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Performance analysis of wind catcher integrated with shower cooling system to meet thermal comfort conditions in buildings

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ABSTRACT

In this study, natural ventilation and cooling of a two-floor building connected to a wind catcher were studied in which a shower cooling system has been used to reduce ambient air temperature. The capability of the system to meet thermal comfort conditions based on adaptive thermal comfort and ISO/EN 7730 standards was evaluated under different operating conditions. In order to estimate the air change per hour and air flow simulation around and inside the test building, ANSYS FLUENT 6.3 software was utilized and the air temperature at the outlet of the shower cooling system was computed using a thermodynamic model. The results showed that for the wind velocity beyond 0.4 m/s, the ACH value for the rooms could be set in the range of 3–20 h^{-1} with the regulation of window's aperture. Under this condition, the temperature and relative humidity of air stream into the building did not change with the wind velocity. Also, it was found that when three buildings are situated in one direction, ACH value for the middle building is less than others. As the ACH value increases, thermal comfort conditions are met for larger values of required cooling demands. Although electrical energy consumption of the proposed system is already lower than evaporative air coolers, it cannot compete with split inverter air conditioners where the relative humidity of ambient air is high.

1. Introduction

Nowadays, people need more energy. From past up to now, many techniques have been employed to make life comfortable and using fossil fuels was considered significantly. However, it has caused destructive effects on the environment. The climate change, air pollution, destroying organisms, and global warming all are the negative effects of fossil fuels consumption that are more common. The notion that consequence of using these kinds of fuels generates more carbons and puts ecosystem at risk of extinction is strictly evident. These issues and high cost of fossil fuels direct human toward another alternative and the past before discovering these fuels and utilizing renewable energy.

The use of renewable sources has become a global phenomenon, and people are eager to apply them. These sources include wind, water, soil, and sun that are inexpensive and according the climate, a certain type is used. Among them, wind power plays an active role in providing thermal comfort and natural ventilation in buildings in many countries, particularly in the Middle East. Wind catcher, domed roof, and aqueduct are symbols of Iranian civilization and architecture (Fig. 1). Ancient Iranians have utilized towers at the top of buildings' roof in order to provide passive cooling effects and comfortable surroundings. However, wind catchers have just been utilized in regions with hot and dry weather. Nevertheless, the application of wind catcher is not limited to the Middle East. Lately, buildings which are equipped with wind catcher are common in oversea. For instance, the Queen's Building at De Montfort University, Zion National Park's Visitor Center, Torrent Research Center, Malta Stock Exchange building and the Inland Revenue building in Nottingham are in this category.

1.1. Literature review

As far as evidences show, many researchers have conducted studies in this field, and various parameters have been investigated in order to raise the efficiency. Bahadori (1985) propounded a plan to develop wind tower efficiency. He showed that the new plan delivers air to the building above the flow rate. It can decrease the air temperature utilizing the evaporative cooling effect. Bansal et al. (1994) verified the concept of a solar chimney coupled with a wind

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Fig. 1. The wind catcher of Dolat Abad Garden in Yazd (a central city of Iran).

tower to provide natural ventilation. He presented that solar chimney has much higher effect for lower wind speeds, as well. Bardan (2003) investigated and analyzed the design of traditional cooling towers that use evaporative cooling technique. In this study, an analytical method was used to compute the air velocity through the building as well as wind catcher. It was assumed that wind catcher was filled with uniformly moist clay conduits. It was also found that the essential elevation of the tower to prepare coherent condition for providing cool air flow into the building is less than 9 m where the traditional design may achieve up to 15 m in height. The result also demonstrated that less elevation is required to provide reasonable cooling effect. Kalantar (2009) numerically and experimentally studied cooling performance of a wind tower in a hot and dry region. In this study, only wind catcher was considered as the computational domain and FLUENT 6.1 software was used to simulate air flow through it. Wet cooler pad located on top of the wind catcher was considered as heat and mass transfer area. The effect of some variables such as wind tower height, variety of the materials used in structure of walls, the amount of vaporized water, the temperature of air, wind velocity and relative humidity on performance of wind catcher were investigated in this study. The findings indicated that the evaporative cooling technique is more effective in hot and dry regions and the temperature reduced considerably in this way. Saffari and Hosseinnia (2009) investigated a new design of wind tower under different structural parameters and environmental conditions using Open FOAM software. It had some wetted columns consisting of wetted curtains hung in the tower column. The wetted columns were modeled as the surfaces that inject water droplets with very low speed. The three-dimensional CFD simulation was adopted for both the Eulerian approach for the air phase and the Lagrangian approach for the water phase. The effects of water droplet diameter and its temperature on system performance were investigated at certain inlet air velocity, relative humidity, and elevation of wetted curtains. The result indicated that 10 m height of wetted curtains reduces 12 K of the ambient air temperature and increases 22% of its relative humidity. In this study, a wind catcher connected to a two-story building was considered as the computational domain and one wall of each room was assumed fully open. Soutullo et al. (2011a,b) estimated a theoretical model to assess the thermal performance of an evaporative wind tower fixed in open space. The results indicated that average cooling power achieved by this way changes from 13 to 16 kW, with maximum peaks around 20 kW. He also concluded that the average temperature drop is around 6.5°C with an average increasing of relative humidity by 27%. Hughes and Ming (2011) studied the relationship between external wind and buoyancy forces due to temperature difference using FLUENT 6.2 software. This study provided that external driving wind is the primary driving force providing 76% more internal ventilation than buoyancy driven flow. It is also found that the effect of buoyancy is negligible without an external airflow passage other than the wind tower itself. Soutullo et al. (2011a,b) experimentally studied the thermal comfort levels gained in open space via evaporative wind tower. He concluded that the average temperature drop is around 3.5°C with an average saturated cooling efficiency about 32%. Bouchahm et al. (2011) theoretically studied the thermal performance of a bioclimatic housing equipped with wind towers in a hot and dry region. They employed performance monitoring and location measurement of the system which provided data to assist model validation. They also offered a number of advances on wind tower configurations for more effective evaporative cooling. It was also assumed that wind catcher was filled with conduits and their internal walls were supposed to be constantly wet. Hughes et al. (2012) investigated the promotion of wind tower and their integration into buildings. They prepared a general review of current and potential of wind tower developments. This review emphasized the different cooling methods which can be integrated with wind tower systems to promote ventilation and thermal performance. Haw et al. (2012) numerically and experimentally examined the performance of wind-induced natural ventilation tower coupled with stand-alone building under hot and humid climate. The result showed that the wind-induced ventilation tower has more derivation air flow rate comparing to other wind ventilators. Analysis showed that the wind-induced natural ventilation tower can produce high air changes per hour for indoor building environment in the hot and humid climate. For example, it produces average of 57 ACH at external wind velocity of 0.1 m/s. Soutullo et al. (2012) worked on optimizing the energy performance of evaporative wind tower with cylindrical cross section. A thermal model was developed to analyze the operation of the evaporative system when the fan and nozzles are working. A fluid model was utilized to evaluate the operation of wind tower when the system is working just based on natural ventilation. TRANSYS 16.1 and FLUENT 6.3 software were used for thermal and fluid modeling. Additional configurations of the wind tower were also evaluated: changing the number of the wind catcher openings, varying the height of the internal walls of the tower and modifying the geometry of the lower ventilation apertures. It should be pointed out that the connection between the wind tower and building was not considered in this study, too.

As mentioned above, the performance of wind catcher for natural ventilation and cooling of building have been investigated in many studies. In most of them, there were some wetted conduits, curtains or clay surfaces under water spraying nozzles. These moist surfaces create alga that is a perfect place for the proliferation of fungus and bacteria which are harmful and contaminate the air that enters the rooms. In the present study, conduits or curtains have been completely omitted in the wind catcher and the water droplets are sprayed into the air stream and directly evaporate. Generally, there are some distinct differences between the present and previous studies which are as follows:

1. Wetted surfaces have been completely omitted in the wind catcher and air temperature reduces in a shower cooling system.
2. A one-dimensional thermodynamic model considering diameter reduction equation for water droplets (due to evaporation) is used to compute the temperature and relative humidity of air stream into the building.
3. In order to evaluate the performance of the system under real operating conditions, a wind catcher connected to a two-story building is located in a rectangular large computational