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Evaluation of a two-sided windcatcher integrated with wing wall (as a new design) and comparison with a conventional windcatcher

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ABSTRACT

In buildings, 60% of the energy consumption is associated to Heating, Ventilation and Air-conditioning (HVAC) systems. One solution to reduce this share is the application of natural ventilation systems. Windcatcher and wing wall are two well-known techniques for natural ventilation which have been used in different regions. Nevertheless, in areas with low wind speed such as the tropical climate of Malaysia there is hesitation for application of natural ventilation systems. The integration of windcatcher with wing wall can potentially enhance the ventilation performance. However, this configuration was not looked into by previous investigations thus, this study aims to address this research gap by first evaluating the effect of wing wall with various angles on the ventilation performance and second compare the performance of this new design with a conventional windcatcher. This research used two main investigative steps: experimental scaled wind tunnel testing and Computational Fluid Dynamics (CFD) simulation. Four reduced-scale models of two-sided windcatcher were tested in a low speed wind tunnel. Three models were integrated with wing wall in 30°, 45° and 60° incident angles and another windcatcher was a conventional two-sided windcatcher, which is typical in regions with predominant wind direction. The CFD validation against experiment showed good agreement. The best operation was observed in the windcatcher with 30° wing wall angle which could supply 910 L/s fresh air into the room in 2.5 m/s wind speed. Hence, the new design had 50% more ventilation performance comparing with conventional two-sided windcatcher in the same external wind speed. Finally, it was concluded that the new design satisfied requirements of ASHRAE 62.1.

1. Introduction

Buildings are responsible for 40% of the global energy consumption and accounts for around 40–50% of the carbon emissions all over the world [1]. Moreover, almost two-thirds of total energy consumption in buildings is used for space heating, ventilating, and air-conditioning (HVAC) systems [2]. Generally, less energy use for HVAC systems is required but without compromising a comfortable and healthy indoor environment [3]. In this regard, one promising solution that has gained attention is incorporating free and natural resources from nature such as natural ventilation [4]. Recently, natural ventilation techniques such as windcatchers are increasingly being employed in new buildings for increasing the fresh air rates and reducing the energy consumption [2,5].

A windcatcher can be defined as an architectural element placed on the building roof [6] which provides fresh air to the interior living spaces and releases stale air through windows or other exhaust segments [7]. Traditionally, Persian Gulf countries such as Iran, Iraq, Qatar and Emirates as well as North African region like Egypt and Algeria have utilized windcatcher for cooling [8].

It is not straightforward to ascertain the first origin of windcatcher in the world. However, the first historical evidence of windcatcher was found in Tappeh Chackmaq near Shahrood, Iran during archaeological investigations done by Masouda (1970s) which dates back to 4000 BCE [9,10]. Generally, the windcatcher systems employ both wind driven and stack effect ventilation [11].

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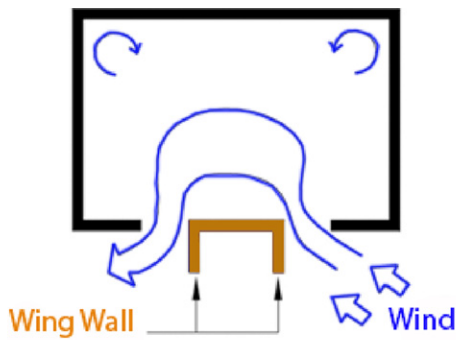

Fig. 1. The illustration of wing wall applied for natural ventilation enhancement in building [19].

The first one works on wind pressure difference between the windcatcher's inlet and outlet which is usually sufficient to drive air into the room, and remove warm and stale air out [12]. Moreover, the windcatcher can also induce airflow movement in and out of the building when there is temperature variation between the indoor and outdoor space, this mode is known as the stack effect [13]. Bahadori et al. [14] stated that the main benefit of windcatcher, like other passive technologies, is that it exploits wind renewable energy for their operation so they are considerably cost effective and more healthier. In addition to improving human comfort, they have low maintenance cost due to having no moving parts, exploit clean and fresh air at roof level compared to low level windows [15]. Windcatchers are generally classified in five groups; one-sided, two-sided, four, six and eight-sided with respect to the number of the openings. Based on the study [7], the efficiency of the two-sided windcatcher is higher than other types, particularly in zero wind incident angle, which can induce the most volume of air flow into the room. Hence, this windcatcher type is typical employed in regions with predominant wind direction [16,17].

Beside the windcatcher, wing wall is another architectural element for natural ventilation to direct the external air flow into the building by projecting portions of the walls vertically from the openings [18]. Broadly, the ventilation rate can be improved by wing wall application owing to creation of pressure differences. For instance, Khan et al. [12] reported that the average air velocity in the room with wing wall is 40% of the outdoor wind speed while without winging wall it is only 15%. Fig. 1 illustrates the provision of wing wall in a building facade vertically between two openings [19].

Despite all advantages of windcatcher, this passive cooling system has less efficiency in low wind speed conditions because the wind driven force is the primary driving force for the windcatcher [17]. For this reason, most of the previous investigations studied windcatcher in medium to high wind speed (3–5 m/s) conditions such as [20,21]. Therefore, in some regions where the speed of ambient wind is low (e.g. tropical climate of Malaysia), windcatcher cannot be implemented efficiently and the numbers of windcatcher studies in this climate are very limited.

In contrast, wing walls can be very effective in situations with low wind speed and variable wind directions [22]. Thus, the combination of windcatcher with wing wall can potentially improve the natural ventilation rates in low wind speed conditions. Hence, the current study introduces a new design consisted of a two-sided windcatcher (due to predominant wind direction in Malaysia climate) integrated with wing walls, called here TWIW (two-sided windcatcher integrated with wing walls). Therefore, the current research has two main objectives including:

- First, to study the effect of wing wall angle on the ventilation performance of the windcatcher and find the optimum angle which provides the best ventilation performance (based on the supply airflow rates) in low wind speed climate such as Malaysia.
- The second objective is to compare the TWIW with a conventional two-sided windcatcher (CTSW).

2. Literature review

Different researchers studied the ventilation performance of two-sided windcatcher as well as other types of windcatcher by wind tunnel testing and numerical methods [5,21,14]. In addition, few investigations evaluated the performance of wing wall –alone– for natural ventilation. In this section a brief review of related pervious researches are summarized.

Afshin et al. [5] investigated ventilation performance of a two-sided windcatcher in different wind angles (α from 0° to 90°) by wind tunnel experiment. A 1:50 reduced-scale model of a conventional two-sided windcatcher in the city of Yazd (Iran) was modeled. The results demonstrated that the transition angles of the house window and windward opening for all wind velocities occurred at wind angles of 39° and 55°, respectively. Based on results, it was concluded that the windcatcher performed as a chimney when wind angle was greater than the windward transition angle (α = 55°) and the highest ventilation rate was seen when the wind was perpendicular to the windcatcher opening.

Montazeri et al. [16] studied the natural ventilation performance of a reduced-scale model (1:40) of two-sided windcatcher system. For various air incident angles, the pressure coefficients of all surfaces of the model and volumetric airflow were measured in an open-circuit wind tunnel. Moreover, to validate the accuracy, the research developed analytical and numerical CFD models of the experimental setup and satisfying agreement among the results was observed. It was established that in higher incident angles of the wind, short-circuiting emerges in the windcatcher and reaches the maximum at wind incident angle of 60. The study highlighted the capacity of the two-sided wind catcher for improving the natural ventilation inside dwellings. The results of comparison factor for one and two-sided wind catcher pointed out that the one-sided windcatcher was more suitable in regions with predominant wind direction.

Haw et al. [23] assessed the ventilation performance of a windcatcher with a Venturi shaped roof (for providing considerable negative pressure to induce air movement) in hot and humid climate Malaysia using CFD and experimental methods. The obtained results showed that at a low outside air velocity of 0.1 m/s, the windcatcher was capable of supplying airflow at 57 air changes per hour (ACH) inside the building. Moreover, the indoor air velocity was observed to be between the range of 0.05 m/s and 0.45 m/s. The study demonstrated the capability of a windcatcher in achieving adequate indoor air quality and enhancing thermal comfort of the inhabitants under hot and humid climate.

Givoni [24] carried out the first investigation of the effect of wing wall on natural ventilation performance of room with two lateral openings. Based on the obtained results of the wind tunnel test, the study concluded that the incorporation of wing wall had high potential to increase the air speed inside the room. Later, Mak et al. [19] used numerical CFD technique to validate the experimental results of Givoni's study. Three different room configurations with and without wing walls at varying wind directions were modeled. The simulation results were generally in good agreement with Givoni's experimental measurements and confirmed that both air change per hour and the average air velocity inside the room were increased by installation of wing walls. The wing wall at the air incidence angle of around 45° showed the best ventilation performance. Furthermore, the highest value of the percentage of mean