel. The values of the angles 15-25 represented the optimal angles in increasing the air flow and the best operation at the 25 angles up to 2.5 m/s. The air temperature decreased to 18 °C from July in summer, when it was outside at 27.2 and inside at 29.2 and improved the relative humidity change was 24%. The temperature increased to 6.5 °C from January winter, it was at 15.6 outside and indoor at 23.6. The presence of aid in the exchange system is represented by airflow contributes to increasing the movement of air during the period of silence of the wind. The presence of the air turbine contributes to the generation of electric energy to charge the batteries and the continued work of water. In the equation of thermal comfort between efficiency and temperature, the limits of comfort are met when the airspeed is 1.5 m/s and reaches 22 °C. The efficient system can be improved by expanding the pipe network and enhancing the wind force. Finally, it can be said that the proposed new design is close to indicators ASHRAE 62.1.

Nomenclatures

ACR	Air change rate
COP	Coefficient of performance
c_p	Specific heat capacity at constant pressure, kJ/kg °C
$\dot{m}$	Mass flow rate, kg/s
Q_{out}	Heat added by the air, W
T_i	Inlet temperature, °C
T_o	Outlet temperature, °C
V	Volumetric flow rate, m^3/s
vel	Air velocity, m/s
v	Air specific volume, m^3/kg
W_{in}	Energy input, W

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