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CFD evaluation of wind catcher geometry and internal partitions for enhanced ventilation in Nizwa

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ABSTRACT

This study aims to evaluate the effectiveness of wind catchers as a passive cooling strategy in regions with hot climates, where their potential remains largely unexplored. Focusing on a mosque building in Nizwa, Oman, the research investigates the impact of windcatcher geometry and internal partitions on indoor ventilation. The existing case is analyzed, and indoor ventilation conditions are simulated, followed by the generation of various scenarios, including different windcatcher shapes (Square and Rectangular) and various internal partition types (X blades, + blades, and H blades). Each scenario is subjected to CFD analysis. Results show that a Square windcatcher with X+ combination type partitions increase indoor ventilation, raising air velocity from 0.333508 m/s (base case) to 0.693379 m/s (scenario), leading to a 51.9% improvement in indoor ventilation rate. This research suggests valuable insights for architects and designers, advocating for the utilization of windcatcher principles to promote more sustainable architectural practices.

I. INTRODUCTION

Passive cooling design relies heavily on the concept of natural ventilation. This principle plays an essential role in sustainable and bioclimatic architecture, defined as "the passive low-energy design approach that uses the ambient energies of the climate of the locality to create conditions of comfort for the users of the building" [1]. To enhance human thermal comfort, sustainable building design incorporates strategies that respond to climatic and environmental conditions [2-4]. Most of the studies concluded that the fundamental solution of sustainable building design is most likely found in vernacular architecture, where many worthy traditional examples still exist. Within this context, passive heating and cooling subjects play an essential role that depends on the concept of natural ventilation [5-8]. Sorensen [9] identifies three primary methods for achieving passive cooling through natural ventilation: cross ventilation driven by pressure differences, chimney ventilation exploiting the stack effect, and wind-driven ventilation using wind towers or catches (Figure 1).

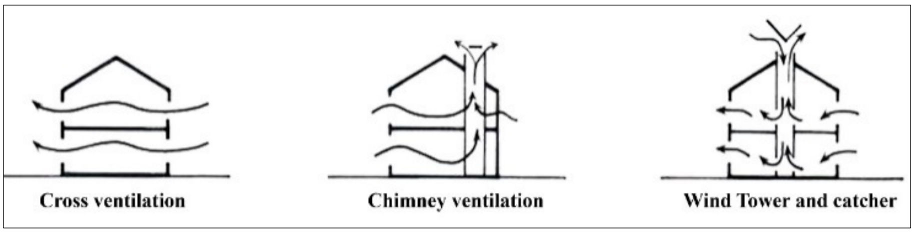

Figure 1. Natural ventilation basic models [9]

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Wind catchers are taller and smaller in hot, dry climates compared to humid ones. To capture cooler air, they are positioned to draw air from higher altitudes where it is cleaner and cooler [10, 11]. Unlike humid regions, wind catchers in arid climates typically extend to the lowest inhabited floor [12-15]. Wind towers are passive cooling systems that harness natural ventilation. Similar in principle, wind catchers utilize both the stack effect and wind pressure to induce airflow. The design of wind catcher openings and the vertical shaft geometry influence how effectively wind is captured and directed into the building [16, 17]. The fundamental workings of a wind catcher are visually represented in Figure 2.

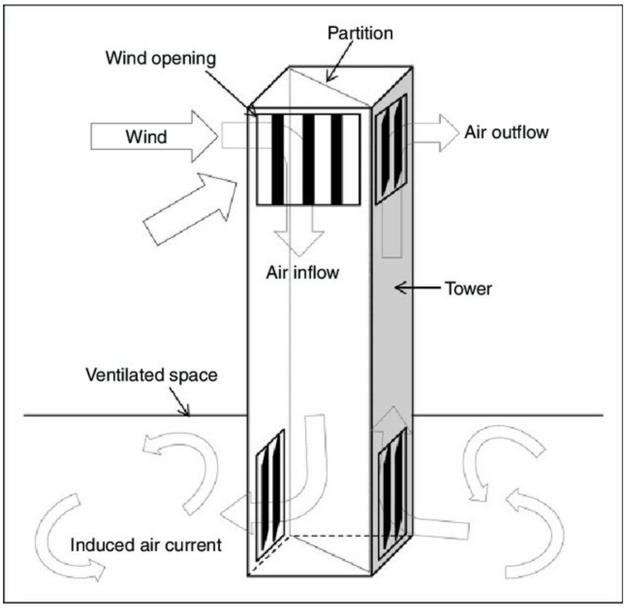

Figure 2. Windcatcher basic principles [28]

Wind catchers are categorized into two primary types: traditional and modern designs [6, 18]. Traditional wind catchers consist of several components, including openings, a roof, a head section, a channel, and internal partitions, as illustrated in Figure 3.

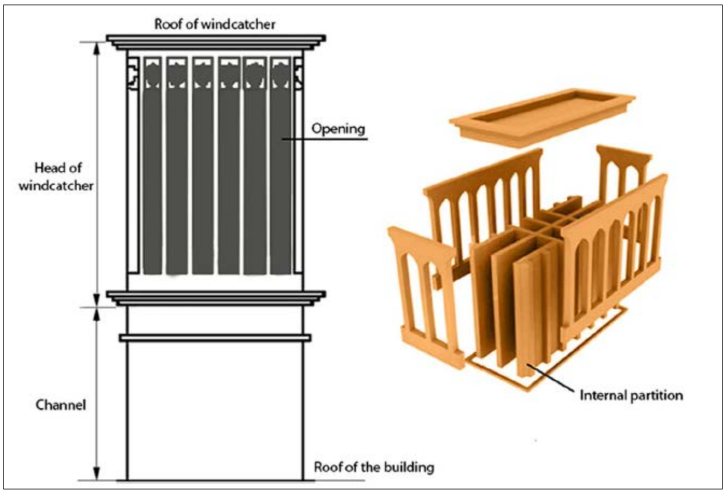

Figure 3. Traditional windcatcher components [19].

Wind catchers can be categorized by their shape, typically circular, square, or rectangular, as shown in Figure 4. [20]. Additionally, they can be classified based on the number of wind-facing sides, ranging from one to eight, or by their internal configuration [20, 21].

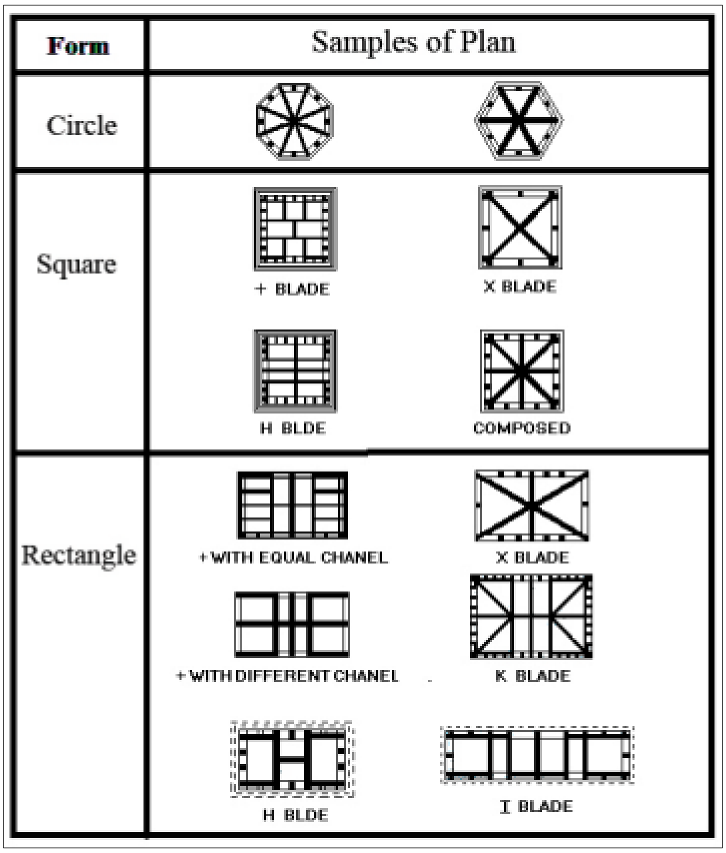

Figure 4. Plan shape-based classification of wind catchers [22]

Wind catchers, traditional architectural elements that harness natural wind for ventilation, are gaining renewed interest due to their potential to reduce energy consumption in modern buildings. Evaluating their performance is crucial for optimizing their design and effectiveness.

Existing research employs various methods to assess wind catchers, including Computational Fluid Dynamics (CFD) simulations, field measurements, and comparative studies. Studies by Lia and Mak [17], Hosseini et al. [23], Kabir et al. [24], Montazeri et al. [25], Abdo at al. [26] Sheikhshahrokhdehkordi et al. [27] and Ghadiri et al. [28] demonstrate the effectiveness of CFD simulations in evaluating wind catcher performance and airflow patterns. Mahmoudi et al. [22] explored the architectural design principles of wind catchers through field surveys, while El-Shorbagy [23] highlighted the historical and cultural significance of wind catchers in traditional architecture.

While these studies provide valuable knowledge on wind catcher effectiveness, a more nuanced understanding is needed regarding their optimal design for specific climates and building types. This is particularly relevant for regions that share similar climatic characteristics to traditional wind catcher applications, but may have variations in wind patterns, building materials, or urban contexts.

This study aims to address this gap by investigating the potential of wind catchers as a passive cooling strategy in Nizwa, Oman. Nizwa experiences a hot, dry climate like Yazd, Iran, where wind catchers are prevalent. However, there might be subtle differences in wind patterns or urban layouts that could influence wind catcher performance. By employing CFD simulations to analyze the impact of wind catcher geometry and internal configurations on indoor air velocity in the context of Nizwa, this research seeks to identify the relationship between windcatcher design parameters and indoor air velocity, providing insights for enhancing ventilation in similar climatic conditions.

II. METHODOLOGY

This study aims to investigate the impact of windcatcher geometry and internal partitions on indoor ventilation performance within a mosque building located in Nizwa, Oman. By conducting computational fluid dynamics (CFD) simulations of various windcatcher configurations, this research seeks to identify the optimal design parameters for enhancing indoor air quality and thermal comfort in hot arid climates.

To achieve this objective, a case study was selected in Nizwa City, Oman, representing a typical hot and dry climate. The chosen case study is a mosque building centrally located within the old town of Nizwa, situated adjacent to the historical Nizwa castle. This urban context provides a representative environment for evaluating the windcatcher's performance under real-world conditions.

The research methodology involves a comparative analysis between the base case of the selected building (without a wind catcher) and successive windcatcher scenarios with different geometries and internal partition types. The existing case study was modeled in Autodesk Revit Architecture to create a 3D BIM model, along with the scenarios. These models were then exported to Autodesk Computational Fluid Dynamics (CFD), with details such as location, orientation, and wind flow input and output. Each model was prepared separately in CFD using the SAT file format to transfer information from Revit. Boundary conditions, such as air velocity from the prevailing wind direction (2.36 m/s) and pressure output, were set for the models. The windcatcher models adhered to fixed criteria, ensuring consistency across scenarios.

The CFD simulation phase involved solving 100 iterations to ensure reliable results for comparative analysis, focusing on airflow (air velocity) due to the research's scope of comparing natural ventilation rates before and after adding windcatcher scenarios. The simulation covered three key points (A, B, C) in the base model and the scenarios: Point A at the windcatcher opening, Point B above the water bond before entering the indoor space, and Point C within the extended mosque space. The results were compared at these points, leading to conclusions and suggestions for future studies connected to previous research and findings. Figure 5 illustrates the location of the reference points.

Since the study's main purpose is to examine the effect of windcatcher on natural ventilation rate in hot-arid regions, it was essential to determine various scenario of windcatcher geometry and internal partitions. The study assumes some scenarios of wind catchers with some fixed and variable parameters. Some parameters were specified, such as windcatcher height, location, the opening ratio of the windcatcher, and the gross area of the windcatcher. In addition, all wind catchers were suggested to be in a four-sided direction. In this context, the variables were also determined as windcatcher geometry (Square and Rectangular) and type of internal partitions (+ type X, H, and X+ combination type).

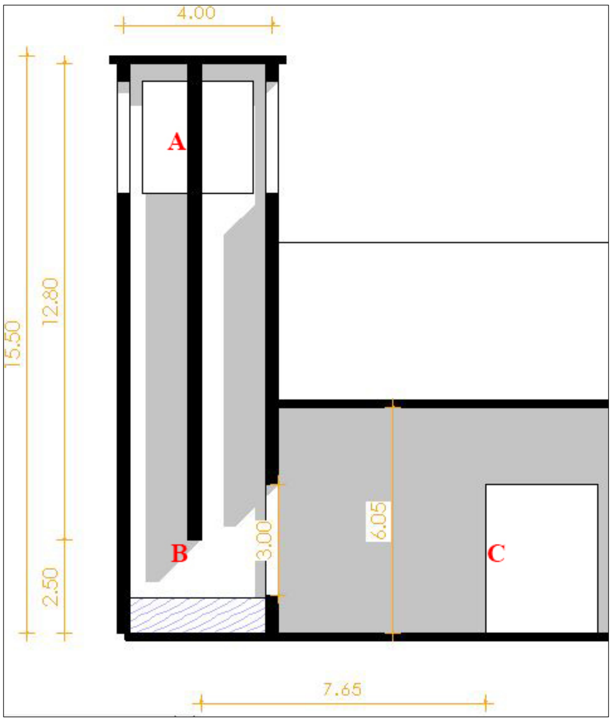

Figure 5. Location of reference points.

2.1. Case Study

The case study was selected as a mosque building that is called "Alqala' mosque" or "mosque of Fort" in Nizwa city of Oman. The selection of the case depended on some pre-set criteria that included:

1. The case study location is in an urban context to include the effect of the surroundings on the wind rate flow.
2. The case study has natural ventilation problems due to the opening ratio compared to the opaque parts.
3. The case study is public building with frequent uses to examine the effect of using a windcatcher on the occupant comfort.

The mosque consists of two main sections: the original structure and a subsequent 1980s extension. The building's orientation deviates slightly from the north-south axis, with the prayer direction (Qibla) facing west. Accessed from the north, worshippers enter the newer section first, then proceed to the older part through four interior doors (Figure 6). The extension features are fixed, arched glass windows on the east and operable windows with a 16% window-to-wall ratio on the south. Both the original and extended sections are primarily constructed of clay.
Weather data for Nizwa was collected using the Ladybug tool for the period between 2007 and 2021. Temperatures in Nizwa fluctuated between 7.4 °C and 46.7 °C annually, with July as the hottest month (36 °C) and January as the coldest (19 °C). Relative humidity varied from 12.7% to 100%, peaking in January (41%) and reaching a low of 19% in May. Predominant wind directions in Nizwa were south and southwest, with an average speed of 2.36 m/s. Figure 97 visually represents the wind speed variations throughout the year.

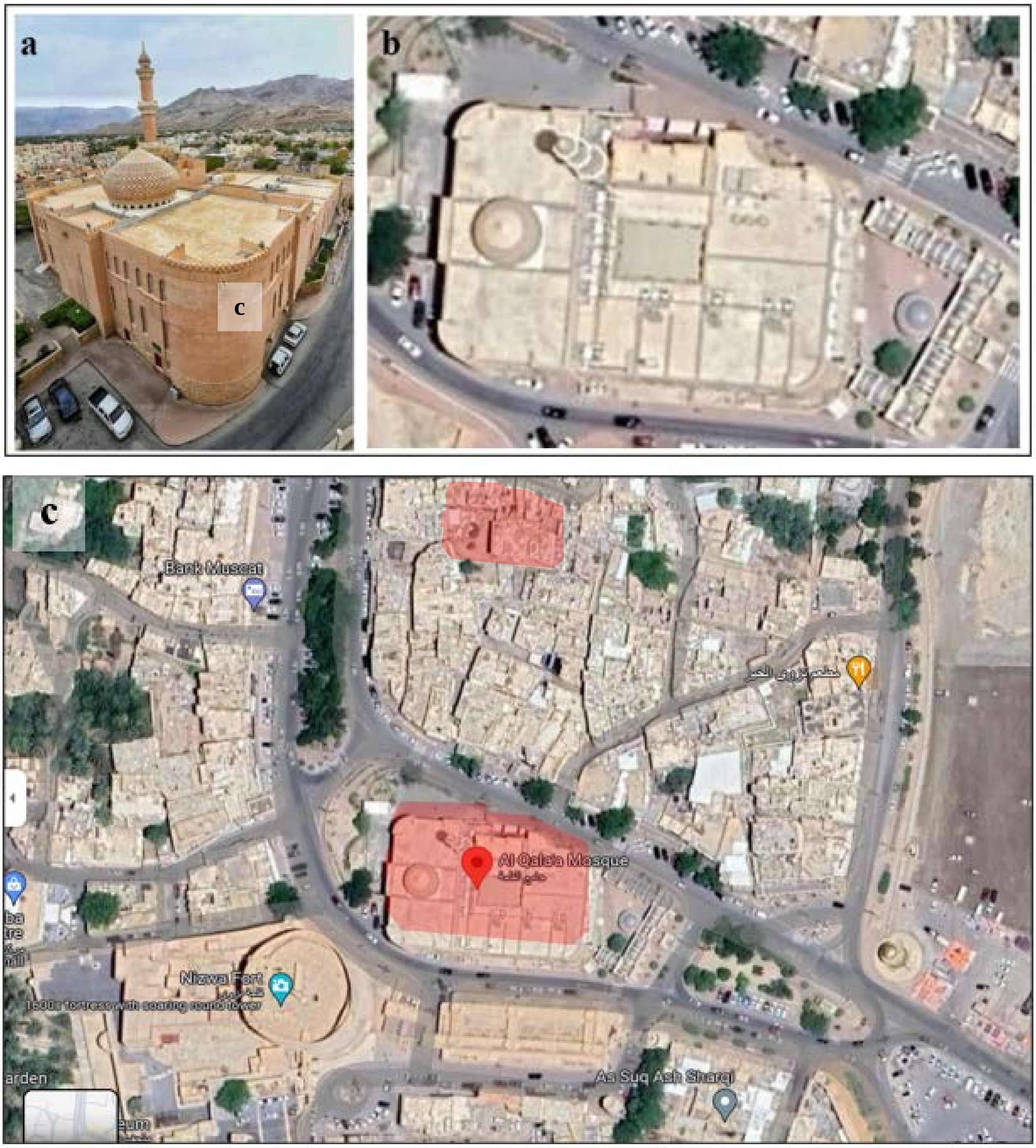

Figure 6. a) Southwest view of the mosque b) Master Plan of the mosque c) The position of the mosque on map [29, 30]

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	19.4 °C (66.9) °F	21.6 °C (70.9) °F	25.4 °C (77.7) °F	30.1 °C (86.2) °F	33.8 °C (92.8) °F	35.5 °C (95.8) °F	35.3 °C (95.5) °F	34.1 °C (93.3) °F	32.3 °C (90.1) °F	29.5 °C (85) °F	24.7 °C (76.4) °F	21 °C (69.8) °F
Min. Temperature °C (°F)	13.1 °C (55.5) °F	14.8 °C (58.7) °F	18.1 °C (64.5) °F	22.5 °C (72.5) °F	26 °C (78.8) °F	27.8 °C (82.1) °F	28.4 °C (83.2) °F	27.6 °C (81.6) °F	25.8 °C (78.4) °F	22.7 °C (72.9) °F	18.5 °C (65.4) °F	14.5 °C (58) °F
Max. Temperature °C (°F)	25.1 °C (77.3) °F	27.6 °C (81.7) °F	31.7 °C (89) °F	36.4 °C (97.6) °F	40.2 °C (104.4) °F	41.9 °C (107.5) °F	41.4 °C (106.5) °F	40.1 °C (104.2) °F	38.2 °C (100.8) °F	35.4 °C (95.7) °F	30.2 °C (86.3) °F	26.8 °C (80.2) °F
Precipitation / Rainfall mm (in)	8 (0)	10 (0)	20 (0)	12 (0)	5 (0)	7 (0)	16 (0)	15 (0)	2 (0)	6 (0)	12 (0)	6 (0)
Humidity(%)	41%	34%	25%	21%	19%	22%	28%	33%	30%	25%	37%	39%
Rainy days (d)	1	1	2	1	1	1	2	3	1	1	1	1
avg. Sun hours (hours)	9.4	9.9	10.6	11.3	11.9	12.1	12.0	11.6	11.0	10.4	9.6	9.2

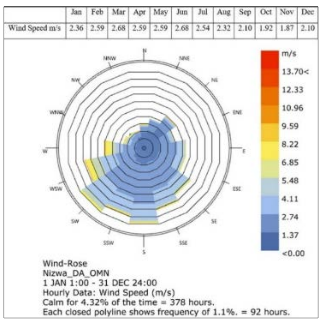

Figure 7. The climate data of Nizwa [31]

To understand the existing wind patterns, the case study building, a mosque, was oriented 20 degrees deviating from the north-south axis, with its longer elevation facing north and south on a rectangular 50x70 meter plan. Given the predominant wind direction in Nizwa - south, southeast, and southwest - the windcatcher was strategically positioned on the southern facade, 25 meters from the building's eastern extremity. This orientation aimed to optimize wind capture and maximize its potential impact on indoor ventilation. Figure 8 illustrates the mosque's floor plan, outlining the placement of windcatchers for each of the simulated scenarios.

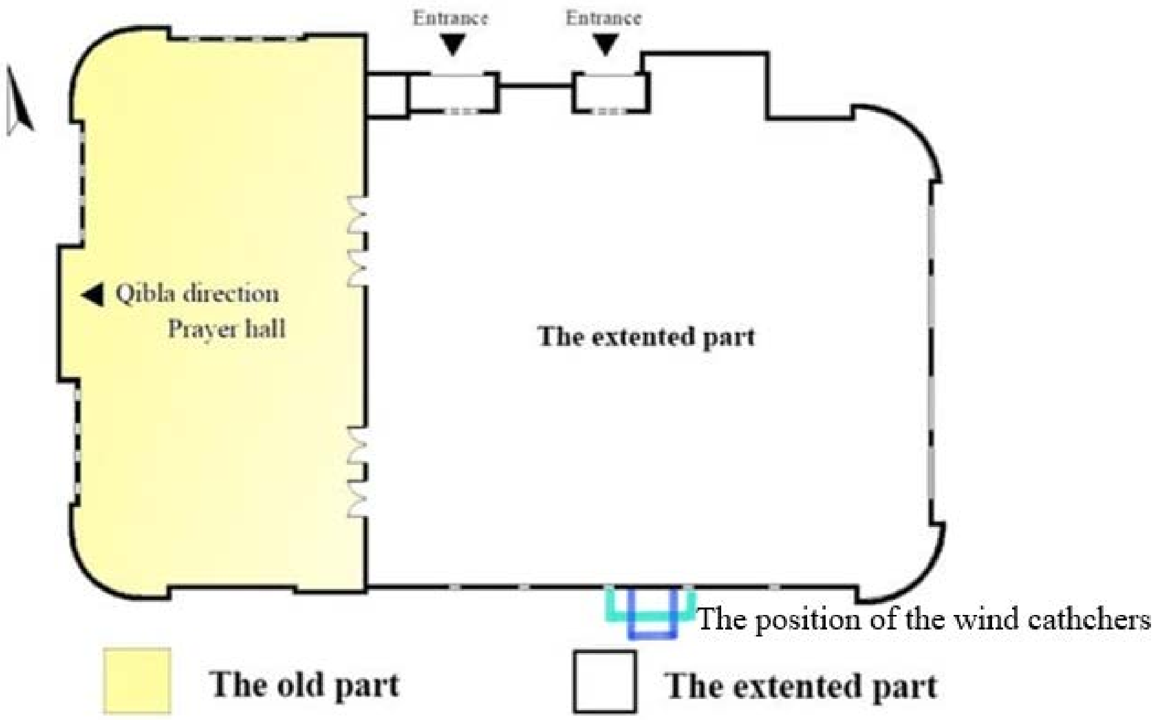

Figure 8. The Ground floor plan of the mosque, windcatcher locations and configurations [29]

It is also worth mentioning that the location and height of the windcatcher were determined after the CFD simulation of the existing case where the highest magnitude of air velocity was found. The location of the windcatcher was determined to be at the southern facade of the building and in the middle distance, while the height of the windcatcher was fixed to be 15.50 meters from the ground floor level. The windcatcher height of 15.50 meters was established by considering both general design guidelines and site-specific factors. While a typical range of 5 to 20 meters is often recommended for windcatchers in hot, arid climates [16], the final height for this study was determined through an analysis of the surrounding building environment. Drawing on the findings of Afshin et al. [32], which demonstrated the significant influence of neighboring building height and placement on windcatcher performance, the windcatcher height was optimized to enhance airflow and ventilation. By carefully considering these factors, the chosen height aimed to maximize the windcatcher's effectiveness in the specific context of the study. The following explains the suggested solutions and properties for the added wind catchers. The general workflow of the study is shown in Figure 9.

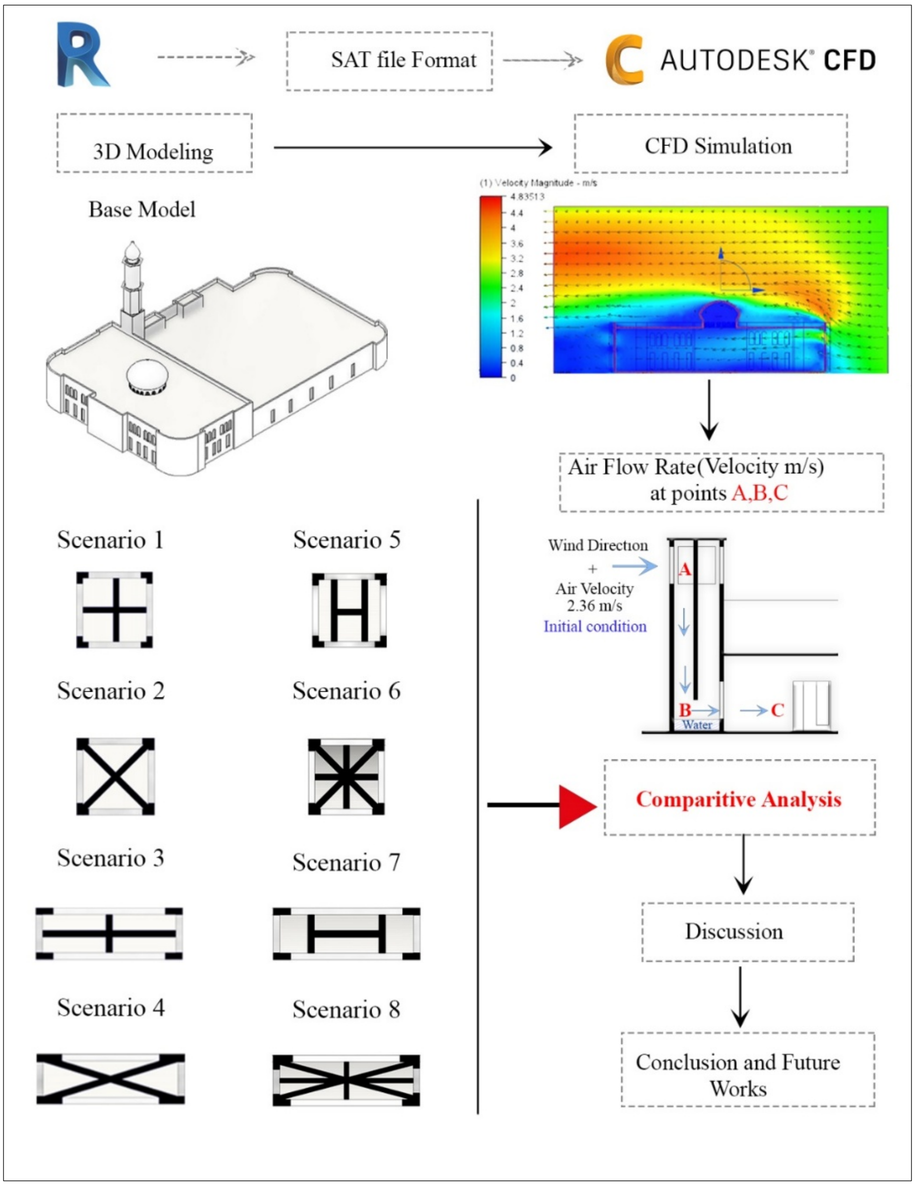

Figure 9. General workflow of the study

III. RESULTS

This study examines how effective a win catcher can be as a cooling method in a hot and dry region. An analysis of a mosque in Nizwa, an Omanian city, was conducted as part of the study. In general, the results of this study provide useful insight into the potential of windcatchers to reduce energy consumption in hot-arid climates. The findings of this study can also be used to inform the design of future buildings.

The methodology was based on establishing different Scenarios of windcatcher typology to be applied to the existing case study. This study is intended to test scenarios that might suggest that architects and designers in hot-arid zones should incorporate windcatcher principles into their future designs as passive cooling systems. In that respect, windcatcher scenarios were determined by geometry and partition parameters, whereas other design parameters were fixed. There were fixed parameters such as height, construction materials, opening ratio, and gross area of the suggested windcatchers. Accordingly, the primary variable parameters in the simulation are shown in Table 1. In this study, squares and rectangles were examined as plan-based shapes with specific dimensions. Additionally, different X, +, and H types of internal blades of scenarios were selected. A total of eight scenarios were developed and examined to come up with an overall conclusion. The results of the scenarios were used to identify the best course of action. The results of the scenarios were then used to develop a comprehensive solution. Using a CFD analysis, the indoor ventilation rate was determined in terms of air velocity (m/s) based on the existing case and the generated scenarios. An analysis and comparison of the results of the study were conducted to determine and compare the optimal solutions.

Table 1. Variable Parameters in the Windcatcher Simulation

Variable Parameter	Values
Windcatcher Geometry	Square, Rectangular
Windcatcher Dimensions	4x4 m (Square), 2x8 m (Rectangular)
Internal Partitions	+, X, H, X+

Using air velocity (m/s), the results were assessed. A specific analytical plane was established to measure air velocity at designated points in this study. Analytical Plane 1 intersects all openings on the ground floor and is positioned horizontally 2 meters above the ground floor. On the other hand, Analytical Plane 2 traverses the windcatcher location, heading into the mosque's extension and ending at the northern entrance.

The base model results showed that the average indoor air velocity at analytical plane 1 is 0.327872 m/s (Figure 10b). At analytical plane 2, points A and B do not exist in the base model, whereas the air velocity at point C was 0.333508 m/s, as shown in Figure 10 (c), respectively.

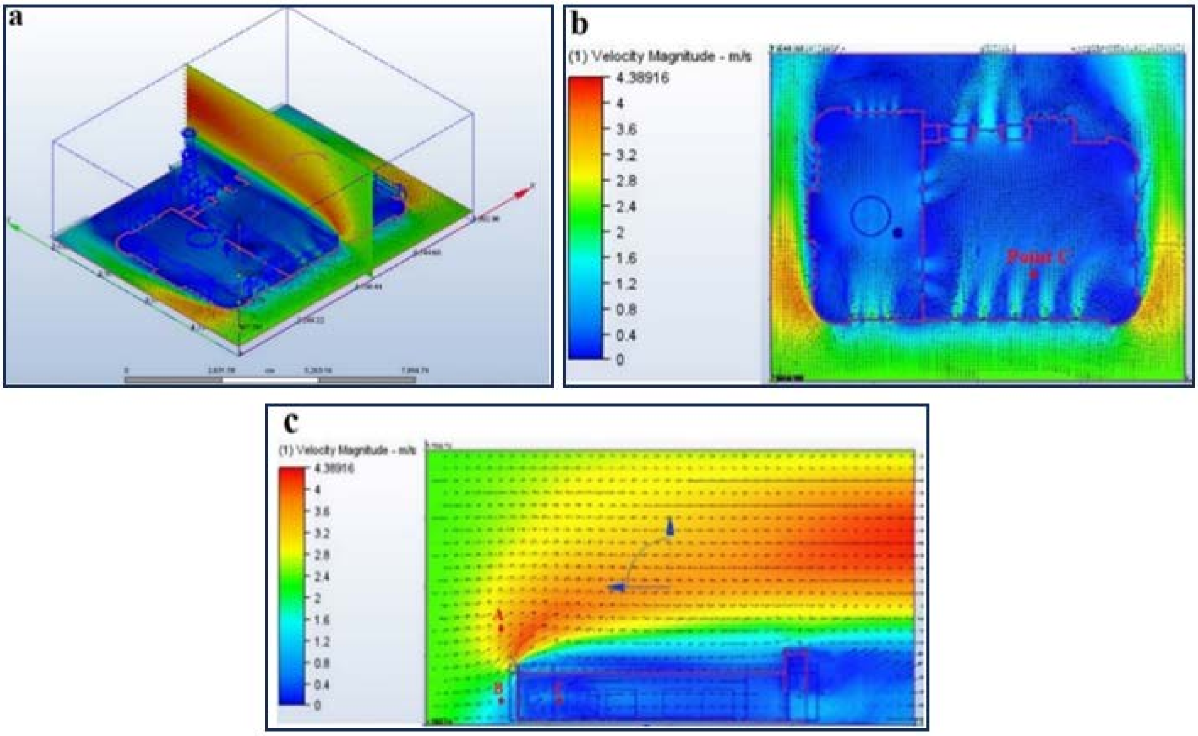

Figure 10. (a) CFD simulation of the base model (b) Analytical plane one results (c) Analytical plane two results.

3.1. Analyses of results at analytical plane 1

The results showed that all the windcatcher Scenarios increased the average air velocity at analytical plane one compared to the base case. Within this context, the square geometry of the windcatcher with X-type internal partitions achieved the highest ventilation rate at analytical plane 1. In this scenario, the average air velocity increased from 0.327872 m/s in the base model to 0.457457 m/s.

Compared to the base model, the square geometry of the windcatcher with + type and H type internal partitions also increased the ventilation rate up to 0.437706 m/s and 0.424831 m/s, respectively. It seems that the square geometry has a better effect on the overall ventilation rate in the building. However, the Square X+ combination type has less impact on increasing the overall ventilation rate.

On the other hand, the rectangular geometry of the windcatcher with X, +, and H types also increased the ventilation rate compared to the base model results at analytical plane 1. However, this increase is less than the square geometry shown in Figure 11. In addition, it can be noticed from the results of rectangular geometry Scenarios that the X and + internal partition types increased the overall ventilation rates more than the H and X+ Scenarios. The Rectangular H-type internal partition achieved the lowest improvement, where the air velocity increased from 0.327872 m/s to only 0.334773 m/s, as shown in Figure 11.

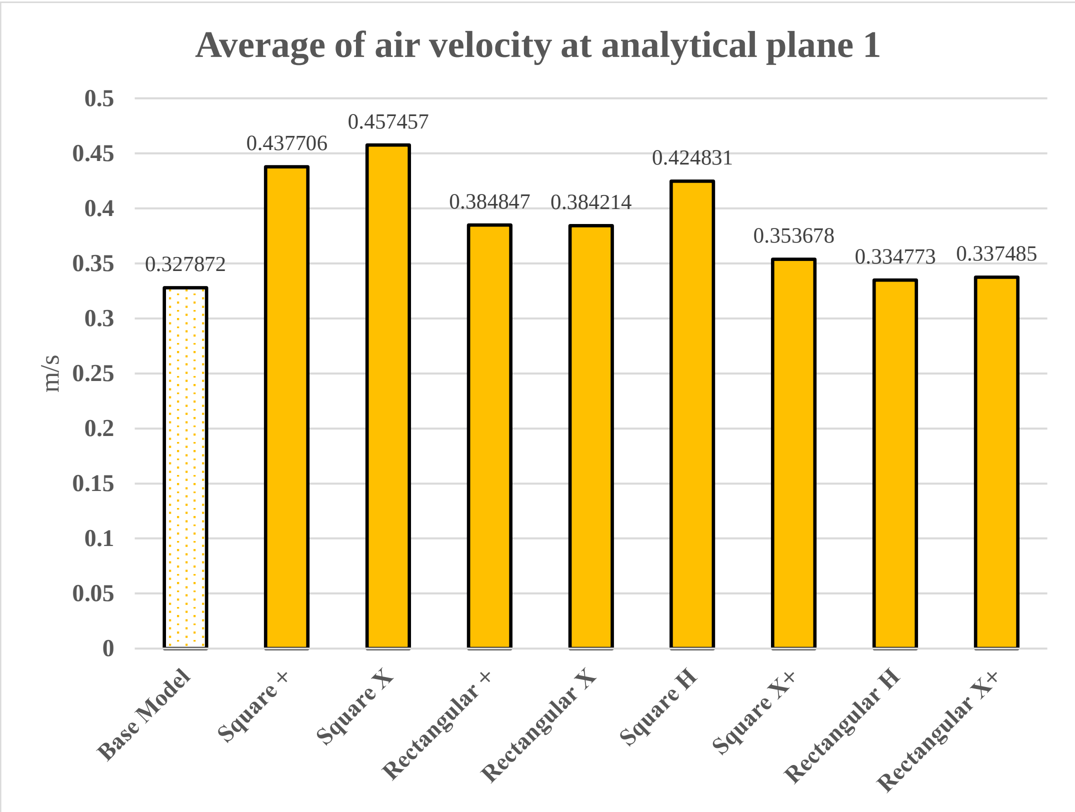

Figure 11. The results of average air velocity at analytical plane 1

3.2. Analyses of results at analytical plane 2

The findings as shown in Figure 12 provide valuable insights for optimizing wind catcher design in Nizwa's hot, dry climate:

- While the annually averaged simulated wind speeds at Point C within the mosque fell within the generally accepted comfort range of approximately 0-5 m/s [33], it's crucial to consider that human comfort is influenced by a combination of factors including temperature, humidity, and individual perception.
- Square Geometry with X or X+ Partitions: Square wind catchers equipped with X-shaped internal partitions, or a combination of X and + partitions (X+), exhibited superior performance across all measurement points. Notably, at point C, situated within the occupied space, the square X configuration achieved a remarkable 51.9% increase in air velocity compared to the baseline scenario. This significant improvement leads to enhanced natural ventilation and improved occupant comfort.
- Rectangular Geometry with X or + Partitions: While less effective than square geometries, rectangular wind catchers with either X or + type internal partitions still demonstrated positive impacts on indoor air velocity at point C. The X type partitions yielded slightly better results compared to the + type in rectangular configurations. These findings suggest that rectangular wind catchers can be a viable option, but their effectiveness is not as pronounced as that of square geometries.
- H Type Internal Partitions: Regardless of the wind catcher geometry (square or rectangular), the H type internal partitions consistently resulted in the lowest air velocity across all reference points. This suggests that H partitions are not suitable for maximizing ventilation performance in Nizwa's climate.

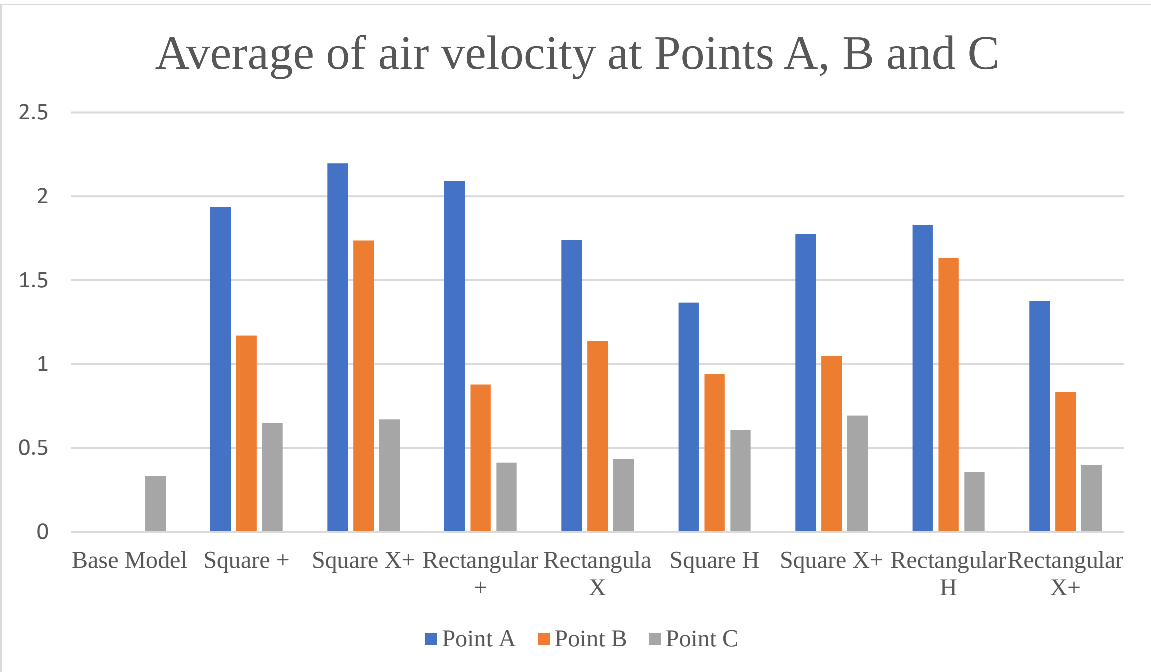

Figure 12. The results of air velocity at Points A, B and C at analytical plane 2

IV. DISCUSSION

This study [34] investigated the effectiveness of wind catchers as a passive cooling strategy in Nizwa, Oman, a hot, dry climate. The research employed CFD simulations to evaluate the impact of wind catcher geometry (square vs. rectangular) and internal partition configuration (X, +, and H types) on indoor air velocity at three key points within the building. The findings align with and expand upon existing literature, providing valuable insights for optimizing wind catcher design in similar climates. Table 2 compares the ventilation performance of different wind catcher designs to an existing model for point C.

Table 2. Comparing the indoor ventilation rate results of the wind catcher Scenarios with the existing model

Scenario	Windcatcher Geometry	Internal Partitions	Increase (%)
1	Square	+	48.48
2	Square	X	50.34
3	Rectangular	+	19.47
4	Rectangular	X	23.24
5	Square	H	45.18
6	Square	X+	51.90
7	Rectangular	H	6.97
8	Rectangular	X+	16.81

4.1. Optimizing wind catcher design

The study confirms the importance of wind catcher geometry and internal partition configuration for maximizing ventilation performance, as previously highlighted by Jomehzadeh et al. [35]. Square wind catchers with X or X+ partitions emerged as the most effective design in this context. These configurations achieved significantly higher air velocity at all measurement points than other scenarios, particularly at point C within the occupied space. This finding aligns with prior research emphasizing the benefits of square geometries and specific internal partition arrangements. The study also observed that rectangular wind catchers with X or + partitions offered some improvement in air velocity compared to the baseline scenario. However, their effectiveness was consistently lower than that of square geometries. This reinforces the notion that square geometries are generally more suitable for enhancing ventilation rates in hot, dry climates like Nizwa.

The research discourages the use of H type internal partitions for wind catchers in Nizwa, regardless of the chosen geometry. This aligns with the limited studies on H partitions, as noted by Jomehzadeh et al. [35], which suggest their inferiority compared to other configurations in terms of airflow optimization.

Integration with Other Strategies:

While this study focused solely on wind catchers, it underscores the potential benefits of combining them with other passive cooling systems. Previous research by Liu et al. [36] demonstrates the positive effects of integrating wind catchers with open windows on the leeward side of buildings to enhance ventilation rates. Future research could explore the integration of wind catchers with other passive cooling strategies, such as solar chimneys (investigated by Nejat et al. [37]) or PV panels prepared by Hughes and Ghani [38], to achieve optimal natural ventilation and energy efficiency in Nizwa's climate.

Based on the study's outcomes, the following design recommendations are proposed for wind catchers in Nizwa:

- Prioritize Square Geometry: Square wind catchers offer a clear advantage in terms of enhancing indoor ventilation rates. Their superior performance justifies their prioritization during the initial design stages.
- X or X+ Partitions: When employing square wind catchers, X-shaped internal partitions or a combination of X and + partitions (X+) are highly recommended. These configurations demonstrably optimize airflow within the wind catcher, leading to significant improvements in indoor air velocity.
- Rectangular Geometry as Alternative: If spatial constraints necessitate the use of rectangular wind catchers, consider X or + type internal partitions. While their effectiveness is lower compared to square geometries, they can still provide some improvement in ventilation rates.

- Avoid H Type Partitions: The study discourages the use of H type internal partitions for wind catchers in Nizwa, irrespective of the chosen geometry (square or rectangular). Their consistently low performance across all scenarios indicates their ineffectiveness in promoting optimal ventilation.

V. CONCLUSION AND FUTURE WORKS

This study investigated the effectiveness of wind catchers as a passive cooling strategy for buildings in Nizwa, Oman, a hot-dry climate. Employing CFD simulations, the research analyzed eight scenarios with varying wind catcher geometries (square vs. rectangular) and internal partitions (X, X+, and H types). The primary focus was on assessing the impact of windcatcher geometry and internal partitions on indoor air velocity through computational fluid dynamics simulations.

The findings demonstrate that wind catchers can significantly improve indoor ventilation in Nizwa. Square wind catchers with X or X+ internal partitions emerged as the most effective configurations, achieving over 50% improvement compared to a scenario without a wind catcher. Rectangular wind catchers with X or X+ partitions were also beneficial, although less impactful (around 23% improvement). H-type partitions proved to be the least effective design for both square and rectangular geometries.

These results highlight the potential of wind catchers as a sustainable cooling technique for buildings in Nizwa. Interestingly, the most successful design – square wind catchers with X or X+ partitions – deviates from the traditional wind catcher practices observed in Yazd, Iran, where rectangular shapes and + type partitions are more common. This underlines the importance of tailoring wind catcher designs to specific regional climatic conditions for optimal performance. Furthermore, the observed discrepancies suggest that established design principles from one region may not translate directly to another, even with similar climates. This underscores the need for research that investigates wind catcher performance in various geographical contexts to establish a comprehensive knowledge base for informed design decisions.

This study acknowledges limitations inherent to CFD simulations, such as the difficulty in accurately capturing real-world phenomena like dust storms. As noted by Liu et al. [39], field studies alongside computational modeling would provide valuable insights for refining wind catcher design strategies in regions with high dust levels. Future research should consider the following areas for further investigation in External Design Parameters. Expanding the analysis to include the impact of external factors, such as neighboring buildings, vegetation, and air/noise pollution, is crucial, especially in urban environments. This aligns with the call for future studies highlighted by Calautit et al. [40].

To further refine wind catcher design for Nizwa's climate and broaden the knowledge base for wind catchers in general, several avenues for future research are suggested:

- Explore additional wind catcher geometries and partitions (hexagonal, octagonal, circular) for a broader design toolbox.
- Investigate the impact of wind catchers on thermal comfort and indoor air quality for a more holistic understanding of occupant well-being.
- Consider a wider range of design parameters (height, opening ratio, blades, materials) in future simulations using a parametric modeling workflow.
- Analyze wind speed variations within the wind catcher to optimize placement and design.

- Explore wind catcher integration with other passive cooling strategies and their impact on building energy efficiency.

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REFERENCES

1. Yeang K (1991) Designing the green skyscraper. Habitat International 153:149-166.
2. Daemei AB, Eghbali SR, and Khotbehsara EM (2019) Bioclimatic design strategies: a guideline to enhance human thermal comfort in Cfa climate zones. Journal of Building Engineering 25:100758.
3. Sultan Qurraie B and Sertyamaç R (2024) Investigation of energy performance of nanotechnological material and double-skin facade system in office buildings in Turkiye. Intelligent Buildings International 15(6):251-265.
4. Salehi A, et al (2019) Investigation of thermal comfort efficacy of solar chimneys under different climates and operation time periods. Energy and buildings 205:109528.
5. Sultan Qurraie B and Kılıç Bakırhan E (2023) Evaluation of facade systems in different climate zones regarding energy, comfort, emission, and cost. Arab Journal of Basic and Applied Sciences 301:123-136.
6. Jomehzadeh F, et al. (2017) A review on windcatcher for passive cooling and natural ventilation in buildings, Part 1: Indoor air quality and thermal comfort assessment. Renewable and Sustainable Energy Reviews 70:736-756.
7. Karimi H, Adibhesami MA, Hoseinzadeh S, Salehi A, Groppi D, and Astiaso Garcia D (2024) Harnessing Deep Learning and Reinforcement Learning Synergy as a Form of Strategic Energy Optimization in Architectural Design: A Case Study in Famagusta, North Cyprus. Buildings 145:1342.
8. Qurraie BS and Havva K (2023) The Energy Performance of Shading Element and Double Skin Facade System Integration into Office Buildings in Turkey. Journal of Materials and Engineering Structures «JMES» 102:293-309.
9. Widera B, 2014, Bioclimatic architecture as an opportunity for developing countries. Presented at Proceedings of the 30th International PLEA Conference, Sustainable Habitat for Developing Societies: Choosing the Way Forward, Centre for Advanced Research in Building Science and Energy CEPT University, Ahmedabad, India.
10. Amiri-Kordestani M (2014) Natural air conditioning, traditions and trends: high performance of sustainable indoor ventilation in a hot and dry climate. Dissertation, Universite de Montreal.
11. Chohan AH and Awad J (2022) Wind catchers: an element of passive ventilation in hot, arid and humid regions, a comparative analysis of their design and function. Sustainability 1417:11088.
12. Noroozi A (2019) Augmenting traditional wind catcher with combined evaporative cooling system and solar chimney. Dissertation, National Technical University of Athens.
13. Nazir H, Abro S, and Iqbal A (2024) Windcatchers as a Green Ventilation Device: A Lost Tale From Hyderabad, Sindh, Pakistan. Journal of Asian and African Studies, 00219096241230486.
14. Qurraie BS and Arslan B (2022) Investigation of Thermal and Energy Performance of Double Skin Facades in Hot Climate Regions in Turkey. Computational Research Progress in Applied Science & Engineering 8(3), 2811.
15. Salehi A, Delfani S, Karami M, and Bozorgi M (2020) The effect of climatic conditions on the performance of a new configuration of solar chimney. Journal of Solar Energy Research 51:332-340.
16. Maleki BA (2011) Wind catcher: passive and low energy cooling system in Iranian vernacular architecture. International Journal on Technical and Physical Problems of Engineering (IJTPE) 8:130-137.
17. Li L and Mak CM (2007) The assessment of the performance of a windcatcher system using computational fluid dynamics. Building and environment 423:1135-1141.
18. Sangdeh PK and Nasrollahi N (2022) Windcatchers and their applications in contemporary architecture. Energy and Built Environment 31:56-72.
19. Zarandi MM (2009) Analysis on Iranian wind catcher and its effect on natural ventilation as a solution towards sustainable architecture (Case Study: Yazd). International Journal of Humanities and Social Sciences 36:668-673.
20. Masrour M, Abbasi M, and Hallaj HM (2012) Study of wind catchers: the mass flow rate and inlet air to the building in traditional wind catchers. Australian Journal of Basic and Applied Sciences 610:159-165.
21. Bahadori MN, Dehghani-sanij A, Sayigh A, Bahadori MN, Dehghani-sanij A, and Sayigh A (2014) The Architecture of Baudgeers. Wind Towers: Architecture, Climate and Sustainability, 63-100.
22. Branch CT (2013) Ancient Iran, the origin land of wind catcher in the world. Research Journal of Environmental and Earth Sciences 58:433-439.

23. Hosseini S, Shokry E, Hosseini AA, Ahmadi G, and Calautit J (2016) Evaluation of airflow and thermal comfort in buildings ventilated with wind catchers: Simulation of conditions in Yazd City, Iran. Energy for Sustainable Development 35:7-24.
24. Kabir IFSA, Kanagalingam S, and Safiyullah F (2017) Performance evaluation of air flow and thermal comfort in the room with Wind-Catcher using different CFD techniques under neutral Atmospheric Boundary Layer. Energy Procedia 143:199-203.
25. Montazeri H, Montazeri F, Azizian R, and Mostafavi S (2010) Two-sided wind catcher performance evaluation using experimental, numerical and analytical modeling. Renewable Energy 357:1424-1435.
26. Abdo P, Taghipour R, and Huynh BP (2020) Three-dimensional simulation of wind-driven ventilation through a windcatcher with different inlet designs. Journal of Thermal Science and Engineering Applications 124:041008.
27. Sheikhshahrokhdehkordi M, Khalesi J, and Goudarzi N (2020) High-performance building: Sensitivity analysis for simulating different combinations of components of a two-sided windcatcher. Journal of Building Engineering 28:101079.
28. Ghadiri MH, Lukman N, Ibrahim N, and Mohamed MF (2013) Computational analysis of wind-driven natural ventilation in a two sided rectangular wind catcher. International Journal of Ventilation 121:51-62.
29. Nizwa (2009) Nizwa – The State Visits – In the City. https://thestatevisitsinthecity.home.blog/2009/01/02/nizwa/ Erişim 10.05.2023.
30. GoogleMap (2024) Al- Qala Mosque. https://www.google.com/maps/place/Al+Qala'a+Mosque/@22.9339101,57.5301356,306m/data=!3m1!1e3!4m6!3m5!1s0x3e8ef0c0260783c5:0x969c0a8d5d5fe9e3!8m2!3d22.9336105!4d57.5308966!16s%2Fg%2F1v6p2rs1?authuser=0&entry=ttu. Erişim. 10.05.2024
31. weatherspark (2019) Climate and Average Weather Year Round in Nizwá. https://weatherspark.com/y/105716/Average-Weather-in-Nizw%C3%A1-Oman-Year-Round. Erişim 02.05.2023.
32. Afshin M, Sohankar A, Manshadi MD, Daneshgar M, and Kamaragi GD (2014) Visualized Flow Patterns around and inside a Two-Sided Wind-Catcher in the Presence of Upstream Structures. International Journal of Energy and Power Engineering 812:1312-1317.
33. Willemsen E and Wisse JA (2007) Design for wind comfort in The Netherlands: Procedures, criteria and open research issues. Journal of Wind Engineering and Industrial Aerodynamics 959:1541-1550.
34. Alhraki AR (2023) The impact of wind catcher's typology on ventilation rate of buildings in hot dry climates: An example on a mosque in Nizwa-Oman. Dissertation, Karabuk University.
35. Jomehzadeh F, Hussen HM, Calautit JK, Nejat P, and Ferwati MS (2020) Natural ventilation by windcatcher (Badgir): A review on the impacts of geometry, microclimate and macroclimate. Energy and Buildings 226:110396.
36. Jones BM and Kirby R (2010) The performance of natural ventilation windcatchers in schools-A comparison between prediction and measurement. International Journal of Ventilation 93:273-286.
37. Nejat P, Calautit JK, Majid MZA, Hughes BR, Zeynali I, and Jomehzadeh F (2016) Evaluation of a two-sided windcatcher integrated with wing wall (as a new design) and comparison with a conventional windcatcher. Energy and Buildings 126:287-300.
38. Hughes BR and Ghani SA (2011) A numerical investigation into the feasibility of a passive-assisted natural ventilation stack device. International Journal of Sustainable Energy 304:193-211.
39. Liu M, Jimenez-Bescos C, and Calautit J (2022) CFD investigation of a natural ventilation wind tower system with solid tube banks heat recovery for mild-cold climate. Journal of Building Engineering 45:103570.
40. Calautit JK, O'Connor D, and Hughes BR (2014) Determining the optimum spacing and arrangement for commercial wind towers for ventilation performance. Building and environment 82:274-287.