Windcatcher as sustainable passive cooling solution for natural ventilation in hot humid climate of Malaysia

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Abstract— Two third of buildings’ energy consumption is associated to HVAC systems. Windcatcher is a green traditional method of natural ventilation which has been applied for centuries in Middle East. Nevertheless, tropical climate, this green feature is not a common architectural element. In Malaysia as a developing country, buildings account for 23% of total energy consumption and statistics reveals that the their CO₂ emissions boomed in recent decade. Due, to high ambient temperature and humidity a great share of buildings energy consumption is related to cooling and ventilation systems. Windcatcher can reduce temperature and provide fresh air for occupants as well as reduction in CO₂ concentration inside the building. This old traditional technique can be merged with new building designs to raise the green concept in the building sector. This paper aimed to present a perspective of windcatcher implementation in tropical climate of Malaysia.

Keywords— Natural ventilation, Windcatcher, passive cooling, Badgir.

1. INTRODUCTION

The most important challenges of the world are related to the environmental threats and among them global warming is the most serious. Building with 30% [1] of CO₂ emissions and 40% global energy consumption [2] Play significant role in climate changes which it is predicted to rise in future on account of urbanization and population growth [3]. Energy is used for different purposes in the buildings. Different services the heating ventilating and air conditioning (HVAC) systems has the most share. With more than 50% than of energy consumption [4].

A considerable number of countries have been placed in tropical regions and face with high humidity and temperature [5]. Fast economic and population growth of these countries has led to more penetration of air conditioning systems, therefore the energy consumption has increased significantly in tropical areas [6] [7][5]. In addition, it can be claimed that nearly 80% of total life span building energy consumption in hot climate is allocated to operation of air conditioning systems and rest 20% to 30% is used for material production, construction and demolition etc. [8] that consequently, has made the energy used for cooling as the major contributor of Greenhouse Gas (GHG) emissions in this climate [9].

In Malaysia as a developing country, buildings account for about 30% of the total Electricity consumption in 2008 and during 2005 to 2010, its consumption rose by 34% growth. Similar Trend can be found in other tropical countries like Thailand. [10][11]. More over Malaysia has one of the fast growing construction industry in the world with rapid population growth and purchasing power of households which led to greater use of mechanical cooling systems.

In most of countries, the per capita energy utilization has been significantly raised particularly in the developed countries. Recently, in developing countries energy consumption increased and has high level which is as a result of general growth in different segments like transportation, residential, commercial, and industrial developments. Therefore, it is essential to think through new degrees and methods to energy preservation in both developed and developing countries for building sector. Conservation of energy is explained as practical method in energy consumption without influencing the standard of occupants living in house [12, 13]. Total energy consumption in Malaysia was 49.5 Mtoe in 2012 which buildings’ (including commercial, public and residential) share reached to 8.8 Mtoe. As Figure. 1 demonstrates the share of building is 23% of total energy consumption in the country (Fig.1) [14].
Fig. 1 shares of different sectors from final energy consumption in Saudi Arabia [14]

Moreover, the greenhouse gas emissions are the other important issues in this country. As Fig.2 demonstrates the total CO2 emissions boomed during 1971 to 2012 which cause that Malaysia be placed among top countries in South West Asia countries which have the most CO2 emissions. Malaysia produced totally 196 Giga ton CO2 which the share of residential building was 1.88 Giga ton CO2. Thus, from this view it is also very important for Malaysia to reduce fossil fuels consumption in all sectors including buildings and increase the share of renewable resources such as wind which can be applied directly for cooling purposes [15].

Energy efficient buildings’ design is currently a noticeable subject on account of the energy costs growth, environmental influences and energy consumption, particularly for global warming. In fact, in many countries, research studies on efficient building design are growing rapid and commercial and residential buildings must include enhancements on energy saving policies [16-18]. Natural ventilation is one of energy efficient methods which can be addressed in sustainable design to decrease overall consumption in buildings. In this paper windcatcher (as one type of natural ventilation methods) will be reviewed briefly in types performance, function and analysis.

2. Different type of natural ventilation

In natural ventilation the initial force to cause the ventilation is the wind which is an important renewable resource. The natural ventilation techniques can be divided to three types as followings:
A. Window opening or vents

This type forms the simplest one of natural ventilation. Via appropriate arrangement of openings, the enough current of natural ventilation can be achieved inside the building to decrease needs of conventional cooling. Joined with windows, vents also can be used in designed position where windows are not needed. Since this technique is economic option, various experimental and numerical studies have been done.

B. Atria and courtyards

Courtyard which can be seen in many regions has been an impactful method to supply natural ventilation for thousands of years for mankind across the world. Courtyards provide a relatively enclosed area to channel and direct airflow to some openings and cause convective natural ventilation inside and nearby the buildings. Different investigations generally admit that the wind-driven ventilation can be raised by application of courtyard and atria but mostly efficient for low rise buildings. Nonetheless, the passive nature of this method shows that its efficiency depends basically on the existence of its driving forces.

C. Windcatcher

One of the conventional systems for providing natural ventilation inside the buildings without utilization of conventional energy is windcatcher. Over three thousand years, people in Middle East used the windcatchers for many buildings. They are known by various names like Badgir, Malghaf, etc. in different areas of this district.

Windcatcher is usually a tall construction which has height between 3 and 33m placed on the building roof (Fig.3). The windcatcher design traditionally depended on the social condition and wealth of house landlords, architects’ personal experience as well as, and differed in the height of tower, number and position of openings, cross-section of the air channels, and tower position with attention to the structure [19].

![Fig. 3 Wind effect on Wind-catcher](image)

3. Types of windcatcher

In terms of external shape, it is generally considered two main categories for wind catcher including unidirectional and multidirectional wind catcher. The former also called one-sided wind catcher and the latter is classified under three sorts: two, three and four-sided wind catcher which usually have square plan, hexahedral and octahedral wind catcher.

A. One-Sided Windcatcher

Many countries of the Middle East enjoyed unidirectional windcatcher for those houses settling in regions which have a permanent prevailing wind. The performance of this system is mostly dependent upon the wind direction. In other words, if there is an unfavorable wind directions, one-sided windcatcher will not well function. Hence, inlet
openings of windcatcher should be at as much as high level to enjoy stack effect (buoyancy effect) like a solar chimney function for that special condition. Fig. 4 depicts the structure of one-sided windcatcher, the wind goes in from the single opening and passes via the living space and leaves the exhaust vents, doors, and windows.

![Fig. 4 one sided wind catcher.](image1)

**B. Two-Sided Windcatcher**

In regions with strong predominate wind, two-sided wind catcher is generally utilized which have two vents and two distinct underneath halves. Fig. 5 shows the bidirectional wind catcher is separated into two channels in order to supplying (suction) and extraction of air flow. The incident angle is the principal advantage of this device compared to one-sided windcatcher in which the unidirectional tower opening exposed under the transition angle and the airflow rate through it tends to zero [21].

![Fig. 5 two sided windcatcher [21]](image2)

**C. Three-Sided Windcatcher**

Fig. 6 illustrates the three-sided wind catcher which often has larger windward side with more openings to capture as much predominant wind as possible. When air flow enters through the wind catcher, air velocity increases owing to curved form of openings [22].
D. Four-Sided Windcatcher

Based on previous studies, an abundance of four-sided windcatcher is more than other types of this system in the Middle East. In areas where there is no specific direction for wind, four-sided windcatcher can be seen; therefore, its design is mainly dependent upon capturing the wind from all directions. Four-sided windcatchers with decorations belong to a famous family’s house in the city of Yazd, Iran as shown in Fig.7 [21].

![Fig.6 A cross section of a three-sided windcatcher [21]](image1)

![Fig. 7 four-sided windcatcher [21]](image2)

E. Hexahedral and Octahedral Windcatchers

These types of windcatchers have been usually seen with regular multifaceted plans and they were designed in the shape of hexagon or octagon. Generally, they are higher than other windcatchers, especially eight-sided windcatcher; therefore, they will have more stability against wind pressure as well as tower form causes passing air flow with lower pressure. The utilization of six-sided windcatchers is limited in the world, however some of them are found as water-reservoirs in Iran. Fig. 8 shows the tallest traditional windcatcher of the world with octagonal plan and approximately 40 meters high, which places in a famous garden (Dolat Abaad) in the city of Yazd, Iran [21].

![Fig. 8 Hexahedral windcatcher [21]](image3)
4. Function and Performance of windcatcher

Windcatcher’s performance is based on the natural ventilation with implementing both stack effect and wind driven ventilation. There are two principal functions of windcatcher: the first is to related to opening which should bring in fresh air inside the building and second related to exit of windcatcher which should remove hot and polluted air of inside the building (the suction functions) and thus works such as a sucked and ventilation system. The windcatcher function can be explained by the fact that when the wind faces with an obstacle, and due to air density on the wind direction, there will be a positive pressure; however, on the other side a negative pressure part. So, there is a flow from positive pressure to negative pressure which cause the ventilation. According to this fact, in windcatcher, the opening in the wind direction absorbs the air into the building inside and the inside air with negative pressure depart from the exit of the windcatcher (Fig. 3).

5. Windcatcher effects on indoor Temperature and co₂ level

Windcatcher can be effective to provide for occupants thermal comfort inside the building and decreasing meaningfully the level of CO₂ concentration. One of the studies which conducted by Kirk [23] in summer 2002, on council offices in Kings Hill, UK, indicate that by night cooling the temperature of internal air was freshen up to 4 °C. So, it is suitable to provide cooled thermal inertia to the building structures and have a fresh start to the day. The study result also shows that when the outside hotness was in high-level (31°C) the interior temperature was quite a few degrees lesser (25 °C on the ground floor, and 28 °C on the first level), while when the external heat was low (approximately under 23 °C), merely the internal warmth was 3 °C to 5 °C above it.

Jones et al [24] explored features of air in two school rooms in UK; in one of them which were test room installed a 800 mm square windcatcher, whereas one conventional opening windows was used for ventilation in the other room. The related measurement which done in the summer (in May and June 2006), indicates that the control room was about 1.5 °C hotter than the test room averagely. Moreover, in the test room’s highest temperature, Night cooling with the wind catcher results was approximately 3 °C lower than the external highest temperature (27.8 °C vs. 30.5°C), while in the control room the parallel highest temperature was 28.9 °C. CO₂ level was also lower in the test room, 840 ppm vs 1324 ppm in the May test, and 575 ppm vs 588 in the June test.

Recently a simulation which done by Khan [25] with utilizing a secure software in a classroom in Sydney, during a February which is one of the hottest months of the year, (external temperature 34 °C), has illustrated that for changing the air in night having a 1000 mm square Windcatcher with solar boost can preserve the internal hotness under 28 °C in 72% of the fixed time.

It can be states that just in less than 11% of the determined time the internal warmth would excel to 30 °C. For other months that are not hotter than February, the air hotness should be less than other. In the simulation process it revealed that in the classroom just 17% of the new air driving proportion in the determined time would be fewer than 240 l/s. This ratio for driving is needed to support 30 individuals with the enough 8 l/s per person.

6. Analyzing methods for windcatcher

Computational Fluid Dynamics (CFD) is widely used for studying windcatcher performance. The CFD models consist of RANS (Reynolds Averaged Navier-Stokes equation) modeling and LES (Large Eddy Simulation). The conservation equation of permanency, energy, momentum, and concentrations of chemical-species can be solved by RANS modeling. An overview of applications of ventilation indicated that CFD is the most popular tool used to assess the ventilation systems including windcatcher. CFD has become a reliable tool for the analysis of flows, heat transfer for any kind of ventilation and cooling systems. With results of CFD software the performance and efficiency of windcatcher can be assessed and easily can study temperature distributions, air velocity, humidity, CO₂ concentration, thermal comfort etc [26]. To validate the results wind tunnel experiment is done. The wind tunnel can extract the air velocity, pressure coefficient, and air flow directions.

7. Conclusion

In Malaysia as a developing country, buildings account for 23% of total energy consumption and statistics reveals that the their CO₂ emissions boomed in recent decade. Due, to high ambient temperature and humidity a great share of buildings energy consumption is related to cooling and ventilation systems. To control this trend, sustainable
solutions should be applied. One efficient strategy for cooling purpose is natural ventilation which is very promising in this country. In recent years, attention toward wind energy as a green source for natural ventilation has been drawn. Natural ventilation has different types which windcatcher is one of the most effective ones.

Windcatcher can reduce temperature and provide fresh air for occupants as well as reduction in CO$_2$ concentration inside the building. Windcatcher has different types which everyone is suitable for a specific condition. This old traditional technique can be merged with new building designs to raise the green concept in the building sector. Finally, this technique can have a prominent share to reduce energy used for cooling in Malaysia.

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