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Review Paper

The Technology of Modern Windcatchers: A Review †

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Abstract

Using the concept of passive cooling systems has been utilized as a solution to improve thermal and wind comfort and to decrease energy consumption and environmental pollution, recently. Modern windcatcher, as its name denotes, is an architectural element which is using the concept of Badgir and combined proper devices to create ventilation in buildings using wind energy, but including modern technology. It means that the modern windcatcher is an improved model of traditional windcatchers and the design of modern windcatchers is based on computations and they have been analyzed and improved, unlike the ancient ones. The current investigation focused on the technology of modern windcatchers to face how modern technology uses various methods to foster the windcatchers' performance. The purpose of this manuscript is to summarize previous studies on the technology of modern windcatchers and gives insight into the application of windcatchers as passive cooling systems. different employed methods to foster the windcatchers' performance.

Keywords: *Technology, Modern windcatcher, Badgir, Passive cooling, Thermal comfort.*

1. INTRODUCTION

Two techniques of ventilation are natural and mechanical ventilation. Natural ventilation depends on the outer wind conditions to convey the necessary fresh air gradually. (Shun & Ahmed, 2008)

Numerous mechanical devices are utilized for natural building ventilation; the modern windcatcher is one of them. In other words, the modern windcatcher combination of both natural and mechanical ventilation. The examination of the Building Research Establishment demonstrated that this sort of innovation can give an adequate ventilation rate in a building. (BRE) Modern windcatchers adapt and improve traditional windcatchers' designs (Badgir). Studies have resulted in not conducting enough research on the typology of modern windcatcher. Due to the study gaps in this issue, this manuscript includes comprehensive results of the technology of the modern windcatchers research by the authors.

2. MATERIALS AND METHODS

In this study, modern technologies of windcatchers were undertaken by a comprehensive review of previous studies. The literature review was conducted by browsing through publications that include studies related to modern windcatchers around the world. To conduct the comprehensive review, this study first searched articles published in academic databases such as Google Scholar, Scopus, Web of Science, Science Direct, etc. Only studies that use modern technologies of windcatchers in building scale were selected. If a study only investigates traditional windcatchers (Badgir), or mentions urban scale windcatchers, it was not included in the review. The reviewed articles were conducted in different climatic regions all over the world. The publications collected were reviewed, and their study area, type of building, modern technologies, the study parameters, and their findings and opinions, etc. were noted. This process leading to describe the main findings of the reviewed bibliographies and recognize the significant gaps and future titles.

† This article is based on the first author's Ph.D. thesis.

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3. THEORY/CALCULATION

Modern Windcatchers

A conscious expansion of the utilization of windcatchers in the world, lead to numerous new windcatchers. These windcatchers are efficient because they can improve buildings' energy consumption and ventilation of the buildings. The major disadvantages of the traditional wind towers may be summarized as follows: Dust and insects can enter the building. A portion of the air admitted in the tower is lost through other tower openings and never enters the building. The amount of coolness that can be stored in the tower mass is generally limited. so it is not able to completely cool the building during hot summer days The evaporative cooling potential of the air is not fully utilized. (Omer, 2008) Nowadays by using new technology, modern windcatchers were born, which are eliminate the disadvantages of a traditional one. The literature shows various types of modern windcatchers: chimney cowls, Two-sided windcatchers integrated with wing wall, Combination of Wind towers and various renewable energy sources, wind-cater integrate with suncatcher, Rotary windcatcher, windcatchers with evaporate cooling systems. Another point is that most investigations were done in the United Kingdom. But, other countries like Australia, Spain, and the US are using modern windcatchers. The country network is displayed in Figure 1.

4. RESULTS

CATEGORIZATION OF MODERN WINDCATCHERS

Modern windcatchers use new technologies to improve the effect of windcatchers or prevent adverse effects like damper, fan, louver, heat pipe, and so on. We investigated the following issues.

Wind Towers

Wind towers have different shapes but the same function which Includes the following subsections.

A. Modern Simple Windcatchers

Modern simple windcatchers have used the idea of traditional windcatchers (like Iranian traditional windcatchers (Badgir), which are providing ventilation but they combined traditional basic with modern technology (using dampers, sensors, *etc.*). For instance, a basic sort of windcatcher whose commercial name is Mono draught windcatcher. Mono draught can take various structures, the mechanism of this type of windcatchers are automatic and adjustable depending upon the need of the space. (El-Shorbagy, 2010)

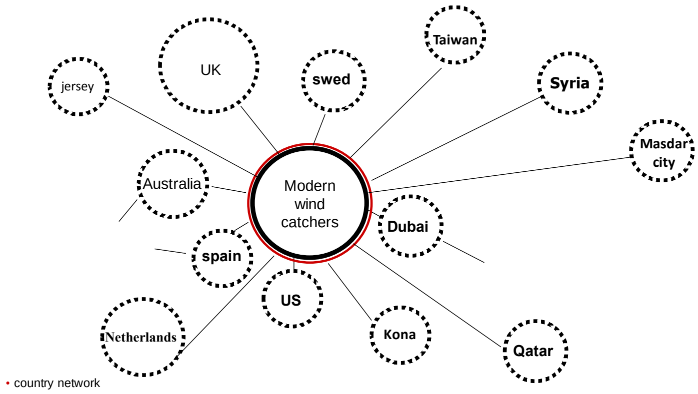

Fig 1. Country Network

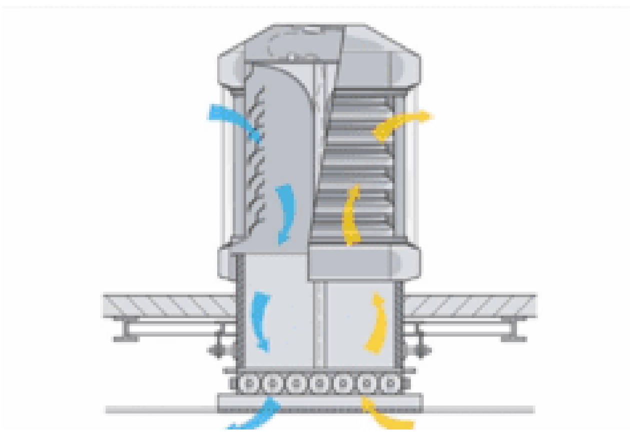

Fig 2. Air Circulation in a Mono Draught,(Mono Draught Windcatchers)

B. Combination of Windcatchers (Chimney Cowls)

A general name for a rooftop ventilation structure that is utilized to combine wind towers is named wind or chimney cowls (Khan, Su, & Riffat, 2008). This type of windcatchers can autonomously rotate with changing wind directions, so the air inlet always faces the windward and the air outlet on the leeward side. In this way, airflow headings inside the pipes alter with the rate twist course. Adekoya (1992) describes two kinds of cowls: pressure cowls and suction cowls. Large cowls can be coordinated into building structure from the first stage of design because its features often working with other concepts such as atria or hybrid ventilation systems to perform optimally, for instance at Bed ZED, this system was created to convey preheated outside air to each home and concentrate its vitiated air, total with heat recuperation from the extricated ventilation air. The positive and negative pressure has to be maximized to increase the airflow and the suction effect, respectively. The cowl can rotate with changing wind directions cause its shape to contain geometric elements (Waibel, 2012).

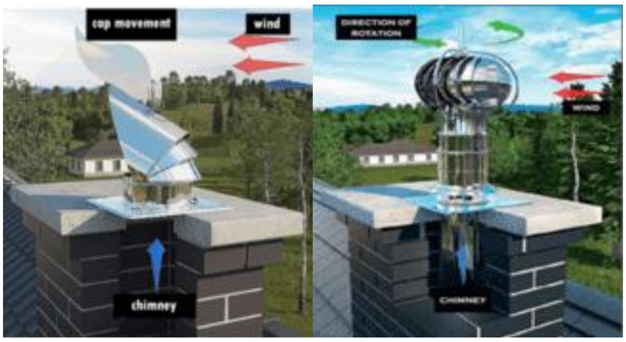

Fig 3. Chimney Cowl

C. Combination of Wind Towers and Various Renewable Energy Sources

Modern windcatchers can be combined with various renewable energy sources

C.1. Wind-cater Integrate with Passive Cooling

C.1.1. Shower Cooling System

Poshtiri & Mohabbati (2017) evaluated the performance of a windcatcher with a shower cooling system. This system reduces temperature and brings thermal comfort inside the building. Figure 4 shows a schematic view of the windcatcher integrated with a shower cooling system. When water is sprayed into windcatcher pipes water is collected in a reservoir (under the first floor's gate). When warm air passes through the windcatcher, because of different pressure and temperature between the water and air, the mass transfer process takes place and the convective heat transfer mechanism becomes active, respectively. This process reduces the indoor temperature and brings cool air to the building.

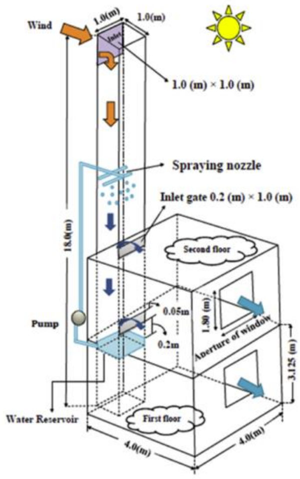

Fig 4. Schematic View of a Two-story Building with Shower Cooling System

C.2. Wind-cater Integrate with Suncatchers (Wind Chimney)

Modern windcatchers can integrate with suncatchers to bring fresh air and natural light together. The suncatcher, which is a natural lighting system, brings daylight to the inside of the building by using a patented dome passing it through a super-silver mirror finished aluminum tube that reflects the daylight to the diffuser. The diffuser distributes the natural daylight evenly inside. (Mono draught windcatchers)

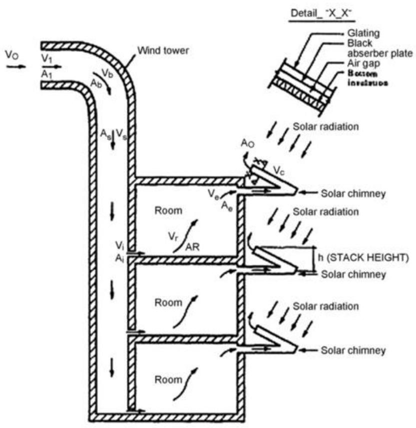

Fig 5. A Windcatcher with the Solar Chimney to Enhance Ventilation (Khan et al., 2008)

C.3. Wind-cater Integrate with Solar-powered Fan

wind-cater integrate with solar-powered fan is a commercial four-sided windcatcher with solar panel, louvers, solar-powered fan, and adjustable dampers. Airflow rates achieved through windcatchers depend on the speed and direction of the wind and sometimes cannot meet the required indoor ventilation. For fixing this issue, Hughes and colleagues (2012) suggested a system which provides a continuous supply of fresh air even when there is no wind. This system is using a low-powered fan installed inside the wind tower with the assist fan. The Solar fan-assisted can also function as an exhaust device for extracting stale air out of the building (see Figure 6).

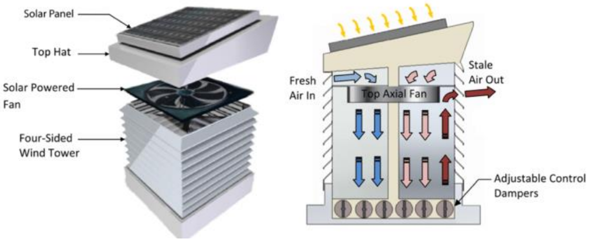

Fig 6. Schematic of a Wind Tower System Integrated with a Solar-powered Fan (Hughes et al., 2012)

D. Two-sided Windcatchers Integrated with Wing Wall

Nejati and colleagues (2016) studied a new design of a Two-sided Windcatcher integrated to Wing Wall (named as TWIW) in order to enhance the ventilation performance of windcatcher in low wind speed climatic conditions of Malaysia (Figure 7). The wing wall brings fresh air inside through openings embedded in the walls (Siew, Che-Ani, Tawil, Abdullah, & Mohd-Tahir, 2011). For enhancing ventilation performance, wing walls can combination with windcatchers. In low wind speed and variable wind directions, wing walls are very useful (Wang, 2014). Nejati and colleagues (2016) present the effect of the wing wall on the airflow distribution using windcatchers as ventilation equipment. The windcatcher with a 30° wing wall, the windcatcher with 45° wing wall, and the windcatcher with 60° wing wall are shared in the article. The best operation was observed in the windcatcher with 30° wing wall angle that could supply 910 l/s fresh air into the room in 2.5 m/s wind speed and this new design had 50% more ventilation performance comparing with conventional two-sided windcatchers in the same external wind speed.

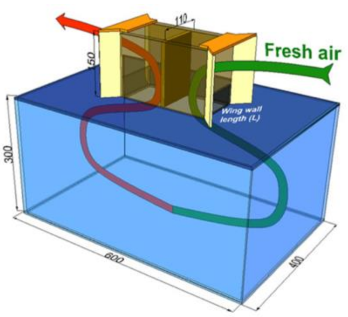

Fig 7. The Schematic of the Model of a Room Ventilated with a TWIW, Dimensions are in Centimeter (Nejat et al., 2016)

E. Windcatchers with Evaporate Cooling Systems

The evaporative cooling system provides more thermal comfort by making the entered airflow cool and humid. Evaporative cooling systems could be integrated with windcatchers by using various techniques, such as wetted surface and wetted column, wetted pads and blades, water spray, shower-cooling systems, and so on we will briefly explain the issue in the following sections.

E.1. Wetted Surface and Wetted Column Windcatchers

Bahadorinejad carried out two new windcatchers, namely wet surfaces and wet columns, which are useful during low wind and high wind, respectively. (M. Bahadori, Mazidi, & Dehghani, 2008) In comparison with traditional windcatchers, the new windcatchers are more efficient, because of reducing inner temperature and increasing relative humidity (Jomehzadeh et al., 2017).

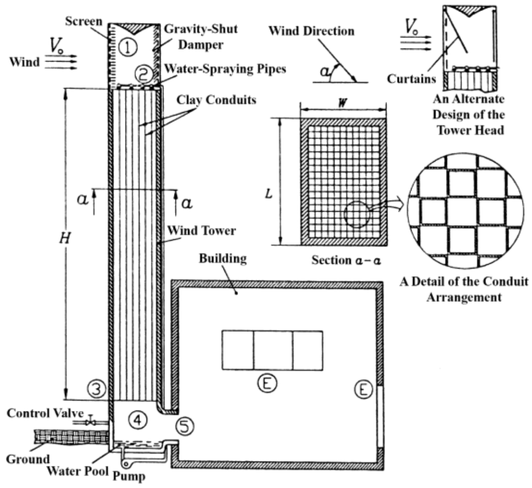

Fig 8. Section of a wind tower with wetted columns (M. N. Bahadori, Dehghani-Sanij, & Sayigh, 2016)

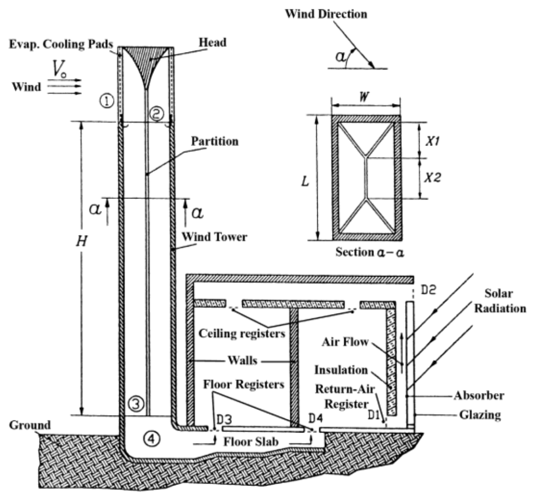

Fig 9. Section of a wind tower with wetted surfaces which integrated with solar chimney (Ibid)

Saffari & Hosseinnia (2009) developed a new feature of wetted column windcatchers that is consisting of wetted curtains hung in the tower column. The curtains injected droplets of water at a very low speed. This kind of windcatchers increases the air relative humidity (by 22%) and decreases inside air temperature (12 K). Figure 10 showed the droplets and wetted surface of curtains.

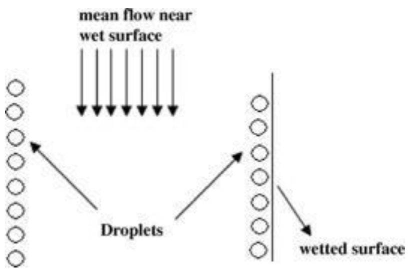

Fig 10. Droplet and the windcatcher with Wetted Curtains (Saffari & Hosseinnia, 2009)

E.2. Wetted Pads and Wetted Blades

Noroozi and Veneris investigated a new design of windcatcher which combined evaporating cooling system and moist blade section and wetted pad unit (2018). In windy conditions, inner air velocity is slightly higher than when the pads are open and in zero wind speed, the close pad doubled the inside airflow.

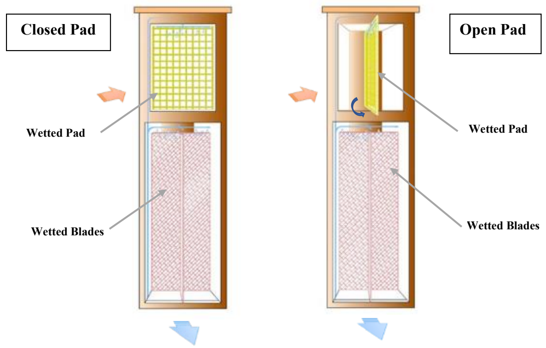

Fig 11. windcatcher with open and closed wetted pads, (Noroozi & Veneris, 2018)

E.3. Water Spray

Using water spray in the windcatcher which benefits from evaporative system leads to increaseing the relative humidity and decreasing the air temperature inside the windcatcher (Ahmadikia, Moradi, & Hojjati, 2012). Kalantar (2009) studied the cooling performance of a windcatcher with water sprayers on top in a hot and dry region and the results show that this kind of system is very efficient in hot and dry regions like Yazd-Iran because water spray decreases the temperature considerably.

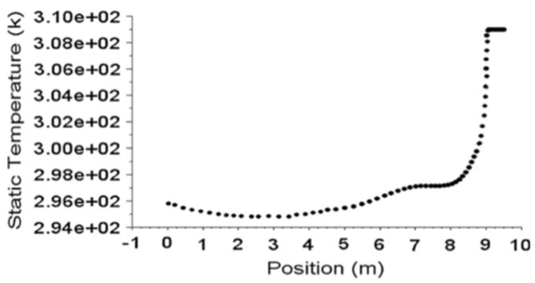

Fig 12. The Variation of Density of Airflow from Entering to Exiting (Kalantar, 2009)

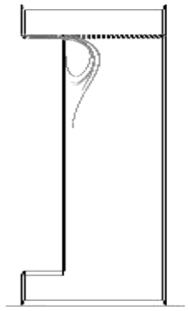

Fig 13. Windcatcher with Water Spray (Ibid)

In Figure 13, when water spray in windcatcher airs density increase (it becomes heavier) then air temperature decrease and then because the walls of wind tower are not isolated against heat transfer the air temperature and capable of releasing conserved heat will slightly increase.

F. Heat transfer device (HTD)

Windcatchers with the evaporative cooling system have some disadvantages. First, they usually have a taller channel with a bigger size to provide sufficient time for contacting the wetted surfaces and the airflow (Jomehzadeh et al., 2017), and finally they use a significant amount of water. Heat transfer device developed to cover these shortcomings in a hot climate (Calautit, Hughes, & Shahzad, 2015). HTD is a compact and an indirect cooling system. It is essentially a conserved slender tube containing a wick structure lined on the inner surface and a small amount of fluid such as water at the saturated state (Calautit, Chaudhry, Hughes, & Ghani, 2013).

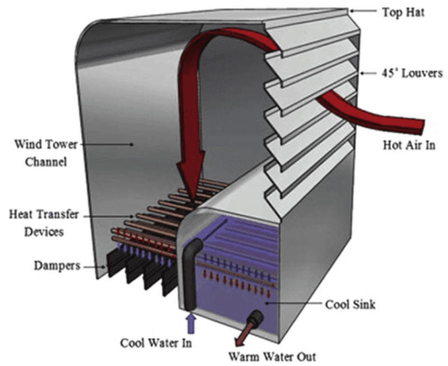

Fig 14. A One-sided Windcatcher Integrated Heat Transfer Devices (Calautit et al., 2015)

G. Rotary Windcatchers

This new design of the windcatcher has several parts like heads (including a moving column), fix parts, and the openings (two openings are installed at the lower end of the column to control the airflow).

The rotary part of the windcatcher can adjust its opening to face the maximum wind speed. This windcatcher can be integrated with a solar chimney or one-sided windcatcher to eliminate imperfections of the low wind speed. using transparent materials in these windcatchers brings natural light inside the building (Dehghani-sanij, Soltani, & Raahemifar, 2015). For instance, the Bluewater shopping mall located in Kent has 39 units of rotary windcatchers. These windcatchers are very efficient because the rotary cowls adjusting the windcatcher to the wind (Elmualim & Awbi, 2004).

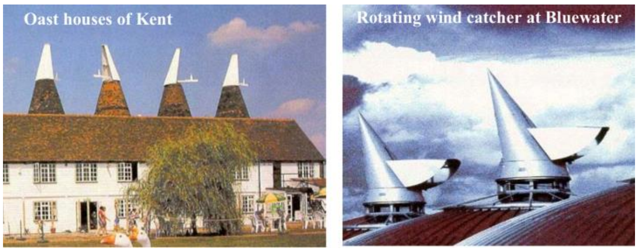

Fig 15. The Rotary Windcatchers in the Bluewater Shopping Mall (Elmualim & Awbi, 2004)

H. Windcatchers with Attached Ingress and Egress Funnels

Varela-Boydo and colleagues (2020) simulated a new design of windcatchers. In their model, funnels combine with the windcatcher. Their simulations show that this new type of windcatcher enhances its efficiency (the volumetric airflow rate increases by 10.7 %). Later, Varela-Boydo & Moya (2020) investigated windcatchers with inlet extensions which can increase windcatcher's performance in low-pressure regions (Varela-Boydo & Moya, 2020).

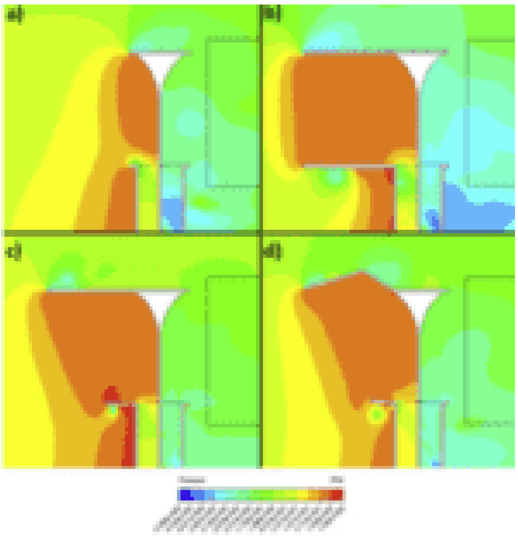

Fig 16. Simulation of Extentions for Inlet of Windcatchers (al Wahid Jassim, Hassan, & Maula, 2020)

I. Integration of PCM with Wind-Catcher Skin Material

Seidabadi and colleagues (2019), introduced a hybrid system of windcatcher and PCM in order to Increase heat transfer rate. The results show that this modern type of windcatchers decreases the interior temperature by about 25°C for 7 hours that can be very efficient in hot regions to meet comfort.

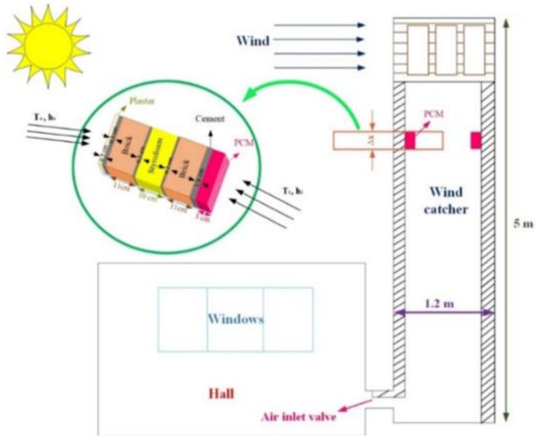

Fig 17. Schematic of Integration of a Windcater with PCM (Seidabadi, Ghadamian, & Aminy, 2019)

J. Earth-to-air Heat Exchanger Assisted by a Wind Tower

The concept of an earth-to-air heat exchanger refers to Naghb which uses in Iran's traditional buildings for cooling the air and accordingly the relative humidity increases (Valipour & Oshrieh, 2013). Some studies (Benhammou et al., 2015), (Dwivedi & Sharma, 2018), (Jassim, 2015), (al Wahid Jassim et al., 2020), (Sadeghi, Samali, Wood, & de Dear, 2020) investigated the combination of an Earth-to-air heat exchanger with a windcatcher to decrease the temperature of spaces. They indicate the efficiency of this system that could reduce fossil fuels' consumption. In this way, we could save energy.

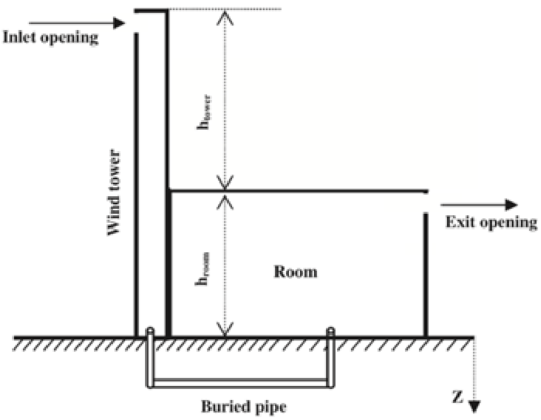

Fig 18. schematic of Badgir and Naghb (Valipour & Oshrieh, 2013)

5. SUMMERY

Modern windcatcher technologies were reviewed before summarizing in Table 1.

Table 1. Classification of Modern Windcatchers

section	Wind cater techniques	Type of building	Method of system	Employed methods to foster the windcatchers performance	Climate features	Results
A	Modern simple windcatchers	Hospital, School, Houses	Dry system	Using damper, sensors and adjustable mechanism	Various kinds of hot region (wind speed,…)	Providing ventilation similar to traditional wind caters with adjustable methods according to regions need
B	chimney cowls	Small scale buildings	Dry system	combination of windcatchers	Regions with variable wind directions	Its features often working with other concepts such as atria or hybrid ventilation systems to perform optimally
C .1	Shower cooling system	Small scale buildings	Wet system	Evaporating cooling system	Hot	Reducing temperature and brings thermal comfort inside the building
C .2	wind chimney		Dry system	sun catcher , diffuser	Low radiation areas	Bring fresh air and natural light together
C .3	wind-cater integrate with solar-powered fan		Dry system	Using solar panel, louvers, fan and dampers	Low wind power (no wind)and polluted regions	providing a continuous supply of fresh air even when there is no wind and can extracting stale air out of the building
D	Two-sided windcatcher integrated with TWIW	Experimental scaled wind tunnel testing and CFD simulation (room-scale analysis)	Wet system	Using wing wall	In low wind speed and variable wind directions	Enhancing ventilation performance
E.1	Wetted surface and wetted column windcatchers	Simulation stage		Evaporating cooling system	Hot and dry	Reducing inner temperature, increasing relative humidity
E.2	Wetted pads and wetted blades					
E.3	Water spray					
F	HTD integrated with windcatcher	Public buildings	Dry system	Heat transfer device, conserved slender tube and a small amount of fluid	Hot	covering shortcomings of Windcatchers with evaporative cooling
G	Rotary windcatcher			Adjustable openings	low wind speed regions	Facing max wind, bring natural light inside
H	Windcatchers with attached ingress and egress funnels	wind tunnel and CFD model (testing scale)		Using funnels	low-pressure regions	Enhancing the ventilation
I	Integration of PCM with Wind-Catcher Skin Material	Public buildings such as shopping malls		Using PCM	Hot	Decrease the interior temperature about 25°C for 7 hours
J	EAHE assisted by a wind tower	Public buildings		Using Earth-to-air heat exchanger	Arid and hot	Decreasing temperature, reducing fossil fuel

6. DISCUSSION

Recent major advances and discoveries and current debates on modern windcatchers have suggested that we face various issues that we will continue to discuss. This study shows that reviews proceed to various issues in this regard which we refer to them below.

The study of modern technology of windcatchers as undertaken in this study are the initial efforts towards providing a more comprehensive guide of modern wind-catchers technologists for passive cooling. Modern windcatcher ventilation techniques have been reviewed and categorized, a summary of their features and types is given in Figure 20.

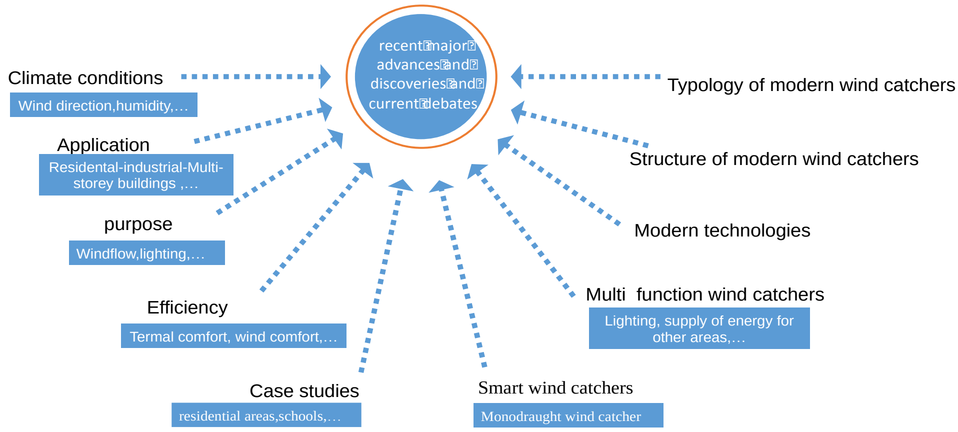

Fig 19. Recent Major Advances and Discoveries and Current Data

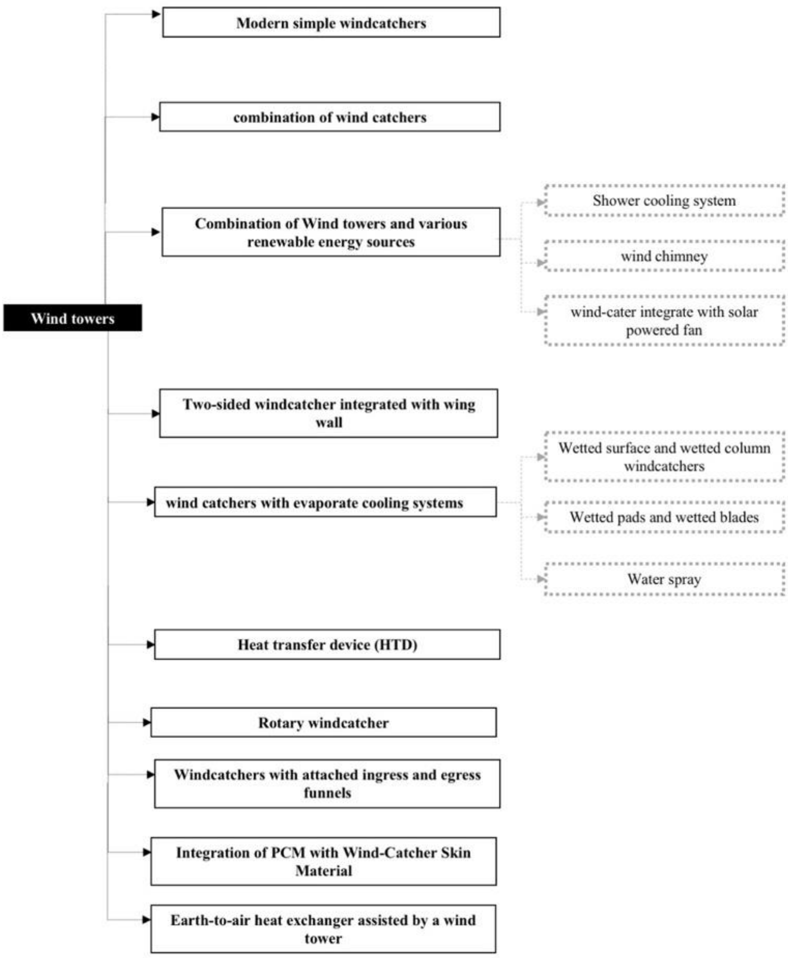

Fig 20. Overview of Previous Studies with different techniques in Modern Windcatchers

7. CONCLUSION

This study aims to investigate the application of modern windcatchers and summarize previous studies on this topic. Previous studies investigated different employed methods to foster the windcatchers' performance. Therefore, the current study addressed this issue by providing a holistic overview of modern windcatchers in terms of technical aspects. It was found that most modern windcatcher studies used basic ideas of traditional ones (mostly Iranian windcatchers) then face their shortages by using modern techniques. For this purpose, they employed various methods: fan, sensors, dampers, evaporating cooling system, funnels, PCM, etc. to foster windcatchers performance. Despite the advantages of Traditional wind towers, they have some limitations which can be fading out with modern technology. The basic standards of each technique were summarized along with their advantages, applications, and their mechanism. The survey shows that models were conducted all over the world (because the beneficiary of windcatchers is proven) using experimental and theoretical testing. Most studies of modern windcatchers were conducted in hot and arid climates and were used in public buildings and houses. Furthermore, previous researches indicated that modern windcatchers enhance users' thermal comfort because modern windcatchers enhance ventilation, reduce temperature, and in some cases, increase relative humidity.

By reviewing the recent results in this area the identification of the significant gaps in the research and where research might go next displayed in the following diagram. The following suggestions can be considered by researchers in the future. For example, the effect of the modern windcatchers material on its function, night and day effect on modern windcatchers performance, the effect of weather conditions and modern windcatchers in a cold climate, pollution of cities, and the use of modern windcatchers, modern windcatchers in a variety of applications (rural, coastal… areas) and modern windcatchers on a city scale, accelerators. In addition to these cases and despite the improved performance of modern windcatchers compared to traditional ones, they also have weaknesses that can be improved therefore improvement of modern windcatchers is a branch that can be considered in the future. The mentioned items are most concerned with the technical issues of modern windcatchers but aesthetic issues are not only very important in the buildings and urban landscape but also in favor of the specialized community and public taste.

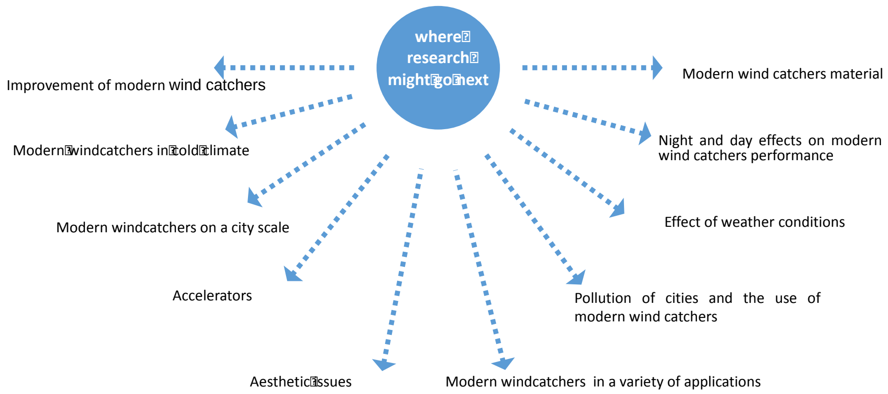

Fig 21. Prospects for Further Studies

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