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Enhancing Natural Ventilation in Buildings: The Integrative Role of Wind Catchers and Atriums, Insights from Ancient Mesopotamian Architectural Elements

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Abstract. Atriums and wind catchers are architectural design elements that have been used to improve airflow inside buildings since first civilization in Mesopotamia. Previous studies have shown the various effects of wind catchers on increasing natural ventilation in buildings in different climates. This research problem is to discover the integration role of wind catchers and atriums in enhancing natural ventilation for buildings in a hot, dry climate. A school building design in Baghdad city was chosen as a case study. A proposed wind catcher were added to the building design in addition to the exist atrium and comparison were made to various effects on natural ventilation. The results demonstrated that the integrated of the wind catchers and atrium is an efficient ventilation system that contributes to the increased airflow average speed to 2.41 m/s, The achieved air velocity can generate thermal comfort with constant climatic conditions and temperature increases up to 31.5 degrees Celsius, according to CBE Thermal Comfort Tool for ASHRAE-55 for thermal comfort building.

1. Introduction

Here Wind catchers are towers connected to buildings used for cooling and natural ventilation and are commonly found in residential buildings, mosques, hospitals, and so on. It's one of the architectural elements that have been used in ancient civilizations. First, it appeared in ancient Babylonian architecture to enhance natural ventilation and later developed in different regions of the world. In the Baghdad Abbasid era, all hospitals were equipped with wind catchers; in addition, most residential were with wind catchers above them to draw cold air into the building and reach through them to the interior rooms. The air movement that passes at the top of the wind catcher creates a pressure difference that helps draw cold air from the outside to replace the hot air in the internal spaces. The types of wind catchers vary according to their shapes, functions and way of dealing with the surrounding climatic conditions, including mono and multi-directional slingshots [1]. Wind catchers rely in their work on a combination of wind and convection effects. They are constructed on the roof of the building and directed towards the prevailing wind where the catcher pulls air from the outside and introduces it into the space. When the wind is exposed to the head of the wind catcher, it creates a high-pressure zone (positive) on the wind-facing side and a low-pressure (negative) zone on the other side of the head of the wind catcher.

The air flows from the high-pressure zone to the low-pressure zone, resulting in fresh air entering through the wind front side and the old hot air inside exits towards the negative pressure zone on the wind-facing side. This phenomenon is called the wind effect, the predominant effect in natural ventilation. The action of wind catcher is also dependent on the effect of convection and is a secondary mechanism that helps in natural ventilation [2]. This mechanism depends on the difference between the density of fresh outdoor air and hot indoor air due to temperature differences. The colder, denser air sinks while the warmer, less dense air rises and exits through the holes in the wind catcher, the side vents, or the atrium. In general the previous studies have examined the formal and functional characteristics of the wind catcher itself and the comparison between the different effects of these characteristics using CFD programs.

Jomehzadeh et al. [3] studied the geometric properties of wind catchers and their impact on natural ventilation and air speed inside the buildings in terms of the design of the cross-section of the wind catcher and openings in addition to the height and roofing of the scaffolding. It also looked at the impact of neighboring buildings and vegetation in influencing the efficiency of the natural ventilation of wind catchers and focused on indoor air quality from a health point of view. The study pointed to the role of ventilation systems and photovoltaic technologies in promoting ventilation inside buildings. Elmualim & Awbi [4] showed the importance of the wind catcher in the formation of air flow inside buildings, and used computer simulation using computational fluid applications (CFD) and applied to selected samples and compared with practical experiments using (wind tunnel) by making a miniature model and applying the experiment to it and calculating the volumetric flow rate of wind speeds and then comparing it with (CFD) and reached the importance of the speed and direction of the external wind in enhancing the ventilation rate in addition to the ideal angle of air flow, which amounted to (45º).

El-Shorbagy [5] also studied the characteristics of natural ventilation in traditional architecture in Central Asia and the Middle East through the microclimate and its impact on people's culture and environmental needs, which produced a range of design treatments. He also focused on the importance of reviving traditional elements in the face of successive energy problem in the world. The study focused for combining traditional approaches with advanced modern technology and considering them an essential formal and functional part of developing twenty-first-century architecture. While the study of Ghadiri [6] dealt with rectangular and open wind catches from two sides by analyzing the airflow inside them and measuring the speed of those flows and their impact on the ventilation of the building using CFD programs. In addition to making a miniature model of the wind catchers, analyzing the speed of air flows inside it using wind tunnels and comparing the results with CFD. The results obtained from the CFD programs were very accurate. They were identical to the results of the air tunnel applied to the wind catcher of a building with a simple design, taking into account the insulation of the inner surface of the air input and the neglect of the engineering of the building and the size of the internal and external ventilation holes.

A study by Al-Jawadi,et.al [7] used brand-new, enormous windcatcher with a cross sectional area of more than two square meters in Iraqi house designs that were suited to the country's hot temperature. These wind-catchers have demonstrated their effectiveness in allowing for natural ventilation and reducing interior temperatures on spring, fall, and summer evenings. Thus, the notion for this study arose to improve performance in the summer by hydrating the wind catcher walls. To achieve this, a practical investigation was conducted by constructing a windcatcher walled with bricks that were burned between 1150- 750 C, a temperature at which the water content became moderate due to capillary action integration. Measurements reveal that on days when the temperature is 43°C, the moistened wind catcher lowers the air temperature of space connected to the wind catcher to about 12 ° C. This research aims to demonstrate the role of the wind catcher and atrium to increase the airflow in building. The importance of research is submitting a design proposal achieving thermal comfort in buildings by adopting the complementary role of the wind catcher and atrium.

2. Background of wind catchers

Many ancient archaeological sites containing indicating wind catchers' presence in the designs of temples and residential houses. Historians differ in determining the historical time period in which the concept of the wind catchers brought in the region in general. But there is an evidenced that wind catcher appeared firstly in Mesopotamia, Iraq in particular, through the analysis of some studies of the historical buildings of the Babylonian civilization, the summer palace of King Nebuchadnezzar in the historical city of Babylon, and through the process of research and examination of the details of the palace Its ruins, which contain large halls overlooking two large courtyards (south courtyard, north courtyard) show the presence of 4 square foundations with a narrow and deep section and located in the corners of the courtyard. The openings of the walls were towards the north, which is the direction of the prevailing winds in Babylon [8]. As for the ancient Egypt, one of the historical drawings found in the tomb of Amun, shows the presence of the wind catchers integrated with the staircase. Little information has been obtained regarding the use of wind catchers in different countries around the world. [9]. Wind catchers have been used since ancient times in different cities worldwide.

Each of these cities has been characterized by a special design for a wind catcher that differs from other cities in proportion to that region's environmental and geographical characteristics.

2.1 Air Catchers in Iraqi Traditional Architecture

The wind catchers in Iraq are generally characterized by being one-way and contain only one opening at the top for the entry of air, whether the wind catcher is directly connected with the inner courtyard or with the internal spaces, and is often rectangular in shape with dimensions (0.2 * 0.5 m) and a height of (1 m) and the head of the wind catcher also contains inclined curves at an angle (45º) that help to enter the air smoothly into the ventilator of the wind catcher where the air inside is cooled by placing a dangling water tractor inside Homemade building materials such as bricks, which have a capillary property and many pores that help retain water and moisturize the air[11], the traditional architecture feeders are based in their work on three basic principles:

1. The driving force of the wind pushes the air inside the wind catcher.
2. The transfer of air from the cold lower space to the warm courtyard creates a negative pressure zone inside the space that draws air into the envelope.
3. Saturation of the walls of the wind catcher with moisture helps reduce the temperature of the downward air by the occurrence of the evaporation process.

2.2 Wind catchers in Egypt

The climate of Egypt is characterized hot and dry desert climate where Egyptian engineers relied on the wind catcher for natural ventilation [10]. Wind catchers is connected with the upper floor of the house where the summer residence of the inhabitants is located, and the wind catcher was placed above the roof of the northern iwan, which together with the southern iwan forms one space called (the hall), which is the main reception room for guests where the wind catcher allows air coming from the north to enter the hall due to the high atmospheric pressure caused by the wind at the entrance to the wind catcher and moves the air slowly towards the hall and then rises to its upper part to come out through the mashrabiya on the last floor [11]. The wind catcher sometimes communicates directly with the spaces on the house's ground floor, it dating back to the nineteenth century which were ventilated in this way. The wind catchers consists of a simple column that rises above the roof of the building up to (3 m) and is equipped with its opening that is directed towards the prevailing north-west winds, while the upper part of wind catcher is covered with a 30-degree inclined roof to direct air inwards [10].

2.2.1 Wind catchers in Arabian Gulf

The Arabian Gulf region is characterized by a dry and hot desert climate in addition to the high relative humidity on most days of the year, especially in the UAE, Bahrain, Qatar, Kuwait and to the some extent in Saudi Arabia and Oman. Wind catchers in these areas are characterized by being based on the structural characteristics of the wind catcher itself, where it uses heat-insulating building materials in the walls of the indoor and outdoor wind catcher to help cool the air inside and maintain moisture. The wind catcher's cross-section is square in shape, has dimensions (2.5 * 2.5 m), and is built on the roofs of buildings with a height between (3 - 5 m). It connects with one or more internal spaces of internal space and this depends on the type of wind catcher itself and some houses contain one or more wind catchers depending on the area of the house and the material possibilities of its owners [7].

2.2.2 Wind Catchers in Iran

A wind catcher is called "Badkir" in Iran, which means in Persian (wind trap). Wind catchers in Iran are characterized by their internal divisions, which divide the air vent into more than one section to distribute air from within the spaces. They often contain an entry duct and an exit stream, and the air catcher is toward the prevailing wind. While the air out in the opposite direction [11] The places of the wind catcher vary within the same building, where they are sometimes connected with the ground floor and with one space, and other times the wind catcher is associated with the inner courtyard. The cross-section of the wind catcher varies, whether square, rectangle, pistol or octagonal, and the height varies from city to city, where it varies between (3 – 5) meters from the roof of the building. Wind catcher dimensions have ranged in width between (0.5 – 0.7 m), and the length of it was between (0.8 – 1.1 m) [7].

3. Methodology

All Schools in Iraq generally lack the simplest means of cooling and air conditioning, making natural ventilation the optimal solution to get thermal comfort for this type of building. There are relationship between air speed and thermal comfort, the mean skin temperatures decreased by 0.2 °C–0.6 °C for every 1 m/s increase in air speed [12] thus through the fallowing.

1. Heat exchange: Faster-moving air increases the rate of heat exchange between the body and the environment. This can make a person feel cooler because the body loses heat more quickly
2. Perception of Temperature: Even at the same temperature, increased air speed can make the environment feel cooler. This is why fans are effective in hot weather—they don’t lower the temperature but increase air movement, enhancing comfort.
3. Humidity and Sweat Evaporation: Higher air speeds can also help evaporate sweat more efficiently, which is crucial for maintaining thermal comfort in humid conditions.

The study was carried out in public school buildings in Iraq, especially those containing an atrium in their interior design. Then make, some design modifications, which are represented by the addition of several wind catchers, which work as a natural ventilation system integrated with the atrium of the building. The internal air speed was calculated using the experimental method employing computational fluid dynamics (CFD) programs to predict the airflow speed inside the building.

3.1 Case Study Description

The model (No. 6) was selected for a secondary school classified within the National Project for Schools in Iraq as a case study. It is considered one of the most important pioneering projects in the development of the educational reality in Iraq, where this part of the practical study aims to investigate the impact of the addition of a wind catcher to the internal spaces surrounding the atrium and analyze the speed of air design adjustments to a truncated part of the architectural plan of the building. The study was carried out by adopting the climatic data for the day of the spring solstice, 21/3/2021. A computer simulation of the proposed model consists of two floors that include 18 classrooms and a building area of 6000 m^2 based on the architectural plans of the building (Figure 1). This model will be implemented in all Iraqi provinces except the Kurdistan region based on the available land areas in each section. The height of the building is (8.2 m) on two floors, in addition to large outdoor courtyards for the student gathering, service accessories and parking lots. The building consists of three functionally connected wings, where the first wing is allocated to the administration, the second wing to laboratories and libraries and the third wing to the classrooms, and the third wing (study) is the focus of our practical study, which contains an open atrium and is overlooked by the classrooms and on the various floors of the building. In order to obtain the desired results and enhance the airflow within the building, it was proposed to make some architectural modifications to the design as follows:

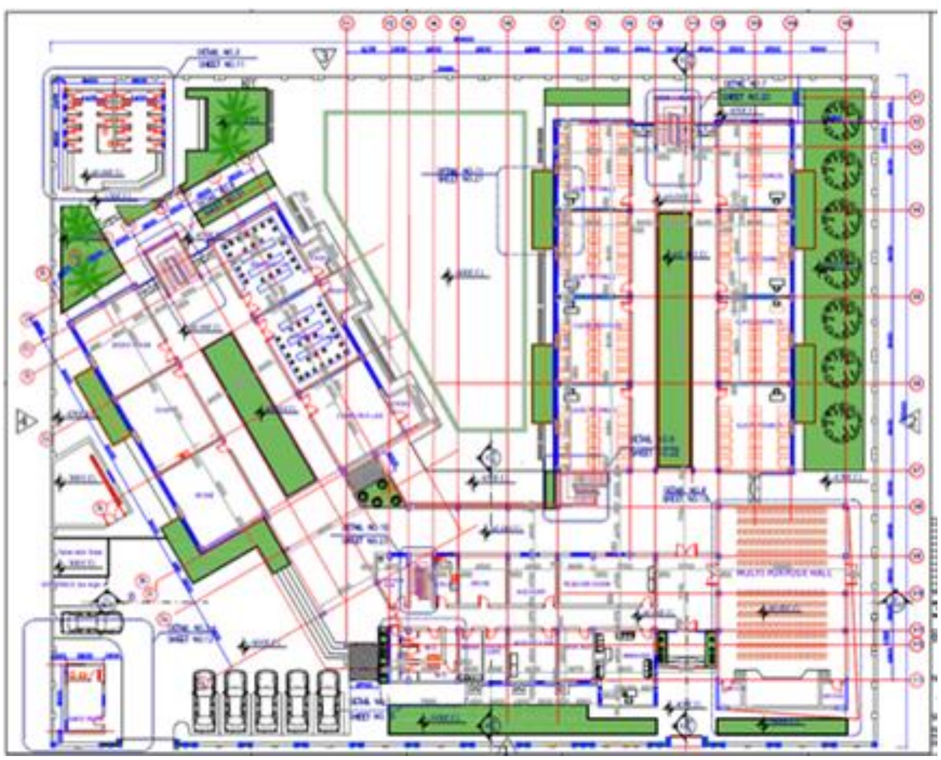


Figure 1. School Ground Floor Layout.

3.2 Atrium Dimensions

An increase was made in both the width and height of the atrium, where the width (10 m) and the height (13 m) were made. This is done by adding a third floor to the classrooms with the expansion of the sunroof of the atrium, which amounted to (5 m). (Fig .2) illustrates the modifications made to the dimensions of the atrium.

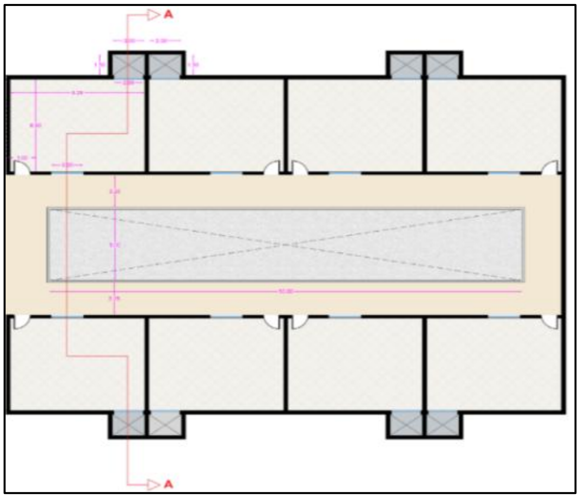


Figure. 2. Modified Ground Floor Layout for the Studied Case.

3.3 Adding Wind Catcher

A wind catcher were added to the case study sample to enhance the airflow inside buildings. Accordingly, it was proposed following dimensions (length 2 meters, width 1.5 meters, and height 21 meters), as well as a wind catcher for each classroom (Fig. 3).

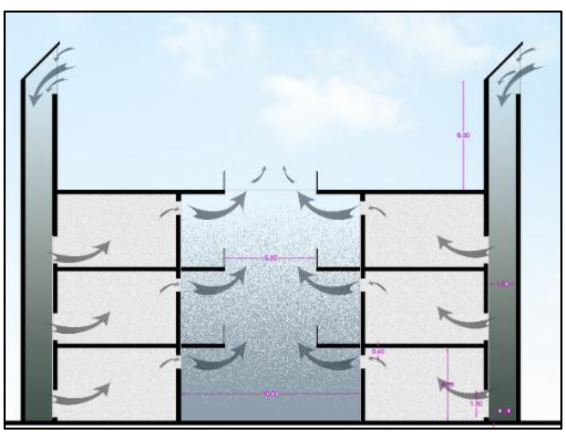


Figure 3. Cross Section of the Wind Catcher with Atrium**.**

The wind catcher rises (6 m) from the last surface of the building and opens directly to spaces through a low-rise and rectangular vent with dimensions (1.5 m * 2 m) in order to ensure that as many air flow as possible enter the classroom this is the case study proposal. The cold air currents entering from the low-rise wind catcher vent cool the air inside the classroom, pushing the hot air currents into the central space directly through tape-shaped air vents and at a high altitude in the room wall.

3.4 Simulation Analysis

A three-dimensional simulation was made using the Ansys program for the atrium and the surrounding classrooms, where the building was analyzed after making design modifications and studying the effectiveness of these solutions in enhancing air flows within the atrium. Based on the weather data for temperatures during (March, the day of the spring solstice and coinciding with 21-3-2021, at 10 am) and wind speed rates (Table1) approved by the General Authority for Meteorology and Seismic Monitoring in Iraq which is the boundary condition for the calculations.

Table 1. Case study weather data.

Weather/Date and Tiem	Value
Date	21/03/2021
Time	10:00 AM
Temperature C°	22
Wind Speed m/sec	3.1
Relative humidity %	34
Prevailing Winds direction	Northwest

4. Results

For more accurate results, the cross-section of the atrium and wind catchers was divided into a set of points, where the airflow was studied at (22) points distributed at a height of (5) different levels (A-B-C-D-E), Figure (4). No air speed was recorded below (1) m/s at any point of the total points studied, while (5%) of the points recorded air speed ranging between (1 - 1.5) m/s, and (18%) ranged between (1.5-2) m/s, and (50%) of the points recorded speed ranging between (2-3) m/s, while (27%) of the points recorded air speed more than (3) m/s, The average speed at 10 a.m. was 2.41 m/s

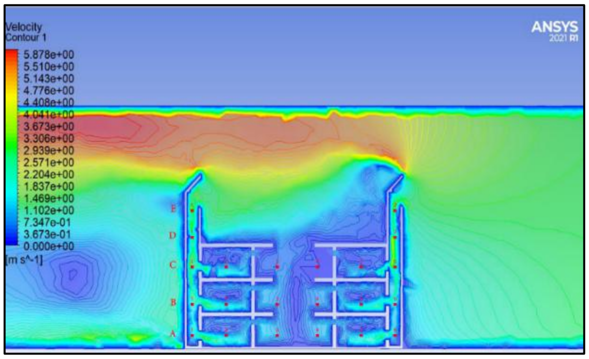


Figure 4. Results of Ansys. Simulation to calculate air speed

Table 2. Percentage of the average air speed and recorded thermal comfort values

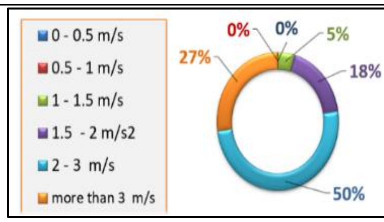
Case	Secondary School
Percentage of air speed values m/s	
Time	10:00 AM
Humidity %	34
Thermal feeling	cold
Temperature C°	22
Average indoor air speed for total points m/s	2.41
Limits of thermal comfort	30-32

Table 3. Value of air speed recorded at each point.

Selected Points		Time 10:00 AM
Air Speed at Level A m/s	A 1	2.6
	A 2	2.2
	A 3	1.9
	A 4	2
	A 5	2.4
	A 6	2.5
Air Speed at Level B m/s	B 1	2.9
	B 2	2.4
	B 3	1.8
	B 4	1.9
	B 5	2.6
	B 6	2.3
Air Speed at Level C m/s	C 1	3
	C 2	2.2
	C 3	1.6
	C 4	1.3
	C 5	1.9
	C 6	3.2
Air Speed at Level D m/s	D1	3
	D2	3.3
Air Speed at Level E m/s	E1	3
	E2	3.1

The achieved air velocity rate 2.41 m/s, can generate thermal comfort with constant climatic conditions and temperature increases up to 31.5 degrees Celsius, according to the thermal comfort chart in the (Figure 5) according to CBE Thermal Comfort Tool for ASHRAE-55 with a 31°C Air Temperature.

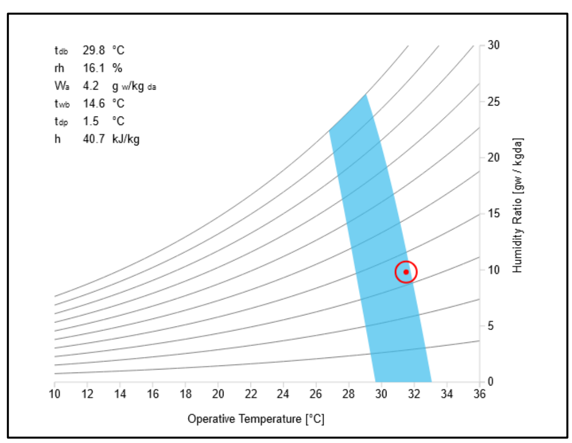


Figure 5. CBE Thermal Comfort Tool for ASHRAE-55 with a 31°C Air Temperature

5. Conclusions

The In this paper, the integration role of wind catchers and atrium design as an effective strategy in promoting natural ventilation within buildings was studied, studying their evolution throughout history during different periods of time. A range of design solutions was also introduced to increase the speed of air flows. For this reason, a secondary school model was selected in Baghdad, Iraq, modifications were made to the atrium of the school, wind catchers were added, and their effects on air speed were studied using the Ansys program. High air speed rates were recorded inside the atrium and classrooms taking advantage of the pressure difference caused by the wind catchers.

The study recommends relying on the results of computer programs in the design of buildings to reach the best-proposed model to enhance natural ventilation in buildings, and the research recommends taking advantage of the mutual and effective impact between wind catchers and atriums to form an active nature ventilation organization, because of the health and economic benefits it brings in buildings.

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