

Research Article

Analytical study of Wind Catchers and Their Application in Contemporary Architecture

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Abstract

The present study examines the architectural and environmental relevance of wind catchers, focusing on their role in enhancing natural ventilation and improving energy efficiency in traditional buildings. Wind catchers, or badgirs, are passive cooling systems used in arid climates to capture wind for ventilation, reducing dependence on mechanical cooling. The study explores different geometries and designs across cultures, evaluating their effectiveness in improving indoor air quality and thermal comfort. Through historical analysis, case studies, and performance simulations, it demonstrates applications in contemporary design and emphasizes their potential for sustainable construction practices. Results show that integrating wind catchers in modern design significantly contributes to energy conservation and climate-responsive architecture. This study also aims to raise awareness among architects and planners about the value of traditional passive cooling systems in addressing current environmental challenges.

Keywords: Wind Catchers, Natural Ventilation, Energy Efficiency, Sustainable Architecture, Passive Cooling Techniques.

1. Introduction

Wind catchers are among the most recognized architectural elements associated with air movement within spaces. They remain one of the oldest techniques still used today, especially in hot regions—both arid and humid—and were widely used in Arab countries. Wind catchers enhance natural ventilation, control air speed and distribution inside buildings, and are found from India and Pakistan through Iran, Afghanistan, and the Gulf states, to North Africa. Over time, the single-direction wind catcher evolved into the multi-directional badgir, which captures air from all directions. The traditional wind catcher is common in both arid and humid regions, whereas badgirs are used mainly in humid areas.

1.1 Study Importance

- To explore natural ventilation as a sustainable alternative to mechanical systems.
- To analyze how traditional wind catchers can be applied in contemporary architecture.
- To propose innovative solutions for climate adaptation and resource scarcity.

1.2 Research Problem

This study integrates wind catchers with low-energy strategies like solar design and evaporative cooling, enhancing their effectiveness across climates. It aims to trace their historical evolution, classify their types, and develop design principles for optimal natural ventilation and reduced environmental impact.

1.3 Research Objectives

- Identify key factors influencing natural ventilation inside buildings.
- Understand the history and concept of wind catchers.
- Study their use across regions and analyze factors affecting performance.
- Define main and additional design elements of wind catchers.

1.4 Methodology

The research adopts an analytical-descriptive method based on a systematic literature review from databases like Scopus, Web of Science, and ScienceDirect. Keywords included “wind catcher” and “natural ventilation.” Studies underwent filtering and classification to ensure relevance to contemporary applications.

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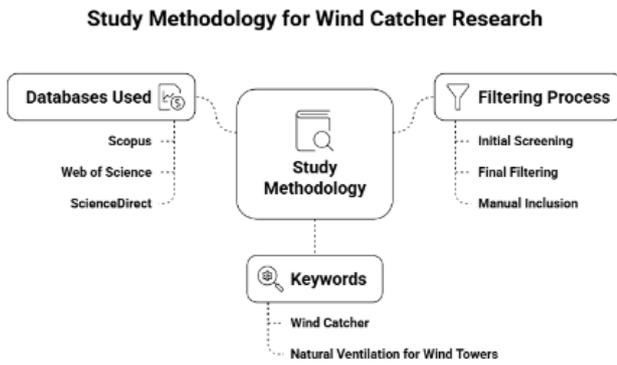


Figure 1: Research Methodology

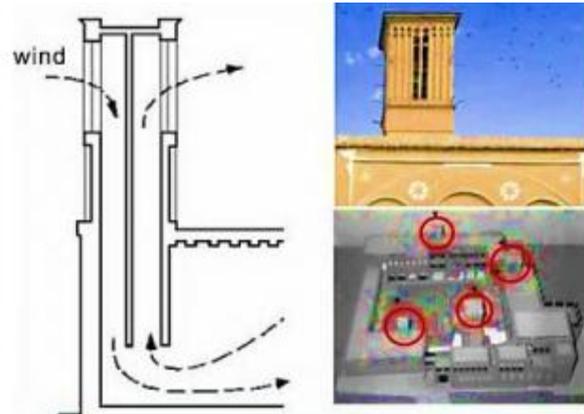


Figure 2: Wind Catcher (El-Ahwal et al, 2017)

2. Theoretical Background on Natural Ventilation

2.1 Wind Towers and Wind Catchers

Wind towers are architectural elements designed to harness the potential of wind energy. They can be positioned on the roof of a building, adjacent to it, or built as independent structures connected to the building through an integrated duct. Unlike chimneys, wind towers typically have openings on multiple sides. The flow of wind around the building causes air separation, generating positive pressure on the windward side and negative pressure on the leeward side. Airflow follows these pressure gradients within the tower and exits through specially designed openings, including those facing the windward side. The size and position of the openings (such as windows, doors, etc.), as well as the arrangement of internal walls, play a significant role in promoting cross-ventilation and improving indoor air mixing. The orientation of wind towers also varies according to the desired prevailing wind directions. A variety of traditional wind catcher designs have been identified across the Middle East, as illustrated in Figure 4 (Maleki, 2011).

Openings for air inlets and outlets within rooms stimulate the movement of cool air inside interior spaces, especially when an inlet is provided on one wall and an outlet directly opposite it, creating an airflow similar to the stack effect. Ideally, one end of the system should be located at a lower level (such as the ground or basement floor), while the other end should be positioned higher (such as the roof) to achieve the pressure difference needed to drive the airflow, as illustrated in Figures 2 and 3. The choice of construction materials used for wind towers and catchers depends on the prevailing climatic conditions. These materials—through their thermal mass and insulation capacity—significantly influence the tower’s performance as a natural cooling element. Such materials include adobe bricks, stone, or concrete, which help absorb coolness during the night and release it during the day, thus enhancing the tower’s effectiveness as part of a natural ventilation system (Kamal, 2012).

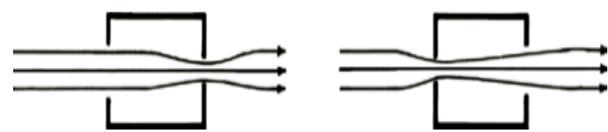


Figure 3: The inlet and outlet openings should be of equal size; however, if equal dimensions are not possible, the inlet should be smaller to achieve maximum airflow velocity (Ahmed & Aboul-Leil, 2017)



Figure 4: Traditional Wind Catchers in the Middle East (Saedi, 2015)

2.2 Types of Wind Catchers

(a) **Single-direction wind catchers:** These are designed to face the prevailing wind and are usually built within the wall thickness itself. They typically end at the bottom with an opening located no more than one meter above the floor level (Al-Serri, 2000).

(b) **Well-type wind catcher:** This type is constructed as air shafts within the walls. It has high thermal capacity, which contributes significantly to cooling the indoor air. The top of this catcher features an inclined barrier that helps direct airflow into the shaft, allowing cool and humid air to reach the interior spaces (Ibrahim, 2020).

(c) *Movable wind catcher*: This type includes a square or rectangular opening integrated into a wooden ceiling. The opening is covered by a movable wooden shutter of the same size, which can be tilted to allow cool natural air to enter the building during summer and closed in winter, becoming part of the ceiling structure (Ibrahim, 2020).

(d) *Single-direction inclined wind catcher*: This catcher has a slanted umbrella-like form that projects above the building's roof. It typically has a rectangular or square section measuring around 3 × 3 meters. The top surface is usually covered with wood, while the sides may be finished with wood or brick, coated with insulating materials, or lined with lead sheets to improve thermal resistance (Adel, 2016).

(e) *Lightwell wind catcher*: This type functions as a corridor or shaft located at the beginning or end of a building. Some structures may have two such catchers—one at the front and one at the rear—to facilitate both ventilation and natural lighting (Ibrahim, 2020).

2.3 Factors Affecting the Efficiency of Wind Catchers

(a) The orientation of air inlet openings relative to prevailing wind directions.

(b) The difference in the sizes of air inlet and outlet openings—where the inlet facing the wind should be smaller than the outlet to maintain airflow velocity.

(c) The position and number of air outlet openings within the tower, which influence pressure balance and airflow paths.

(d) The cross-section and internal dimensions of the wind tower—smaller or circular air passages tend to increase wind speed.

(e) The inclination angle of the catcher's surface, which should ideally be around **30 degrees** for optimal performance.

3. Historical Development of the Wind Catcher

The use of wind catchers dates back to ancient civilizations such as the Mochica Indians in Peru and ancient Egypt, where they were utilized as early as **1500 BCE**. Historical examples include:

- **In Egypt**, wind catchers were depicted in maps and architectural drawings from the Pharaonic era, as illustrated in **Figure 5**, and similar systems were also found in **Babylon**, as shown in **Figure 6**.
- **In Iran**, it is believed that the Persians were the first to use wind catchers extensively, with evidence indicating their application as early as **4000 BCE** (Di Nardo & Rossi, 2016).

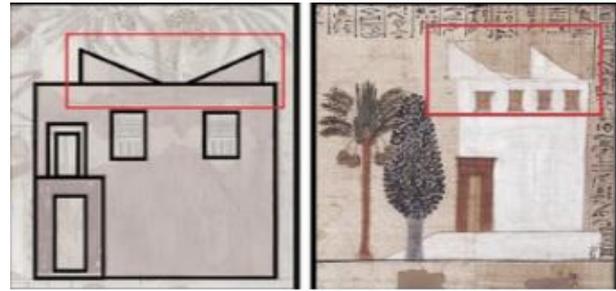


Figure 5: Wind Catchers in the Pharaonic House of Neb-Amun

(a) Reconstruction by the authors based on Fathy, *Elevation of the House of Neb-Amun*. (b) *Book of the Dead*, depicting a building with a wind tower in the lower right corner (highlighted in the red box), dated approximately **1336–1294 BCE** (Di Nardo & Rossi, 2016).

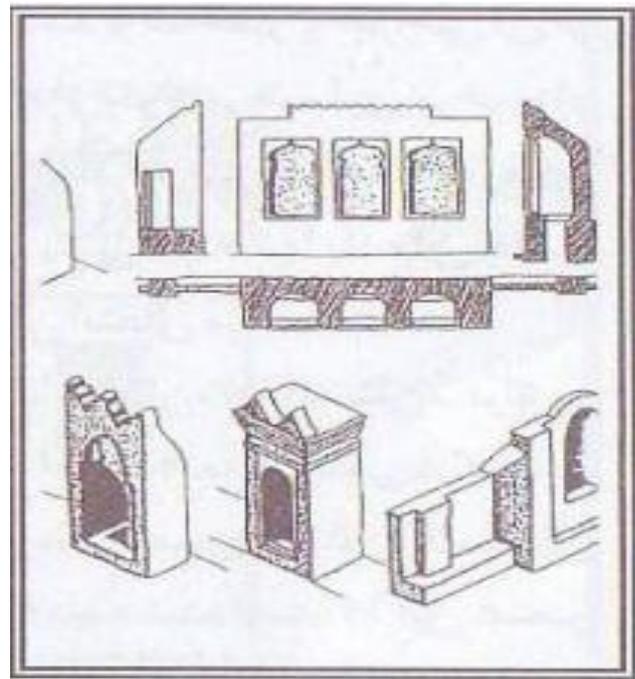


Figure 6: Wind Catcher in Iraq (Roaf, 1988)

The **wind catcher** is considered one of the most effective traditional architectural elements for improving natural ventilation and creating a comfortable indoor environment in hot and arid regions. Its design and application have varied across different climatic and geographical conditions, reflecting its adaptability and responsiveness to the local environment.

Table 1 presents a range of wind catcher applications across various countries and regional climates, highlighting their **design characteristics**, **prevailing wind directions**, and **integration with evaporative cooling techniques**

Table 1: Use of wind racks in different geographical areas

| Evaporative cooling | Number of parts of the cover | The wind roof | Dimensions of the rounded cross-section | Height (meters) | Cross-section of the clip | The lovely wind direction | The regional climate | Country |
|---------------------|------------------------------|---------------|---|-----------------|--|---------------------------|----------------------------------|---|
| There it is | Single or multi-sided | °45 | 0.5x0.8 0.7 x1.1 | 3-5 | Square/ rectangle/ hexadecimals and octal. | Northeast | It is hot and dry | Iran's |
| There it is | One-sided | °45 | 0.5 x0.15 | 1.8-2.10 | Rectangle | Northwest | It is hot and dry | Iraq |
| There it is | Multi-faceted | °30 | 1 x 1 | 3-5 | Square/Circular | South-West/ Northeast | It is hot and humid | Bahrain, Kuwait, Oman, Qatar and United Arab Emirates |
| It does not exist | One-sided | °45 | 1 x 1 | 2-4 | Square | Southwest | Warm and humid It is hot and dry | Pakistan |
| There it is | One-sided | °30 | 2 x0.5 | 3-4 | Rectangle | Northwest | It is hot and dry | Egypt |
| It does not exist | One-sided | °30 | 1 x 1 | 1-1.2 | A box above a circular design | North | It is hot and dry | Afghanistan |

3.1 Development of the Wind Catcher in Contemporary Architecture

3.1.1 Factors Influencing the Improved Performance of the Traditional Wind Catcher

(a) Number of Openings: The number of openings in a wind catcher directly affects its performance and efficiency in providing natural ventilation. Modern designs, such as the **four-sided wind catcher**, enhance a building’s ability to harness wind effectively, thereby improving indoor air quality and reducing dependence on mechanical cooling systems (Montazeri, 2011).

(b) Shape of the Openings: The shape of the wind catcher’s openings significantly impacts its ventilation performance. Different blade configurations—whether fixed or adjustable—play a crucial role in optimizing airflow and minimizing energy consumption. More efficient designs, such as **divergent inlets** and **X-shaped blades**, have shown positive results in improving indoor thermal comfort (Abdo et al., 2020).

(c) Size of the Openings: The size of the wind catcher’s openings also greatly influences its performance. Experimental studies have shown that **reducing the height of the openings** can help maintain airflow and stabilize air distribution inside the building (Kubota et al., 2022).

(d) Height of the Wind Catcher: According to a study by Ismail & Miran (2019) conducted on a classroom where wind catchers of different heights (3 m, 6 m, and 9 m) were tested—illustrated in Figure 7—the **height of the wind catcher** has a significant effect on its performance. Tower height influences air velocity, flow rate, and the rate of air exchange. The study found that

increasing the height improves performance up to a certain limit, with heights between **6 and 9 meters** being the most effective. The surrounding building heights must also be considered to ensure effective wind flow.

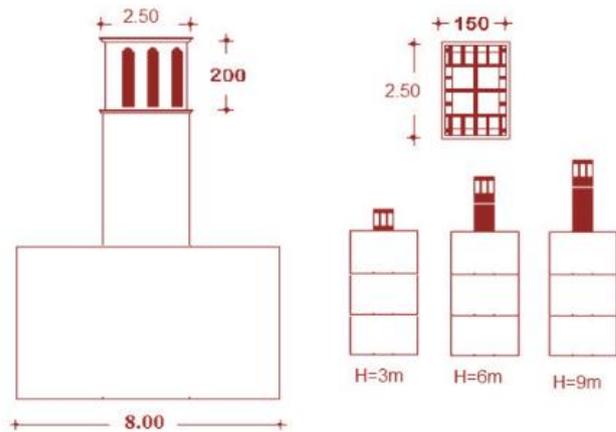


Figure 7: Wind Catchers of Different Heights (3 m, 6 m, and 9 m) Integrated into a Classroom (Ismail & Miran, 2019)

(e) Cross-Sectional Shape: The **cross-sectional shape** of the wind catcher has a significant influence on its performance:

- A **hexagonal shape** enhances airflow and reduces sensitivity to wind direction.
- A **square shape** provides better thermal comfort due to higher average internal air velocity.
- A **rectangular shape** demonstrates greater airflow efficiency compared to a circular one.
- The **geometric structure** plays a critical role in performance improvement, as increasing both the

cross-sectional area and height enhances ventilation efficiency (Jafari et al., 2018).

directly affect ventilation effectiveness (Dehghan et al., 2013).

(f) Roof Shape of the Wind Catcher: The roof configuration of the wind catcher also plays a vital role in its overall effectiveness:

- **Increased airflow:** Curved roofs exhibit higher efficiency under certain wind conditions.
- **Improved ventilation performance:** Proper roof angles can optimize wind capture and airflow under various environmental settings.
- **Air distribution:** Geometric characteristics-such as the direction and placement of inlet openings-

In recent years, **wind catcher systems** have undergone remarkable development. Their role has expanded beyond mere natural ventilation to become part of **integrated environmental systems** aimed at improving a building's overall environmental performance, particularly in **hot and arid climates**.

Researchers have explored the **efficiency of wind catchers** when combined with **cooling or heating systems**, to enhance thermal comfort and reduce dependence on conventional energy sources.

Table 2 summarizes several studies that have examined this topic

| Results | Mechanism of study | Type of wind | Standard design | Reference | | | | |
|--|--------------------|-----------------|-----------------|------------------|--------------|---------------|---|----------------------------|
| | Theory | Experiment ally | | | | | | |
| | Other | CFD | A small model | A complete model | The openings | Cross section | | |
| The wind outlet equipped with thermal piping technology has a cooling capacity of up to 12°C of the supply air temperature. | | ✓ | ✓ | | One-sided | Rectangle | A refrigerator with a cooling system (Thermal Pipe Technology) | (Calauja & Hughes, 2016) |
| The integration of a wind farm and ground-to-air heat exchanger (FAHE), can reduce electrical power consumption and carbon dioxide emissions, while providing the required ventilation. | ✓ | ✓ | ✓ | | One-sided | Rectangle | A refrigerator with a cooling system (Ground-so-air heat exchanger (EAHE) | (Gilvaci et al., 2022) |
| Integrate an integrated system consisting of a solar chimney with a wind catcher, with an indirect evaporative cooler with the help of a fan for fresh air conditioning, capable of meeting the temperature and air quality requirements of the place throughout the summer. | ✓ | | | ✓ | One-sided | Rectangle | A refrigerator with a cooling system (Solar chimney with wind rack with evaporative cooler) | (Harrouz et al., 2021) |
| The clamping process with the humidified brick, which does not raise the air humidity level much, reduced the air temperature by about 12 degrees Celsius on hot days. | ✓ | | | ✓ | One-sided | Rectangle | A refrigerator with a cooling system (Walls covered with proud bricks) | (Al-Jawadi, Darwish, 2016) |
| The addition of heat pipes and extended surfaces reduces the flow of air through the windmills, but does not hinder the flow even at low wind speeds in the open air. | ✓ | | | ✓ | One-sided | Rectangle | Heated floor (Thermal Pipe Technology) | (Calautit & Hughes, 2016) |
| Although the rotary Heating wheel has been clogged, the ventilation rates have managed to provide adequate ventilation. | | ✓ | ✓ | | Six-sided | Circular | Heated floor (Rotary thermal wheel) | (Calautit, RT al., 2019) |

3.2 The Contemporary Wind Catcher

Recent studies on wind catchers have focused on developing **innovative designs** to enhance ventilation performance and energy efficiency.

Li (2023) proposed a **dual-channel wind catcher** equipped with a **rotating scoop**, as illustrated in **Figure 8**. This design enables effective airflow regardless of wind direction and demonstrated significantly higher efficiency compared to traditional models.

Similarly, Nejat et al. (2016) developed an **anti-short-circuit device** to improve ventilation performance. Experimental results showed that it effectively **reduces carbon dioxide concentration** and **increases airflow velocity** within indoor spaces.

Additionally, a **double-sided wind catcher** with a **side wall** was evaluated, showing a **50% improvement in ventilation performance** compared to conventional designs.

Other research, such as that conducted by Ghoulem et al. (2020), investigated the impact of **evaporative cooling systems** and analyzed the **performance of wind catchers under various climatic conditions**, emphasizing the importance of **innovation in design** to achieve effective natural ventilation and thermal comfort in buildings. The **design concept proposed by Ghoulem et al.** is illustrated in Figure 9.

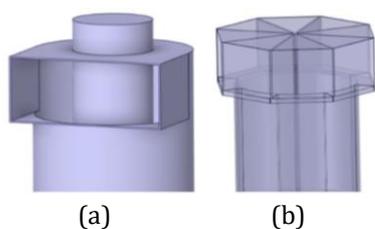


Figure 8: (a) Dual-channel wind catcher equipped with a rotating air scoop (b) Traditional octagonal wind catcher (Li, 2023)

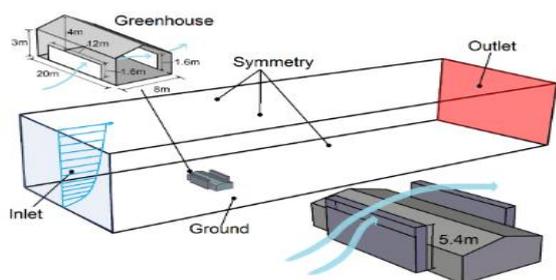


Figure 9: Simulation of a Greenhouse Integrated with a Wind Catcher System Equipped with an Evaporative Cooling System (Ghoulem et al., 2020)

The **experimental model** used in the study, illustrated in Figure 10, involves conducting an **experimental investigation** using a **scaled model** combined with **Computational Fluid Dynamics (CFD) analysis** to evaluate the **cooling and ventilation efficiency** of a **solar chimney integrated with a wind catcher and a water-spray system**.

The results demonstrated that this design can provide **suitable thermal conditions** and **adequate airflow** for two building floors even during **hot and sunny days**, without relying on wind power. Moreover, the system showed the capability to **reduce the average indoor temperature by 5.2°C during peak hours**, achieving up to **75% savings in total cooling demand** and **90% savings in ventilation energy consumption** during peak summer working hours.



Figure 10: Experimental Model of the Study Design (Ghoulem et al., 2020)

The **natural ventilation mechanism** in the study model is closely linked to improving **airflow within the building**, thereby enhancing the efficiency of cooling and ventilation—particularly under extreme climatic conditions. This mechanism relies on **pressure and temperature differences** to drive air movement, which contributes to **temperature reduction through evaporative cooling** within the wind catcher and increases **freshwater production** by enhancing available humidity. The model also demonstrates how a **balance between airflow and energy** can be achieved, reducing dependence on traditional energy sources and improving the system's overall efficiency.

4. Results

4.1 Design Principles of the Wind Catcher

Through analysis and research, the author identified the fundamental components that constitute the wind catcher. These elements are crucial in determining the efficiency of natural airflow inside the building and directly influence both ventilation quality and environmental conditioning performance.

These design principles were derived from a comprehensive review of previous studies and the analysis of architectural models. They are summarized in Table 3, which presents the design foundations of both the primary and auxiliary components of the wind catcher.

The table reveals that certain factors—such as cross-sectional shape, number and form of openings, and height of the tower—play a decisive role in improving air circulation within indoor spaces. Meanwhile, auxiliary components such as extensions, partitions, nozzles, and integration systems have proven effective in enhancing overall performance, both by increasing ventilation rates and reducing indoor temperature significantly.

These findings highlight the importance of maintaining a balanced relationship between the primary and supplementary design components to achieve optimal performance of wind catchers in contemporary buildings.

Table 3: Design Principles of Primary and Auxiliary Wind Catcher Components

| The design details | Primary/ additional | Component |
|--|---------------------|--------------------------------------|
| A rectangular handle provides higher air flow efficiency compared to a square or ring. | Primary | Cross section |
| Four-sided decks increase air flow, and the two-sided decks achieve the highest efficiency at a 90-degree angle. | Primary | Number of openings |
| The "-shaped blade windfalls have a lower ability to lower internal temperature, while the Kh and X- shaped blade wind outlets have higher potential. | Primary | The shape of the openings |
| There is a difference in the results of research on increasing the size of the openings, as the relationship between the size of the aperture and the speed of the air is not always linear. | Primary | Size of openings |
| A height of 6 meters is considered to be the optimal height for wind caters. | Primary | Height of the handle |
| A curved ceiling is better than a flat and inclined ceiling. | Primary | The ceiling |
| Add a number of 2 to 4 breakers at the entry slots. | Additional | Crackers at the entrance slot |
| Conical extensions are more effective and can increase ventilation efficiency by up to 29%. | Additional | إمدادات عند فتحة الدخول (Extensions) |
| The conical nozzle lowers the temperature by 11.5°C. | Additional | الفوهة (Nozzle) |
| The width of the section should be 20% to 30% of the width of the air tunnel. | Additional | Cutters |
| Achieve the principle of cross ventilation that improves natural ventilation. | Additional | The corresponding slot |
| Increases the capacity of the apron to capture air, due to the increased exposure surface to air. | Additional | الجدار الجانبي (Side wall) |
| Helps increase air flow by 30% and reduce temperature by 5 degrees Celsius. | Additional | System of integration |

Based on the analysis of the previous results, the researcher concludes that the optimal configuration of wind catchers, in terms of achieving the highest ventilation efficiency and increased airflow rate, consists of a dual-sided wind catcher with a rectangular cross-section and an ideal height of 6 meters, combined with a curved roof to enhance the smoothness of airflow.

It was also found that adding an extension at the air inlet in the form of a conical nozzle significantly improves cooling efficiency and reduces indoor temperature compared to straight designs. Drawing on these design insights derived from the studies and analytical results, the researcher developed a proposed wind catcher model that integrates both primary and auxiliary components which demonstrated the highest levels of performance in improving natural ventilation.

This proposed configuration is illustrated in Figures 11 and 12.



Figure 11: Cross-Sectional Illustration of the Proposed Wind Catcher Showing Primary and Auxiliary Components (Prepared by the Researcher)



Figure 12: Proposed Design of the Wind Catcher Incorporating Primary and Auxiliary Components (Prepared by the Researcher)

4.2 Challenges of Applying Wind Catchers in Contemporary Architecture

Although numerous studies have demonstrated the efficiency of wind catchers in improving ventilation quality and reducing energy consumption, the application of this traditional system in modern architecture faces several **practical challenges**, including:

- **Architectural Integration:** Difficulty in functionally and aesthetically incorporating wind catchers into high-rise or multi-story buildings without affecting the exterior form or internal spatial organization.
- **Climatic Changes:** Certain regions no longer benefit from natural ventilation as effectively due to shifts in wind patterns and increasing pollution levels.
- **Regulatory Constraints:** Urban planning and building codes in some countries do not yet accommodate the integration of traditional passive

elements such as wind catchers into modern architectural designs.

- **Awareness and Acceptance:** Limited awareness among architects and end-users regarding the benefits of passive cooling systems, which reduces the likelihood of their widespread adoption.

Conclusion

This study on **wind catchers and their applications in contemporary architecture** represents an important step toward enhancing the general understanding of **natural ventilation techniques** and their impact on **energy efficiency** in buildings.

Through the analysis of historical and modern designs, the research highlights the benefits of integrating wind catchers into contemporary architectural projects, contributing to reduced reliance on mechanical cooling systems. The findings indicate that the use of wind catchers can significantly improve indoor air quality and occupant comfort, while also reducing carbon emissions.

Furthermore, the study promotes greater awareness among architects and urban planners about the importance of utilizing traditional passive cooling methods as effective responses to current environmental challenges.

This research opens new avenues for innovation and development in the field of sustainable architecture, encouraging exploration of new and creative wind catcher designs adaptable to various contexts. Integrating these traditional systems with modern design solutions will help create more sustainable and energy-efficient environments.

In conclusion, wind catchers remain a fundamental architectural element that should be reconsidered in modern contexts as part of sustainable solutions to climate change and environmental challenges.

The study confirms that wind catchers continue to offer effective means for improving building environments, enhancing natural ventilation, and reducing dependence on mechanical systems. Results demonstrate that rectangular designs with optimal height and efficient blade configurations (such as X and H shapes) achieve the highest thermal performance and indoor air quality.

The scientific contribution of this research lies in presenting a clear and practical design framework that strengthens the integration between traditional architectural solutions and modern sustainable practices. It also underscores the potential of wind catchers as adaptable and innovative tools, particularly when combined with supporting systems such as evaporative cooling or conical nozzles.

In light of current environmental and energy challenges, the study recommends the integration of wind catchers into new construction projects, especially in hot climates, and calls for further research into hybrid systems that combine natural ventilation with smart environmental control technologies.

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