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THE REVIVAL OF TRADITIONAL PASSIVE COOLING TECHNIQUES FOR SCHOOL BUILDINGS THROUGH WINDCATCHERS

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ABSTRACT

Windcatcher is a traditional element that has been used as a passive cooling technique in hot, dry regions many centuries ago. This study, assess the thermal performance of integrated windcatcher to a prototype school building and its influence on classroom and occupants in a hot arid climate. The research examines the effect of changing the windcatcher morphological feature, specifically the height on its functioning concerning the thermal performance parameters of mean radiant temperature, relative humidity, and CO_2 concentration. The simulation process was adopted by using the 2018 IES Virtual Environment simulation tool plus CFD analysis. The results indicate that under the climatic conditions of Erbil city, the height of the windcatcher affects directly the thermal conditions of an integrated space. To create appropriate airflow and provide adequate ventilation rate with the potential to reduce mean radiant temperature 5°C, the height should be less than 9m. Windcatcher with a height of 9m achieved the best results in comparison with higher models as it reduced the cooling load by nearly 60% of the demand energy, compared to the traditional windcatchers design with height more than 15m. Additionally, the findings indicated that constructing a windcatcher with height less than 6m can achieve a similar result to the higher design, besides it costs less and has a more aesthetic preference.

Disciplinary: Sustainable Architecture, Cultural Sciences, Energy Conservation, Education Sciences, Environmental Sciences.

1 INTRODUCTION

The reduction of natural resources, climate change, and the increase of nonrenewable energy prices are real challenges for the next decades. Furthermore, the world witnessed a massive rise of 200% of CO_2, caused by population growth from 1995 to 2011 (Masoso and Grobler 2010). According to International Energy Agency (IEA) 2009 data, the building sector represented the

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highest energy consumer in the world, with 34%, followed by transportation 28%, the industry came third with 27%, and the least was the non-energy uses with 11% (IEA, 2003).

However in the after years, the building sector reached more than 40% of the overall world's energy consumption (Saadatian et al., 2012), which had a significant effect on increasing greenhouse gas emissions and its predicted to rise further by reasons of urbanisation and population growth (Wheeler and Beatley, 2004). Many non-domestic buildings have often used air conditioning systems and mechanical ventilation to establish better interior environments and the use of such systems has increased dramatically all spread the world during the last decade (Sharples and Bensalem, 2001). Thus, the energy used in the buildings, including ventilation, heating, and air conditioning systems account for almost two-thirds of total buildings energy consumption (Chan et al. 2010; Brown and Dekay, 2006; Saadatian et al., 2012; IEA, 2003), and of this 30–50% is concerned with ventilation and infiltration (Khan et al., 2008). As a result, these systems are considered the main drivers of energy consumption in buildings (Almahoozi 2012).

There have also been significant inhabitants' health problems (Sharples and Bensalem, 2001), ie., sick building syndrome (Ruan et al., 2012). Also, many side effects like overheating, excessive humidity, the build-up of odors, smokes, and pollutants, and condensation as a result of low ventilation (Khan et al., 2008). Ventilation can be used to control many criteria like temperature, humidity, odor, and contamination (Hamzanlui et al., 2011). On the other hand, natural ventilation air can discourage the positive ions that cause depression and drowsiness while substituting it with negative ions (Al-Jawadi and Darwish, 2016).

Increasing the CO_2 concentration in space is an indication of a lack of ventilation rate leading to a problem series for students such as absenteeism, poor student performance, drowsiness, and the inability to concentrate (Kilpatrick 2017). High levels of CO_2 indicate a lack of fresh air intake, which has a negative impact on the occupants' health and learning ability. The majority of building standards use CO_2 as the key indicator of performance (ASHRAE 2007). Some studies link the internal CO_2 concentration with health, performance, and attendance issues. Mendell & Heath (2005) shows strong correlations between sick building syndrome symptoms and CO_2 concentrations exceeding 1500 ppm, indicating insufficient ventilation supply.

The importance of natural ventilation is to decrease energy consumption and unpleasant environmental pollutants while with acceptable thermal comfort and satisfactory indoor air quality (Ruan et al., 2012; Sharples and Bensalem, 2001). The windcatcher or wind tower method has been neglected in the building design (Jones and Kirby, 2009). These traditional elements provide natural ventilation and passive cooling in hot arid and humid regions thousands of years ago. Lately, there has been an increasing concern about the application of windcatcher in modern buildings, which initiated the use of the concept of windcatcher more widely, including new technologies.

2 LITURATURE REVIEW

Zhe et al. (2012) assessed thermal comfort performance and energy consumption of commercial wind catcher integrated into an office building in Beijing, China. Simulation results in a drop of 2°C in the indoor temperature and showed good potentiality to minimise 17% of the cooling load.

Dehnavi et al. (2012) investigated the performance of different designs for square wind catchers in the hot arid climate of Yazd city, on reducing the indoor air temperature. An experimental method conducted by using four selected wind catchers that had almost the same descriptions, including height, plan dimension and size, but with different types of blades representing +, x, H, and K in square wind catchers. The results reduced 3-7ºC in wind catcher room for all types with the most efficient is the plus blade form. This result agrees with numerical simulations (Zarandi, 2009; Calautit et al. (2012) Reyes et al. (2013) and Badran (2003). Ghadiri et al. (2011) indicated that vernacular windcatcher of a square plan with 6m height could reduce air temperature from 25°C to 21°C in a hot and arid climate of Yazd.

Al-Jawadi and Darwish (2016) did a full-scale experiment on a house integrated with a two-sided rectangular windcatcher (dimensions 2.5m * 1.75m). Also, a water spray system was equipped for humidification purposes. The results indicated the effectiveness of the moisturised wind catcher in decreasing inner air temperature 12°C.

There is a need for more studies concerning the influence of windcatcher (optimum) height on its performance and potentiality to achieve thermal comfort in particular for a school building in a hot arid climate to improve the thermal comfort of the students and reduce the energy consumption required for cooling. This study deals with the effect of height on windcatcher performance in terms of the parameters of thermal comfort, including air temperature, velocity, and relative humidity for a school building in Erbil city as a hot arid climate region by using IES VE simulation tools.

3 MATERIALS AND METHOD

3.1 PASSIVE COOLING TECHNIQUES

According to UNEP (2003), the heating or cooling of a building to provide thermal comfort is a highly energy consuming process accounting for as much as 60-70% of total energy spending in non-industrial buildings. Of this, nearly 30-50% lost through ventilation and air infiltration (Viktor, 2002). The multi-directional approach is needed, including demand-control, energy-efficient technologies, renewable energy, and energy recovery (Oakley, 2002; McQuiston, *et al.*, 2005; Olsen and Chen, 2003). Natural passive cooling systems are options for maintaining a cool building and decreasing air conditioning costs (Haggag and Elmasry, 2011).

The use of passive cooling techniques involving thermal mass, responsive landscaping, natural ventilation, and shading devices have been adopted towards sustainable buildings (Faggianelli et al, 2014; Kamoona, 2016; Khan et al., 2008). Additional cooling techniques such as green façades and green roofs have also been applied recently (Haggag and Elmasry, 2011).

The windcatcher is one of the ventilation and cooling techniques in vernacular Middle Eastern architecture (Raof, 2018). It is passive, necessitating no energy to operate (Elmualim, 2006).

3.2 WINDCATCHERS

Windcatcher utilises wind renewable energy (Saadatian et al., 2013; Afshin et al., 2016), improving indoor air quality and thermal comfort inside the buildings (Elmualim, 2009; Soni et al., 2016). The predominant of wind towers and wind catchers in the Middle East and North Africa returns to so many years, and have formed a vital element of the indigenous architecture of these areas. (Sharples and Bensalem, 2001). These uses can also be found in India and Pakistan (El-Shorbagy, 2009). Using roof elements to increase the ventilation of buildings is not new. There is evidence that the idea of windcatcher traced back to the early Paranoiac periods. Examples can be recognised in the Eighteenth Dynasty Houses of Tal Al-Amarna. The paranoiac of Neb-Amun House displays a windcatcher with two openings (Almahoozi, 2012; Boloorchi and Eghtesadi. 2014; Roaf, 2005), one for cold air to channeled in, while the other for hot air to get out (El-Shorbagy, 2010).

Windcatcher is an architectural feature/spatial devices constructed on the roof to extract fresh air into the rooms and the interior corridors in building (Aljofi, 2016), and providing passive cooling and natural ventilation to the building (Almahoozi, 2012). Tall towers windcatcher rooftops vents catch the wind for cooling the interior spaces (Ghadiri et al., 2013). Windcatcher called Bating in Syria, Malkaf or Malqaf in Egyptian architecture (Saadatian et al., 2012), and Badger or Baud-Geer in Iran (Hughes et al., 2011), Iraq, and Pakistan (Almahoozi, 2012), while it known in Imarets as "Barjeel", Bahrain as "Casteel", and in Qatar as "badkeer" (Aljofi E K. 2016), see Figures 1 and 2.

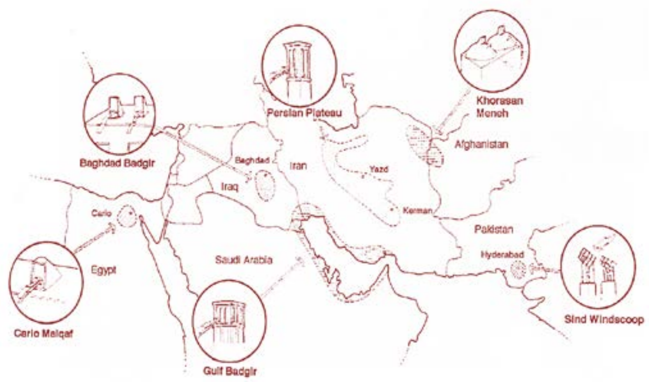

Figure 1: Different windcatcher forms in the Middle East (Al-Shaali, 2002).

Figure 2: An example of vernacular windcatcher (Saadatian *et al.*, 2012)

Inspired by the vernacular architecture of the Middle East, contemporary architects and engineers have innovated modern windcatchers, to take benefits of traditional windcatcher and eliminate their limits to adopt them with improved building types and technologies (Jomehzadeha 2017). Within this trend, many modern and commercial windcatchers were invented. For example, the University of Qatar in Doha, Qatar, was built between 1985-1991, integrated with a new type of simple windcatcher with several openings on each side (Saadatian *et al.*,2012; Almahoozi, 2012). Another distinguish example is the French school, named Lycee Charles de Gaulle in Damascus, Syria, with a design to revive the use of local materials and a combination of passive design strategies for natural ventilation.

These techniques included installing wind towers, shading classroom roofs, the use of building thermal mass, and small courtyards with landscaping. (Elgendy, 2010). Al Jawadiin (2011) modeled a modern windcatcher installed on a two-floor house with a courtyard in the hot dry climate of Baghdad city. The house also applied other vernacular treatments and proved to reach the house to thermal comfort (Al Jawadi, 2011).

The concept of windcatcher has been commercially utilized in the UK for the past 30 years (Jones and Kirby, 2009), with more than 7000 windcatchers installations in the public buildings during the last 15 years (Nejat *et al.* 2018; Jomehzadeha et al., 2017). Additionally, the windcatcher has been installed in more than 1100 UK schools, achieving thermal comfort and cooling in the summer season (Jones, 2010; Ford *et al.* , 2010). A windcatcher installed at Stanford Ecology Centre, California, USA, provides passive cooling of the building main lobby without the use of air conditioning (Malin, 2007).

3.3 WINDCATCHER FUNCTION

With two main windcatcher functions, the first function is to catch the prevailing wind and direct it down to the interior spaces of the buildings (Khan et al., 2008; Hamzanlui et al., 2011), the second function extract the stale and polluted air out, thus supplying clean ventilation instead of it (Moghaddam et al., 2011). The natural ventilation provided by the windcatcher has two major goals, the first one is the gain of effective indoor air quality (IAQ) without any electricity consumption and the second the enhancement of thermal comfort by ventilating the occupants. (Chenari et al., 2016; Al-Hemiddi and Megren, 2001; Schulze and Eicker, 2013; Reyes et al., 2013).

The operation of a windcatcher natural ventilation system depends on two principals: wind-driven ventilation and stack (buoyancy) effect (Coles and Jackson, 2007; Hejazi and Saradj, 2014; Khan et al., 2008). Extensive researches using computational fluid dynamics (CFD) in addition to full-scale experimental tests have been carried out on different types of windcatchers to conclude the driving forces behind its operation, and it was affirmed that there are two driving forces, the first force is due to the temperature difference and it is called buoyancy effect, while the second force is external wind (Saadatian et al., 2012), see Figures 3 and 4.

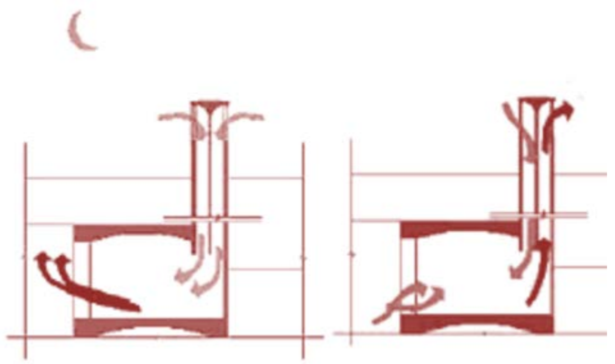

Figure 3: Building section showing windcatcher function according to temperature difference.

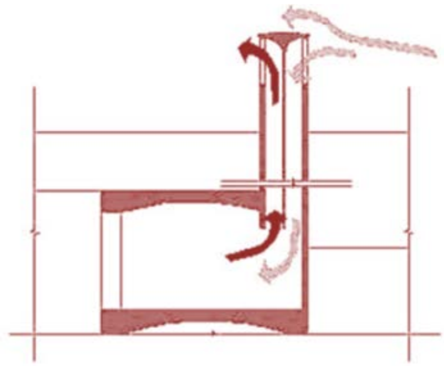

Figure 4: traction and suction (after Hamzanlui M E., *et al.*, 2011).

Concerning the cooling techniques, the windcatcher cools the air depending on two techniques, the sensible method, and the evaporative cooling. The first is based on decreasing temperature when air passed through space but with no changes in the humidity level, while the evaporative cooling uses a different technique to reduce air temperature by increasing water vapor rate as dry air passes on the water body (Aljofik, 2016). Thus, this technique used successfully in hot arid climates like Jordan, Egypt, Iraq, and Iran (Bouchahm et al., 2008). In spite of the advantage, studies indicate that this method is not efficient for a very humid climate without using modifications, which consume more energy (Chan *et al.*, 2010; Florides *et al.*, 2002). The use of this system is continuous in modern architecture, as water spry and new material to retain wet surface, are some types of this technique (Saadatian, et al., 2012).

3.4 WINDCATCHER TYPES

Generally, windcatchers classified into two groups based on their openings: unidirectional and multi-directional or bidirectional (Erell *et al.*, 2008). Unidirectional windcatcher, which consists of a shaft constructed on the roof a building, is open from one side only facing the prevailing wind. This type of windcatcher attracts the wind and channel it down into the inner spaces then the air is let to exit from another part of the building (Saadatian, *et al.*, 2012). Unidirectional needs to be very high to catch greater wind velocity, especially in crowded areas. The limitation of this type is the location of

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opening as it can catch wind from one direction only and cannot attract it from other directions (Hughes *et al.*, 2012). The multi-directional or bidirectional takes the wind from the top, circulates it across the building and then turns it out again through the lee side of windcatcher (Saadatian O. et al., 2012). It catches the wind from any direction and directs it into the interior spaces of the building (Keshtkaran P., 2011). The bidirectional windcatchers generally divided into their vertical axis. They can be obtained in diverse cross-sectionals with diverse efficiency (Almahoozi S., 2012). The traditional windcatchers were typically divided into four quadrants which made the windcatcher more adaptive to periodic wind changes (Ghaemmaghami and Mahmoudi, 2005).

3.5 WINDCATCHER PROPERTIES

Many researchers have investigated the factors affecting the efficiency of windcatchers. Hughes et al. indicated the design factor that influences the Windcatcher performance; these are; height, number of openings, a cross-section of the air channel, size, and positioning of the openings, construction materials, and form (Hughes et al., 2012). Montazeri and Azizian (2008) identified that cross-section, numbers of opening, the position of windcatchers and the height, represent the main factors that contribute to windcatcher efficiency. Saadatian et al. (2012) showed the effective design factors of windcatcher are; cross-section, height, and the number of openings. On the other hand, Liu et al. (2011) concluded that windcatchers influenced by heights, a number of openings, cross-section, locations in a building, and internal configuration of the windcatcher.

3.5.1 SHAPE (CROSS-SECTION)

Maleki (2011) illustrated four types of traditional windcatchers based on cross-sectional plan; rectangular, square, hexagon and octagon windcatchers, see Figure 5.

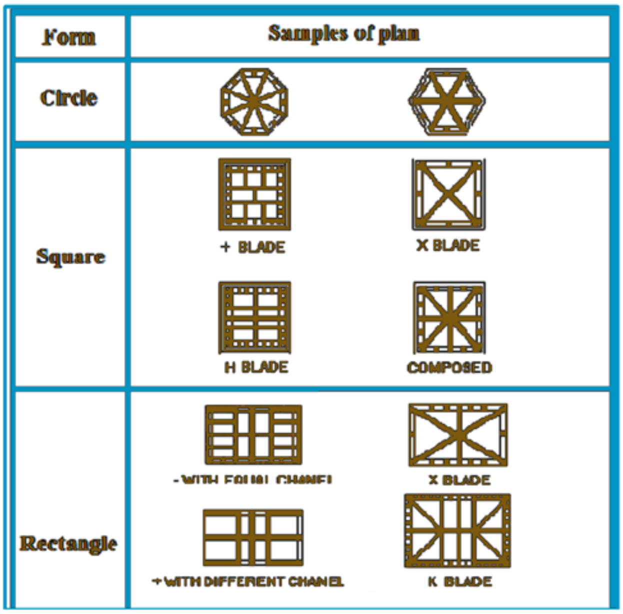

Figure 5: Cross-sectional plan for diverse vernacular windcatcher shapes (Dehnavi et al., 2012).

Elmualim (2002) investigated the efficiency of windcatcher to its cross-section. The findings of the experiment and CFD simulations proved that the performance of the square plan form is much better than the circular cross-sectional due to the sharp edges of the square cross-section windcatcher. Liu and Mak (2007) used CFD simulation to evaluate the efficiency of a 500 mm square plan windcatcher, confirmed the findings of Elmualim. Instead, Gage & Graham (2000) indicated the outperform of rectangular cross-section over those of further geometries, like circular and hexagonal.

These results agree with Montazeri (2010) that a one-sided windcatcher for a zero angle wind direction channels airs into the interior spaces nearly four times more than the two-sided circular windcatcher. The study also determined that a rectangular one and two-sided windcatcher catch a higher induced airflow(Montazeri, 2010). Similarly, Jawadiand and Darwish (2016) find that a windcatcher with rectangular shape is the most effective form plan to be used in the hot arid climate.

3.5.2 OPENINGS

The openings number on the windcatcher sides allows it to catch air from various directions. Accordingly, there are classifications for windcatchers based on the number of openings. As for Montazeri et al. (2010) categorized into one-sided opening wind-catcher (unidirectional), two-sided, three-sided, and four-sided wind-catcher. Ghaemmaghami and Mahmoudi (2005) have identified four types of windcatchers based on the number of openings which are; one-directional, two-directional, four directional and eight directional wind catchers.

Montazeri examined the performance of windcatchers with a different number of openings. Thus, five models: two, three, four, six and twelve-sided windcatcher experimented. The findings of the study showed that as the number of opening increased, the windcatcher efficiency decreased. The study also indicated that increasing openings number makes the windcatcher less sensitive for different inclination angel (Montazeri, 2010). As a result, in areas with no prevailing wind, the best option is the multi-opening windcatchers (Saadatian et al., 2012). These experimental results go with studies about the ancient windcatchers, as concerning the direction of the openings. The traditional windcatchers positioned in areas where there is a strong prevailing wind directional, the openings aimed in the same direction, contrary to regions, where there is no prevailing wind direction windcatchers with multi openings were used (Lechner, 2014).

According to the directional windcatchers are the most popular as they have four main vertical shafts divided by partitions (Roaf, 1982). More than half of wind towers were the four-sided types used in hot dry climates and almost all wind towers in Hot humid climate (Mahmoudi and Shemirani, 2009). This renders the windcatcher as being operational whichever way the wind is blowing.

3.5.3 HEIGHT

The height of the windcatcher is an essential aspect that influences its performance. Mainly traditional wind-catcher in the middle east constructed with heights 1.5-32m from the ground level (Montazeri and Azizian, 2008), Gage and Graham (2000) indicated the heights 5-33m. Importantly, the height of traditional windcatcher in hot dry climate areas is different from those in hot humid regions, as the windcatcher in hot dry climate regions has more height compared with hot humid regions. For greater heights in hot dry areas, the air temperature is less while the wind velocity is high (Ghaemmaghami and Mahmoudi, 2005). On the other hand, the height of windcatchers may vary between two regions with the same environmental conditions as hot dry climates.

A study conducted by making a comparison between Iranian (Yazd's) windcatchers with those of Egypt. The results showed that Iranian windcatchers have a column with height reaches 3-5 meters from ground level because there is a favourable high-speed wind and windcatcher height has to enlarged via a column. On the contrary, Egyptian windcatchers are one story higher than the roof with no columns, due to the low-altitude favorable wind in Egypt (Boloorchi, and Eghtesadi, 2014). It

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concluded that there is a direct connection between height, air temperature, and wind speed. By expanding the structure's height, wind speeds increase. In addition, air temperature decreases in higher areas. Badran (2003) proved that there is a direct effect between the windcatcher's height and its performances. Similarly, Hughes et al. (2012) demonstrated that the positive pressure on the vertical side of the windcatcher raised due to the increase in height.

3.5.4 MATERIALS

Traditional windcatchers in hot dry climates were built either of mud brick or more frequently of baked brick covered with mud plaster (Ghaemmaghami and Mahmoudi, 2005; Maleki, 2011). These mentioned materials act as thermal insulators, for instance, mud can delay the heat transferal from outside to inside areas for approximately eight hours; thus, they are very efficient and applicable (Keshtkaran, 2011).

In modern windcatchers, insulation materials are used as well to improve the performance and the efficiency of these windcatchers. Al Jawadiand and Darwish (2016) conducted a full-scale experimental study by building a windcatcher lined with a brick burned at a temperature varying at 750-1150°C. The model proved to be efficient in the hot arid climate. Vali (2009) used computation modelling program and experimental test, demonstrating that when the walls of the windcatcher were insulated, the windcatcher performance became more efficient.

3.6 WINDCATCHER AND ARCHITECTURE IDENTITY

From the very beginning, vernacular architecture has been trying to achieve harmony between nature and buildings as its architectural elements consist of a rhythm between environment, materials, use of space and the needs of living (Kirbas and Hizli, 2016). The architectural heritage stands for as evidence of people's history. Thus, nations attempt to maintain, explore and evolve the principle of its architectural vocabularies to conserve their values (Aljofi, 2016). Many countries are well known for their architectural features that developed from their geographic, topographical, and climatic conditions. An example can be found in the cities of the middle east as they are rich with architectural elements that been emerged as a result of climatic solutions (Aljofi, 2016). The purpose of these elements was to decrease the severe high temperature along the summer months, enabling people to endure the climatic problems (Almahoozi, 2012).

The windcatchers represent one of these architectural devices, which were used to obtain thermal comfort in the interior spaces. (Boloorchi and Eghtesadi, 2014), thus it's a sign of the design in agreement with the climate (A'zami, 2005). The nowadays buildings ignore the traditional architectural devices of the past, passive systems were replaced by the active methods, which led to more energy consumption for ventilation and cooling. As a result, the cities are about to lose their identity when the new buildings do not retain ecological solutions (Kirbas and Hizli, 2016).

Contrary, if contemporary architecture applies traditional elements, it could assist in achieving cultural continuity. Also, it can be directed to reach climate-adaptation and sustainable architecture (Spentzou et al., 2017). Thus, climate consideration is a crucial factor in architectural design with the increase of environmental awareness all around the world. Its goal is to restore identity and harmony with the surrounding environment by using traditional values in a modern way. Climate has a vital effect on identity formation as it is an essential aspect in shaping architectural identity (Al-Shwani and Baper, 2011). Eventually, the use of traditional devices as a windcatcher will aid the restoration of architectural identity.

4 METHODOLOGY

For Semi Hot dry climate zone, the amount of solar heat absorbed by a building is high and causes an increase in the air temperature of the classrooms. Thus, will lead to poor indoor environmental quality and affects the student discomfort thermally and physically (Wargocki et al., 2005). The most defects in schools include insufficient outside air supplied to occupied spaces; inadequate exhaust airflows, poor air distribution or balance; and poor maintenance of heating, ventilation and air-conditioning (HVAC) systems (Angell. and Daisey, 1997; Wargocki. et al., 2002). To provide thermal comfort to the students, windcatcher applied in this project

The natural ventilation strategy combined with a four-sided rectangular windcatcher installed in an existing school and the measured results for the hot period from (1/April to 30/Sept) is described. In summer and intermediate seasons outside air is introduced into the building of three stories with a total height of 9 m^2. Four of this study four-directional windcatchers integrated into the classes. The tower divided into four shafts by a vertical brick partition, which brings cool air for the internal space of the classes. The purpose of selecting windcatchers with four directional openings is to serve four different orientations (South, North, west, east).

4.1 MODEL AND THE OPERATIONAL PROFILE

In this work, an IES VE sustainable tool is used to examine the efficiency of the passive system on three -floor classroom in a hot arid climate (Erbil city). Figure 6 presents the physical attributes of the Base Case model (the prototype of schools in Erbil city). The windows extend from 1m above floor level to the ceiling, providing a glazed area of 1.8 x 205m. Glazing is assumed to be clear and single glazing and covers a 14% WWR (Window to wall ratio). The constructions of the walls constructed of a single un-insulated leaf wall with a concrete block wall. Classes dimension is 8m x 5m x 4m. The average school classroom occupancy density is 0.65-0.80 persons/m^2. An opening set point of 19°C in the winter and 16°C in the summer for both windcatchers and windows. The input parameter is shown in Table 1.

Table 1: Base case parameters used in this study.

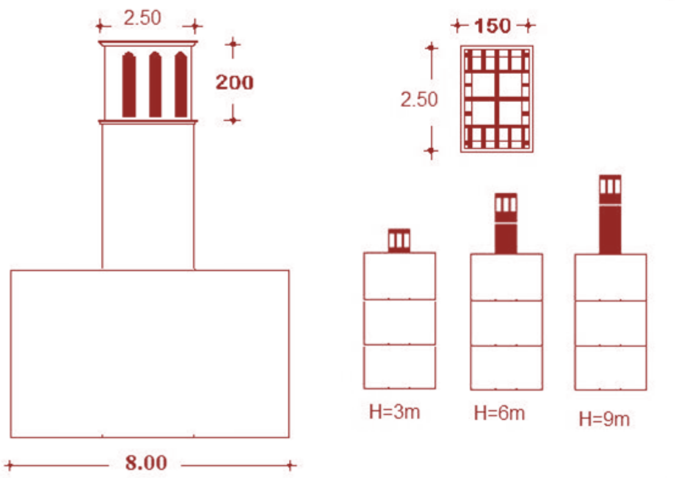
Construction	NO.	Material (Construction layers from (outside to inside)	No.of Layers	Thickness (mm)	Total U value W/m2*K
External Wall	1	Limestone hard	1	100	2.15
	2	Cement plaster - sand aggregate (ashrae)	1	20	
	3	Hw concrete block	1	200	
	4	Gypsum plastering	1	20	
Internal ceiling /floor	1	Clay tile	1	10	2.07
	2	Fine sand	1	50	
	3	Reinforced concrete	1	150	
	4	Gypsum/ plaster board	1	10	
Roof concrete	1	Roof insulation (ashrae)	1	5	1.58
	2	Felt/bitumen layers	1	5	
	3	Reinforced concrete	1	150	
	4	Cavity	1	10	
	5	Ceiling tiles	1	10	
Glazing		Clear float 4mm	1	4	5.7
partitions	1	Plaster (lightweight)	1	13	2
	2	Hw concrete undried aggregate - hf-c12	1	100	
	3	Plaster (lightweight)	1	13	

(a) The plan of the base case (b) The physical appearances of the base case

Figure 6: Classroom building located in Erbil city, Iraq.

4.2 GEOMETRICAL MODEL

A 3D rectangular wind catcher model of dimension 1.5 m x 2.5 m with same plan geometry of the plus blade and three different height of 3.0 m, 6.0 m and 9 m connected to a room with a length of 8 m and width of 5 m, Figure 7. The position of the wind tower was chosen based on the location of the classrooms. The geometry of these models were generated and simulated by IES VE 2018 software and using the integrated Microflo to simulate the CFD. For the run of CFD simulation, the wind speed was set at 12 mph with an angle of 0 degrees, and outdoor temperature was 97F degree which is the average temperature of Erbil city on hot days in summer.



Model #1 (H. 3 m) Model #2 (H. 6 m) Model #3 (H. 9 m)

Figure 7: proposed windcatcher dimension (all dimensions are in meters).

4.3 SIMULATION PROCESS

IES adopted for this research to assess the effect of windcatcher performance on the occupants' thermal comfort conditions of a school building in Erbil. The first step includes evaluating the impact of each height on the thermal comfort of the classrooms and the attendance. Due to the unpredictability of weather and continually varying wind speed and direction, three main parameters were selected (mean radiant temperature of the class, Relative humidity, and CO_2 concentration). Furthermore, the cooling load was studied to see the amount of energy use after the collaboration of windcatcher. Through each case of wind catcher’s interventions, IES apache simulation been used in this research to examine the thermal comfort of the classroom and the energy performance of wind-catchers. Apache is a dynamic tool used for thermal calculation and analysis based on the heat transfer process and it is driven by real weather data (ASC, 2015). Figure 8 shows the alternatives of windcatcher models in IES.

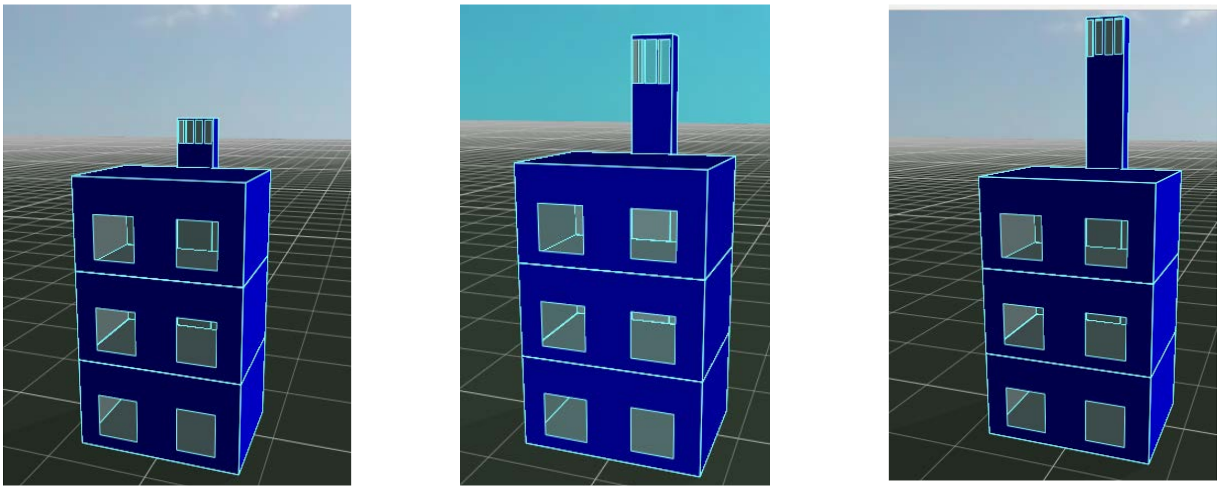


Figure 8: IES VE model of the three alternatives (Author)

With the analysis of the base case completed and results obtained similar to published literature, detailed analysis into CFD run for best height performances conducted. Based on the literature, the CFD method was found to be a more attractive approach as it gives reliable results in predicting ventilation parameters and the advancement in digital computing(Chen, 2009; Liu, *et al.,* 2009). CFD modeling has been used as analytical modeling and for all types of the experimental approach, thus it can analyze and optimize complex 3d designs with high accuracy of temperature, velocity and airflow pattern around or inside the three-dimensional model (Jahar and Soumen, 2009) see Figure 9.

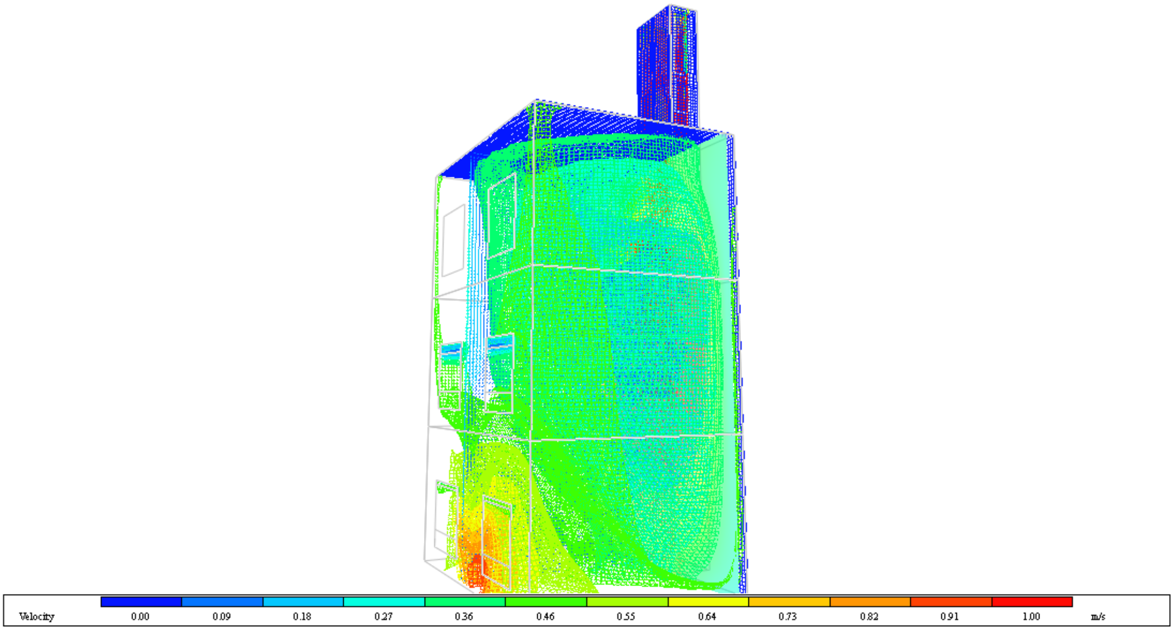


Figure 9: CFD analysis model for windcatchers (created by Authors).

5 RESULTS AND DISCUSSION

5.1 BASE CASE SIMULATION RESULTS

The primary results obtained from the analysis of the base case classroom show that the indoor temperature is exceeding 32◦C in almost 90% of hours during the day time, and only 8% is within comfort temperature (22-28˚C). Figure 10 shows Indoor mean radiant temperature in August in the afternoon 1:00 PM is over 40◦C which indicates the need for mechanical ventilation.

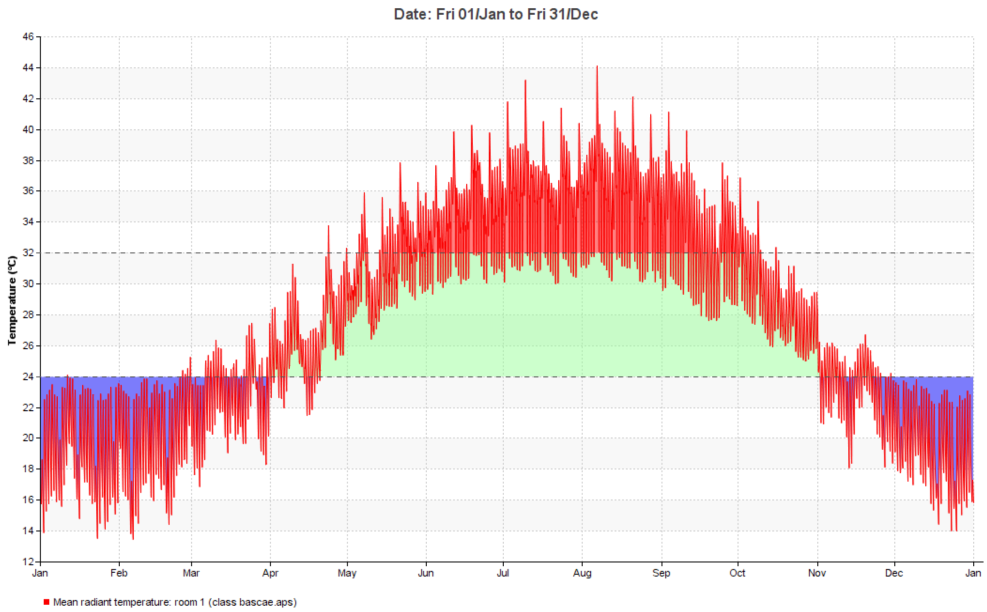


Figure 10: Mean radiant temperature for the Base case classroom

Another result to indicate the poor indoor quality is the measuring of the CO_2 concentration in class, Figure 11. The average accepted standard for CO_2 level in a classroom is 1000 (ASHRAE, 2007)., however, the results show that CO_2 concentration exceeds 2000 ppm for more than 75% of the total hours that student spends in class, which is more than twice the recommended level. Also, the rate can reach more than 6000ppm when space is fully occupied. This high range may lead to many problems for the occupants and lead to people dissatisfaction.

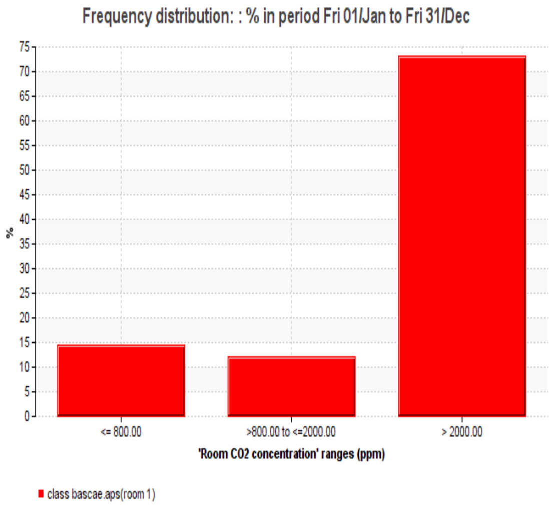


Figure 11: Room CO_2 concentration for Base Case classroom.

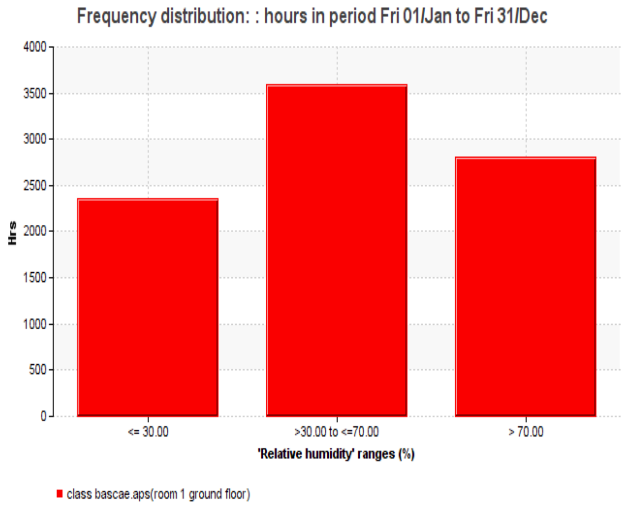


Figure 12: Average relative humidity in Base Case classroom.

The acceptable level of Relative humidity (RH) should be between(30-70%) (CEC., 1992). The Figure 12 shows that only 40% of the total time in hot period RH is within an acceptable range, while over 30% of the time RH is more than 70% which adds extra heat (latent heat) into space. Besides, 25% of the total hours the RH is <30 %. These results demonstrate that the classrooms insufficient thermal comfort for the occupants because the rate of human transpiration reduced by high RH and so leads to discomfort, while it increased by a low RH that leads to dehydration (Ibid).

The total cooling load of the room was approximately 20 Mwh for the whole year.

5.2 INTEGRATING WINDCATCHER TO THE CLASSROOM AS A MEAN FOR PASSIVE COOLING, THE RESULTS ARE AS FOLLOWING:-

5.2.1 MEAN RADIANT TEMPERATURE

When the outdoor temperature is maximised to 31.5ºC at 1:30 pm, the windcatcher room temperature is 27.5ºC in Model #1, 28 ºC in Model #2 and 28.5 ºC in Model #3. Hence these kinds of wind catchers can decrease the temperature between 3-5ºC while the outdoor temperature is at the highest level. Outdoor temperature decreases gradually in the afternoon while indoor air temperature decline 3-5ºC up to 4 pm Figure 13. As we can see through the chart, indoor air temperature in the windcatcher room with plus form blade windcatcher is than other samples. As 29 ºC is not an ideal comfort temperature, ancient architects used water pond under the windcatcher for evaporative cooling to decrease the indoor air temperature.

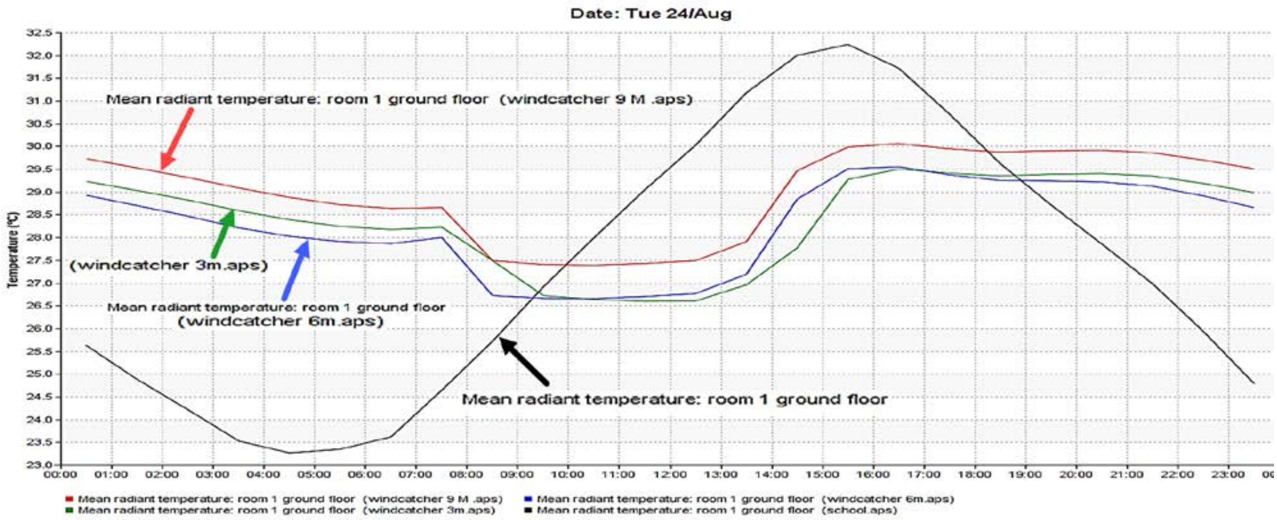


Figure 13: Mean radiant temperature comparison between the Base case and other three alternatives, Produced by IES VE by the author.

Figure 14 indicates the best performance attained by Model #2 while Model #3 has the least active. The best performance accomplished by Model #2 as the number of hours that the mean radiant temperature is within the comfort zone is nearly 65% in comparison with 60% and 50% for Models #1 and #2 respectively. This result shows an increase of more than four times the base case results during the hot period. These results come in agreement with outcomes found by the study (Malcolm and Agnieszka-Cwiek, 2012) that indicates the air temperature distributions through the natural ventilation system during a hot summer week (31 May to 6 June) for a typical classroom and caused reduction of classroom temperature with 8◦C when the outside air temperature hits its peak at 34.5. Also, it can see that Model #2 has the least number of hours in which temperature exceeded 28◦C with slightly 20% in comparison with more than 85% of total hours that exceeded 28◦C in the base case. Similarly, Model #1 reduced the number of hours that exceeded 28°C into less than 25%. Model #3 also decreased the number of hours exceeding 28°C by 35% and increased number of hours' that is less than 22◦C by less than 15% similarly with Model #2 15% and 16% for wind towers with 9m height.

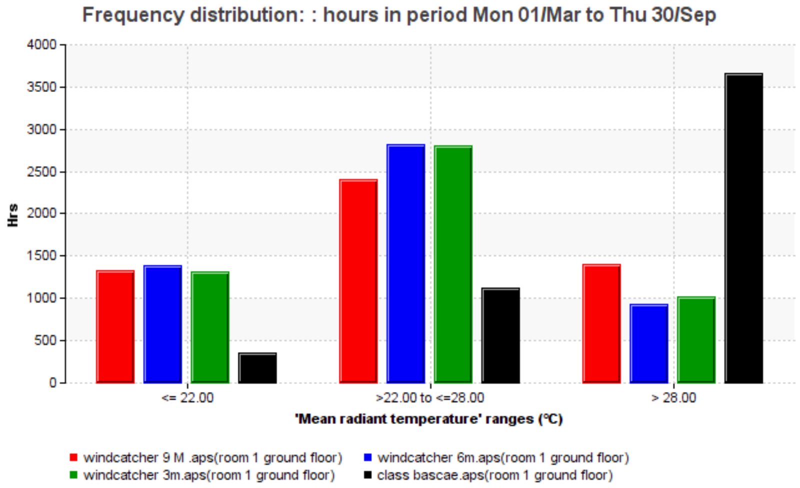


Figure 14: The percentage of mean radiant temperatures in hours of the classroom after introducing windcatchers.

5.2.2 CARBON DIOXIDE CONCENTRATION ANALYSIS

Figure 14 shows the effect of windcatcher on the CO_2 concentration of an occupied classroom with 30-35 students and its influence on the thermal properties. The general trends indicate that there is a tremendous enhancement in the level of the CO_2 in comparison with the Base case. Model #3 has the best performance in reducing the level of the CO_2 to less than 1000ppm (an average 550ppm) for nearly 90% of the whole time from 8.00 am to 3:00 pm. Models #1 and #2 have similar performance with slightly more than 1000ppm. This result agrees with Mahyuddin *et al.* (2014) that shows with the operation of the windcatcher, CO_2 concentration was not so high regardless of the number of occupants 30-35 students per class. Figure 15, CO_2 level starts with a low level in the early morning form 8-9 am with less than 800 ppm due to the less number of occupants. After that, it starts to rise till it reaches to its peak with 1300pmm in the afternoon, which is within the comfort range and remains steady until the end of the classes. Gaining this level of comfortable internal conditions in the classroom are a requirement for student's health, wellbeing and productivity.

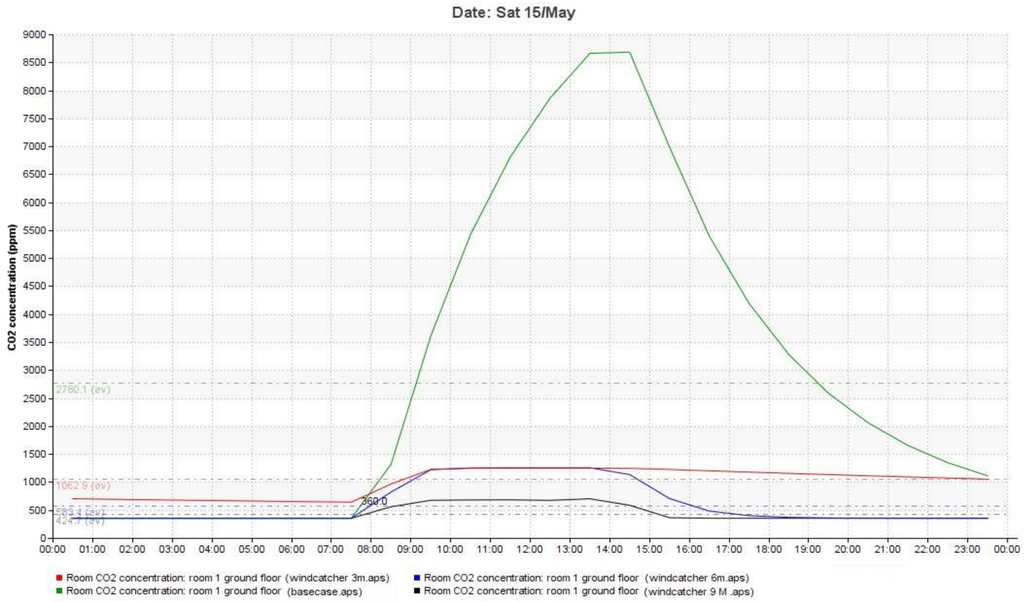


Figure 15: Spatial distribution of CO_2 concentrations with the intervention of three windcatcher models.

The results established that according to the adaptive comfort standard and ASHRAE standard, CO_2 concentration should not exceed 1000 ppm. A difference was obtained in CO_2 concentration before and after the parametric studies for the hot period (April -30 June) as in Figure 16. The results indicate that there is a considerable enhancement in the total level of CO_2 after introducing passive cooling into the classroom. Firstly Model 2 has achieved best result with more than 75% of the total time the space is less than 800ppm and nearly 25% of total hours within comfort range . while Model 1 with height of 3 m has lowest results with only 57% of overall hours the CO_2 concentration is less than 2000ppm including more than 37% less than 800ppm. However, more than 40% of the total hours the CO_2 is over 2000ppm, which is similar to the base case results. These results may be due to the less amount of the ventilation rate of the space when using a height of 3m. This result agrees with the study by Mahyuddin *et al.* (2014) as it indicates that with the operation of the windcatcher, CO_2 concentration was not so high regardless of the number of occupants 30-35 students per class as the CO_2 concentration was below the acceptable value (<1500 ppm) during the morning.

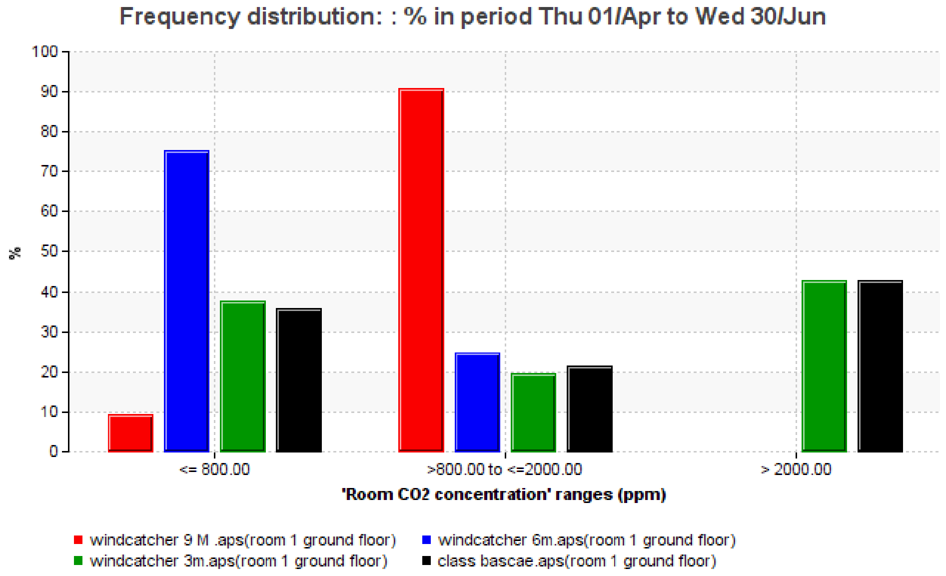


Figure 16: CO_2 concentration of the three windcatcher models compared with the base case.

Furthermore, mean CO_2 values also meet the requirements for Models #2 and #3 of the European Standards 15251 (BSI, 2007) and 13779 (BSI, 2004) and so may be considered to have high indoor air quality and also within thermal comfort Figure 17 which is for the most of the time in summer period the level of CO_2 is less than 1500pp. The maximum and mean values for the current study in the summer are: maximum values 3430 ppm, 1268ppm and 1255ppm and mean values are: 1220ppm, 1062ppm, 584 ppm for Models #1, #2, #3 respectively. These results are equivalent to data measured by Jones (2002) who reported maximum and mean CO_2 levels of 3383 ppm and 682 ppm, and 227 ppm, respectively when averaged over all of their measured classrooms. His strategy relies on fully open windcatchers over 70% of the time and never fully closed during the summer. Hence, improvement in ventilation rate appears when using a windcatcher with an opening window.

This current study indicates that the higher the windcatcher, the more ventilation rate in the space as the maximum CO_2 concentration reduced with increasing the height.

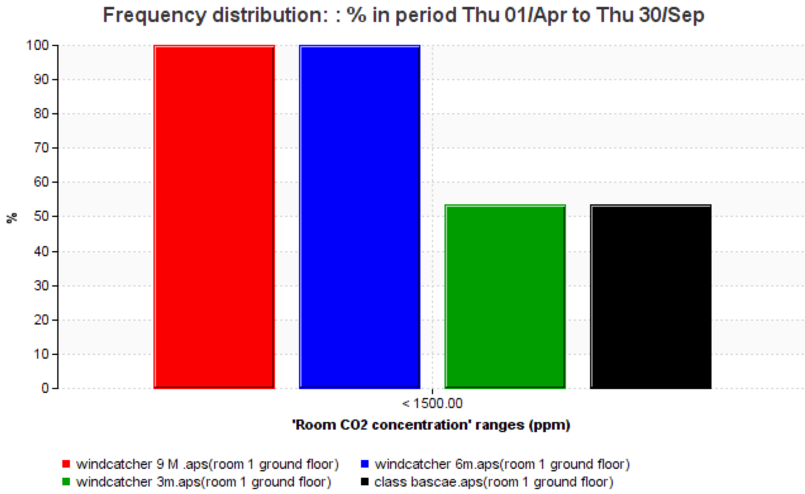


Figure 17: Measured CO_2 for occupied hours in summer.

5.2.3 RELATIVE HUMIDITY

Form literature, CO_2, and RH levels are constantly monitored over some time to determine their effect on occupants, such as its influence on the learning performance of children in schools (Bako-Biro *et al.*, 2004). Relative humidity levels in the summer and winter season presented in Figures 18,19, and 20 which show that the mean levels are below 70% for both Models #2 and #3 for the full summer semester while nearly 30% of the total time RH is over 70% for Model #1. Thus, it demonstrates compliance within 30-70% and comes corresponding to building regulations (ODPM, 2006) and the guidelines by the Commission of European Communities (CEC, 1992), which indicates that windcatcher has no much influence on the RH of the classroom.

This result is equivalent to Ahmadikia *et al.* (2012) deduced that using a type of wind-catcher with water spry in hot and arid regions leads to a decreased air temperature and increased relative humidity. Therefore, more pleasant thermal comfort conditions are provided for the spaces in hot and dry days in Hot arid climates. During the winter semester, RH is mostly within comfort range under 70 % for more than 70 %, 80%, and 90% of the total time for all the model cases, respectively. To conclude, RH does not appear to be influenced by the height of the windcatcher.

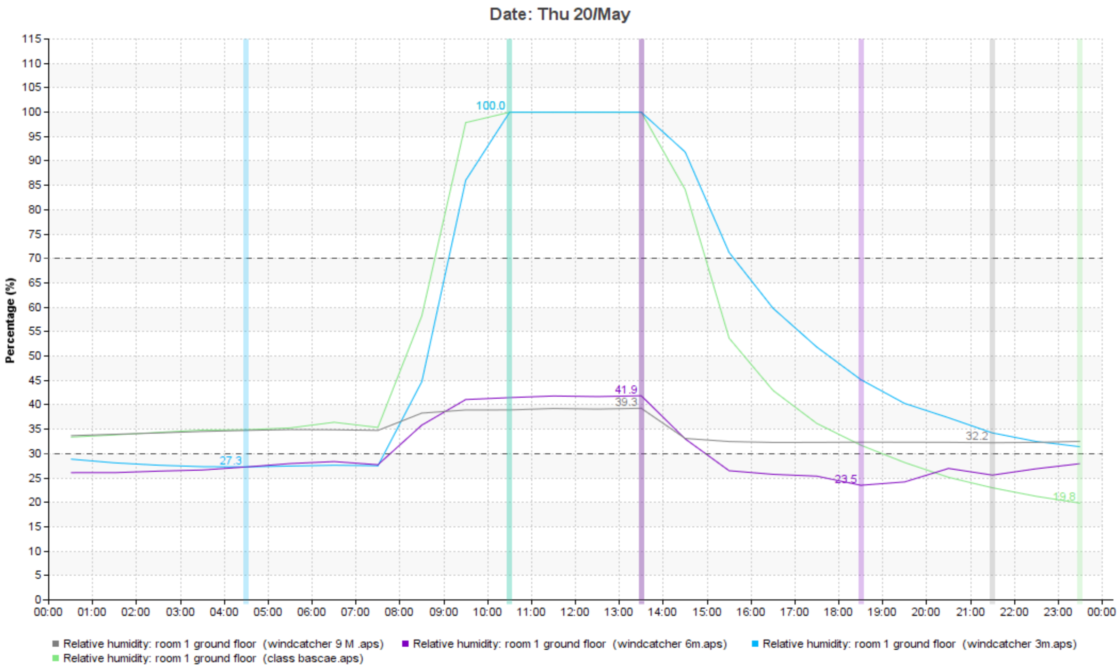


Figure 18: Spatial distribution of RH % for the Base case and the alternatives.

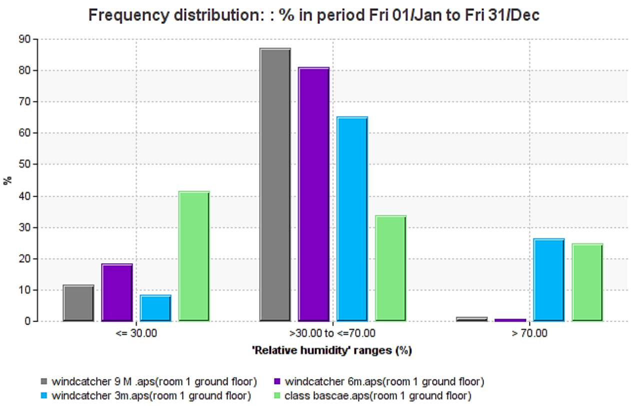


Figure 19: Measured relative humidity for occupied hours in winter

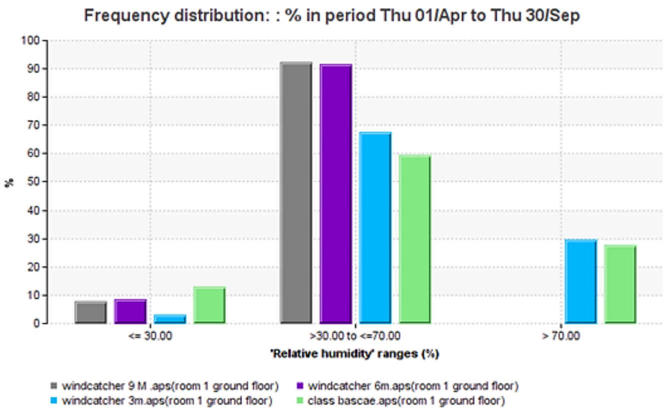


Figure 20: Measured relative humidity for occupied hours in summer

5.2.4 COOLING ENERGY CONSUMPTION

The total cooling load for the base case room was approximately 20 MWh for the whole year. Figure 21 shows the effect of the intervention of three different heights of windcatcher on the total demand for energy by cooling sensible load. The results reveal that windcatcher Model #1 has the potential to reduce energy demand for cooling by nearly 4 kW, which is a reduction of more than 50% in comparison with a base case in one of peak hot days (20th of May). On the other hand, both Models #2 and #3 achieved similar results with a reduction of 4.8 and 5 kW respectively, for the same date.

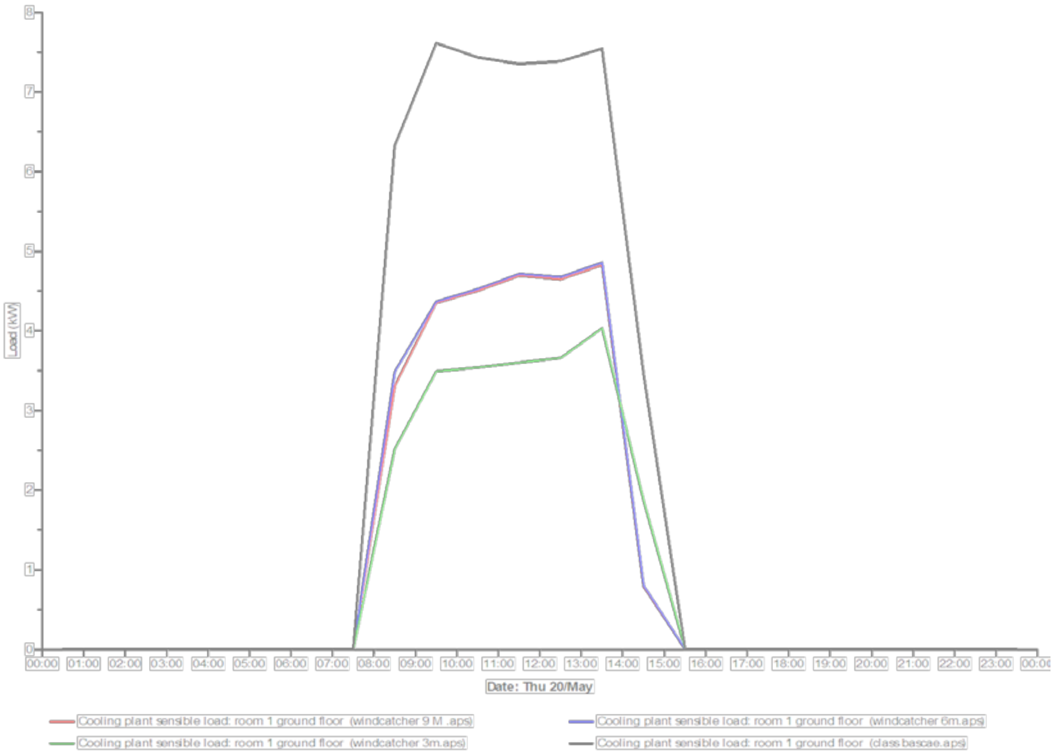


Figure 21: Cooling load for the base case and each model

5.2.5 ENERGY CONSUMPTION ANALYSIS

This study deals with Windcatcher as an architectural element used as a passive cooling design to improve indoor thermal comfort with reducing energy consumption during the hot season. The performance and energy-saving potential of using three different windcatcher systems in Erbil city evaluated through VistaPro simulation in IES of a typical school building installed with commercial windcatchers. Figure 16 shows the results of all the cases demand cooling load in comparison with the base case energy consumption during the summer semester. Figure 22 illustrates a general trend towards reducing the demand for energy during the hottest period. The use of windcatchers is helpful to lower cooling-related energy consumption due to the temperature reduction caused by natural ventilation. According to the design standard of a public building for energy efficiency building (B 50189-2005) reducing the design temperature of 1°C, electricity consumption in air conditioning is reduced 5% of the total energy use.

The simulation process indicates that the building will be cooled by an air-conditioning system if the indoor temperature cannot be maintained below 28°C by natural ventilation. Model #3 achieved a 43% reduction in the total amount of energy from the period (1/Mar.)to (30/Sep.) and also has the least amount of energy use during each month in comparison with Models #2 and #1, and this due to the high percentage of temperature reduce during the period. While Model #2 achieved a nearly 46% reduction in the total cooling load. It was found that the total cooling load can be reduced from 8.65MWh to 3.95Mwh after using windcatchers Model #1. Thus, a 58% cooling load saved when using windcatchers, and this effect is approximately doubled by also using top-hung windows at night. Consequently, the thermal mass of the building fabrics is cooled using cooler outdoor air. The next morning, the building fabric can absorb more heat gains and consequently contribute to reducing indoor temperature and cooling load as well.

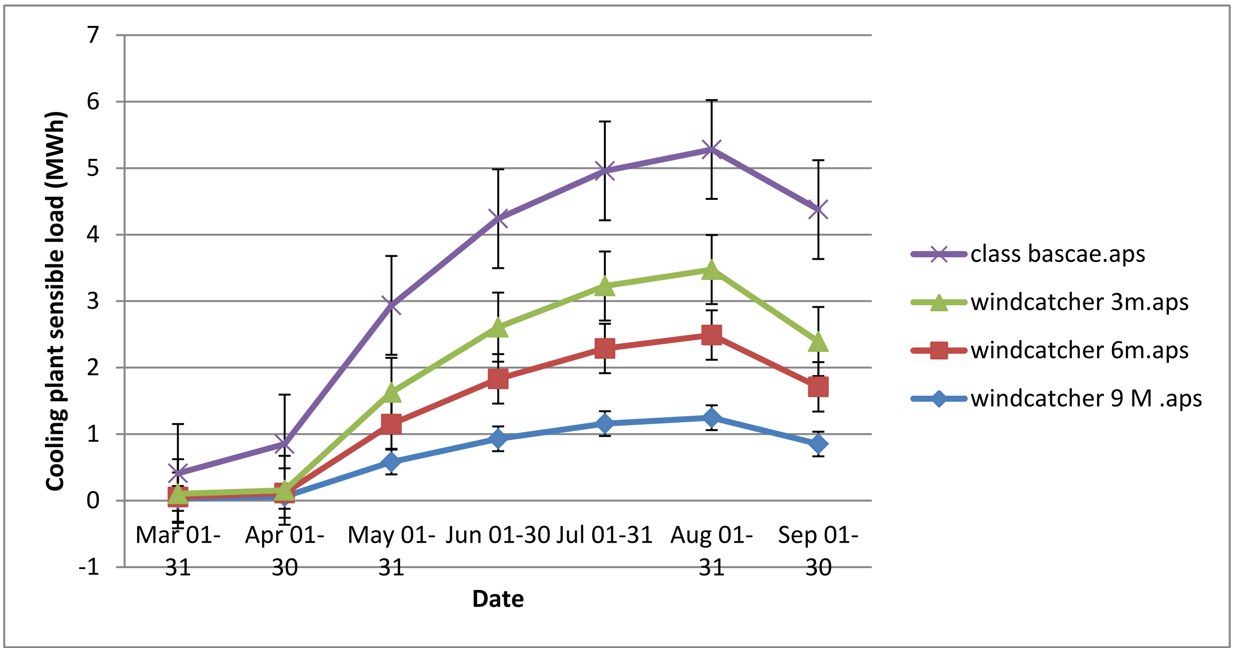


Figure 22: Cooling load distribution for the climate condition in Erbil city.

5.2.6 CFD ANALYSIS FOR WINDCATCHER MODEL

According to the CFD results, Model #2, which was the windcatcher with 6m, provides higher efficiency in ventilating the indoor air. Figure 23 shows the CFD simulation for the windcatcher Model #2 with a height of 6m, and it describes the distribution of the wind and wind velocity for the windcatcher. The results indicate that when the wind contact with the tower, the air velocity is increased in leeward while it decreased in windward. Wind speed reaches its highest velocity of 1m/s at the top of the windcatcher when the wind enters the top of the windcatcher, which leads to an increase in the volumetric rate of the air a causes fresh air to enter the room via the window on the top of the wall.

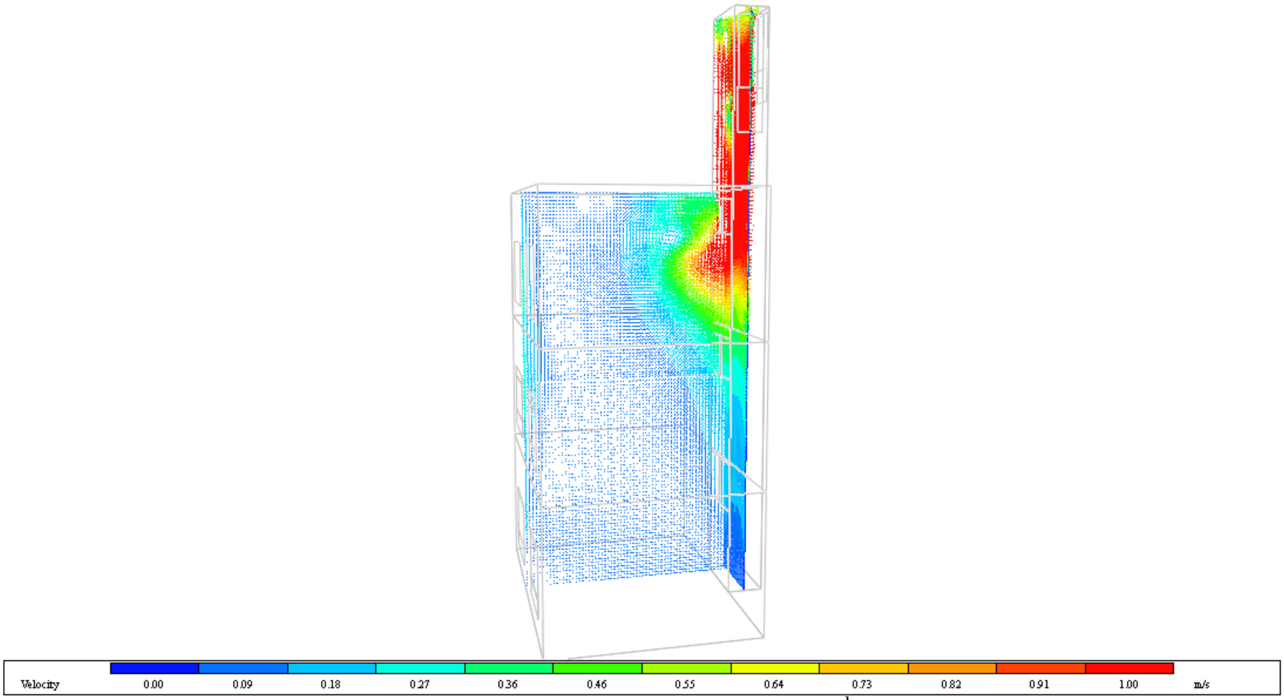


Figure 23: Wind velocity on the openings of windcatcher and 2nd floor CFD analysis (Author)

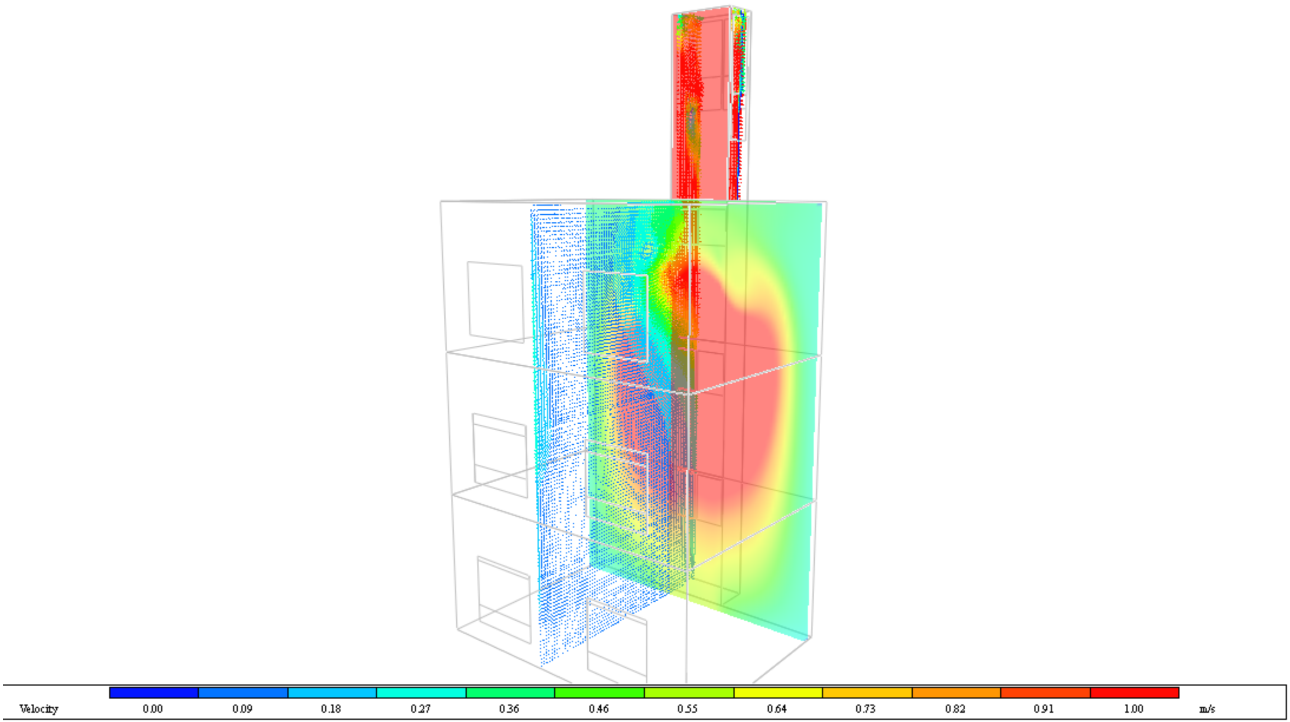


Figure 24: Section on Z-axis wind velocity and airflow movement.

Figure 24 indicates the air velocity distribution with axis z, the results show that airflows inside the windcatcher and the space were best driven and turbulent, and excessive velocity airflow mainly appeared in the centre of the room and at the opening of the windcatcher tunnel, which was in favour of removing indoor heat gain especially after opening the side window. CFD was found to give higher volumetric airflow by almost 100%.

6 CONCLUSION

Windcatcher is a traditional element that been employed for the buildings of the middle east in general and Iraq, in particular, to act as a passive technique via an evaporating cooling system for achieving thermal comfort in a hot dry region. Adopting traditional windcatcher in modern buildings can add aesthetical value, historical and traditional intervention, and a feasible architecture feature. The main benefit of the windcatchers is that they are passive systems needing no energy for their operation. Wind catcher's performance can be affected by its height after optimising other morphological parameters such as width, length, and openings as demonstrated in this study. Three prediction models were used to assess the performance of a windcatcher for natural ventilation purposes in classrooms to enhance thermal comfort of students; the main results concluded as follows

Windcatcher is more effective during the early mooring than a late afternoon with 3◦C difference in temperature between these two periods.

- Increasing the height leads to enhance windcatchers performance in term of reducing the mean radiant temperature and expanding the number of hours that is within the thermal comfort range. The 6 m height achieved the best results, as it raised the percentage of hours within comfort to more than75% of total hours.
- Integrating passive cooling via windcatcher has a major influence on decreasing the amount of CO_2; with increasing the height, there is a potential to drop the amount of CO_2 in the classroom. Due to the rise of the wind pressure on the wind-tower that leads to the expansion of the current wind inside the room as indicated by CFD analysis.
- Changing the height of the windcatcher does not influence Relative humidity as all the models kept the RH within the thermal comfort range during the summer period when the class fully occupied.
- Windcatcher has an impact on bringing low energy demand for the cooling system. Rising the height of the windcatcher will lead to a higher reduction of the total amount of energy required for cooling during the hot period.
- Although the results-driven from height 9m achieved the best outcomes in terms of energy-saving and reduction of the indoor air temperature besides to the dropping of CO_2 level, the height 6m which indicates second-best results can be chosen as an optimum parameter as it costs less and has more visually appealing than the higher one. Therefore, the height of 6m is more preferable due to economic and aesthetic reasons.

From the points above, it can be concluded that height has a direct influence on windcatcher performance. Hence, height affects the wind speed and wind temperature which is taken into the building by the windcatcher's vents. Moreover, in higher areas, the wind-catcher can benefit from the less polluted air. The classification and performance study of wind-catchers, as undertaken in this study, are the initial steps towards providing a more comprehensive guide of wind tower designs for passive cooling.

7 DATA AND MATERIAL AVAILABILITY

Information regarding this study is available by contacting the corresponding author.

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