

**Reusing Minarets as a Passive Cooling
(Wind Catcher/Solar Chimney): A Case Study in the
Emirate of Sharjah**

إعادة استخدام المآذن كوسيلة للتبريد السلبي (ملاقف الرياح/المدخنة الشمسية):

دراسة حالة في إمارة الشارقة

by

TALIB ABDALLA ALI ABDALLA

**Dissertation submitted in partial fulfilment
of the requirements for the degree of
MSc SUSTAINABLE DESIGN OF THE BUILT
ENVIRONMENT**

at

The British University in Dubai

April 2023

Declaration

I warrant that the content of this research is the direct result of my own work and that any use made in it of published or unpublished copyright material falls within the limits permitted by international copyright conventions.

I understand that a copy of my research will be deposited in the University Library for permanent retention.

I hereby agree that the contents of this dissertation for which I am author and copyright holder may be copied and distributed by The British University in Dubai for the purposes of research, private study or education and that The British University in Dubai may recover from purchasers the costs incurred in such copying and distribution, where appropriate.

I understand that The British University in Dubai may make a digital copy available in the institutional repository.

I understand that I may apply to the University to retain the right to withhold or to restrict access to my thesis for a period which shall not normally exceed four calendar years from the congregation at which the degree is conferred, the length of the period to be specified in the application, together with the precise reasons for making that application.

A handwritten signature in blue ink, consisting of stylized, overlapping loops and a long horizontal stroke extending to the right. The signature is positioned above a thin horizontal line.

Signature of the student

Copyright and Information to Users

The author whose copyright is declared on the title page of the work has granted to the British University in Dubai the right to lend his/her research work to users of its library and as an open source and to make partial or single copies for educational and research use.

The author has also granted permission to the University to keep or make a digital copy for similar use and for the purpose of preservation of the work digitally.

Multiple copying of this work for scholarly purposes may be granted by either the author, the Registrar or the Dean only.

Copying for financial gain shall only be allowed with the author's express permission.

Any use of this work in whole or in part shall respect the moral rights of the author to be acknowledged and to reflect in good faith and without detriment the meaning of the content, and the original authorship.

Abstract

The number of mosques in the United Arab Emirates exceeds 9,000 mosques, including approximately 3,000 mosques in the Emirate of Sharjah alone. The minaret accompanies the design of each mosque, which is equivalent to the number of mosques, and more, since some mosque designs have more than one minaret. In this research, the idea of repurposing minarets or adding new uses to them is studied, such as using minarets as a passive cooling method, such as using them as wind catchers/solar chimneys that contribute to the process of directing the wind to the prayer hall and work to increase thermal comfort through environmentally friendly passive cooling methods. The Luqman Mosque in the Al Tay area in Sharjah was studied as a model for a case study. It was drawn using the IESVE computer simulation program, and then different scenarios were created for the idea of creating a connection between the prayer hall and the minaret by making doors and windows. After that, the opening and closing of windows and doors in each case were studied. One side of the prayer hall and the minaret, in addition to scenarios for opening the windows of the dome and adding a divider in the minaret, divides it into two parts. It should be noted that the number of virtual scenarios reaches 34 designs. The results are then analyzed, conclusions are drawn, and the results are then evaluated. The study revealed the possibility, benefit, and feasibility of the idea of repurposing the minaret in reducing overall energy consumption.

الملخص

يتجاوز عدد المساجد في دولة الامارات العربية المتحدة الـ ٩٠٠٠ مسجد منها قرابة مسجد ٣٠٠٠ في اماره الشارقة وحدها وترافق المئذنة في تصميم كل مسجد اي ما يعادل عدد المساجد وأكثر كون بعض تصاميم المساجد بها أكثر من في هذا البحث يتم دراسة فكرة اعادة توظيف المآذن او اضافة استخدامات جديده لها كاستخدام المآذن كوسيلة مئذنة. تبريد سلبية مثل استخدامها كصائدات للرياح/مدخنة شمسية تساهم في عملية توجيه الرياح الى قاعة الصلاة وتعمل على تم دراسة مسجد لقمان في منطقة الطي بالشارقة وجعلها زيادة الراحة الحرارية بوسائل التبريد السلبية الصديقة للبيئة. ومن ثم تم عمل سيناريوهات مختلفة IESVE نموذج لدراسة حالة حيث تم رسمها بوساطة برنامج المحاكاة الحاسوبية لفكرة عمل اتصال ما بين قاعة الصلاة والمآذنة عن طريق عمل ابواب ونوافذ. بعد ذلك تم دراسة فتح وغلق النوافذ والابواب في كل جهة من جهات قاعة الصلاة والمئذنة بالإضافة الى سيناريوهات فتح نوافذ القبلة واطافة فاصل في المئذنة تقسمها الى قسمين، وتجدر الاشارة ان عدد السيناريوهات الافتراضية تصل لـ 34 تصميم. يتم تحليل النتائج بعد ذلك ووضع الاستنتاجات ومن ثم يتم تقييم النتائج.

تبين من خلال الدراسة الى امكانية وجود فائدة وجدوى من فكرة اعادة توظيف المئذنة في حفظ الاستهلاك العام

للطاقة

Dedication

To my father and mother

For my family

For everyone who supported me and taught me a letter

Acknowledgements

All thanks and gratitude to the Sharjah Planning and Survey Department for providing me with the necessary diagrams for the case study.

Table of contents

CHAPTER 1 : INTRODUCTION	1
1.1 Introduction	1
1.2 Background Information	1
1.3 Global and Regional Review.....	5
1.4 Research Motivation	7
1.5 Research Hypothesis	9
1.6 Research Aims and Questions.....	9
1.7 Objective	10
1.8 Research Focus and Limitation	11
1.9 Dissertation Contents and Structure	12
CHAPTER 2 : LITERATURE REVIEW	14
2.1 Literature Review	14
2.1.1 Historical Background.....	14
2.1.2 Pros and Cons Extracted from Literature Reviews	39
CHAPTER 3 : METHODOLOGY	45
3.1 Methodology	45
3.2 Computer Simulation With Case Study	45
3.3 A summary of Research Approaches	47
3.4 Research Method.....	49
3.5 Sharjah Site and Case Study.....	52
3.5.1 Sharjah Site Analysis	52
3.5.2 A Case Study of Luqman Al-Hakim Mosque in Sharjah.....	56
CHAPTER 4 : ANALYSIS.....	60
4.1 Simulation	60

4.2 Air Temperature	60
4.3 Relative Humidity	66
4.3 Mean Radiant Temperature	70
4.4 Air Movement	73
4.4.1 Result Analysis and the Best Scenario	82
4.5 CFD Analysis	88
4.5.1 Air Velocity.....	88
4.5.2 Temperature	89
4.5.3 Pressure	90
CHAPTER 5 : CONCLUSION.....	92
5.1 Conclusion.....	92
5.2 Recommendations	96

List of Tables

Table 1: A Table Showing the Number of Mosques and Eid Prayer Halls in the Seven Emirates From the Period 2015 to 2020.....	6
Table 2: Comparison Between Solar Chimney and Wind Chimney.....	22
Table 3: The Summary of the Research Conducted.....	41
Table 4: Mix Methodology Summary for Analyzing Existing Building	48
Table 5: Wind Direction.....	54
Table 6: Abbreviation & Keyword.....	61
Table 7: Table For Different Air Temperature Design Scenarios.....	62
Table 8: Mean Air Temperature for the Base Design in Different Scenarios.....	63
Table 9: The Minimum Mean Air Temperature for the Best Scenarios Compared with the Base Design.....	64
Table 10: The Maximum Mean Air Temperature for the Scenarios.....	64
Table 11: Minimum Air Temperature of all Design Scenarios Compared to Base	65
Table 12: <i>The Maximum Air Temperature for All Design Scenarios Compared to the Base Design</i>	65
Table 13: Lowest Value for Maximum Air Temperature for all Design Scenarios.....	66
Table 14: Relative Humidity in Different Scenarios	67
Table 15: Minimum Relative Humidity Value Compared to Base Design.....	68
Table 16: Maximum Relative Humidity Value Compared to Base Design.....	69
Table 17: Lowest Mean Relative Humidity	70
Table 18: Highest Mean Relative Humidity of All Scenarios	70
Table 19: Mean Radiant Temperature for all Scenarios	71
Table 20: Comparison of the Minimum MRT and the Base Design	72

Table 21: Comparison of the Maximum MRT and the Base Design.....	72
Table 22: Comparison of the Mean MRT and the Base Design	72
Table 23: MacroFlo External Vent for Different Scenarios.....	74
Table 24: Comparison of the Best Mean Macroflo External Vent with the Average Base Design.....	75
Table 25: <i>Comparison of the Best Maximum Macroflo External Vent and the Base Design</i>	78
Table 26: Comparison of the Minimum Macroflo External Vent and the Base Design	80
Table 27: The Best Scenario for Mean Macroflo Compared to the Base Design	82
Table 28 : A Macroflo Comparison Between the Hybrid Scenario and the Best Chosen Scenario	86
Table 29: An Air Temperature Comparison Between the Hybrid Scenario and the Best Chosen.....	86
Table 30: A Relative Humidity Comparison Between the Hybrid Scenario and the Best Chosen Scenario	86
Table 31: A Mean Radiant Temperature Comparison Between the Hybrid Scenario and the Best-Chosen.....	87
Table 32: A People Dissatisfied Comparison Between the Hybrid Scenario and the Best-Chosen Scenario	87
Table 33: Air Velocities and Thermal Comfort	89

List of Figures

Figure 1: The Graphical Anatomy of the Minaret of the Al-Fadhila Mosque in the Al-Kashisha Area Compared to the Wind Catcher of Doulatabad in Yazd	5
Figure 2: An Illustrative Function of the Wind Catcher	18
Figure 3: Traditional Wind Tower Design and Information	19
Figure 4: Passive Cooling Techniques in Buuilding.....	30
Figure 5: Flow Chart of the Research Process And Methodology.....	51
Figure 6: Average Max/Min Temp(c) Sharjah.....	53
Figure 7: Relative Humidity in Sharjah	53
Figure 8: Average Wind Speed in Sharjah.....	54
Figure 9: Wind Rose. (a) Dubai Airport-August 2020, (b) Dubai Airport-January 2020, (c) Sharjah Airport-August 2020, (d) Sharjah Airport-January 2020.....	55
Figure 10: Plans & Elevation for Luqman Al-Hakim Mosque.....	57
Figure 11: The Picture, in Order from Bottom to Top, Shows the Location of the Luqman Al-Hakim Mosque in the Al Tayy Area in Sharjah, the Residential Villas Surrounding It, and the Main Streets Leadingt to the Area, in Addition to an Illustrative Picture of the Movement.....	58
Figure 12: Dimensions and Measurements of the Payer Hall, Minaret and Dome.....	59
Figure 13: Designs Scenarios.....	60
Figure 14: Settings for Building Materials with Lower U Value and their Values in the IESVE Program.....	76
Figure 15: Settings for Building Materials With Higher U Value and their Values in the IESVE program	76
Figure 16: The Rate of Air Entry and Exit Through Windows and Doors on 24/July At 17:30 in the Scenario: (M) NSEW Win (O), (H) QRLF Win (O), and Cladding Changed.	77

Figure 17: The Rate of Air Entry and Exit Through Windows and Doors on 02/Fe At 07:30 In The Base Scenario: Base Design AC off Win (O) (H) Not Connected with (M).....	77
Figure 18: The Best Maximum Rate of Air Entry and Exit Through Windows and Doors on 17:30, 24/Jul in the Scenario: (M) NSEW Win (O), (H) QRLF Win (O), Cladding Changed.....	79
Figure 19: The Best Maximum Rate of Air Entry and Exit Through Windows and Doors on 24/Jul at 17:30 in the Base Scenario: Base Design AC Off Win (O) (H) Not Connected with (M).....	79
Figure 20: The Minimum Rate of Air Entry and Exit Through Windows and Doors on 10:30, 28/Apr in the Scenario: (Mpwo) NEWS Win(O) (H) Q Win(O) Material Changed	81
Figure 21: The Minimum Rate of Air Entry and Exit Through Windows and Doors on 24/Dec At 18:30 in the Base Scenario: Base Design AC Off Win (O) (H) Not Connected with (M).....	81
Figure 22: Comparing Macroflow During the Year Between the Base Design and the Best Macroflow	83
Figure 23: Explaining the Opening and Closing Times of Ventilation and Air Conditioning Vents in the IESVE Hybrid Design Program for Comfort Ventilation.....	84
Figure 24: Explaining the Opening and Closing Times of Ventilation and Air Conditioning Vents in the IESVE Hybrid Design Program for Night Flush Cooling	84
Figure 25: MacroFlo Vent Peaks for Comfort Ventilation	85
Figure 26: Macroflo Vent Peaks for Night Flush Cooling.....	85
Figure 27: Filled Velocity Contour 7:0, 2/Feb	88
Figure 28: Filed Temperature Contour.....	90
Figure 29: Filled Pressure Contour	91

Chapter 1 : Introduction

1.1 Introduction

1.2 Background Information

Sharjah is the third largest city in the United Arab Emirates, with a population of more than 1.4 million people. It is located on the coast of the Arabian Gulf and is characterized by a hot and humid climate. The average annual temperature is around 27°C and can reach 48°C in summer. The city of Sharjah also faces high solar radiation, high humidity, and dust storms, which affect the thermal comfort and air quality of its residents. Sharjah is also seeing an increase in per capita energy consumption and carbon emissions, mainly due to the extensive use of air conditioning systems to cool buildings.

The city of Sharjah attaches great importance to mosques, as places of worship, education, and socialization. There are more than 3,000 mosques and prayer halls in the city of Sharjah, according to the Department of Islamic Affairs and Endowments in Sharjah, with different sizes, styles, and patterns. Mosques are also planned to occupy distinct places in urban plans, centered on intersections and squares, to highlight the Islamic identity and urban character of the city. One of the most prominent features of the mosques is the minaret, which a tower is attached to the mosque from which believers are called to pray five times every day through the muezzin. Minarets also serve as defining landmarks and symbols for buildings of Islamic houses of worship.

With the increasing number of worshipers in the Emirate of Sharjah daily, coinciding with the increase in the number of mosques in the Emirate, there are significant increases in energy consumption, which prompts us to reconsider the development of advanced and innovative technologies and methods that will make mosques significantly more energy efficient.

Mosques have always formed an important part of the fabric of the United Arab Emirates, notably in the Emirate of Sharjah, and mosques can become an effective role that serves and contributes to achieving the interests and sustainability efforts in the country. Through passive building cooling technologies, we can help reduce energy and carbon emissions in Sharjah and the UAE in general by reducing overall energy consumption in mosques in a relatively simple and affordable way.

Air conditioning represents 60% of annual electricity consumption and 75% of peak consumption in the UAE. Therefore, any effort to reduce the country's energy consumption, especially air conditioner consumption, will not only reduce the energy footprint, but optimal use of air conditioners can certainly reduce energy consumption by up to 30% in commercial buildings.

To meet the increasing demand for energy, specialists and scholars must control the management of energy consumption in mosques. The mosques witness an organized and continuous flow of visitors at five specific times throughout the day, with an average occupancy not exceeding one hour for each prayer, taking into account the maximum occupancy during the actual performance of each prayer, which ranges between 15 to 20 minutes(Erica Solomon 2023).

This is except for Friday prayers and prayers on occasions during the month of Ramadan, such as Tarawih prayers, in addition to other occasions such as lectures, activities, and memorization sessions. Hence the harmful carbon emissions emitted from power plants.

Mosques remain idle for a large portion of the day after the obligatory prayers are performed, during which time they are either empty or nearly empty, and air conditioning remains set to meet the needs of full occupancy, resulting in high levels of energy being wasted.

For example, two prayer times coincide with peak electricity use in the middle of the day, as energy consumption for refrigeration reaches 75% of the UAE's electricity during the summer months, and as the number of worshipers needs higher levels of air conditioning increases. Electricity, which is why the open and use of passive cooling methods is the best way to deal with cooling and is essential to the energy security of the UAE.

“Mosques often choose one of two options to deal with air conditioning,” says Dr. Talal Rahwan, assistant professor of computing and information sciences at Masdar Institute.

“Either the mosque leaves the air conditioning on all day, even when the mosque is empty.

Or, the mosque turns off the air conditioning when no one is there, and then turns it up again to a very high level once the mosque is full, making residents feel hot and uncomfortable.” At the same time, they wait for the entire building to cool down.

Moreover, turning the air conditioning to a very high level to cool users quickly is inefficient and wasteful. What is worse is that by the time the building is cool enough to be comfortable, the worshipers have left the mosque completely (Erica Solomon 2023)

Minaret: The minaret was initially developed as a practical solution to the problem of the Muslim call to prayer in the early Islamic era. The first minarets were simple wooden structures, but over time they evolved into more elaborate towers of stone or brick, often with various geometric shapes inlaid with ornaments and ornaments.

However, minarets also pose some challenges for mosques in the UAE's hot climate. In addition to the high costs of building minarets and the loss of their functional importance with the advent of microphones, minarets can increase mosques' heat gain by absorbing sunlight and transmitting it to the interior space. Furthermore, minarets can hinder the natural ventilation of mosques by blocking wind flow and creating turbulence around the building. These factors can affect the thermal comfort and energy efficiency of mosques

Minarets and windcatchers, two distinctive features of mosques and heritage buildings in the Emirates, may hold the key to bridging the gap in integrating renewable energy sources into mosques.

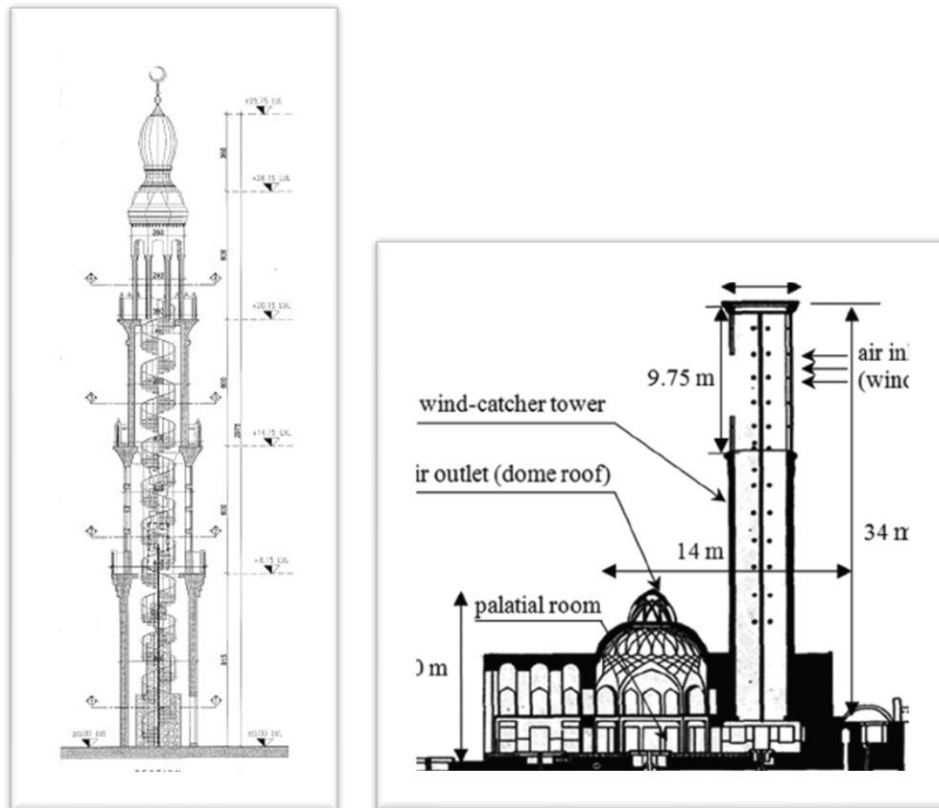
Here comes the role of the minaret, which is currently only an aesthetic element that indicates the location of the mosque and complements the structure of the mosque, along with the dome. As for the wind catcher, which is called locally the barjeel, it is similar to the minaret in that it is a high structure, hollowed out from the inside, allowing air to pass through it. These traditional barjeel have served for several years. For centuries, buildings have been cooled and ventilated naturally through ingenious designs that exploit wind energy.

Of course, by harnessing the power of the past, mosques can become beacons of sustainability for the future, inspiring not only worshipers but the wider community to embrace renewable energy solutions.

The graphical anatomy of the minaret of the Al-Fadhila Mosque in the Al-Kashisha area compared to the wind catcher of Doulatabad in Yazd. What is noticeable is the formal similarity in terms of vertical elongation and the internal cavity that allows air to enter from and to it, noting the presence of a metal staircase in the middle of the minaret that can be dismantled.

Figure 1

The Graphical Anatomy of The Minaret of The Al-Fadhila Mosque in the Al-Kashisha Area Compared to the Wind Catcher of Doulatabad in Yazd



Note. (Dolatabad garden's wind-catcher in Yazd. | Download Scientific Diagram 2023)
(Sharjah Department of Planning & Survey 2023)

1.3 Global and Regional Review

The building sector is considered one of the most important sectors responsible for energy consumption, amounting to the equivalent of 40% of global energy consumption and 33% of greenhouse gas emissions. Mosques are considered to contribute significantly to energy and water consumption in the UAE, as the total electricity consumption was estimated at 7.44% and 7.15% of the total water consumption in 2020. (AlAli et al. 2023)

The study (AlAli et al. 2023) aims to evaluate the energy and water consumption practices used in existing mosque buildings in the United Arab Emirates and provide recommendations to improve the sustainability of mosques.

Methodology

In a study to evaluate energy and water consumption in UAE mosques, data was collected from 146 existing mosques, where energy saving was audited, studied, and analyzed. Descriptive statistical analysis was conducted to analyze data from the period 2018-2019. The study found that the average electricity consumption of mosques in the UAE is 132.5 kilowatt hours/m²/year, and the average water consumption is 1.48 m³/m²/year. The most important factors and causes affecting energy efficiency are:

- 1- Lack or poor insulation
- 2- Using ineffective lighting systems
- 3- Old and inefficient air conditioning systems
- 4- Poor equipment maintenance

(General Authority of Islamic Affairs & Endowments (General Authority of Islamic Affairs & Endowments Sharjah) 2023)

Table 1

A Table Showing the Number of Mosques and Eid Prayer Halls in the Seven Emirates from the Period 2015 to 2020

Period	2015	2016	2019	2020
Mosque Type: Eid Mosques				
UAE	183	163	163	176
Abu Dhabi	39	36	35	35
Dubai	8	8	8	8

Sharjah	32	32	32	32
Ajman	9	8	9	9
Umm Al Quwain	4	4	4	4
Ras Al-Khaimah	64	50	48	50
Fujairah	27	25	27	38
Mosque Type: Mosques				
UAE	6,547	6,747	9,083	9,123
Abu Dhabi	2,106	2,212	2,331	2,305
Dubai	2,036	2,059	2,166	2,154
Sharjah	713	734	2,723	2,813
Ajman	294	302	316	320
Umm Al Quwain	172	176	187	193
Ras Al-Khaimah	932	973	1,042	1,014
Fujairah	294	291	318	324

1.4 Research Motivation

The main motivation and interest in this field of converting the minarets of mosques in the Emirate of Sharjah into passive cooling devices, represented by converting their minarets into windbreaks/solar chimneys, is to reduce energy consumption in mosques, as mosque buildings are usually large with high ceilings, which may constitute a burden on energy consumption. The operating cost of air conditioning devices is high.

Windbreaks/solar chimneys are classified as a traditional passive cooling system that can help reduce energy consumption in buildings in general and in mosques in particular and can improve the comfort of worshipers by providing natural ventilation and cooling.

Mosques are used for worship as well as being a center for community gatherings such as lessons, sermons, and seminars, so it is important to ensure they are comfortable for worshipers.

Minarets are a distinctive feature of mosques and an integral part of the design of mosques and the attention to them constitutes a milestone in preserving the cultural and Islamic heritage of Sharjah. The idea of converting minarets into windbreaks/solar chimneys will be a way to preserve this cultural heritage while improving energy efficiency and comfort in mosques.

Another motivation is that windbreaks/solar chimneys are sustainable cooling technologies that can have an impact on reducing greenhouse gas emissions and a means of promoting sustainable development in the emirate.

In addition to the above-mentioned reasons, Sharjah is a hot and humid city, so using windbreaks/solar chimneys to cool mosques would be particularly beneficial since Sharjah has a large number of mosques (about 3,000 mosques), thus converting minarets into windbreaks/solar chimneys. It can have a significant impact on energy consumption and comfort in the emirate.

In general, there are many strong motivations for writing a paper on converting the minarets of mosques in the Emirate of Sharjah into passive cooling devices. This paper can contribute to the field of sustainable building design, and can also help improve energy efficiency and comfort in places of worship around the world.

1.5 Research Hypothesis

To reach some questions and their answers, there are some research hypotheses about converting the minarets of mosques in the Emirate of Sharjah into passive cooling devices in the form of windbreaks/solar chimneys:

- 1- Converting minarets in mosques into wind traps/solar chimneys would reduce energy consumption in mosques.
- 2- Converting minarets in mosques would improve the thermal comfort of mosques and the comfort of worshipers in particular.
- 3- Converting minarets in mosques in Sharjah into wind traps/solar chimneys can be cost-effective to improve energy efficiency and comfort in mosques.
- 4- Converting the minarets into passive cooling devices can have a positive impact on the cultural heritage of Sharjah.
- 5- Converting the minarets into passive cooling devices would enhance sustainable development in the Emirate of Sharjah.
- 6- It will be more effective to create wind traps/solar chimneys by increasing the openings and directing them towards the prevailing winds, or by relying on pressure and temperature differences and openings against the direction of the wind.

1.6 Research Aims and Questions

This thesis aims to explore the possibility of reusing mosque minarets as wind catchers/solar chimneys to fill the gap in the issues of studying the integration of renewable energy sources into mosque buildings and making the most of expensive construction represented by mosque minarets. The main research question is:

How are physical environmental factors, air temperature, relative humidity, air movement, mean radiant temperature and minaret design affected thermal comfort

What is the feasibility of changing mosque minarets into wind catchers/solar chimneys to improve thermal comfort and energy efficiency in mosques in the Emirate of Sharjah? The sub-questions are:

1. What are the functional and design requirements of both the minaret and the wind catcher/solar chimney?
2. What are the necessary modifications required to convert a minaret into a functional wind catcher/solar chimney?
3. What is the effect of attaching the minaret in the prayer hall in terms of increasing the effectiveness of thermal comfort??
4. What are the potential benefits and drawbacks of reusing minarets as wind catchers/solar chimneys?

1.7 Objective

- Employing the minaret as a means of passive cooling contributes to the sustainability process
- Reviving the function of the Barajil, which was part of the architectural heritage of the Emirates, by merging its functions with the minaret of mosques
- Reducing electricity consumption and carbon emissions by using passive cooling and reducing the periods of need for air conditioning
- Consolidating environmental preservation and making it an integral part of mosque architecture through the use of passive cooling
- Highlight the more than 9,000 mosques that have minarets, and whose minarets can be used for sustainability purposes

1.8 Research Focus and Limitation

The research focuses on converting the minarets of mosques in the Emirate of Sharjah into passive cooling devices capable of saving energy by converting the minarets into windbreaks/solar chimneys that contribute to providing thermal comfort and examining the feasibility and cost-effectiveness of converting minarets to these sustainable elements.

The research will focus on the technical aspects of converting minarets into windbreaks, such as designing windbreaks/solar chimneys in terms of the structure used in the existing minarets. The study of the construction possibility will be skipped due to the need for technical laboratories and the costs related to that. The minaret will also be studied without considering the effect of the presence of spiral staircases. Located inside every minaret.

The research will also focus on studying the energy performance of mosques with minarets through computer simulation to analyze the extent to which energy consumption is reduced and thermal comfort is improved, in addition to considering the cost-effectiveness of converting minarets into windbreaks/solar chimneys.

Regarding the social and cultural impacts, the possibility of promoting sustainable development and adding a new use to the function of the muezzin, which has undergone multiple developments and uses over the years, will be considered.

The limitations that may include research paper can be limited to the following points:

Lack of data: There is limited data available on the energy performance of mosques, in addition to the need for government agencies responsible for this, including the Sharjah Islamic Affairs Department and the Sharjah Electricity and Water Authority. This would make it difficult to determine the extent of energy savings and thermal comfort benefits resulting from converting minarets to baffles. Wind/wind chimneys.

One of the methods used in studying wind traps is to make special models of the building to be studied and then transport them to laboratories equipped with special rooms to study winds. This method is considered expensive.

The cost of research and time: As for the cost and time, it is under possibility and control through the use of a computer simulation program, with the possibility of expanding the research and studying other topics that require time and financial cost, such as the construction study, questionnaires, and interviews with worshipers, those in charge of mosques, and donors.

Despite these limitations, there is a great deal of potential for research into this topic, as the idea of converting minarets into windbreaks/solar chimneys could be an important step towards improving energy efficiency and comfort in the many mosques in Sharjah and other hot and humid cities. In addition, the research has the potential to be a catalyst in preserving Sharjah's cultural heritage while also promoting sustainable development

1.9 Dissertation Contents and Structure

The research consists of several chapters. The first chapter, the introduction, discusses basic information about mosques in addition to an overview of wind farms and solar chimneys and provides an overview of their status at the global and local levels. This chapter also lists the motives for the research, in addition to presenting the hypotheses, objectives of the research, axis, controls, and limits.

The second chapter reviews and studies the literature historically on the development of mosques and the role of minarets, in addition to the history of wind traps and solar chimneys. In addition to that, a general study on passive cooling by wind traps and solar chimneys is clarified, where the factors that influence bringing wind into buildings or removing it from the building are also clarified. Wind trap/solar chimney design

development is examined to include design phases, design format, design strategies, and how to evaluate implementation strategies.

In the third chapter, light is shed on the methodologies used in implementing strategies for converting the minaret into passive cooling elements, based on computer simulation tools using the IES VE program, which are used for tripartite modeling to obtain realistic and effective results. In addition, the methodological framework of this research methodology is described in this chapter.

The fourth chapter presents a case study of a mosque located in the Al Tay area in Sharjah. The case chosen for this research is studied by studying the main features and climatic features of the mosque site. Several scenarios of the openings and materials of the minaret are also studied in this chapter in its original state without any modifications, and it is studied with modifications by adding the openings. Between the mosque and the prayer hall through the IES VE program.

Chapter Five presents the results and analysis related to converting the minaret into wind farms/solar chimneys. The last chapter is the conclusion, and a summary of the research will be presented, where the results of the computer simulation will be discussed, the research hypotheses will be answered, and whether the desired goals and objectives that were discussed in the introduction have been reached. Recommendations for future studies will also be identified.

Chapter 2 : Literature Review

2.1 Literature Review

2.1.1 *Historical Background*

2.1.1.1 The Minaret. The minaret is the place where the call to prayer is called. It is also known as the minaret. It is a sign and guide for the way on land and sea. It is called a minaret because it is lit at prayer times at night to alert those who cannot hear that the time for prayer has arrived. The minaret is a high building linked to the mosque that the muezzin ascends at specific times to call people to prayer. (Lotfi Saleh, Shawkat Al-Qadi 2018)

According to the Oxford Encyclopedia, the minaret is a tall, slender tower that forms a distinctive part of mosques in Islamic architecture. Minarets were not part of mosques at the beginning of their appearance, but they gradually became an important part of mosque design, and they have functional and aesthetic purposes. Throughout history, minarets in mosques have been influenced by many cultures and historical changes in their design and use.(Oxford Encyclopedia of the Modern World 2008)

It is believed that the first minarets built in the Middle East were in the eighth century. They were built in Damascus Syria, and they are the beacon of the Umayyad Mosque. They were a simple square tower that served as a platform for the call to prayer and observation.

The design and function of the minaret evolved with time, so the tower became thinner, with decorative elements added to its design and its height increased, some of which reached more than 70 meters. The minaret has become an important symbol of Islamic architecture and culture.

The main purpose of the minaret is to call people to prayer, through the call. The muezzin responsible for the call stands at the top of the minaret and calls out loudly to the

surrounding community. The use of the minaret was associated with the spread of Islam, as the minarets acted as distinguishing signs that could be seen from afar. (Bloom & Blair 2009)

According to (Gottheil 1910) the minaret evolved into a distinctive architectural element in Islamic mosques during the early Islamic period. Minarets were initially simple and practical structures used to call Muslims to prayer through the muezzin at fluted and fixed times. With time, the minarets began to adopt more detailed and aesthetic designs, as they included decorative elements inspired by the distinctive architectural environment of each region. Minarets are symbols of Islamic identity and architectural excellence. In addition, minarets act as architectural focal points and enhance the overall visual appearance of mosques and the urban landscape around them.

The minaret in contemporary architecture is constantly evolving in line with the requirements of the times by using modern technologies and materials while preserving traditional principles.

2.1.1.2 Windcatcher. Windcatcher, known as "Barjeel" or "Badger", is a functional architectural element used in traditional buildings to provide natural ventilation and passive cooling. They are popular in the Middle East and Central Asia. Wind Catchers Long structures or chimneys connected with buildings, with upper and side openings to catch the wind and direct it inside or outside the building.

The basic principle of the wind catcher is the existence of a pressure difference between the top and bottom of the tower, or in other words, negative and positive pressure when the wind blows, which causes the process of drawing hot, unclean air outside and pulling fresh air into the building, so it works with the natural ventilation system of the building, which is a sustainable system. (Sangdeh & Nasrollahi 2022)

According to (Pirhayati et al. 2013) Windcatcher is also known as the Tower of the

Winds or Badgir. Windbreaks are traditional structures designed to harness natural ventilation and provide cooling in hot, arid climates. It creates comfortable living spaces for residents and represents a sustainable solution against extreme hot weather conditions

Many experts (Pirhayati et al. 2013) trace the origins of wind catchers to ancient Iran in the fifth millennium BC. Windcatcher structures are mostly found in regions such as Iran, Iraq, parts of Central Asia, and the countries of the Persian Gulf, where the climates of these regions are characterized by extreme heat and scarcity of water resources. The main purpose of a wind catcher is to capture and redirect prevailing winds into buildings and create a cooling effect. The wind catcher consists of a tall tower with multiple openings at the top and bottom facing different directions to increase air circulation in the required space. Clay and bricks are usually used in the construction of air towers, with the addition of some patterns and engineering elements in their decoration . Some models of wind catchers cause the wind to flow through a series of chambers or channels, often underground, to reach the desired living space. Ground channels act as sustainable natural air channels. We also find some designs for windbreaks added to palaces and mosques, and this is evidence of their importance and effectiveness in designing buildings .Air ducts represent a sustainable solution for ventilation and cooling during the hot summer and reduce dependence on energy-consuming alternatives such as air conditioning.

The wind catcher also contributed to enriching the aesthetic appearance of the buildings associated with them and making them prominent and immortal building landmarks.

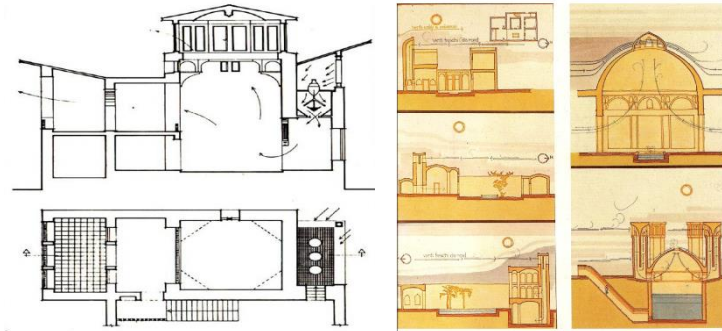
Windbreaks are towers used to create pleasant temperatures and are part of traditional architecture in dry and warm regions. We can define a Wind-Catcher as a traditional structure of natural ventilation and sustainable air conditioning. Traditional

windbreaks are designed and built using the technology and materials of their time (Maleki & Shabestari 2015)

In an early study by (Al Suliman 2014) Wind catchers were an urgent necessity in the era before mechanical cooling devices to mitigate the severity and harshness of the hot weather. Windcatcher is a sustainable natural solution to harsh conditions in hot climates, as it works on the principle of suctioning cold air from high altitudes into buildings or through underground ducts for heating exchange with cooler soil. Wind catchers are defined as towers with air inlets on their façade to suck in cold air and direct it to the interior spaces of the building. The cause of air movement is negative air pressure versus positive air pressure. The presence of wind catchers alongside the Mashrabiya represents a continuous supply of air, although they differ in design, shape, and height. Some wind catchers are equipped with a net that purifies the air from pollutants and dust.

Other fenders are also equipped with charcoal, which acts as an odor absorber from the air.

For dry and hot climates, water surfaces, fountains, or pottery urns can be used to help humidify the atmosphere and lower the temperature of the air that flows through the channels for the required spaces. To get the most benefit from wind catchers, the wind speed and direction must be appropriate and well thought out. (Al Suliman 2014)

Figure 2*An Illustrative Function of the Wind Catcher*

Note. (Al Suliman 2014)

The study (Nessim et al. 2023) was conducted on wind towers in Egypt and the Middle East, where the designs of wind towers in several historical buildings in Egypt and the Middle East were studied.

Wind towers have been used in Egypt and the Middle East for centuries for cooling and passive ventilation purposes. It has been shown that the design of wind towers has evolved to adapt to different climatic conditions and architectural styles.

The author identified three main eras of wind tower design in Egypt and the Middle East:

Ancient Era: Wind towers were usually simple in design and consisted of a vertical shaft with holes at the top and bottom.

Middle Ages: Wind towers became more sophisticated in design, incorporating features such as multiple columns, vents, and dampers.

Modern Era: In this era, wind towers have been adapted to new technologies and materials, and are often incorporated into the design of modern buildings.

According to the study, the design of wind towers in Egypt and the Middle East varies from one region to another. For example, wind towers in Egypt are usually taller and have more openings than wind towers in the Arabian Peninsula.

The researcher concluded that wind towers have been an important part of domestic architecture in Egypt and the Middle East for centuries. He also noted that wind towers can be an effective means of providing cooling and passive ventilation in hot climates. The author also suggested that wind towers could be used to improve the thermal comfort of buildings in modern cities, such as using them as wind towers to ventilate public spaces and cool buildings with large glass facades.

Figure 3

Traditional Wind Tower Design and Information

						
Climatic zone	Hot and dry	Hot and dry	Hot and humid	Hot and dry	Hot and humid	Dry and semi-hot
Prevailing wind direction	Northwest	Northeast	Breeze	Northwest	Southwest	North
Shape of cross-section	Rectangle	Square/rectangle/hexagon, octagon	Square	Rectangle	Square	Square
Average dimensions (m)	-	0.5 × 0.8 0.7 × 1.1	1 × 1	0.5 × 0.15 1.20 × 0.60	1 × 1	1 × 1
Height (m)	One story above roof	3-5	3-5	1.80-2.10	5 and above	1.5 from roof
Orientation to the prevailing wind direction	Ordinary	Diagonal	Diagonal	Ordinary	Diagonal	Ordinary
The ceiling of the wind tower	30° Slope	45° Slope	30° Slope	45° Slope	45° Slope	30° Slope
Ventilated area	Dining plus one room	Dining room and basement	Dining plus others	Only the basement	All rooms	All rooms
Air flow	One side	Multi-side	Multi-side	One/two sides	One side	One side
Evaporative cooling	Sometimes	Sometimes	Never	Sometimes	Never	Never

Note. (Nessim et al. 2023)

2.1.1.3 Passive Cooling Systems Including Wind Catchers/Solar Chimney. This summary focuses on energy-efficient cooling solutions that include windbreaks and indirect evaporative cooling. The research studies the effectiveness of this system in providing sustainable and effective cooling for building applications.

Evaporative cooling is defined as a process that uses the principles of evaporative cooling without introducing moisture into the air-conditioned space. Indirect evaporative cooling is used to achieve the desired indoor temperature reduction while maintaining appropriate humidity levels. A wind catcher is an architectural feature that captures and redirects natural airflow into buildings. Wind catchers play an important role in providing the airflow required for the ventilation and cooling objective as they facilitate the entry of

outside air into the system and help maintain the required thermal comfort rates.

The thesis (Elzaidabi 2008) studies indirect evaporative cooling systems (IEC) for building applications. The system works by evaporating water in a room separate from the air that is cooled. This system is characterized by preventing the entry of moisture that causes mold to form into the building.

The thesis discusses the design and construction of an IEC system supported by wind catchers. The wind shed is defined as a building element that contributes to providing passive ventilation by drawing wind into the building, which contributes to improving the efficiency of the IEC system through the continuous supply of fresh air to the evaporation chamber.

The thesis was based on the results of laboratory tests conducted on the IEC system. Tests showed that the system is capable of cooling the air by up to 12 degrees Celsius, which contributes to energy savings compared to traditional air conditioning systems and can help reduce the demand for fossil fuels. They are also a more sustainable option, as they do not produce any harmful emissions.

The study (Chohan & Awad 2022) discussed the different types of wind traps and they can generally be classified into two types: horizontal and vertical. Horizontal wind catchers are installed on the roof of the building and have a long, narrow opening facing the direction of the prevailing winds. Vertical wind catchers are built on a tower or other tall structure and have a large opening at the top.

The paper also discussed the factors that affect the performance of wind catchers. These include factors

1. Size and shape of the wind catcher: The size and shape affect the performance of the wind catcher, as the larger size can draw in more air, and the shape of the wind catcher also affects its performance. For example, wind catchers with a curved shape are more

efficient at catching wind than wind catchers with a straight shape

2. Wind speed: Wind speed is considered one of the most important factors that affect the performance of wind farms. The higher the wind speed, the greater the amount of air drawn into the building. However, wind catchers can be effective in areas with low wind speeds, as long as there is a steady breeze.
3. The difference in temperature between the inside and outside of the building: The difference in temperature between the inside and outside of the building also affects the effectiveness of the wind catchers. The greater the temperature difference, the greater the amount of air drawn into the building.
4. Windcatcher direction: The direction of the wind catcher opposite to the prevailing wind is an essential factor
5. Building design: Buildings with large openings and high ceilings are more efficient in ventilation than buildings with small openings and low ceilings
6. Number of wind catchers: The number of wind catchers also affects performance in general. The higher the number of wind catchers, the more efficient and effective they are in ventilating the building.

It is worth noting that the factors that affect the performance of wind catchers can vary depending on the specific location and climate. For example, wind catchers may be more effective in areas with strong winds compared to areas with weak winds. Similarly, windbreakers may be more effective in regions with hot summers than in regions with cold winters.

The literary of (Valibeig, Nasekhian & Tavakoli 2014) study focuses on the "wind chimney", which is based on the principles of wind catchers and solar chimneys to provide natural ventilation for residents in buildings. The wind chimney system harnesses wind energy and solar heat to create a draft to improve indoor air quality and thermal comfort.

The study confirms the importance of natural ventilation in enhancing the efficiency of buildings and providing energy for the well-being of the population. It also highlights the traditional mechanical ventilation systems, their limitations, and the alternative solutions achieved by the wind chimney to provide environmental sustainability and thermal comfort.

The case study also explores the design principles for wind catchers and solar chimneys. Windcatchers are defined as architectural elements that direct the flow of wind to and from buildings, while the principle of solar chimneys is based on exploiting solar radiation to create a pressure difference effect to create air movement. The study confirms that the combination of these two concepts in one system increases the chances of creating natural ventilation in addition to the possibility of improving air exchange rates, removing indoor pollutants, and reducing the need for mechanical cooling systems.

Table 2

Comparison Between Solar Chimney and Wind Chimney

Feature	Solar chimney	Windcatcher
Effect	Draws air out of the building	Draws air into a building
Mechanism	Solar radiation	Wind
Effectiveness	Sunny climates	Windy climates
Openings	opening at the top	On one or more sides

The literature review (Mazraeh & Pazhouhanfar 2020) is a case study of Qeshm Island it sheds light on renewable wind power in the local elements of wind catchers and clamps. The review aims to explore the impact of these traditional architectural features in harnessing wind energy and promoting sustainable practices. The study begins by explaining the concept of renewable wind energy and its importance in reducing dependence on non-renewable energy sources. It also highlights the potential for using local elements, such as

windbreaks and lattices, as effective means of harnessing wind energy and harnessing it effectively. The review delves into the elements, examining wind catchers and clips found on Qeshm Island, an island in the Persian Gulf with a rich heritage. Construction techniques and design principles are examined and the locations and directions of the winds are analyzed.

The review (Mazraeh & Pazhouhanfar 2020) also discusses the functional aspects of wind catchers and gratings in terms of wind energy utilization. It explores the effect of these elements on the protection of natural ventilation, cooling, and natural airflow inside buildings. As a result of the sustainable use of wind, the review highlights its potential to reduce energy consumption for cooling purposes and improve comfort in indoor spaces. The researcher provided empirical evidence and insights about the performance of windbreaks and grilles in the use of renewable wind energy by examining factors such as airflow rates, thermal comfort, and energy efficiency in buildings that incorporate these elements. The results of the literature review indicate that windbreaks and gratings are of functional importance in harnessing renewable wind energy in Qeshm Island. Contribute to sustainable building practices by utilizing natural ventilation and reducing energy demand for cooling. These elements also preserve local cultural identity and architectural traditions.

The literature review (Prima 2019) aims to incorporate wind catchers and solar chimneys as sustainable ventilation systems for dense urban settlements in tropical climates to enhance natural ventilation and thermal comfort in densely populated urban areas. The review begins by addressing the challenges of providing adequate ventilation and cooling in tropical climates of high temperature and humidity while mentioning the need for sustainable solutions that reduce energy consumption and reliance on mechanical cooling systems.

Literature (Prima 2019) reviews the concept of windbreaks and solar chimneys as

individual passive cooling strategies. Discusses their performance, design principles, and benefits in enhancing natural airflow and cooling within buildings. In addition, the study aims to shed light on the possibility of applying windbreaks and solar chimneys in dense urban settlements. The study evaluates factors such as airflow rates, energy efficiency, heat rates, and thermal comfort related to the occupants.

In conclusion, the study indicates that the incorporation of windbreaks and solar chimneys could be a viable alternative ventilation strategy for dense urban settlements in tropical climates. The combination of these systems can improve natural ventilation, reduce energy consumption, and improve thermal comfort.

According to (Nejat 2018) Sustainable and energy-efficient technologies for cooling buildings are fundamental to architectural design to reduce energy waste and climate change concerns. One of these sustainable technologies is wind catchers. The study provides a comprehensive overview of wind catchers as a sustainable passive cooling solution and explores design principles, their effectiveness, and contemporary applications.

The design principle is based on effectively capturing and directing the wind flow toward the required spaces, which creates a cooling effect through evaporation and convective heat exchange. The height, direction, shape, and size of the openings are carefully considered to obtain optimal natural ventilation and the desired thermal comfort. Studies have shown that wind catchers can significantly reduce internal temperatures in hot climates. The system is particularly effective in arid regions where there are temperature differences and natural winds prevail.

Despite advances in mechanical cooling systems, wind catchers are still relevant and valuable in contemporary architectural design. Architects and engineers are adopting wind catchers as solutions in sustainable building projects to reduce energy consumption and enhance occupant comfort. Recent modifications include integrating windbreaks with other

passive cooling strategies such as shading devices, thermal mass, and natural ventilation systems. Moreover, computational modeling and simulation techniques are used to improve windbreak designs and evaluate their performance in different climatic conditions.

This abstract (Mohamed & Mohammed 2018) focuses on a case study in Jeddah, Saudi Arabia examining the environmental performance of wind farms and their effectiveness in improving indoor thermal comfort and reducing energy consumption in hot and dry climates. Wind catchers are evaluated by considering various factors, including indoor thermal comfort and potential energy consumption and savings. The evaluation is done by taking measurements of indoor air temperatures, air velocity, and humidity levels in buildings. By collecting energy consumption data, the impact of wind catchers on reducing the need for mechanical cooling systems is evaluated. The study proves the effectiveness of wind catchers significantly in improving internal thermal comfort in Jeddah, as the natural ventilation provided by wind catchers allows for improving air movement and circulation, reducing indoor air temperatures, and creating a more comfortable environment for passengers. The study also emphasizes the need to take into account the local climatic conditions when evaluating the environmental performance of wind catchers, especially in climates that prevail in temperature differences and wind patterns, such as Jeddah.

The study (Awad 2021) focuses on exploring current trends in mosque architecture in the northern cities of the United Arab Emirates. It also studies design principles, features, and elements that make up contemporary mosque architecture. One of the prominent trends in mosque architecture is the focus on distinctive designs and their greatness. What distinguishes the mosques in the northern cities of the Emirates are the elaborate facades inlaid with aesthetic ornaments and high-quality materials, such as marble and glass. Among the most prominent elements that distinguish it are the large prayer halls, spacious squares, and decorated domes.

Sustainability is part of contemporary mosque architecture in the United Arab Emirates. Mosques are often characterized by energy-efficient lighting systems, natural ventilation strategies, the use of renewable energy sources such as solar energy, and water conservation techniques to reduce environmental impact and their exploitation in landscaping connected to mosques. Modern mosques often incorporate digital systems for the call to prayer, temperature control, and lighting management which enhance thermal comfort in mosque facilities. Contemporary mosque architecture emphasizes the creation of community-focused spaces that promote community interaction, participation, and knowledge exchange. Mosques often also include educational and cultural facilities, libraries, and meeting rooms.

In conclusion, mosque architecture in the northern cities of the United Arab Emirates shows a balance between the elements of traditional Islamic design and the aesthetics of contemporary and sustainable architecture.

This literature review (Nejat et al. 2019) aims to explore the effectiveness of wind catchers as a passive cooling solution for natural ventilation in Malaysia. By investigating previous studies and research on wind catchers in different contexts, the application feasibility and potential benefits of wind catchers in the climatic conditions of Malaysia are evaluated. Case studies from different regions with similar climates showed the effectiveness of wind catchers in achieving passive cooling and their ability to enhance natural ventilation and reduce heat load in buildings. In addition to their potential to effectively address problems related to indoor air quality, thermal comfort, and energy efficiency.

The literature focuses on the importance of the direction, size, shape, and height of wind catcher openings and the necessity of shading devices. Optimizing these design elements is critical to increasing the airflow and cooling potential of wind catchers. Current literature indicates that wind catchers are an effective and sustainable solution to passive

cooling and natural ventilation in the hot, humid climate of Malaysia. Exploiting wind energy is also a way to reduce the consumption of air-conditioners, thus reducing environmental impact and energy costs.

This study (Dahlan et al. 2019) discusses the use of passive cooling systems to improve the thermal performance of mosque buildings. This review aims to explore the effectiveness and benefits of these systems in improving thermal performance. The literature focusing on passive cooling systems that can be used in mosque buildings suggests that among these techniques are wind catchers, chimney ventilation, and cross ventilation, as well as shading devices, such as chimneys and vents. These systems enhance airflow and reduce heat gain enhance thermal comfort without relying on mechanical cooling. Furthermore, passive cooling strategies contribute to energy savings, reduced environmental impact, and improved indoor air quality.

Specific design requirements for integrating passive cooling systems into mosque buildings are also highlighted. These factors include layout, building orientation, size, placement of openings, and selection of shading and thermal insulation devices. This ensures the integrity of the design. Several case studies have been conducted to evaluate the implementation of passive cooling systems in mosque buildings. These investigations showed positive results, with improved thermal comfort reported in mosques using passive cooling techniques. The case studies also identified challenges and lessons learned.

In conclusion, the integration of passive cooling systems in mosque buildings provides a promising approach to improving their thermal performance. The literature supports the effectiveness of natural ventilation techniques and shading devices in enhancing indoor comfort, reducing energy use, and promoting sustainability.

The literature review (Zafarmandi & Mahdavinejad 2021) examines modern wind catcher technology in terms of its design, performance, and applications, and aims to provide

an overview of technological advances and their potential benefits in different contexts . Wind catchers have evolved in terms of design, materials, and construction techniques. Thanks to these improvements, the wind catchers can adapt to different climates and architectural styles. The review also highlights the transition from traditional windbreaks to modern designs that prioritize efficiency and sustainability .Researchers have explored the importance of factors such as size, shape, orientation, and placement of vents in improving airflow and ventilation efficiency. Studies have also investigated the integration of windbreaks with other passive cooling and ventilation strategies to improve their overall performance .Wind catchers were evaluated by measuring airflow rates, cooling effectiveness, indoor air quality, and thermal comfort. The literature highlights the ability of modern windbreaks to improve indoor environments while reducing the energy consumption associated with mechanical cooling systems .The literature reviews the various applications of modern wind catchers in residential, commercial, and institutional buildings as a viable and sustainable solution for natural ventilation and cooling in various building types and climates.

In conclusion, modern windbreak technology represents a major advance in sustainable building design. The literature demonstrates their ability to provide natural ventilation and cooling solutions, reduce energy consumption, and enhance indoor comfort. With the continuous development in this field, more research is needed to improve design principles, evaluate performance under different conditions, and explore innovative applications

This literature review (Jomehzadeh et al. 2020) focuses on the effects of geometry, microclimate, and macroclimate on natural ventilation by wind catchers. It discusses the engineering of wind catchers and the impact of these design factors on the effectiveness of natural ventilation, including their size, shape, height, and opening configurations. The review stresses the importance of optimizing engineering to ensure maximum airflow

capture and distribution within buildings .Previous investigations have examined local climatic conditions affecting the performance of wind catchers. These factors include ambient temperature, wind speed, wind direction, and humidity. Studies have shown that windbreaks can effectively harness prevailing winds to enhance natural ventilation and provide passive cooling, particularly in arid regions with high daily temperature variations . The researchers evaluated the performance of the windshield using field measurements, computational fluid dynamics (CFD) simulations, and experimental studies. These investigations evaluated parameters such as airflow rates, temperature variances, indoor air quality, and thermal comfort. The review highlights the positive effects of wind traps in improving indoor conditions and reducing reliance on mechanical cooling systems.

In conclusion, windbreaks, or Badgirs, provide a sustainable and energy-efficient solution to natural ventilation and cooling. The literature demonstrates that engineering factors, microclimate, and macroclimate play critical roles in determining windbreak performance. By optimizing the design and taking into account local climatic conditions, wind traps can effectively harness wind energy to provide natural ventilation and passive cooling.

The researcher (Maarof 2014) used a variety of methods to study thermal comfort based on natural ventilation in Malaysian mosques. The study included the following methods:

Field measurements: air temperature, air movement, and humidity were measured in separate locations inside mosques.

The perceived thermal comfort scale was from 1 to 5, where worshipers were asked to rate their thermal comfort.

Statistical analysis: Finally, the data extracted from the field study and the comfort assessments of worshipers were analyzed to determine the factors affecting thermal comfort.

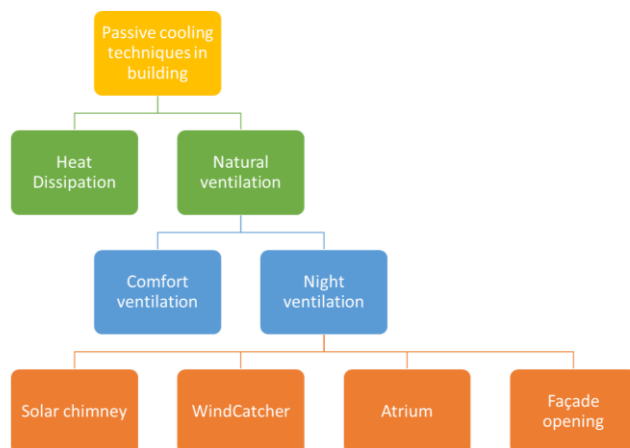
Through the study, it was found that air temperature was the main factor affecting thermal comfort, followed by air movement and humidity. The vaults have a more effective ability to circulate air and distribute it evenly throughout the prayer hall.

Among the limitations affecting the study methodology:

The study was conducted during the hot and humid season only and did not consider other seasons, nor did it consider the effect of other factors, such as the size and shape of the prayer hall, on thermal comfort.

Figure 4

Passive Cooling Techniques in Buuilding



According to (Robert & Brown 2015) passive cooling is the process of cooling buildings using natural means without resorting to mechanical systems such as air conditioners. Passive cooling can be used in all climates, but it is more effective in hot and humid climates.

There are three main strategies for passive cooling:

- 1- Avoid heat: The building is designed to take into account methods and techniques that reduce heat gain in the first place. These methods include using light-colored materials and studying the building's orientation and shading. Shading can be used to prevent sunlight from directly reaching the building. This can be done with trees, umbrellas or

overhangs

- 2- Comfort ventilation: It is the process of removing heat and humidity
- 3- from the building by ventilating it. This can be done by creating appropriate openings or using fans. Fans can be used to distribute air throughout the building, which helps remove heat and humidity
- 4- Night cooling: It is the process of ventilating the building at night, when the outside air is colder, which contributes to cooling the building mass. The cold mass helps reduce the internal temperature and prepares the building during the day.

Passive cooling can be a very effective way to reduce energy consumption and improve comfort in buildings.

The choice of passive cooling techniques depends on the specific climate and building design. However, all of these technologies can be used to create comfortable and energy-efficient buildings.

(Al, Jassim & Sudany 2015) Wind catchers are historically traditional items used for centuries in hot, dry climates to provide cooling and natural ventilation and typically consist of a vertical tower with openings at the top and bottom. The wind enters the tower through the openings at the top and is then drawn down through the tower into the building.

Minarets are tall, slender towers usually associated with mosques. Their purpose is to call Muslims to prayer and to broadcast the call to prayer.

The research deals with the use of minarets as wind catchers in two mosques in Baghdad. The paper found that using minarets as wind absorbers can significantly reduce the temperature inside mosques in Baghdad. The paper found that using minarets as wind absorbers can reduce the temperature inside the Kadhimiya Mosque by up to 19 degrees

Celsius on hot days. In addition, it found that using minarets as wind catchers can improve the relative humidity inside mosques.

The research concluded the effectiveness and simplicity of using minarets as wind catchers to provide natural ventilation and passive cooling in mosques in Baghdad. It also indicates the possibility of using minarets as wind catchers to reduce energy consumption in Baghdad mosques.

The following is the methodology used for the research:

A review of the literature related to the use of minarets as wind absorbers in mosques, a field visit, and a case study of two mosques in Baghdad to study the design and construction of their minarets. The researchers collected temperature and relative humidity data inside and outside the two mosques during the summer months.

The researchers also used computer simulations to calculate (CFD) the airflow inside and outside the two mosques to analyze the effectiveness of the minarets as wind catchers.

Result: The researchers found that the minarets in both mosques were effective in providing natural ventilation and passive cooling. The computer simulation showed that the minarets created a pressure difference between the inside and outside of the mosques, which led to pulling cold air into the mosques and helping them reduce humidity inside the mosques.

In this research paper, the researchers (Abed Wahid Jassim 2018) relied on the following methodologies:

1. Literature review on the use of minarets as wind catchers and wing walls for passive evaporative cooling.
2. Study the development of a new design for a minaret that can be used as a two-sided windbreak integrated with the wing wall.

3. Use computer simulation to calculate (CFD) and study the airflow inside and outside the minaret, then analyze the performance of the new design using the CFD model.

Through this study, they found that the new design is effective in providing passive evaporative cooling in hot climates and can reduce the temperature inside the minaret by up to 6 degrees Celsius on hot days. In addition, the new design can increase the humidity inside the minaret and can help improve Thermal comfort for occupants.

The author suggested that the new design could be used to reduce energy consumption in buildings in hot climates.

The authors (Alzaed & Balabel 2017) reviewed the literature on the design and performance of traditional wind catchers and developed a new four-sided wind catcher design that is particularly suitable for the climate of Saudi Arabia.

Four-sided wind catchers are a common type of wind catcher used in many parts of the world. They are usually square or rectangular, with openings on all four sides. This allows them to catch winds from all directions, regardless of wind direction.

Four-sided wind catchers are a common type of wind catcher used in many parts of the world. They are usually square or rectangular, with openings on all four sides. This allows them to catch winds from all directions, regardless of wind direction.

There are other forms of wind catchers including:

Double-Sided Wind catchers: These wind catchers have openings on the sides and are usually used in areas where the wind direction is relatively constant.

Three-sided wind catchers: These wind catchers have openings on three sides and are often used in areas where the wind direction is variable.

Round wind catchers: They are characterized by their circular shape with openings on all sides, and are usually used in areas where the wind direction is highly variable.

Wind Towers: These are tall vertical structures with openings at the top and bottom. They are usually used in large buildings, such as mosques and palaces.

The shape of the wind catchers is considered an important factor and an influencing factor in capturing the wind and directing it into the building. The optimal shape of the wind catcher is determined based on the local climate and wind conditions.

In addition to the shape, other factors affect the design of wind catchers, such as the size and position of the openings, in addition to the presence of internal baffles and dampers that play a role in the effectiveness of the wind catcher.

The authors supported the new design with a computational fluid dynamics (CFD) model to simulate airflow in and out of the new wind catcher. Then they analyzed the new wind catcher's performance.

As a result of the analysis, the researchers found that the new wind catchers are effective in providing natural ventilation and cooling in residential buildings in the Kingdom of Saudi Arabia. Computer simulation of the CFD model showed the possibility of reducing the temperature inside residential buildings by up to 3 degrees Celsius on hot days using wind catchers. In addition, the researchers found that the new wind catchers can increase airspeed and improve air movement inside residential buildings, which contributes to improving the thermal comfort of occupants.

The researchers concluded that the new windbreaks are a promising solution for natural ventilation and cooling in residential buildings in Saudi Arabia. The authors suggest that new windbreaks could be used to reduce energy consumption in residential buildings in Saudi Arabia.

The research paper (Sivakumar et al. 2018) studies natural ventilation via wind catchers using CFD, where the researchers developed a 3D CFD model of a room equipped with a wind catcher.

The researchers simulated and analyzed airflow inside the room and outside the openings of different directions for the wind catchers.

The researchers found that the direction of the wind catcher openings has a significant impact on the airflow inside the room and that the best direction of the wind catcher openings will depend on the direction of the wind and the design of the room. For example, it was found that the best orientation of the wind catcher openings for a room with one wind catcher is for the openings to face the direction of the wind. In a room that contains many wind catchers, the optimal orientation of the openings will depend on the design of the room and the desired airflow pattern.

Also, the size and shape of the wind catcher openings can affect the airflow within the room. For example, larger wind catcher openings will allow more airflow into the room.

In conclusion, the researchers conclude that their straightforward approach can be used to improve the orientation of wind-capturing openings for natural ventilation in a variety of buildings. The authors also suggest the benefit of this approach in reducing energy consumption in buildings and improving thermal comfort for occupants.

The researchers also found that other factors can affect the airflow inside the room using the wind catcher, such as the height of the wind catcher, the distance between the wind catcher and the building, and obstacles located near the wind catcher. Authors recommend considering these factors when designing a building wind catcher.

The authors(Ahmed, Kumar & Mottet 2021) conducted a literature review of studies related to natural ventilation in warm climates. The author used a case study of a mosque in Baghdad, Iraq, to illustrate the effectiveness of natural ventilation to achieve thermal comfort and interior quality in a hot climate.

Natural ventilation is an effective way to provide thermal comfort and interior quality in warm climates, although some challenges need to be addressed. One of these challenges is

the ability of natural ventilation to provide adequate cooling during heat waves. Another challenge is outdoor air pollution, which can affect the air quality in naturally ventilated indoor spaces.

The author also found that the design and orientation of buildings can have a significant impact on natural ventilation performance.

A case study of a mosque in Baghdad showed that natural ventilation can be used to achieve thermal comfort and interior quality in a hot climate. The design of mosques is characterized by several features that support natural ventilation, such as high ceilings, large windows, and wind catchers. As a result, the internal temperature of the mosque was usually 5-10°C lower than the external temperature.

The author concluded that natural ventilation can be an effective way to provide thermal comfort and indoor quality in warm climates, but it is important to address the challenges of heat waves and outdoor air pollution.

The researcher (Dina Ejlali Vachin 2017) studied thermal comfort in mosques and other religious buildings. The author also studied the design features of mosque buildings and the climatic conditions surrounding them. The researcher found the possibility of applying the following strategies to improve thermal comfort inside the mosque building in a hot climate:

Natural ventilation: Using natural ventilation to cool the mosque building and improve airflow through large windows in the mosque's design and enhancing them with wind catchers.

Thermal mass: The possibility of using thermal mass to absorb and store heat during the day and release it at night, which helps reduce the internal temperature of the mosque building during the day.

Evaporative cooling: Using evaporative cooling to cool the air inside the mosque hall by installing water fountains or misting systems.

Shading: Using shading elements to reduce the amount of heat entering the mosque building by planting trees or installing awnings over the windows.

There are additional features that help improve thermal comfort inside the mosque building, such as high ceilings, which can contribute to improving airflow and reducing the internal temperature of the mosque building, as well as domed surfaces that help dissipate heat and improve airflow.

Open courtyards with fountains can help provide shade, ventilation, cool the air, and improve humidity levels.

The author concluded that a combination of natural ventilation, thermal mass, evaporative cooling, shading, and studied design features can be used to improve thermal comfort inside the mosque building in a hot climate. Improving thermal comfort can help reduce energy consumption in the mosque building. This is because there will be less need to use air conditioning and other mechanical cooling systems.

The researchers (Tan & Shojaei 2019) conducted a study on solar chimney technologies and reviewed the advantages and disadvantages of this technology by reviewing the literature. In addition, they discussed several recent developments in solar chimney energy technology.

The researchers found that solar chimney energy technology has several advantages, including:

- 1- A renewable and sustainable source of energy.
- 2- A non-polluting source of energy.
- 3- Relatively simple and low-cost technology.

The disadvantages of solar chimney technology are:

- 1- It is only suitable for certain geographical locations with high solar radiation and low wind speeds.
- 2- It has relatively low efficiency.
- 3- It can be visually intrusive.

As for the recent developments in solar chimney energy technology, they are as follows:

- 1- Developing hybrid solar chimney plants that combine solar chimney energy technology with other renewable energy technologies such as wind turbines and photovoltaic solar cells.
- 2- Develop floating solar power plants with chimneys that can be installed on online sites.
- 3- Develop solar power plants with chimneys, which can be used to generate electricity at night.

In conclusion, solar chimney energy technology is a promising technology for renewable energy and a major contribution to global energy support. There is a need for more research and development to improve efficiency and reduce the cost of solar chimney energy technology. There is also the possibility of using solar chimney energy technology to provide several other benefits, such as desalination. Water, air conditioning, and supporting technology for remote rural areas.

(AlAli et al. 2023) points out the significant impact of the building sector on global energy consumption and greenhouse gas emissions, as mosques in the United Arab Emirates are among the main buildings consuming energy and water, which necessitates an evaluation of their current practices and a study of potential improvements.

The researchers analyzed data from 146 mosques in the UAE that underwent energy-saving audits between 2018 and 2019. By using descriptive statistical analysis to

identify factors affecting energy efficiency and studying appropriate solutions to reduce energy and water consumption

Several gaps were identified in the literature, including the focus of research mainly on energy and water consumption in mosques, noting the study of new buildings and significant neglect of existing buildings.

There is a scarcity of adequately exploring the social and cultural aspects and behaviors affecting consumption patterns.

He also touched on the existence of a gap in the issues of integrating renewable energy sources into mosque buildings and the need for more research.

2.1.2 Pros and Cons Extracted from Literature Reviews

2.1.2.1 Pros (Jomehzadeh et al. 2020)

- **Energy Efficiency:** The wind catcher relies on the wind as a sustainable and clean natural force to create a refreshing air current, reducing the load on mechanical cooling systems. This makes it an environmentally friendly and energy-efficient system.
- **Indoor air quality:** Wind catchers are based on the process of circulating air in the interior spaces and replacing the stale air with fresh air that improves indoor air quality and reduces pollutants.
- **Cost-effectiveness:** Since wind catchers do not require electrical equipment and connections, they are an effective option for areas with harsh climatic conditions
- **Improve comfort:** Wind catchers create a comfortable and satisfying indoor environment by providing the space with natural ventilation, which contributes to reducing temperatures, continuity of air movement, and humidity levels

- Cultural and aesthetic value: Wind catchers express an aesthetic, urban, and cultural identity of the region|.

2.1.2.2 Cons: (Jomehzadeh et al. 2020)

- Climate dependence: Wind catchers may be considered ineffective in climates with low wind speeds and high humidity and have limited effectiveness
- Limited cooling capacity: The effectiveness of wind catchers may not be at the same level as the cooling systems that people are used to in extreme heat waves.
- Design: There are challenges associated with the design of wind catchers, such as studying the orientation of the building, its size, height, and the number of its openings, which may cause deficiencies in the work of the catchers.
- Maintenance: Wind catchers need regular maintenance as dust, debris, and bird nests can impede airflow and quality.
- Noise and privacy: Wind catchers may cause noise as the wind passes through them, which may affect the comfort of the building and area occupants and disturb quiet environments. In addition, the open design of wind traps may affect privacy.

2.1.2.3 Pros (Prima 2019)

- Provides natural ventilation
- Improved indoor air quality
- Enhance energy efficiency
- Adapted to tropical climates
- Ease of seamless integration into building designs

2.1.2.4 Cons (Prima 2019)

- design intricacies
- maintenance requirements
- Climate dependence
- Potential noise and privacy concerns
- Higher initial costs compared to traditional systems.

Table 3

The Summary of the Research Conducted

Author	Finding/Discover	Comment
Historical background/ minaret (Oxford Encyclopedia of the Modern World 2008) (Gottheil 1910) (Bloom & Blair 2009)	The architecture of minarets in architecture has constantly evolved throughout the ages in line with the requirements of the times using modern techniques and materials while preserving traditional principles.	The development in the elements, form, and function of the minaret has been in line with the requirements and needs of every era and has not stopped. It is currently useful and feasible for the minaret to have uses other than form and signs for people to infer the safety of mosques.
Historical background/ Windcatcher (Sangdeh & Nasrollahi 2022) (Pirhayati et al. 2013) (Maleki &	The basic principle of the wind catcher is that there is a pressure difference between the top and bottom of the tower when the wind is blowing. Windcatcher represents a sustainable solution for ventilation and cooling during the hot summer and reduces dependence on	It is possible to benefit from the northwesterly winds prevailing in the Emirate of Sharjah and also to benefit from the principle of the stack effect to provide thermal comfort to the mosque hall.

Shabestari 2015)	energy-consuming alternatives	
(Al Suliman 2014)	such as air conditioning.	
Passive cooling systems including wind catchers		The designs of the mosque's semi-fixed spaces, along with their common elements, such as minarets, domes, and the prayer hall, along with their height, represent auxiliary and
(Chohan & Awad 2022)	There are fixed factors that affect the performance of wind catchers, such as the size and shape of the wind catcher, building design, direction of the wind catcher, temperature variation, and wind direction.	positive factors that contribute to helping achieve thermal comfort gains and promoting the fulfillment of the function of the air envelopes. Comfort ventilation: It is the process of removing heat and moisture from the building by ventilating it. This can be done by creating suitable openings. Utilizing the night cooling process to ventilate the building at night to help lower the internal temperature and prepare the building during the day. Comfort ventilation: It is the process of removing heat and moisture from the building by ventilating it. This can be done by creating suitable openings. Utilizing the night cooling process to ventilate the building at night to help lower the internal temperature and prepare the building during the day.
(Jomehzadeh et al. 2020)	to ventilate the building at night to help lower the internal temperature and prepare the building during the day.	Providing proper ventilation by providing openings and connecting the mosque's minaret to the prayer hall contributes to the process of removing humidity and heat. The effectiveness of night cooling can be linked to the times of the five prayers, so the mosque remains empty after the evening prayer and until the dawn prayer, and then it opens again for the noon prayer. Consider reducing the heat as a solution to reduce the use of mechanical devices.

	Wind catchers with a curved shape are more efficient at catching wind than wind catchers with a straight shape	The cylindrical minarets of mosques form a common shape in the designs of mosques in the SHJ and help in the effectiveness of the design.
(Chohan & Awad 2022)	The difference between a wind catcher and a solar chimney is the way they create airflow. A windcatcher uses the wind to pull air into the building, while a solar chimney uses the sun's heat to draw air outside the building.	The wind catcher can act as a solar chimney in hot and sunny climates, especially if its building materials are made of reinforced concrete that is not thermally insulated and the colors are dark.
(Prima 2019) (Tavakolinia 2011)		
	The possibility of using thermal mass to absorb and store heat during the day and release it at night, which helps reduce the internal temperature of the mosque building during the day, in addition to the feature of high ceilings, which can contribute to improving airflow and reducing the internal temperature of the mosque building, as well as domed surfaces that help dissipate heat and improve airflow.	There are auxiliary factors that contribute to improving the ventilation process, such as the materials used in covering the mosque, such as natural stone that affects thermal mass, as well as high ceilings and domes.
(Dina Ejlali Vachin 2017)		
	The direction of the wind catcher openings depends on the direction of the wind and the design of the	There is a need for computer analysis and simulation to study the minaret to study its influence on air movement, pressure

(Sivakumar et al. 2018)	room. The best orientation of the wind catcher openings for a room with one wind catcher is for the openings to face the direction of the wind. In a room with multiple wind catchers, the optimal orientation of the vents will depend on the design of the room and the desired airflow pattern. Also, the size and shape of the wind absorber openings can affect the airflow inside the room, so the larger the better. There is a gap in the issues of integrating renewable energy sources into mosque buildings and the need for more research.	difference, and the size and height of the windows.
(AlAli et al. 2023)	Study and research the issue of integrating renewable energy sources into mosque buildings	Study and research the issue of integrating renewable energy sources into mosque buildings

Chapter 3 : Methodology

3.1 Methodology

The section will highlight the methodologies used to study the reuse of minarets as a passive cooling method that has been identified in the literature, as several methodologies have been identified to study thermal comfort in mosques by reusing minarets by using them as wind catchers. The negative and positive attributes of each methodology will be identified and explained. Nowadays, different and modern methods with advanced techniques are being applied to test the movement and nature of the wind, in addition to the thermal comfort of spaces, to obtain results with high accuracy, making up for the difficulties that were faced in studying the factors affecting the movement of the wind and the pressure and temperature difference. Therefore, the methodologies that will be discussed in this section are specifically about computer simulations.

3.2 Computer Simulation with Case Study

The case study is considered a complementary method to computer simulation because it can give a vision of something tangible and the results can be applied to it in the event of its success and feasibility for real life.

Computer simulation tools have gained acceptance due to their speed, accuracy, and availability, as computers have been developed with high capacity to enable researchers to predict and analyze real reality.

In addition, computer simulation tools enable the user to obtain the required readings and data in a short period throughout the year. The time required for the simulation also depends on the size, area, amount of details, their accuracy, in addition to the data that is transcribed when studying the case.

Computer simulations are capable of studying the flow driven by buoyancy, airflow patterns resulting from wind movement, the pressure difference in spaces, the effect of the

surrounding environment, and studying exit of airflow and pressure values at the location of the openings. The ability to calculate the internal heat gains for each space using a computer modeling program (IESVE), through which we can study the internal environment at all times.(Spentzou, Cook & Emmitt 2014).

Researchers (Milano 2021) studied the accuracy of the IES-VE program in predicting the thermal environment of a two-story house in Malaysia. The study found that the software can accurately predict the indoor air temperature and relative humidity of a home. The study also found that the software could be used to evaluate the effectiveness of different passive cooling strategies for the home.

The study also used a case study approach to verify the accuracy of the IES-VE. The case study house was a two-story house located in Kuala Lumpur, Malaysia. The study used IES-VE to simulate the household thermal environment of a typical day in Kuala Lumpur. The study then compared the simulated results with data measured from home.

The study found that the IES-VE was able to accurately predict a home's indoor air temperature. The mean absolute error (MAE) between simulated and measured indoor air temperatures was 0.86°C. The study also found that the IES-VE was able to accurately predict the relative humidity of a home. The MAE between the simulated and measured relative humidity was 3.1%.

The study also found that the IES-VE can be used to evaluate the effectiveness of different passive cooling strategies for a home. The study also simulated the thermal environment of a home with and without different passive cooling strategies, such as natural ventilation and shading. The study found that passive cooling strategies were able to reduce indoor air temperature by up to 3 degrees Celsius.

The study concluded that IES-VE is a reliable tool for predicting the thermal environment of homes.

The (Alkhateeb & Abu-Hijleh 2019) researchers found that the IES-VE is a useful tool for evaluating the potential energy savings and carbon dioxide emission reductions that could be achieved through federal retrofitting. Buildings in the UAE comply with Zero Energy Building (nZEB) standards. Researchers used IES-VE to simulate the energy performance of a typical federal office building in the UAE and found that the building could achieve nZEB status by implementing a range of energy efficiency measures, including upgrading lighting, heating, ventilation, and air conditioning (HVAC) systems and the building envelope. The researchers concluded that the IES-VE is a valuable tool to evaluate the feasibility and cost-effectiveness of nZEB retrofits for federal buildings in the UAE.

The (Bagasi, Calautit & Karban 2021) researchers said the IES-VE is a useful tool to evaluate the potential benefits of using mashrabiya in the ventilation strategy for buildings in hot climates.

The researchers used IES-VE to simulate the performance of a typical building in the city of Jeddah, Saudi Arabia, with and without mashrabiya. They found that using mashrabiya can reduce indoor air temperature by up to 2.4 degrees Celsius and indoor air humidity by up to 10%. The researchers concluded that the IES-VE is a valuable tool to evaluate the potential benefits of using mashrabiya in the ventilation strategy of buildings in hot climates.

predicting indoor air temperatures and velocity to enhance and improve the building's natural ventilation.(Spentzou, Cook & Emmitt 2014).

3.3 A Summary of Research Approaches

Table 4 shows the compiled list of references that adopted computer simulation and case study methodologies to evaluate the conditions of existing buildings and represent them in virtual reality to extract data. The reviewer confirms the reliability of the IES VE

program and these two methodologies will be taken into consideration as the best method and approach for this research case study.

Table 4

Mix Methodology Summary for Analyzing Existing Building

Journal title	Year	Authors	Methods
Assessing natural cooling strategies in apartment buildings using decoupled internal-external airflow Simulations.	2014	Spentzou, Eftychia Cook, Malcolm Emmitt, Stephen	Simulation-IES VE Case study
Use of energy modeling software (IES VE) for HVAC sizing, a comparison with old practices	2021	Milano, Politecnico D I	Simulation-IES VE Case study
Potential for retrofitting a federal building in the UAE to net zero electricity building (nZEB)	2019	Alkhateeb, Enas Abu-Hijleh, Bassam	Simulation-IES VE Case study
Evaluation of the integration of the traditional architectural element mashrabiya into the ventilation strategy for buildings in hot climates	2021	Bagasi, Abdullah Abdulhameed Calautit, John Kaiser Karban, Abdullah Saeed	Simulation-IES VE Case study

3.4 Research Method

Include an analytical case study of a mosque located in the Emirate of Sharjah. The study will evaluate the architectural and engineering challenges involved in these conversions and the extent of the success of these designs in providing natural ventilation and cooling for the buildings.

Computer simulation will use IES software to analyze the thermal performance of the mosque as a case study where a 3D model of the mosque including the minaret will be created.

Initially, the mosque will be studied in its current condition with the minaret, without any openings between the prayer hall and the minaret, where thermal comfort factors will be studied, represented by air temperature, relative humidity, air movement (Air change rate), and mean radiant temperature. Then improvements will be made to the minaret and changes in the four thermal comfort factors will be studied. The effects will be evaluated throughout the day in what is called comfortable ventilation and night cooling, which is best for the mosque hall and worshippers. You will notice changes in the minaret in terms of it drawing in air and performing the tasks of capturing air, or in terms of expelling air and performing the tasks of a solar chimney.

After extracting the data and numbers related to the minaret openings, the direction of each opening, and the building materials of the minaret, they will be analyzed and information will be extracted that will contribute to knowing the feasibility and effectiveness of modifications in the process of thermal comfort and restoring the optimal and integrated exploitation of the minaret.

Wind speed will be the primary factor among the factors and determinants of thermal comfort, and it will determine the choice among the scenarios that will be applied.

Other factors, such as wind temperature, humidity, and average radiant temperature, are useful factors to consider.

Computational fluid dynamics will also be studied to produce drawings showing the wind speed, temperature, and pressure difference in the mosque and the minaret. Figure 4.

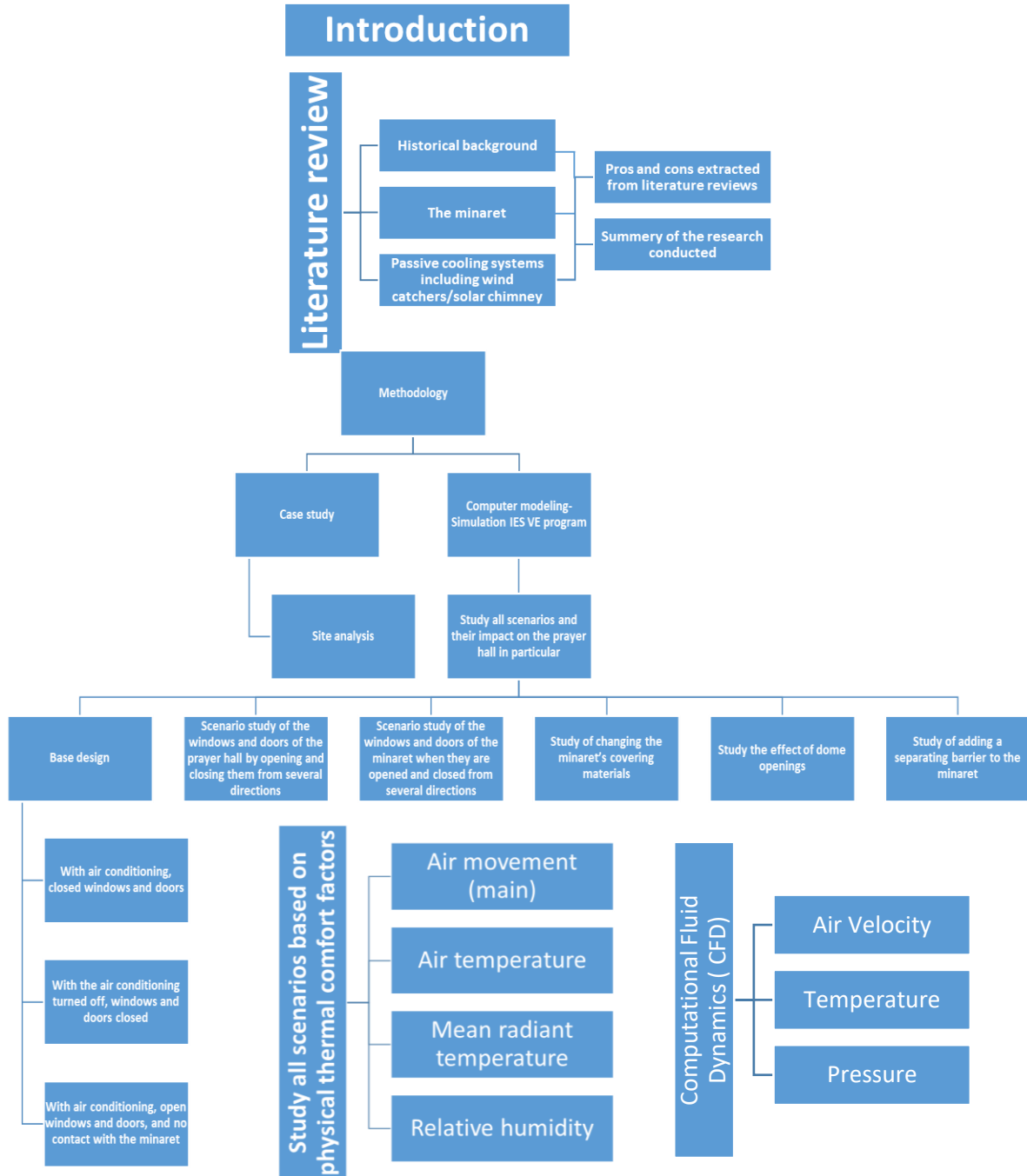
Openings represented by windows and doors are considered one of the most important factors affecting the flow of wind to and from any building. In addition, appropriate openings contribute to the process of removing heat and humidity from buildings through the process of replacing the air in the closed spaces with new air from the outside. One of the reasons that called for creating different scenarios is that there is confusion between a wind catcher and a solar chimney in terms of the way they create airflow, as wind catchers are used for the purpose of pulling the prevailing winds into the building, while a solar chimney uses the heat of the sun and the pressure difference to pull air outside the building or to enter it.

The direction of the wind catcher openings depends on the direction of the wind and the design of the room. The best orientation of the wind catcher openings in a room with one wind catcher is for the openings to face the direction of the wind. In a room with multiple wind catchers, the optimal direction of the vents depends on the design of the room and the desired airflow pattern.

The size and shape of the wind vents can also affect the airflow inside the room, so the larger the better. For this reason, different scenarios were developed for the operations of opening and closing the openings in different directions in the prayer hall with windows close to ground level, and the high openings at the top of the minaret were studied, which are exposed to the air more and are affected by the heat of the sun due to the absence of obstacles in front of them.

Figure 5

Flow Chart of the Research Process And Methodology



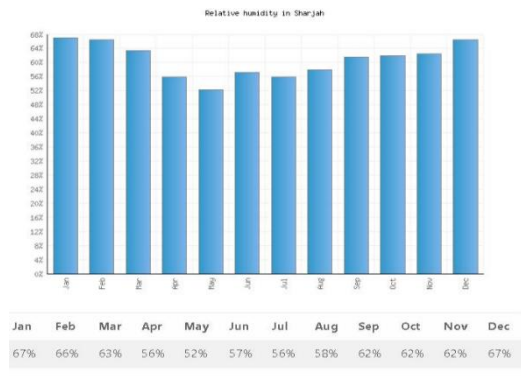
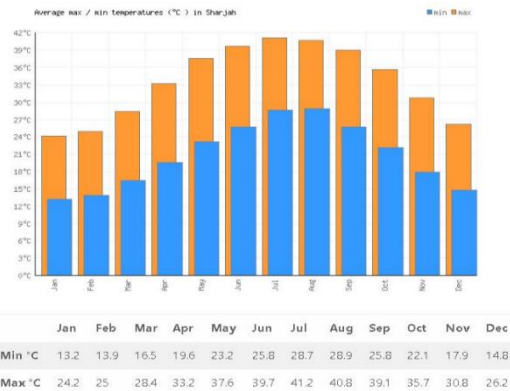
3.5 Sharjah Site and Case Study

3.5.1 Sharjah Site Analysis

Sharjah is the third largest emirate in the United Arab Emirates. It is a coastal emirate on the Arabian Gulf bordered by the Emirate of Dubai to the west and the Emirate of Ajman to the north. With a population of more than 1.4 million, Sharjah is a major business and cultural center and a tourist destination.

The Emirate of Sharjah is bordered on the western side by the Arabian Gulf, and on the eastern side by the Sea of Oman. The eastern side of the emirate also includes the Hajar Mountains extending along the eastern coast. The Hajar mountain range blocks moisture flows coming from the Sea of Oman. The eastern side of the UAE is characterized by higher wind speeds and stronger shear along the mountain valleys. Strong winds represent a factor that limits fog formation, and the mountainous terrain contributes to creating barriers that reduce dust sources in the eastern coastal areas of the United Arab Emirates.

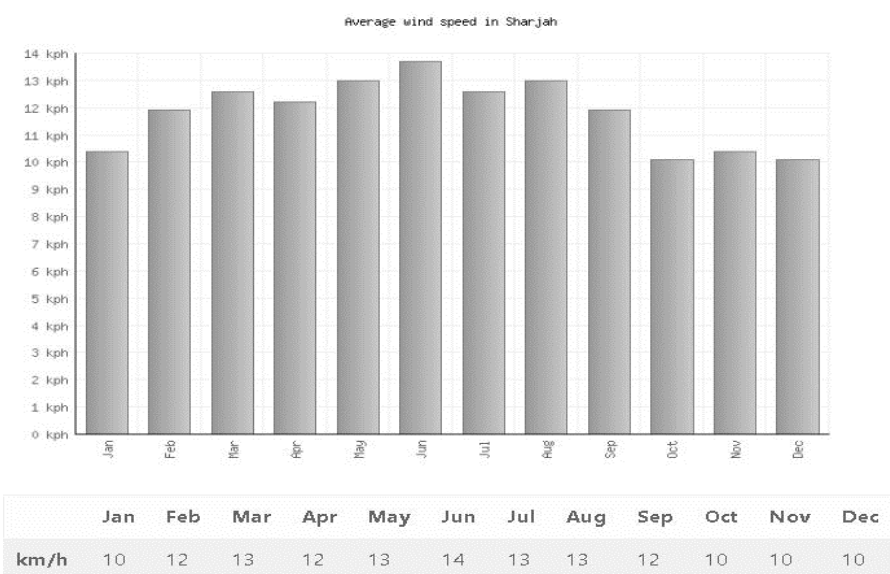
The topography of the western coastal side of the UAE is gentle, which contributes to the penetration of moisture resulting from evaporation over the Gulf. The strong nighttime temperature fluctuations common in arid regions lead to increased condensation and fog formation, which negatively affects visibility. The minimum average daily air temperature in the Emirate of Sharjah is 14°C in winter and the maximum average daily air temperature is 45°C in summer. Temperatures in the desert interior may exceed 50 degrees Celsius during the summer and drop to about 4 degrees Celsius in the summer Figure 6.

Figure 6*Average Max/Min temp(c) Sharjah***Figure 7***Relative Humidity in Sharjah*

Note. (Sharjah Weather averages & monthly Temperatures | United Arab Emirates | Weather-2-Visit 2023)

In winter, the relative humidity in summer reaches 90% Figure 5, and the winds are hot northwesterly. Evaporation rates average 2-3 m per year.

Table No. 7 and Figure No.8 of the wind rose shows indicate that the prevailing winds are from the north and northwest. These winds are generally dry and hot, indicating that the winds in the summer months are strong, reaching speeds of up to 50 kilometers per hour. It also appears that there is a secondary wind pattern from the southeast and southwest that occurs in the winter months, where it is generally cooler and more humid than the north and northwest winds .We can say that the prevailing winds in Sharjah are from the north and northwest, and these winds are generally dry and hot, and the strongest winds occur in the summer months. (Al-Ruzouq et al. 2022)

Figure 8*Average Wind Speed in Sharjah*

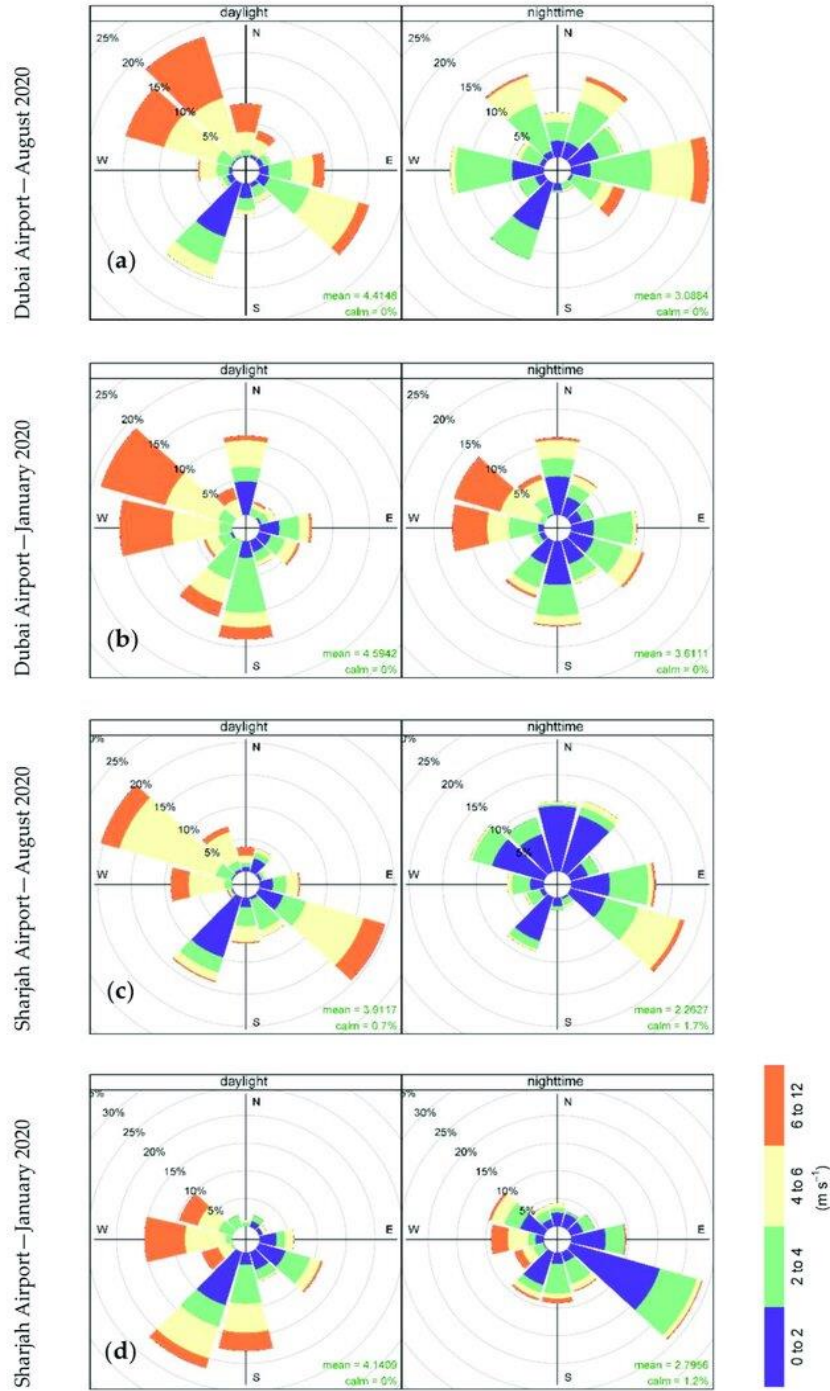
Note. (Sharjah Weather averages & monthly Temperatures | United Arab Emirates | Weather-2-Visit 2023)

Table 5*Wind Direction*

Direction	Frequency (%)
North	13%
Northeast	15%
East	10%
Southeast	10%
south	10%
Southwest	15%
West	10%
Northwest	20%

Figure 9

Wind Rose. (a) Dubai Airport-August 2020, (b) Dubai Airport-January 2020, (c) Sharjah Airport-August 2020, (d) Sharjah Airport-January 2020.



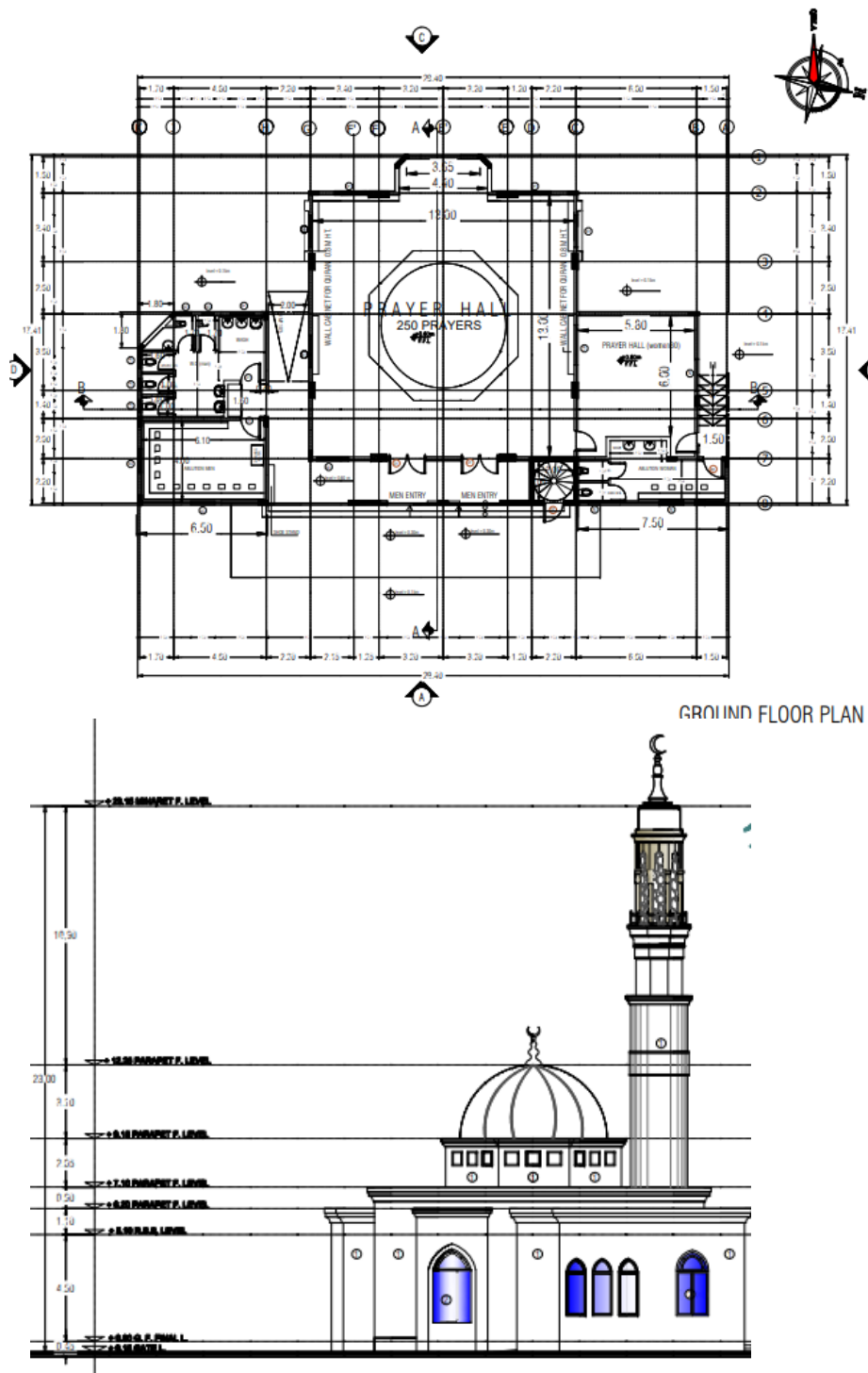
Note: (Al-Ruzouq et al. 2022)

3.5.2 A Case Study of Luqman Al-Hakim Mosque in Sharjah

The Emirate of Sharjah is considered a region with a hot and dry desert climate, with long, hot summers and short, mild winters. The average temperature in summer is 40 degrees Celsius and the average temperature in winter is 20 degrees Celsius. Warm and dry northwestern winds are the prevailing winds over the city of Sharjah. Most of the year.

Luqman Al-Hakim Mosque is located in the Al Tay area in the city of Sharjah, which takes a striped shape in the design the general plan and is located along the main Maliha Street and perpendicular to Emirates Road, which is a border area with the Emirate of Dubai. The Al Tay area is a modern area with a small number of residential villas, with a commercial building containing shops to serve the people. The area, as for the Dubai city side, constitutes an open desert area with raising livestock, and a variety of desert plants and Ghaf trees are observed. Figure 11

The design of the Luqman al-Hakim Mosque consists of a simple prayer hall for men and women, in addition to a minaret and a dome. The area of the prayer hall for men is 13 x 13 square meters with an internal height of 5.9 meters, while the area of the prayer hall for women is 6 x 5.8 square meters with a height of 4.5. As for the minaret, it is 23 meters high with a base area of 2 x 2 square meters. The Luqman Al-Hakim Mosque was built entirely of Natural stone measuring 30 x 90 cm. It accommodates approximately 152 worshipers in the main hall with an occupancy rate of 9.0 according to the Dubai Building Code. (dubai building code 2021) *Figure 10 Figure 12*

Figure 10*Plans & Elevation for Luqman al-Hakim Mosque*

Note. (Sharjah Department of Planning & Survey 2023)

Figure 11

The Picture, in Order From Bottom To Top, Shows The Location of the Luqman Al-Hakim Mosque in the Al Tayy Area in Sharjah, The Residential Villas Surrounding It, and the Main Streets Leadingt to the Area, in Addition to an Illustrative Picture of the Movement.



Note. (OpenStreetMap 2023; Ventusky - Wind, Rain and Temperature Maps 2023; Google 2023)

Figure 12*Dimensions and Measurements of the Payer Hall, Minaret and Dome*

Dimensions and measurements of the mosque and its elements	Prayer hall: 13m*13m*5.9m	Prayer hall windows	Qibla direction: 2 windows, each one measuring 1.6m*3m Right direction: One window size 1.6m*3m Left direction: 2 windows, each one measuring 1.6m*3m front direction: One window size 1.6m*3m
		Prayer hall doors	2 doors, each one measuring 1.8m*3m
	Minaret: 2m*2m	Minaret windows	
		North direction: 3 windows, each one measuring 0.35m*2m	
		East direction: 3 windows, each one measuring 0.35m*2m	
		West direction: 3 windows, each one measuring 0.35m*2m	
Dome		The base of the octagonal dome has a diameter of 7.5m and a height of 2.65m (the length of each side of the octagon is 3m)	Each direction: One window size 1.5m*2.2m
		The diameter of the dome is 6m and its height is 3m	

Chapter 4 : Analysis

4.1 Simulation

4.1.1 Air Temperature

The Luqman al-Hakim Mosque in the Al Tay area of Sharjah was developed as a case study, where the windows of each side of the prayer hall and the minaret were opened and closed, in addition to dividing the minaret and scenarios in the dome of the mosque using the IES VE program. Figure 13.

Figure 13

Designs Scenarios

Designs scenarios	Base design	Base with closed windows and air conditioning, without any connection to the minaret
		With open windows and closed air conditioning, without any connection with the minaret
	Prayer hall	Several scenarios by opening and closing windows on each side of the prayer hall and in connection with the minaret
	Minaret	Several scenarios include opening and closing windows on each side of the minaret and communicating with the prayer hall
	Minaret with partition	Several scenarios by opening and closing windows on each side of the minaret, with a partition dividing the minaret, and in connection with the prayer hall
	Dome	Several scenarios by opening and closing the windows on each side of the dome

Table 6*Abbreviation & Keyword*

Abbreviation	Keywords
(M)	Minaret of the mosque
(MPwo)	The minaret has a partition and there is an open window in the partition
(MPwx)	The minaret has a partition and there is a closed window in the partition
(H)	Prayer hall
(D)	Dome
Win(O)	Windows open
Win(X)	Closed windows
N/S/E/W	The direction of the open windows of the minaret (North N, South S, East E, West W)
Q/R/L/F	The direction of the open windows of the prayer hall (Qibla Q, Right R, Left L, Entrance F)
AC(O)	The air conditioner is on
AC(X)	The air conditioner is off

Table 7

Table For Different Air Temperature Design Scenarios

Var. Name	Location	Filename	Type	Min. Val.	Min. Time	Max. Val.	Max. Time	Mean
Air temp	Main Hall	Base design AC on, Win(X), (H) not connected with (M).aps	Temp (°C)	20.68	07:30,29/Jan	23	15:30,06/Jan	22.86
Air temp	Main Hall	(M) NSEW Win(O), (H) Q Win(O).aps	Temp (°C)	11.03	08:30,02/Feb	41.11	15:30,24/Jul	27.11
Air temp	Main Hall	(M) NSEW Win(O), (H) L Win(O).aps	Temp (°C)	11.03	08:30,02/Feb	41.11	15:30,24/Jul	27.11
Air temp	Main Hall	(M) NSEW Win(O), (H) Q Win(O), Cliding changed .aps	Temp (°C)	11.05	08:30,02/Feb	41.17	15:30,24/Jul	27.12
Air temp	Main Hall	(M) NW Win(O), (H) Q Win(O).aps	Temp (°C)	11.14	08:30,02/Feb	41.08	15:30,24/Jul	27.14
Air temp	Main Hall	(M) SE Win(O), (H) Q Win(O).aps	Temp (°C)	11.14	08:30,02/Feb	41.08	15:30,24/Jul	27.14
Air temp	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O) maerial changed.aps	Temp (°C)	11.41	08:30,02/Feb	40.84	15:30,24/Jul	27.17
Air temp	Main Hall	(MPwx)NEWS Win(O) (H) Q Win(O).aps	Temp (°C)	11.39	08:30,02/Feb	40.78	15:30,24/Jul	27.17
Air temp	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O).aps	Temp (°C)	11.39	08:30,02/Feb	40.78	15:30,24/Jul	27.17
Air temp	Main Hall	(MPwo)NW Win(O) (H) Q Win(O).aps	Temp (°C)	11.5	08:30,02/Feb	40.75	15:30,24/Jul	27.2
Air temp	Main Hall	(M) NSEW Win(O), (H) QL Win(O).aps	Temp (°C)	10.57	08:30,02/Feb	42.08	15:30,24/Jul	27.21
Air temp	Main Hall	(M) W Win(O), (H) Q Win(O).aps	Temp (°C)	11.42	08:30,02/Feb	41	15:30,24/Jul	27.22
Air temp	Main Hall	(M) S Win(O), (H) Q Win(O).aps	Temp (°C)	11.42	08:30,02/Feb	41	15:30,24/Jul	27.22
Air temp	Main Hall	(M) N Win(O), (H) Q Win(O).aps	Temp (°C)	11.42	08:30,02/Feb	41	15:30,24/Jul	27.22
Air temp	Main Hall	(M) E Win(O), (H) Q Win(O).aps	Temp (°C)	11.42	08:30,02/Feb	41	15:30,24/Jul	27.22
Air temp	Main Hall	(M) NSEW Win(O), (H) QRL Win(O), Clading changed.aps	Temp (°C)	10.39	08:30,02/Feb	42.47	15:30,24/Jul	27.24
Air temp	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O) (D) S Win(O).aps	Temp (°C)	10.77	08:30,02/Feb	42	15:30,24/Jul	27.31
Air temp	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O) (D) W Win(O).aps	Temp (°C)	10.77	08:30,02/Feb	42	15:30,24/Jul	27.31
Air temp	Main Hall	(M) NSEW Win(O), (H) QRL Win(O).aps	Temp (°C)	9.85	08:30,02/Feb	44.45	13:30,10/Aug	27.32
Air temp	Main Hall	(M) SE Win(O), (H) QRL Win(O).aps	Temp (°C)	9.87	08:30,02/Feb	44.46	13:30,10/Aug	27.33
Air temp	Main Hall	(M) SW Win(O), (H) QRL Win(O).aps	Temp (°C)	9.87	08:30,02/Feb	44.46	13:30,10/Aug	27.33
Air temp	Main Hall	(M) NE Win(O), (H) QRL Win(O).aps	Temp (°C)	9.87	08:30,02/Feb	44.46	13:30,10/Aug	27.33
Air temp	Main Hall	(M) NS Win(O), (H) QRL Win(O).aps	Temp (°C)	9.89	08:30,02/Feb	44.46	13:30,10/Aug	27.33
Air temp	Main Hall	(MPwx)NEWS Win(O) (H) Win(X) (D) NEWS Win(O).aps	Temp (°C)	11.47	08:30,02/Feb	41.05	15:30,24/Jul	27.34
Air temp	Main Hall	(M) W Win(O), (H) QRL Win(O).aps	Temp (°C)	9.94	08:30,02/Feb	44.47	13:30,10/Aug	27.34
Air temp	Main Hall	(M) S Win(O), (H) QRL Win(O).aps	Temp (°C)	9.94	08:30,02/Feb	44.47	13:30,10/Aug	27.34
Air temp	Main Hall	(M) NSEW Win(O), (H) QRL Win(O), Clading changed.aps	Temp (°C)	9.86	08:30,02/Feb	44.5	13:30,10/Aug	27.34
Air temp	Main Hall	(M) N Win(O), (H) QRL Win(O).aps	Temp (°C)	9.94	08:30,02/Feb	44.47	13:30,10/Aug	27.34
Air temp	Main Hall	(M) E Win(O), (H) QRL Win(O).aps	Temp (°C)	9.94	08:30,02/Feb	44.47	13:30,10/Aug	27.34
Air temp	Main Hall	base (M) not cooncted (H)QRL Win(o) Ac off.aps	Temp (°C)	10.38	08:30,02/Feb	43.16	14:30,23/Jul	27.35
Air temp	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O) (D) NS Win(O).aps	Temp (°C)	10.54	08:30,02/Feb	42.51	15:30,24/Jul	27.35
Air temp	Main Hall	(MPwo)Win(X) (H) Q Win(O) (D) NEWS Win(O).aps	Temp (°C)	10.63	08:30,02/Feb	43.07	14:30,23/Jul	27.51
Air temp	Main Hall	Base design AC off, Win(X), (H) not connected with (M).aps	Temp (°C)	20.71	07:30,29/Jan	41.36	16:30,10/Aug	31.71

Some readings extracted from the air temperature table 8:

The air temperature in the base design was on average 27.35°C if the windows were open and the air conditioning turned off. Table 8

Table 8

Mean Air Temperature for the Base Design in Different Scenarios

Air temp	Base design AC off, Win(X), (H) not connected with (M)	Temp(°C)	31.71
Air temp	Base design AC on , Win(X), (H) not connected with(M)	Temp(°C)	22.86
Air temp	Base (M) not connected (H)QRLF win(o) Ac off	Temp(°C)	27.35

The best average air temperature for all design scenarios is 27.11 degrees Celsius, followed by 27.12 °C, that is, 4.6 °C lower than the base design if the windows are closed and without any contact with the minaret. However, if the windows are open in the base design, the difference is 0.24°C. This feature occurs when one side of the windows in the prayer hall is opened, either in the direction of the Qibla or on the left side, and the lighthouse openings are open on all four sides. Table 9

It is noted that opening the windows of the dome from all sides while opening the windows of the Qibla direction in the prayer hall and without any contact with the minaret recorded the highest average temperature for all scenarios, reaching 27.34 °C, a difference of 0.23 °C from the best average Table 10

Table 9

The Minimum Mean Air Temperature for the Best Scenarios Compared with the Base Design

Air temp	M) NSEW Win(O), (H) Q Win(O)	Temp(°C)	27.11
Air temp	(M) NSEW Win(O), (H) L Win(O)	Temp(°C)	27.11
Air temp	(M) NSEW Win(O), (H) Q Win(O), Cladding changed	Temp(°C)	27.12
Air temp	base (M) not connected (H)QRLF win(o) Ac off	Temp(°C)	27.35

Table 10

The Maximum Mean Air Temperature for the Scenarios

Air	Main	(MPwx)NEWS Win(O) (H) Win(X)	Temp(°C)	27.34
temp	Hall	(D) NEWS Win(O)		
Air	Main	(MPwo)NEWS Win(O) (H) Q Win(O)	Temp(°C)	27.35
temp	Hall	(D) NS Win (O).		
Air	Main	(MPwo) Win(X) (H) Q Win(O)	Temp(°C)	27.51
temp	Hall	(D) NEWS Win(O)		

The lowest air temperature recorded for all design scenarios is recorded when all windows in the prayer hall and all openings in the minaret are opened in the morning. The air temperature is estimated at 9.85 °C at 08:30 on February 2, and if the stone cladding is removed from the minaret, it is recorded at 9.86°C. In comparison, the lowest air temperature in the base design is 10.8°C at 08:30, 02/Feb, with a difference of 0.95°C.

The wind temperature ranges from 44.5 °C at 08:13:30.10 in August to 9.85°C at 08:30.02 in February, which is between the highest and lowest temperatures.

Table 11

Minimum Air Temperature of All Design Scenarios Compared to Base

Air temp	(M) NSEW Win(O), (H) QRLF Win(O)	Temp(°C)	9.85	08:30,02/Feb
Air temp	(M) NSEW Win(O), (H) QRLF Win(O), Cladding changed	Temp(°C)	9.86	08:30,02/Feb
Air temp	Base design AC off, Win(O), (H) not connected with (M)	Temp(°C)	10.38	08:30,02/Feb

The maximum air temperature recorded for all design scenarios was 44.5°C at 1:30 p.m. On August 10, 2019, as a result of removing the stone cladding from the minaret and opening all the openings in the prayer hall and the minaret, a difference of 1.44°C higher than the base model. The second maximum temperature was recorded at 44.47 °C when all the windows of the prayer hall were open with one side of the minaret windows open.

As for the lowest maximum air temperature, it reached 40.75 °C at 15:30,24/Jul, a difference of 3.75 °C, and it was When there is a barrier in the minaret and the window in the barrier is open, with the northern and western windows in the minaret open, with the windows facing the Qibla in the prayer hall open.

Table 12

The Maximum Air Temperature for All Design Scenarios Compared to the Base Design

Air temp	(M) W Win(O), (H) QRLF Win(O)	Temp(°C)	44.47	13:30,10/Aug
Air temp	(M) S Win(O), (H) QRLF Win(O)	Temp(°C)	44.47	13:30,10/Aug
Air temp	(M) N Win(O), (H) QRLF Win(O)	Temp(°C)	44.47	13:30,10/Aug

Air temp	(M) E Win(O), (H) QRLF Win(O)	Temp(°C)	44.47	13:30,10/Aug
Air temp	(M) NSEW Win(O), (H) QRLF Win(O), Cladding changed	Temp(°C)	44.5	13:30,10/Aug
Air temp	Base (M) not connected (H)QRLF win(o) Ac off	Temp(°C)	43.16	14:30,23/Jul

Table 13

Lowest Value for Maximum Air Temperature for All Design Scenarios

Air temp	Main Hall	(MPwo)NW Win(O) (H) Q Win(O)	Temp(°C)	15:30,24/Jul	40.75
Air temp	Main Hall	(MPwx)NEWS Win(O) (H) Q Win(O)	Temp(°C)	15:30,24/Jul	40.78
Air temp	Main Hall	(MPwo)NEWS Win(O)(H) Q Win(O)	Temp(°C)	15:30,24/Jul	40.78

4.1.2 Relative humidity

Relative humidity represents an important factor for human comfort. If the relative humidity is low, this makes the air dry and uncomfortable, but if the humidity increases, it leads to a feeling of discomfort.

Table 14

Relative Humidity in Different Scenarios

Var. Name	Location	Filename	Type	Min. Val.	Min. Time	Max. Val.	Max. Time	Mean
Relative humidity	Main Hall	Base design AC off, Win(X), (H) not connected with (M).aps	(%)	23.96	16:30,10/Aug	79.46	07:30,29/Jan	44.34
Relative humidity	Main Hall	(MPwo)Win(X) (H) Q Win(O) (D) NEWS Win(O).aps	(%)	7.88	12:30,31/May	96.53	05:30,15/Jan	57.97
Relative humidity	Main Hall	(MPwx)NEWS Win(O) (H) Win(X) (D) NEWS Win(O).aps	(%)	9.07	11:30,11/Jul	96.36	05:30,15/Jan	58.04
Relative humidity	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O) (D) S Win(O).aps	(%)	8.52	12:30,31/May	96.83	05:30,15/Jan	58.4
Relative humidity	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O) (D) W Win(O).aps	(%)	8.52	12:30,31/May	96.83	05:30,15/Jan	58.4
Relative humidity	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O) (D) NS Win(O).aps	(%)	8.2	12:30,31/May	96.91	05:30,15/Jan	58.41
Relative humidity	Main Hall	(M) W Win(O), (H) Q Win(O).aps	(%)	9.11	11:30,11/Jul	97.2	05:30,15/Jan	58.43
Relative humidity	Main Hall	(M) S Win(O), (H) Q Win(O).aps	(%)	9.11	11:30,11/Jul	97.2	05:30,15/Jan	58.43
Relative humidity	Main Hall	(M) N Win(O), (H) Q Win(O).aps	(%)	9.11	11:30,11/Jul	97.2	05:30,15/Jan	58.43
Relative humidity	Main Hall	(M) E Win(O), (H) Q Win(O).aps	(%)	9.11	11:30,11/Jul	97.2	05:30,15/Jan	58.43
Relative humidity	Main Hall	(MPwo)NW Win(O) (H) Q Win(O).aps	(%)	9.19	11:30,11/Jul	96.86	05:30,15/Jan	58.46
Relative humidity	Main Hall	new base (M) not connected (H) Q Win(O) AC off.aps	(%)	7.82	12:30,31/May	97.48	05:30,15/Jan	58.59
Relative humidity	Main Hall	(MPwx)NEWS Win(O) (H) Q Win(O).aps	(%)	9.17	11:30,11/Jul	97.01	05:30,15/Jan	58.59
Relative humidity	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O).aps	(%)	9.17	11:30,11/Jul	97.01	05:30,15/Jan	58.59
Relative humidity	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O) maerial changed.aps	(%)	9.16	11:30,11/Jul	97	05:30,15/Jan	58.6
Relative humidity	Main Hall	(M) NW Win(O), (H) Q Win(O).aps	(%)	9.07	11:30,11/Jul	97.54	05:30,15/Jan	58.75
Relative humidity	Main Hall	(M) SE Win(O), (H) Q Win(O).aps	(%)	9.07	11:30,11/Jul	97.54	05:30,15/Jan	58.75
Relative humidity	Main Hall	(M) NSEW Win(O), (H) QL Win(O).aps	(%)	8.44	12:30,31/May	97.57	05:30,15/Jan	58.8
Relative humidity	Main Hall	(M) NSEW Win(O), (H) QRL Win(O), Cladding changed.aps	(%)	8.22	12:30,31/May	97.62	05:30,15/Jan	58.82
Relative humidity	Main Hall	(M) NSEW Win(O), (H) Q Win(O).aps	(%)	9.05	11:30,11/Jul	97.67	05:30,15/Jan	58.87
Relative humidity	Main Hall	(M) NSEW Win(O), (H) Q Win(O), Cliding changed .aps	(%)	9.05	11:30,11/Jul	97.67	05:30,15/Jan	58.87
Relative humidity	Main Hall	(M) NSEW Win(O), (H) L Win(O).aps	(%)	9.05	11:30,11/Jul	97.67	05:30,15/Jan	58.87
Relative humidity	Main Hall	(M) W Win(O), (H) QRL Win(O).aps	(%)	7.48	11:30,11/Jul	98.75	09:30,28/Nov	59.12
Relative humidity	Main Hall	(M) S Win(O), (H) QRL Win(O).aps	(%)	7.48	11:30,11/Jul	98.75	09:30,28/Nov	59.12
Relative humidity	Main Hall	(M) N Win(O), (H) QRL Win(O).aps	(%)	7.48	11:30,11/Jul	98.75	09:30,28/Nov	59.12
Relative humidity	Main Hall	(M) E Win(O), (H) QRL Win(O).aps	(%)	7.48	11:30,11/Jul	98.75	09:30,28/Nov	59.12
Relative humidity	Main Hall	(M) NSEW Win(O), (H) QRL Win(O), Cladding changed.aps	(%)	7.48	11:30,11/Jul	98.78	09:30,28/Nov	59.16
Relative humidity	Main Hall	(M) NS Win(O), (H) QRL Win(O).aps	(%)	7.49	11:30,11/Jul	98.79	09:30,28/Nov	59.16
Relative humidity	Main Hall	(M) SE Win(O), (H) QRL Win(O).aps	(%)	7.49	11:30,11/Jul	98.79	09:30,28/Nov	59.17
Relative humidity	Main Hall	(M) SW Win(O), (H) QRL Win(O).aps	(%)	7.49	11:30,11/Jul	98.79	09:30,28/Nov	59.17
Relative humidity	Main Hall	(M) NE Win(O), (H) QRL Win(O).aps	(%)	7.49	11:30,11/Jul	98.79	09:30,28/Nov	59.17
Relative humidity	Main Hall	(M) NSEW Win(O), (H) QRL Win(O).aps	(%)	7.49	11:30,11/Jul	98.81	09:30,28/Nov	59.19
Relative humidity	Main Hall	Base design AC on, Win(X), (H) not connected with (M).aps	(%)	67.25	15:30,27/Jun	79.6	07:30,29/Jan	68.98

Table 14 shows the relative humidity in the main hall of the mosque under different design conditions. The relative humidity ranges from 7.48% to 98.81%. The lowest relative humidity occurs when the minarets' openings are open on one side and all windows are open in the prayer hall. The highest relative humidity occurs when the prayer hall windows are fully open and the minaret windows are fully open or open on both sides.

Comparing the lowest relative humidity in the scenarios, 7.48%, with the lowest relative humidity in the base model, 7.82%, the base model is 0.34% higher.

Table 15

Minimum Relative Humidity Value Compared to Base Design

Var. Name	Locat	Filename	Ty	Min.	Min.
	ion		pe	Val.	Time
Relative humidity	Main Hall	(M) W Win(O), (H) QRLF Win(O)	(%	7.48	11:30,11
			)		/Jul
Relative humidity	Main Hall	(M) S Win(O), (H) QRLF Win(O)	(%	7.48	11:30,11
			)		/Jul
Relative humidity	Main Hall	(M) N Win(O), (H) QRLF Win(O)	(%	7.48	11:30,11
			)		/Jul
Relative humidity	Main Hall	(M) E Win(O), (H) QRLF Win(O)	(%	7.48	11:30,11
			)		/Jul
Relative humidity	Main Hall	(M) NSEW Win(O), (H) QRLF Win(O), Cladding changed	(%	7.48	11:30,11
			)		/Jul
Relative humidity	Main Hall	Base design (M) not connected	(%	7.82	12:30,31
		(H)QRLF win(o) Ac off	)		/May

Table 16*Maximum Relative Humidity Value Compared to Base Design*

Var. Name	Locati on	Filename	Ty pe	Max. Val.	Min. Time
Relative humidity	Main Hall	Base design AC off Win(O) (H) not connected with (M)	(%)	98.81	09:30,28 /Nov
Relative humidity	Main Hall	Base design AC off Win(O) (H) not connected with (M)	(%)	96.97	09:30,28 /Nov
Relative humidity	Main Hall	Base design (M) not connected (H)QRLF win(o) Ac off	(%)	97.48	05:30,15 /Jan

The lowest mean relative humidity is 57.97%. Table 17. This means that the air contains about 57.97% of the water vapor it can hold at a given temperature. As for the highest average relative humidity, it is 59.19%, Table 18, which is less than 60%, as the comfortable relative humidity for the population is considered to be between 40% and 60% according to the Saafat code for Dubai. A relative humidity of less than 40% can be too dry and can cause dry skin and eyes, while a relative humidity of more than 60% can be too humid and can cause sweating and feeling tight.(Al-Safat 2020)

Comparing the average of the lowest relative humidity in the base design, 58.59%, and the lowest relative humidity in all scenarios, 57.97%, there is a difference of 0.62%.

Table 17*Lowest Mean Relative Humidity*

Relative	Main	base (M) not connected (H)QRLF win(o) Ac off	58.5
humidity	Hall	(%)	9
Relative	Main	(MPwo) Win(X) (H) Q Win(O) (D) NEWS	57.9
humidity	Hall	Win(O) (%)	7
Relative	Main	(MPwx)NEWS Win(O) (H) Win(X) (D) NEWS	58.0
humidity	Hall	Win(O) (%)	4

Table 18*Highest Mean Relative Humidity of All Scenarios*

RH	Main Hall	(M) NSEW Win(O), (H) QRLF Win(O)	(%)	59.19
----	-----------	----------------------------------	-----	-------

4.1.3 Mean Radiant Temperature

The mean radiant temperature (MRT) is the average temperature of all the surfaces that surround a person. It is an important factor in determining how comfortable a person feels, as it affects the amount of heat that is exchanged between the person and their environment.(Robert & Brown 2015)

The mean radiant temperature surge in July is due to several factors, including:

- Longer days
- Sun angles are higher, which means receiving more direct sunlight.
- Increased humidity levels

The high MRT in July can make it difficult to stay cool and comfortable, especially during the afternoon and evening hours.

The MRT is lowest in the early morning hours. This is because the Earth's surface heats up during the day and cools down at night.

Table 19

Mean Radiant Temperature for All Scenarios

Var. Name	Location	Filename	Type	Min. Val.	Min. Time	Max. Val.	Max. Time	Mean
MRT	Main Hall	Base design AC on , Win(X), (H) not conected with (M).aps	Temp (°C)	20.69	07:30,29/Jan	24.3	15:30,25/Jul	23.32
MRT	Main Hall	(M) NSEW Win(O), (H) Q Win(O).aps	Temp (°C)	14.25	07:30,29/Jan	39.55	15:30,29/Jul	27.32
MRT	Main Hall	(M) NSEW Win(O), (H) L Win(O).aps	Temp (°C)	14.25	07:30,29/Jan	39.55	15:30,29/Jul	27.32
MRT	Main Hall	(M) NSEW Win(O), (H) Q Win(O), Cliding changed .aps	Temp (°C)	14.26	07:30,29/Jan	39.58	15:30,29/Jul	27.33
MRT	Main Hall	(M) NW Win(O), (H) Q Win(O).aps	Temp (°C)	14.3	07:30,29/Jan	39.55	15:30,29/Jul	27.35
MRT	Main Hall	(M) SE Win(O), (H) Q Win(O).aps	Temp (°C)	14.3	07:30,29/Jan	39.55	15:30,29/Jul	27.35
MRT	Main Hall	(M) NSEW Wind(O), (H) QL Win(O).aps	Temp (°C)	14.06	07:30,29/Jan	40.02	16:30,24/Jul	27.41
MRT	Main Hall	(M) W Win(O), (H) Q Win(O).aps	Temp (°C)	14.45	07:30,29/Jan	39.55	15:30,29/Jul	27.42
MRT	Main Hall	(M) S Win(O), (H) Q Win(O).aps	Temp (°C)	14.45	07:30,29/Jan	39.55	15:30,29/Jul	27.42
MRT	Main Hall	(M) N Win(O), (H) Q Win(O).aps	Temp (°C)	14.45	07:30,29/Jan	39.55	15:30,29/Jul	27.42
MRT	Main Hall	(M) E Win(O), (H) Q Win(O).aps	Temp (°C)	14.45	07:30,29/Jan	39.55	15:30,29/Jul	27.42
MRT	Main Hall	(MPwx)NEWs Win(O) (H) Q Win(O).aps	Temp (°C)	14.71	07:30,29/Jan	39.06	15:30,29/Jul	27.43
MRT	Main Hall	(MPwo)NEWS Win(O) (H) Q Win(O).aps	Temp (°C)	14.71	07:30,29/Jan	39.06	15:30,29/Jul	27.43
MRT	Main Hall	(M) NSEW Win(O), (H) QRL Win(O), Clading changed.aps	Temp (°C)	13.98	07:30,29/Jan	40.26	15:30,24/Jul	27.43
MRT	Main Hall	(MPwo)NEWs Win(O) (H) Q Win(O) maerial changed.aps	Temp (°C)	14.71	07:30,29/Jan	39.1	16:30,25/Jul	27.44
MRT	Main Hall	(MPwo)NW Win(O) (H) Q Win(O).aps	Temp (°C)	14.76	07:30,29/Jan	39.07	15:30,29/Jul	27.46
MRT	Main Hall	(M) NSEW Win(O), (H) QRLF Win(O).aps	Temp (°C)	13.76	07:30,29/Jan	41.32	14:30,29/Jul	27.5
MRT	Main Hall	new base (M) not cooncted (H)QRLF win(o) Ac off.aps	Temp (°C)	14.23	07:30,29/Jan	40.14	15:30,24/Jul	27.51
MRT	Main Hall	(M) NS Win(O), (H) QRLF Win(O).aps	Temp (°C)	13.78	07:30,29/Jan	41.33	14:30,29/Jul	27.51
MRT	Main Hall	(M) SE Win(O), (H) QRLF Win(O).aps	Temp (°C)	13.77	07:30,29/Jan	41.33	14:30,29/Jul	27.51
MRT	Main Hall	(M) SW Win(O), (H) QRLF Win(O).aps	Temp (°C)	13.77	07:30,29/Jan	41.33	14:30,29/Jul	27.51
MRT	Main Hall	(M) NE Win(O), (H) QRLF Win(O).aps	Temp (°C)	13.77	07:30,29/Jan	41.33	14:30,29/Jul	27.51
MRT	Main Hall	(M) W Win(O), (H) QRLF Win(O).aps	Temp (°C)	13.8	07:30,29/Jan	41.33	14:30,29/Jul	27.52
MRT	Main Hall	(M) S Win(O), (H) QRLF Win(O).aps	Temp (°C)	13.8	07:30,29/Jan	41.33	14:30,29/Jul	27.52
MRT	Main Hall	(M) N Win(O), (H) QRLF Win(O).aps	Temp (°C)	13.8	07:30,29/Jan	41.33	14:30,29/Jul	27.52
MRT	Main Hall	(M) E Win(O), (H) QRLF Win(O).aps	Temp (°C)	13.8	07:30,29/Jan	41.33	14:30,29/Jul	27.52
MRT	Main Hall	(M) NSEW Win(O), (H) QRLF Win(O), Clading changed.aps	Temp (°C)	13.77	07:30,29/Jan	41.36	14:30,29/Jul	27.52
MRT	Main Hall	(MPwo)NEWs Win(O) (H) Q Win(O) (D) S Win(O).aps	Temp (°C)	14.5	07:30,29/Jan	39.84	16:30,24/Jul	27.65
MRT	Main Hall	(MPwo)NEWs Win(O) (H) Q Win(O) (D) W Win(O).aps	Temp (°C)	14.5	07:30,29/Jan	39.84	16:30,24/Jul	27.65
MRT	Main Hall	(MPwx)NEWs Win(O) (H) Win(X) (D) NEWS Win(O).aps	Temp (°C)	14.81	07:30,29/Jan	39.48	16:30,25/Jul	27.68
MRT	Main Hall	(MPwo)NEWs Win(O) (H) Q Win(O) (D) NS Win(O).aps	Temp (°C)	14.41	07:30,29/Jan	40.12	16:30,24/Jul	27.68
MRT	Main Hall	(MPwo) Win(X) (H) Q Win(O) (D) NEWS Win(O).aps	Temp (°C)	14.48	07:30,29/Jan	40.44	15:30,24/Jul	27.82
MRT	Main Hall	Base design AC off, Win(X), (H) not conected with (M).aps	Temp (°C)	20.71	07:30,29/Jan	41.35	16:30,10/Aug	31.71

Table 19 The MRT in the table ranges from 13.76 °C to 41.36 °C. The lowest MRT is when all the windows are open in the minaret and prayer hall at 7:30 on 29/Jun

The MRT is generally higher during the summer months than during the winter months. The MRT is also higher when the windows are open or when the air conditioning

is turned off. This is because there is less to block the transfer of heat from the outside to the inside of the building.

The MRT also is affected by the type of cladding on the building. A cladding with a higher absorption coefficient will absorb more solar radiation. Tables 20, 21, 22

Table 20

Comparison of the Minimum MRT and the Base Design

Var. Name	Filename	Type	Min. Val.	Min. Time
MRT	(M) NSEW Win(O), (H) QRLF Win(O)	Temp (°C)	13.76	07:30,29/Jan
MRT	Base (M) not connected (H)QRLF win(o) Ac off	Temp (°C)	14.23	07:30,29/Jan

Table 21

Comparison of the Maximum MRT and the Base Design

Var. Name	Filename	Type	Max. Val.	Max. Time
MRT	(M) NSEW Win(O), (H) QRLF Win(O), Claddings changed	Temp (°C)	41.36	14:30,29/Jul
MRT	Base (M) not connected (H)QRLF win(o) Ac off	Temp (°C)	40.14	15:30,24/Jul

Table 22

Comparison of the Mean MRT and the Base Design

Var. Name	Filename	Type	Mean
------------------	-----------------	-------------	-------------

MRT	(M) NSEW Win(O), (H) Q Win(O)	Temp (°C)	27.32
MRT	(M) NSEW Win(O), (H) L Win(O)	Temp (°C)	27.32
MRT	Base (M) not connected (H)QRLF win(o) Ac off	Temp (°C)	27.51

4.2 Air Movement

Table 23 shows a study of different scenarios for the total air flows entering the room from the external environment. The study was conducted using MacroFlo in the IES VE program, which simulates natural ventilation in buildings.

The scenarios depend on different configurations of window openings. ACH is a measure of how often the air inside a building is replaced with fresh air. A higher ACH means that the air is replaced more frequently, which can help remove pollutants and improve indoor air quality. (Environment 2023)

Table 23

MacroFlo External Vent for Different Scenarios

Var. Name	Location	Filename	Type	Min. Val.	Min. Time	Max. Val.	Max. Time	Mean
MacroFlo external vent	Main Hall	(M) NSEW Win(O), (H) QRLF Win(O), Cladding changed .aps	Air change rate (ACH)	4.64	09:30,10/Mar	111.32	17:30,24/Jul	26.01
MacroFlo external vent	Main Hall	(M) SE Win(O), (H) QRLF Win(O).aps	Air change rate (ACH)	5.13	09:30,21/Dec	111.2	17:30,24/Jul	25.55
MacroFlo external vent	Main Hall	(M) SW Win(O), (H) QRLF Win(O).aps	Air change rate (ACH)	5.13	09:30,21/Dec	111.2	17:30,24/Jul	25.55
MacroFlo external vent	Main Hall	(M) W Win(O), (H) QRLF Win(O).aps	Air change rate (ACH)	5.01	09:30,21/Dec	111.02	17:30,24/Jul	25.55
MacroFlo external vent	Main Hall	(M) S Win(O), (H) QRLF Win(O).aps	Air change rate (ACH)	5.01	09:30,21/Dec	111.02	17:30,24/Jul	25.55
MacroFlo external vent	Main Hall	(M) NE Win(O), (H) QRLF Win(O).aps	Air change rate (ACH)	5.13	09:30,21/Dec	111.2	17:30,24/Jul	25.55
MacroFlo external vent	Main Hall	(M) NS Win(O), (H) QRLF Win(O).aps	Air change rate (ACH)	5.11	09:30,21/Dec	111.16	17:30,24/Jul	25.55
MacroFlo external vent	Main Hall	(M) N Win(O), (H) QRLF Win(O).aps	Air change rate (ACH)	5.01	09:30,21/Dec	111.02	17:30,24/Jul	25.55
MacroFlo external vent	Main Hall	(M) E Win(O), (H) QRLF Win(O).aps	Air change rate (ACH)	5.01	09:30,21/Dec	111.02	17:30,24/Jul	25.55
MacroFlo external vent	Main Hall	(M) NSEW Win(O), (H) QRLF Win(O).aps	Air change rate (ACH)	5.18	09:30,21/Dec	111.27	17:30,24/Jul	25.54
MacroFlo external vent	Main Hall	new base (M) not connected (H) QRLF Win(O) Ac off .aps	Air change rate (ACH)	0.99	18:30,24/Dec	14.11	07:30,02/Feb	8.36
MacroFlo external vent	Main Hall	(MPwo) Win(X) (H) Q Win(O) (D) NEWS Win(O).aps	Air change rate (ACH)	0.51	14:30,18/Jun	13.56	07:30,02/Feb	8.02
MacroFlo external vent	Main Hall	(MPwo) NEWS Win(O) (H) Q Win(O) (D) NS Win(O).aps	Air change rate (ACH)	0.83	15:30,18/Jun	14.17	07:30,02/Feb	7.11
MacroFlo external vent	Main Hall	(M) NSEW Win(O), (H) QRLF Win(O), Cladding changed .aps	Air change rate (ACH)	0.69	09:30,28/Apr	12.53	07:30,02/Feb	6.33
MacroFlo external vent	Main Hall	(MPwo) NEWS Win(O) (H) Q Win(O) (D) S Win(O).aps	Air change rate (ACH)	0.78	14:30,26/Jun	12.53	07:30,02/Feb	5.89
MacroFlo external vent	Main Hall	(MPwo) NEWS Win(O) (H) Q Win(O) (D) W Win(O).aps	Air change rate (ACH)	0.78	14:30,26/Jun	12.53	07:30,02/Feb	5.89
MacroFlo external vent	Main Hall	(M) NSEW Win(O), (H) QL Win(O).aps	Air change rate (ACH)	1.48	15:30,28/Apr	11.32	07:30,02/Feb	5.3
MacroFlo external vent	Main Hall	(MPwo) NEWS Win(O) (H) Q Win(O) maerial changed .aps	Air change rate (ACH)	0	10:30,28/Apr	9.19	07:30,02/Feb	4.15
MacroFlo external vent	Main Hall	(MPwx) NEWS Win(O) (H) Win(X) (D) NEWS Win(O).aps	Air change rate (ACH)	0.5	12:30,03/Mar	9.16	07:30,02/Feb	4.15
MacroFlo external vent	Main Hall	(M) NSEW Win(O), (H) Q Win(O), Cladding changed .aps	Air change rate (ACH)	0	10:30,28/Apr	8.88	07:30,02/Feb	4.04
MacroFlo external vent	Main Hall	(MPwx) NEWS Win(O) (H) Q Win(O).aps	Air change rate (ACH)	0.61	13:30,29/Dec	9.22	07:30,02/Feb	3.87
MacroFlo external vent	Main Hall	(MPwo) NEWS Win(O) (H) Q Win(O).aps	Air change rate (ACH)	0.61	13:30,29/Dec	9.22	07:30,02/Feb	3.87
MacroFlo external vent	Main Hall	(M) NSEW Win(O), (H) Q Win(O).aps	Air change rate (ACH)	0.61	14:30,28/Apr	8.91	07:30,02/Feb	3.75
MacroFlo external vent	Main Hall	(M) NSEW Win(O), (H) L Win(O).aps	Air change rate (ACH)	0.61	14:30,28/Apr	8.91	07:30,02/Feb	3.75
MacroFlo external vent	Main Hall	(MPwo) NW Win(O) (H) Q Win(O).aps	Air change rate (ACH)	0.64	13:30,29/Dec	8.81	07:30,02/Feb	3.74
MacroFlo external vent	Main Hall	(M) NW Win(O), (H) Q Win(O).aps	Air change rate (ACH)	0.65	14:30,28/Apr	8.52	07:30,02/Feb	3.63
MacroFlo external vent	Main Hall	(M) SE Win(O), (H) Q Win(O).aps	Air change rate (ACH)	0.65	14:30,28/Apr	8.52	07:30,02/Feb	3.63
MacroFlo external vent	Main Hall	(M) W Win(O), (H) Q Win(O).aps	Air change rate (ACH)	0.86	14:30,28/Apr	7.59	07:30,02/Feb	3.35
MacroFlo external vent	Main Hall	(M) S Win(O), (H) Q Win(O).aps	Air change rate (ACH)	0.86	14:30,28/Apr	7.59	07:30,02/Feb	3.35
MacroFlo external vent	Main Hall	(M) N Win(O), (H) Q Win(O).aps	Air change rate (ACH)	0.86	14:30,28/Apr	7.59	07:30,02/Feb	3.35
MacroFlo external vent	Main Hall	(M) E Win(O), (H) Q Win(O).aps	Air change rate (ACH)	0.86	14:30,28/Apr	7.59	07:30,02/Feb	3.35
MacroFlo external vent	Main Hall	Base design AC off, Win(X), (H) not connected with (M).aps	Air change rate (ACH)	0	00:30,01/Jun	0	00:30,01/Jun	0
MacroFlo external vent	Main Hall	Base design AC on, Win(X), (H) not connected with (M).aps	Air change rate (ACH)	0	00:30,01/Jun	0	00:30,01/Jun	0

The results of the study showed that the design with the maximum mean MacroFlo external vent rate is the design:

Table 24

Comparison of the Best Mean Macroflo External Vent with the Average Base Design

Var. Name	Locatio n	Scenarios	Type	Mea n
MacroFlo external vent	Main Hall	(M) NSEW Win (O), (H) QRLF Win (O), Cladding changed.	(ACH)	26.01
MacroFlo external vent	Main Hall	(M) W Win(O), (H) QRLF Win(O)	(ACH)	25.55
MacroFlo external vent	Main Hall	Base (M) not connected (H)QRLF win(o) Ac off	(ACH)	8.36

Table 24 has an average air change rate of 26.01 air changes per hour (ACH).

When the cladding is changed to a material with a higher U value, Figure14, the average air change rate for the same scenario decreases by lowering the value of U, as it decreases to 25.55 ACH when the cladding is changed to a stone material, which is considered to have higher heat resistance. Figure15

It is noted that there is a difference equivalent to 17.65 ACH between the best averages of the scenarios compared to the base design. Table 23 Figures 16, 17

Figure 14

Settings for Building Materials with Lower U Value and their Values in the IESVE Program

Performance: **ASHRAE**

U-value: W/m²·K Thickness: mm Thermal mass Cm: kJ/(m²·K)
 Total R-value: m²·K/W Mass: kg/m² Mediumweight

Surfaces Functional Settings Regulations RadianceIES

Outside Inside

Outside: Emissivity: Resistance (m²·K/W): ☒ Default
 Solar Absorptance:

Inside: Emissivity: Resistance (m²·K/W): ☒ Default
 Solar Absorptance:

Construction Layers (Outside To Inside) System Materials... Project Materials...

Thickness mm	Conductivity W/(m·K)	Density kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² ·K/W	Vapour Resistivity GN's/(kg·m)	Category
250.0	2.300000	2300.000000	1000.000000	0.1087	-	Concretes
12.5	0.210000	700.000000	1000.000000	0.0595	0.000	Plaster

Figure 15

Settings for Building Materials With Higher U Value and their Values in the IESVE program

Performance: **ASHRAE**

U-value: W/m²·K Thickness: mm Thermal mass Cm: kJ/(m²·K)
 Total R-value: m²·K/W Mass: kg/m² Mediumweight

Surfaces Functional Settings Regulations RadianceIES

Outside Inside

Outside: Emissivity: Resistance (m²·K/W): ☒ Default
 Solar Absorptance:

Inside: Emissivity: Resistance (m²·K/W): ☒ Default
 Solar Absorptance:

Construction Layers (Outside To Inside) System Materials... Project Materials...

Thickness mm	Conductivity W/(m·K)	Density kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² ·K/W	Vapour Resistivity GN's/(kg·m)	Category
90.0	0.840000	1700.000000	800.000000	0.1071	0.000	Brick & Blockwork
70.0	0.025000	30.000000	1400.000000	2.8000	550.000	Insulating Materials
90.0	0.840000	1700.000000	800.000000	0.1071	0.000	Brick & Blockwork
90.0	0.500000	1300.000000	1000.000000	0.1800	50.000	Plaster
90.0	0.075900	32.000000	837.000000	1.1858	13.000	Insulating Materials
90.0	1.802000	2243.000000	837.000000	0.0499	262.000	Sands, Stones and Soils

Note. (IESve 2023)

Table 25

Comparison of the Best Maximum Macroflo External Vent and the Base Design

Var. Name	Locat	Filename	Typ	Max.	Min.
	ion		e	Val.	Time
MacroFlo	Main	(M) NSEW Win(O), (H) QRLF	(AC	111.3	17:30,2
external vent	Hall	Win(O), Cladding changed	H)	2	4/Jul
MacroFlo	Main	Base design (M) not connected	(AC	14.11	07:30,0
external vent	Hall	(H)QRLF win(o) Ac off	H)		2/Feb

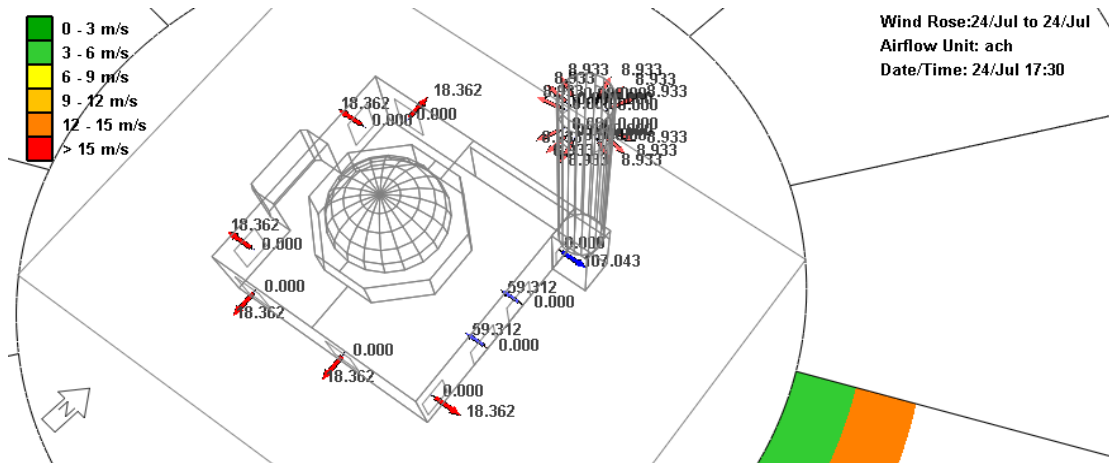
The base design has a maximum external MacroFlo rate of 14.11 ACH at 07:30/02/Feb. On the other hand, the scenario with the minaret open from all directions and the stone cladding removed from it and connected to the open prayer hall as well as its windows from all directions had a maximum air change rate of 111.32 ACH, a difference of up to 97.21 ACH from the base design. Table 25, Figure 19, Figure 20

As for other designed scenarios, air change rates range from 7.59 to 111.16 ACH. Table 20

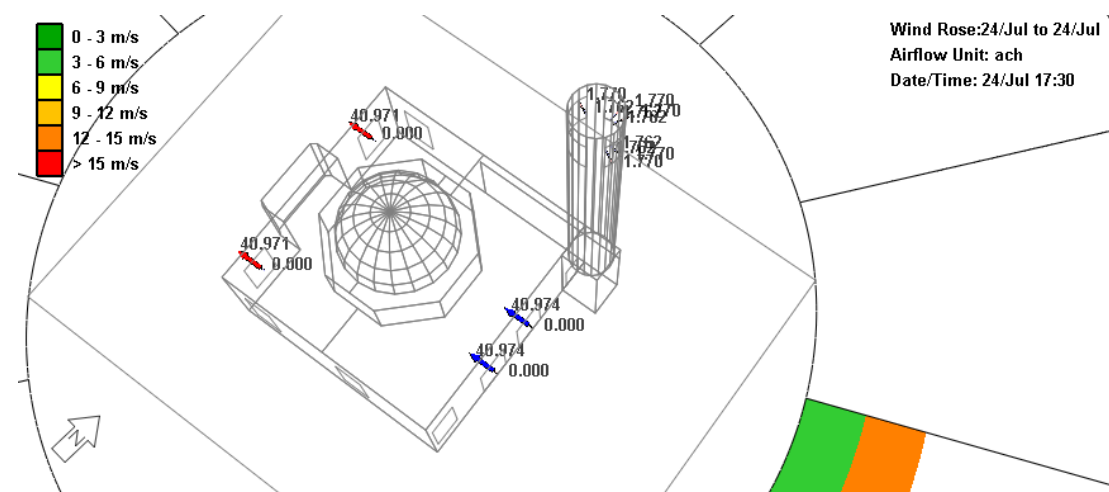
Results for different scenarios indicate that the design of openings is an important factor in determining the rate of air change in a building and also indicate that the cladding materials used in a building can also affect the rate of air change.

Figure 18

The Best Maximum Rate of Air Entry and Exit Through Windows and Doors on 17:30, 24/Jul in the Scenario: (M) NSEW Win (O), (H) QRLF Win (O), Cladding Changed

**Figure 19**

The Best Maximum Rate of Air Entry and Exit Through Windows and Doors on 24/Jul at 17:30 in the Base Scenario: Base Design AC Off Win (O) (H) Not Connected with (M)



The minimum MacroFlo external vent for different scenarios is between 0 and 5.18 (ACH).

Table 26

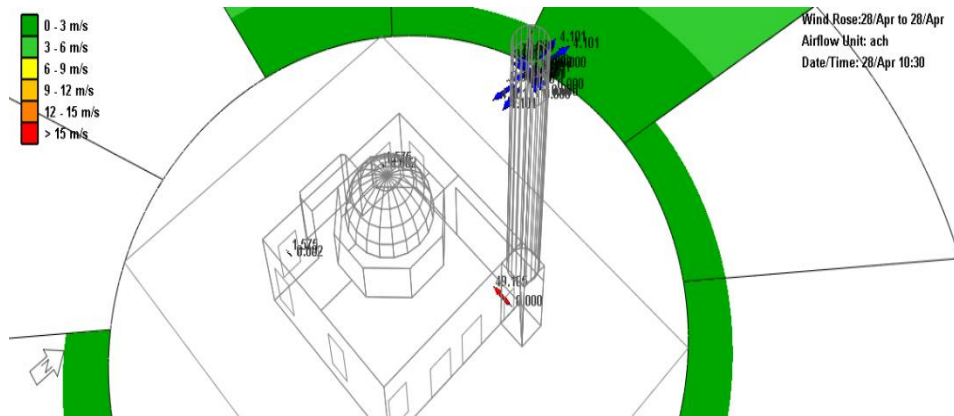
Comparison of the Minimum Macroflo External Vent and the Base Design

Var. Name	Locat	Scenarios	Typ	Time	Min.
	ion		e		Var
MacroFlo	Main	(MPwo)NEWs Win(O) (H) Q	(AC	10:30,2	0
external vent	Hall	Win(O) material changed	H)	8/Apr	
MacroFlo	Main	Base (M) not connected (H)QRLF	(AC	18:30,2	0.99
external vent	Hall	win(o) Ac off	H)	4/Dec	

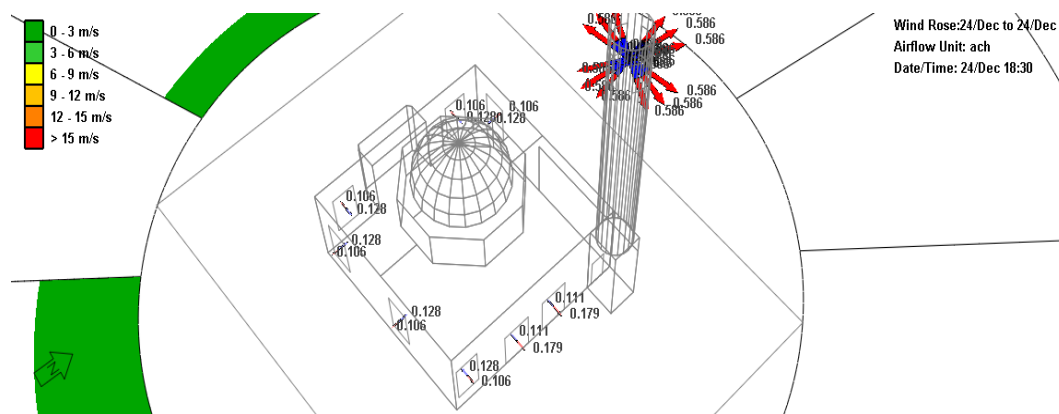
The base design has a minimum external MacroFlo external vent of 0.99 ACH at 18:30, 24/Dec. On the other hand, Scenario a minaret divided by a partition, open in all directions, from which the stone cladding was removed, and connected to the prayer hall with windows open in all directions. The minimum air change rate was 0 ACH at 10:30, 28/Apr, with a difference of up to 0.99 ACH from the base design. Table 26, Figure21, Figure22

Figure 20

The Minimum Rate of Air Entry and Exit Through Windows and Doors on 10:30, 28/Apr in the Scenario: (Mpwo) NEWS Win(O) (H) Q Win(O) Material Changed

**Figure 21**

The Minimum Rate of Air Entry and Exit Through Windows and Doors on 24/Dec At 18:30 in the Base Scenario: Base Design AC Off Win (O) (H) Not Connected with (M)



4.2.1 Result Analysis and the Best Scenario

4.2.1.1 The Main Factor is Macroflow to Choose the Best Scenario. The best scenario among the various scenarios is if you focus mainly on the wind speed factor only, which is the rate of air change, as it is the factor that explains the effectiveness of wind absorbers/solar chimneys in the process of drawing and directing the wind into the building or the process of discharging the air to the outside.

Wind speed has a significant impact on the feeling of thermal comfort, as it helps cool the body and reduces the effect of moisture on the skin. The rapid entry speed of the wind helps cool the body by removing moisture from the skin, which enhances the feeling of comfort. Comparing the scenarios, it was found that the MacroFlow system with windows open from all directions in the prayer hall and the minaret, with the removal of the stone cladding that increased the U value, was the best scenario, with a noticeable difference of 17.65 (ACH) with a base design. Table 27, Figure20

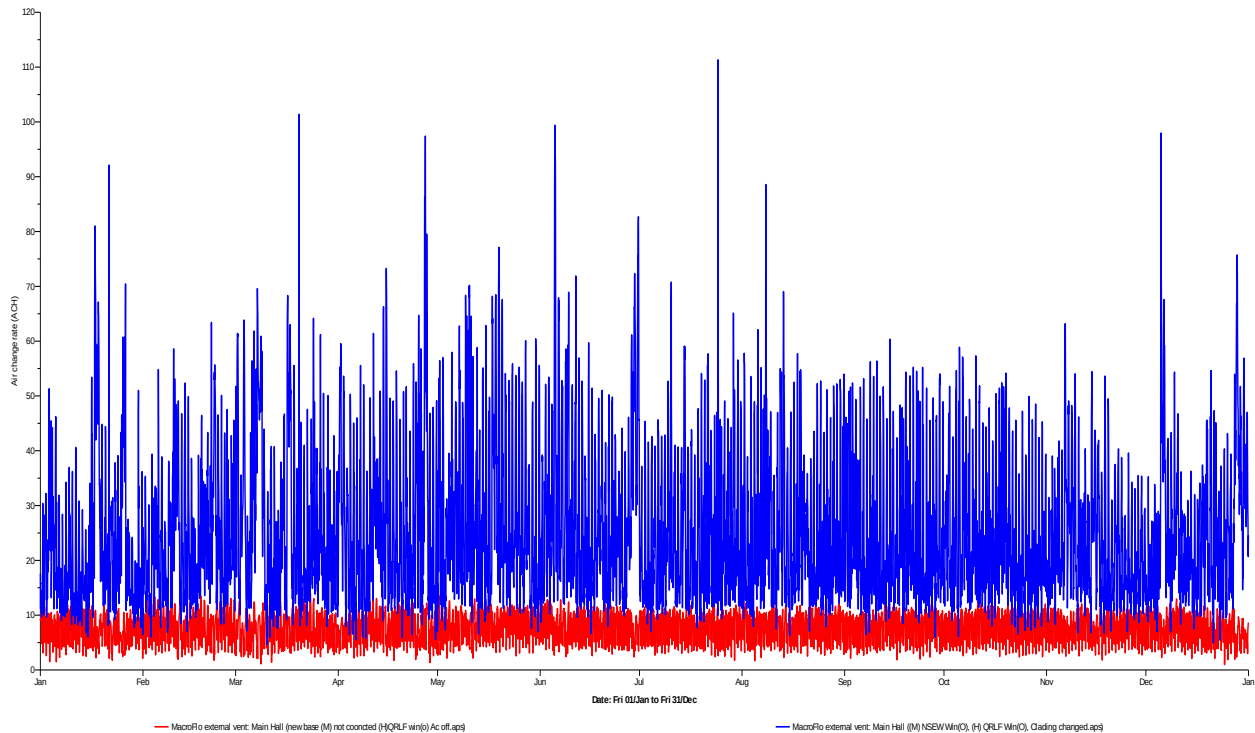
Table 27

The Best Scenario for Mean Macroflo Compared to the Base Design

Var. Name	Scenarios	Type	Mean
MacroFlo external vent	(M) NSEW Win (O), (H) QRLF Win (O), Cladding changed.	(ACH)	26.01
MacroFlo external vent	Base (M) not connected (H)QRLF win(o) Ac off	(ACH)	8.36

Figure 22

Comparing Macroflow During the Year Between the Base Design and the Best Macroflow



4.2.1.2 Hybrid Scenario for Macroflo Best Scenarios . A hybrid scenario is a

design that balances modern technologies such as electricity and air conditioning with sustainable technologies based on passive cooling.

In the hybrid scenario, the effect of comfort ventilation versus night flush cooling is also observed. (Robert & Brown 2015)

Comfort ventilation: bring in outdoor air, especially during the daytime when the temperatures are at their highest. (Robert & Brown 2015)

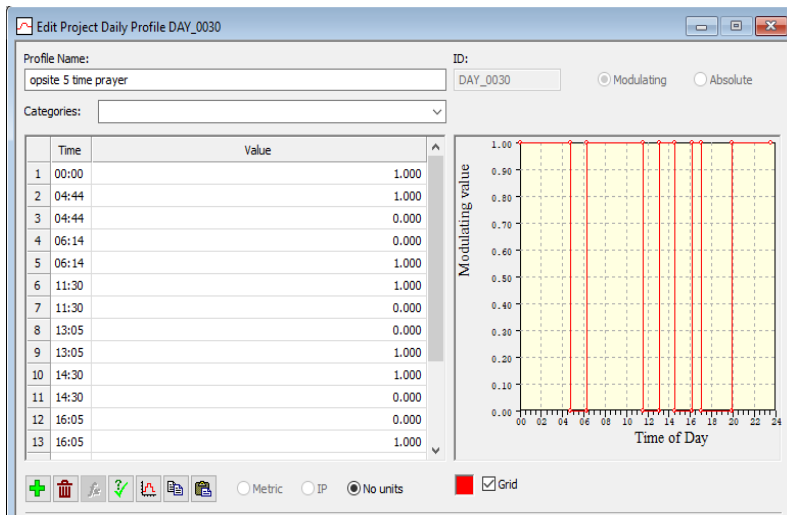
Night flush cooling: is to flush out the heat of the building while during the day very little outside air is brought indoors so that heat gain to the building can be minimized.

The timing settings for opening and closing the vents in the mosque were adjusted in the computer simulation program IESVE. Half an hour was set for closing the vents

before the time of each prayer, as the air conditioning devices also operate and shut down an hour after the prayer time. Figure 23, 24

Figure 23

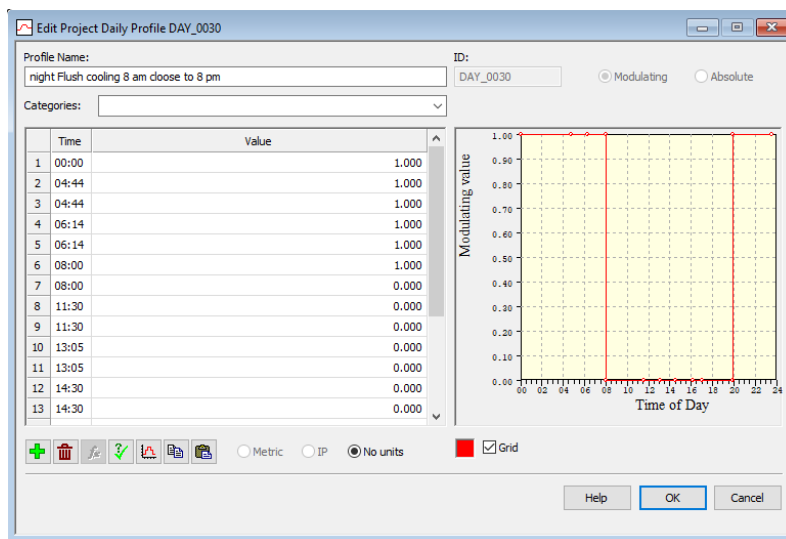
Explaining the Opening and Closing Times of Ventilation and Air Conditioning Vents in the IESVE Hybrid Design Program for Comfort Ventilation



Note. (IESve 2023)

Figure 24

Explaining the Opening and Closing Times of Ventilation and Air Conditioning Vents in the IESVE Hybrid Design Program for Night Flush Cooling



In the night cooling process, the opening of the windows at night was set from 8 pm until 8 am, because the two times are the best in terms of ventilation. Figure 24

Figure 25

MacroFlo Vent Peaks for Comfort Ventilation

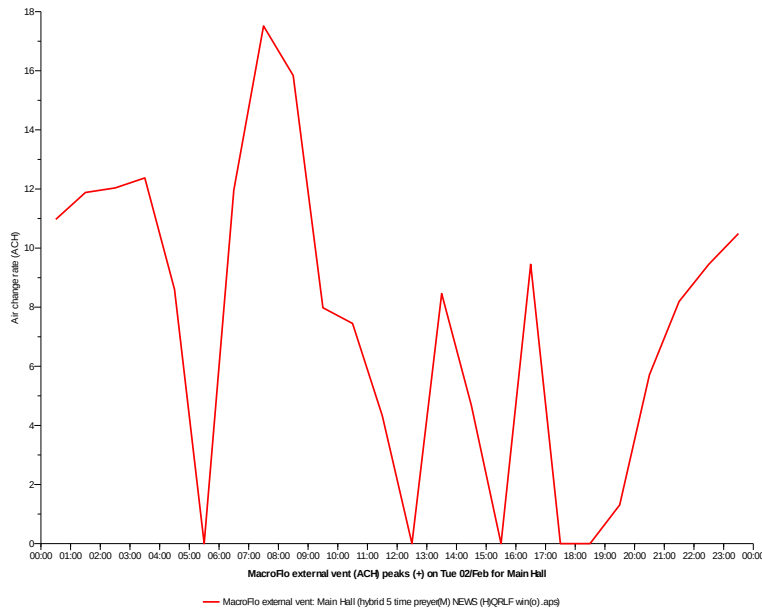


Figure 26

Macroflo Vent Peaks for Night Flush Cooling

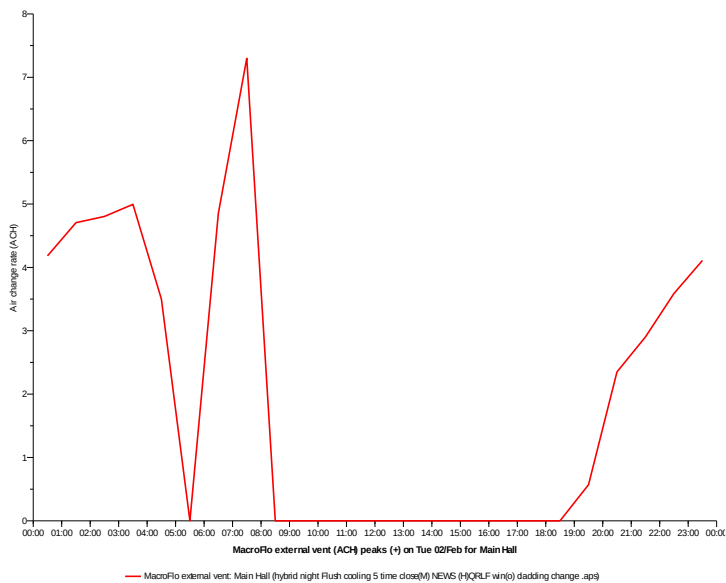


Table 28

A Macroflo Comparison Between the Hybrid Scenario and the Best Chosen Scenario

Var. Name	Filename	Type	Min. Val.	Min. Time	Max. Val.	Max. Time	Mean
MacroFlo external vent	hybrid (M) NEWS Win(o) (H) QRLF Win(o) cladding changed	Air change rate (ACH) ↓		0 05:30,01/Jan	↑ 17.39	07:30,02/Feb	6.15
MacroFlo external vent	(M) NEWS Win(o) (H) QRLF Win(o) cladding changed	Air change rate (ACH) ↓		1.08 11:30,26/Jan	↑ 17.44	07:30,02/Feb	9.37

In Table No. 28, we note that the macro flow in the hybrid scenario is 6.15 ACH due to closing the openings at the times of the five prayers, compared to 9.37 ACH for the best scenario that was adopted, i.e. a difference equivalent to 3.22 ACH.

Table 29

An Air Temperature Comparison Between the Hybrid Scenario and the Best Chosen

Var. Name	Filename	Type	Min. Val.	Min. Time	Max. Val.	Max. Time	Mean
Air temperature	hybrid (M) NEWS Win(o) (H) QRLF Win(o) cladding changed	Temperature (°C) ↓	9.99	08:30,02/Feb	↑ 39.63	10:30,26/Aug	24.53
Air temperature	(M) NEWS Win(o) (H) QRLF Win(o) cladding changed	Temperature (°C) ↓	10.01	08:30,02/Feb	↑ 43.13	14:30,23/Jul	27.23

In Table No. 29, we note that the air temperature decreased in the hybrid scenario to 24.5°C, the effect of nighttime cooling when the windows are open, as they are generally open at night times and in the period after the morning prayer and before the noon prayer, due to the timing of the prayers, compared to 27.23°C for the best scenario that was adopted, that is, a difference equivalent to 2.7°C Which are prominent and close to the required thermal comfort rates

Table 30

A Relative Humidity Comparison Between the Hybrid Scenario and the Best Chosen Scenario

Var. Name	Filename	Type	Min. Val.	Min. Time	Max. Val.	Max. Time	Mean
Relative humidity	hybrid (M) NEWS Win(o) (H) QRLF Win(o) cladding changed	Percentage (%) ↓	10.69	10:30,11/Jul	↑ 99.99	17:30,08/Jun	67.18
Relative humidity	(M) NEWS Win(o) (H) QRLF Win(o) cladding changed	Percentage (%) ↓	7.84	12:30,31/May	↑ 97.96	05:30,15/Jan	59.09

In Table No. 30, we note that the relative humidity increased to 67.18% in the hybrid scenario due to the decrease in macro flow rates compared to 59.09% for the best

scenario that was adopted, i.e. a difference equivalent to 8.09%, and this difference can be dealt with by installing humidity control devices and air conditioning devices.

Table 31

A Mean Radiant Temperature Comparison Between the Hybrid Scenario and the Best-Chosen

Var. Name	Filename	Type	Min. Val.	Min. Time	Max. Val.	Max. Time	Mean
MRT	(M) NSEW Win(O), (H) QRLF Win(O), Cladding changed.aps	Temp (°C)	↓13.77	07:30,29/Jan	↑41.36	14:30,29/Jul	→27.52
MRT	hybrid last (M) NEWS (H) QRLF cladding changed.aps	Temp (°C)	↓14.15	07:30,29/Jan	↑35.03	10:30,26/Aug	→24.85

We notice in Table No. 31 that the mean radiant temperature decreased to 24.85 C in the hybrid scenario compared to 27.52 C for the best scenario adopted, i.e. a difference equivalent to 2.67 C, and this makes the hybrid scenario better.

People dissatisfied: An index that predicts the percentage of occupants expressing dissatisfaction with the room's thermal environment. (Environment 2023)

We notice in Table 32 that the number of people dissatisfied decreased to 49.74% in the hybrid scenario compared to 60.96% for the best scenario adopted, i.e. a difference equivalent to 11.22%, and this makes the hybrid scenario better.

Table 32

A People Dissatisfied Comparison Between the Hybrid Scenario and the Best-Chosen Scenario

Var. Name	Filename	Type	Min. Val.	Min. Time	Max. Val.	Max. Time	Mean
People dissatisfied	hybrid (M) NEWS Win(o) (H) QRLF Win(o) cladding changed	Percentage (%)	↓	5 07:30,28/Jan	↑	98.41 10:30,26/Aug	→ 49.74
People dissatisfied	(M) NEWS Win(o) (H) QRLF Win(o) cladding changed	Percentage (%)	↓	5 06:30,28/Jan	↑	99.88 15:30,24/Jul	→ 60.96

Chapter 5 : CFD Analysis

5.1 Air Velocity

Figure 28 shows a map of the air velocity of the mosque where the air velocity is highest near the top of the minaret 2 m/s and lowest near the ground 0.18 m/s. This is because the minaret creates a chimney effect, drawing air upwards and away from the prayer hall.

The high air movement near the top of the minaret can help cool the prayer hall during the hot summer months and the low air velocity near the ground can help keep the mosque warm during the cold winter months.

The amount of airflow through the prayer hall each day is approximately equal to the volume of the mosque divided by the average air velocity in the prayer hall.

Airflow = Volume mosque / Average air velocity

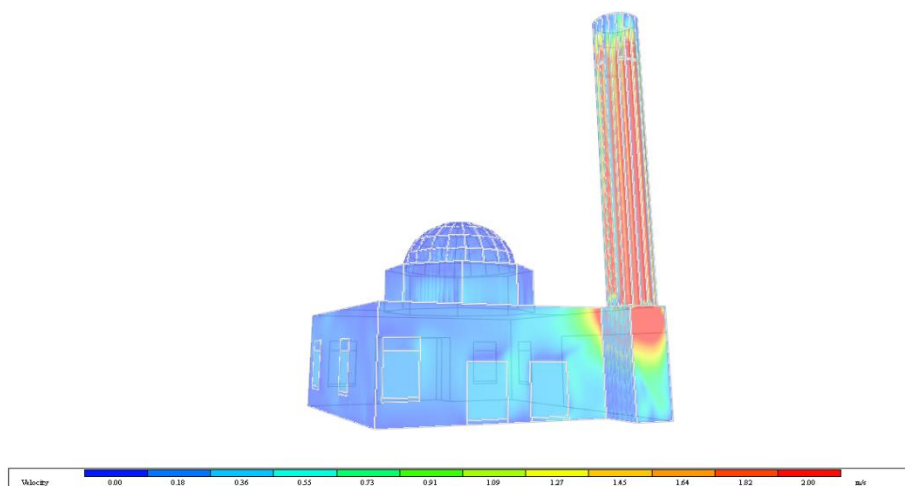
$$= ((13 * 13 * 5.9) + (2 * 2 * 23)) / 0.75$$

$$= 1089 / 0.75 = 1452 \text{ m}^3/\text{s}$$

According to (Robert & Brown 2015) Table 33 and from the average air speed of 0.75 meters per second, it is equivalent to reducing temperatures by 1.9 Celsius.

Figure 27

Filled Velocity Contour 7:0, 2/Feb



Note. (Robert & Brown 2015)

Table 33*Air Velocities and Thermal Comfort*

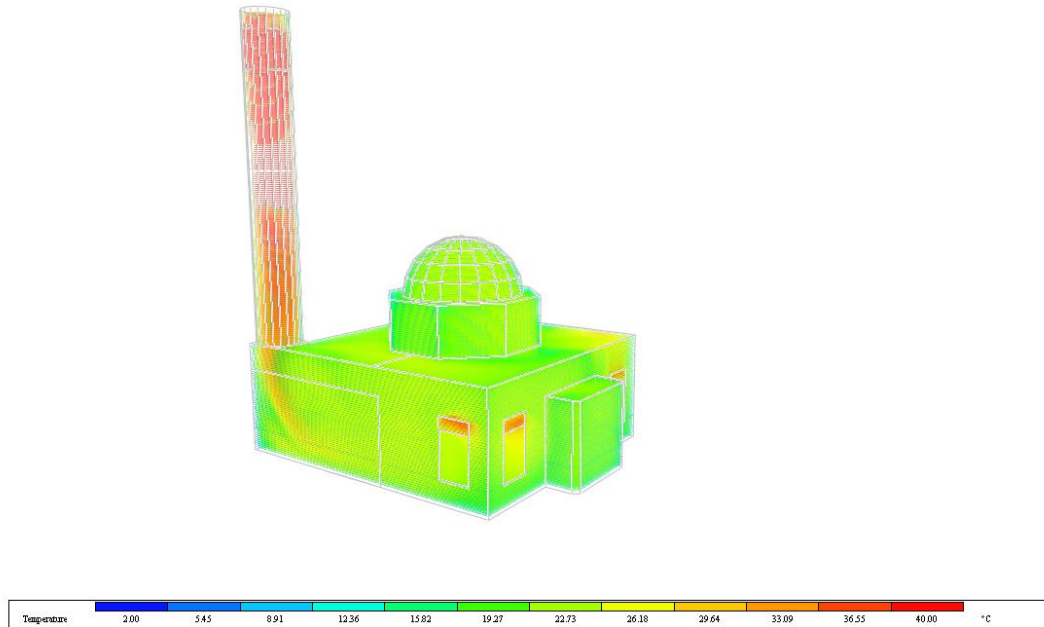
Table 10.8 Air Velocities and Thermal Comfort						
Air Velocity				Equivalent Temperature Reduction*		Effect on Comfort
I-P		SI		°F	°C	
fpm	mph	m/s	kph			
10	0.1	0.05	0.2	0	0	Stagnant air, slightly uncomfortable
40	0.5	0.2	0.8	2	1.1	Barely noticeable but comfortable
50	0.6	0.25	1.0	2.4	1.3	Design velocity for air outlets that are near occupants
80	1	0.4	1.6	3.5	1.9	Noticeable and comfortable
160	2	0.8	3.2	5	2.8	Very noticeable but acceptable in certain high-activity areas if air is warm
200	2.3	1.0	3.7	6	3.3	Upper limit for air-conditioned spaces Good air velocity for natural ventilation in hot and dry climates
400	4.5	2.0	7.2	7	3.9	Good air velocity for comfort ventilation in hot and humid climates
900	10	4.5	16	9	5.0	Considered a gentle breeze when felt outdoors

*The values in this column are the number of degrees that the temperature would have to drop to create the same cooling effect as the given air velocity.

5.2 Temperature

Figure 29 represents the filled temperature contour of the mosque, as it shows that the temperature is highest at the top of the dome and the minaret, and gradually decreases down to the ground. This is because hot air rises to the top of the mosque and exits from the minaret, while cold air descends to its bottom.

The temperature contour also shows that the top of the dome is hotter due to the buoyancy effect and the minaret is hotter due to the Stack effect.

Figure 28*Filled Temperature Contour*

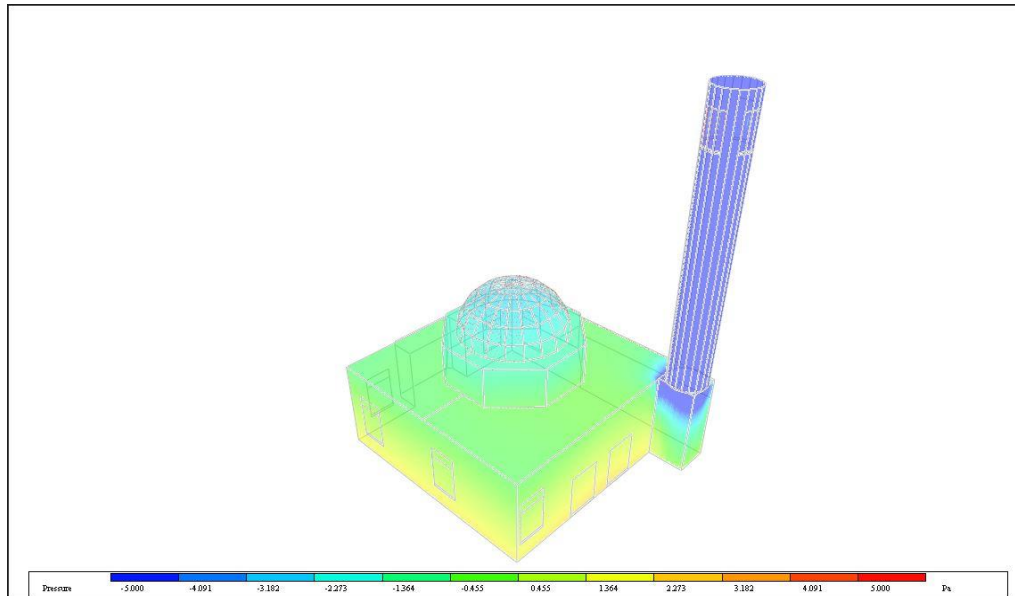
5.3 Pressure

Figure 30 of the filled pressure perimeter of the mosque shows that the pressure reaches its highest levels at the top of the dome and the minaret, and gradually decreases towards the ground because hot air rises to the top of the mosque, and cold air descends to its bottom.

The pressure diagram also shows that the pressure inside the mosque is lower than the pressure outside the mosque, and this is a contributing factor to using natural ventilation to cool and ventilate the mosque.

The prevailing winds create a high-pressure area on the side facing it and a low-pressure area on the other side.

The pressure on the concave surfaces of the mosque, such as in the dome, is higher than on straight surfaces because domes create an area of high pressure and straight surfaces create an area of low pressure.

Figure 29*Filled Pressure Contour*

Chapter 6 : Conclusion

6.1 Conclusion

The United Arab Emirates enjoys a hot desert climate, with average temperatures often exceeding 40 degrees Celsius, which has contributed to raising rates of reliance on air conditioning devices to achieve thermal comfort in enclosed spaces, specifically in mosques, which are often used for the times of the five obligatory daily prayers. Air conditioning devices constitute a major contributor to energy consumption and cause an increase in carbon emissions and greenhouse gases.

Reusing mosque minarets as passive cooling elements is one of the potential solutions to reduce cooling consumption and resulting emissions. Minarets are tall structures exposed to prevailing winds, making them ideal for use as wind traps or solar chimneys. Enhancing natural ventilation in mosques by using minarets as passive cooling elements, such as windbreaks or solar chimneys, is an innovative method derived from ancient heritage. Moreover, this sustainable idea is not only compatible with environmental considerations, but also enhances the maximum benefit from existing concrete structures represented by minarets, which may reach approximately 9,000 in the United Arab Emirates, including approximately 3,000 minarets in Sharjah.

A three-dimensional model was used in this study to study the potential effectiveness of reusing minarets as passive cooling elements. The case study was of a mosque in Al Tayy area in the Emirate of Sharjah.

Scenario 0 ((Base (M) not connected (H) QRLF win (o) Ac off)):

- Air temperature: 27.35°C
- Air movement: 8.36 ACH
- Relative humidity: 58.59%•Average radiant temperature: 27.51°C

Scenario 1 ((M) NSEW Win (O), (H) QRLF Win (O), Cladding changed)):

- Air temperature: 27.34°C (similar to the base)
- Air movement: 26.01 ACH (significant increase)
- Relative humidity: 59.16% (slight increase)
- Average radiant temperature: 27.52°C (similar)

Scenario 2 ((M) NSEW Win (O), (H) QRLF Win (O)):

- Air temperature: 27.32°C (similar to the original)
- Air movement: 25.54 ACH (similar)
- Relative humidity: 59.19% (slight increase)
- Average radiant temperature: 27.5°C (minimal change)

Air temperature: Scenarios (1) and (2) maintain a temperature close to the base scenario.(0)

Air change rate: Scenario (1) involves a significant increase in air movement, which can enhance thermal comfort. Scenario (2) also saw a significant increase in traffic.

Relative humidity: All scenarios show small changes in relative humidity.

Mean radiant temperature: All scenarios show slight variations

Considering the factors affecting thermal comfort, scenario (1) (2) turns out to be the best design because there is significantly increased air movement, which is beneficial for indoor comfort.

We found that reusing minarets as wind traps or solar chimneys can contribute to reducing the need for air conditioners in mosques and reducing the cooling load to reach the ideal temperature, as we found that the average rate of air change in the mosque can be increased by up to 25% using a minaret. Like a wind catcher.

The average air change rate of 25 (ACH) at 17:30, 24/Jul was achieved in this study, and the lowest air change rate for the mosque after its connection to the minaret was

5 (ACH) This is in scenarios where all the windows and doors are open in the prayer hall and the openings in the minaret are all open, or in one direction, or even two directions with the same average. While the base design of the case study, the average air change was 8 (ACH), and the minimum air change was 0.99 (ACH) at 18:30, 24/Dec.

The recommended air changes per hour for thermal comfort in mosques usually range between 5 and 10. This recommendation is based on ASHRAE, Thermal Environmental Conditions for Human Occupancy, which provides guidance for acceptable thermal comfort conditions in various indoor environments. (ASHRAE Standard 55 2017)

Calculating the amount of air flow through the prayer hall each day is approximately equal to the volume of the mosque divided by the average air speed in the prayer hall. The average air speed in the prayer hall is approximately equal to the average air speed at the top and bottom of the minaret. The average air speed in the prayer hall is about 0.75 m/s. This means that the amount of air flowing through the mosque daily is about 1089 cubic meters / 0.75 meters per second = 1452 m³/s.

To estimate the amount of heat exchanged between the mosque and the surrounding air daily: It is approximately equal to the amount of air flowing through the mosque daily multiplied by the difference between the average temperature of the prayer hall and the average temperature outside the mosque. The average temperature inside the mosque is about 25 °C, and outside the mosque is about 35 °C. This means that the amount of heat exchanged between the mosque and the air surrounding it daily is about 1452 m³/s * (25°C - 35°C) = 14520 watts.

The cost of energy needed to cool the mosque daily is approximately equal to the amount of heat exchanged between the mosque and the surrounding air daily multiplied by the price of electricity. The price of electricity in Sharjah for commercial purposes is about 0.28 dirhams per kilowatt-hour. This means that the energy cost to cool the mosque daily is

about 14,520 watts * 0.28 dirhams per kilowatt-hour = 4,065.6 dirhams. It should be noted that the Sharjah government bears the costs of electricity and water for all Sharjah mosques, so there are no fees for them. (<https://uaeeasy.com/> 2023)

The UAE government has put in place many initiatives to enhance sustainability, including adopting the Leadership in Energy and Environmental Design (LEED) rating system of the Emirates Green Building Council (UGBC) for new buildings.

This study contributes to providing a contribution to the field of sustainable architecture and mosque development in the United Arab Emirates and expresses the country's vision in the field of sustainability and reducing its carbon footprint. In 2015, the United Arab Emirates government announced a plan to generate 75% of its electricity needs from clean sources by the year 2050. One of the contents of the plan is to focus on developing renewable energy sources, such as solar energy and wind energy. In addition to setting special building measures and laws that require the use of energy-saving devices and materials. (UAE Ministry of Climate Change and Environment (MOCCA) 2015)

The positive impact of reusing mosque minarets as passive cooling elements on mosque architecture and heritage is represented by reviving the idea of Barajil. Barajil are traditional wind towers that have been used in the Middle East for centuries to provide natural ventilation and are considered an important part of the country's architectural heritage. They can be seen in the Sharjah Heritage Area and also in other areas of the country such as the Bastakiya area in the Emirate of Dubai.

By reusing minarets as passive cooling elements, we can help preserve this important heritage and enhance the identity of mosques. Through this approach, we can also create mosques that are more sustainable and energy efficient, in addition to their aesthetics and cultural and heritage implications.

The idea of reusing mosque minarets as passive cooling elements could also contribute to raising awareness of the importance of preserving cultural heritage and have a positive impact on the preservation of other cultural heritage sites in the UAE.

6.2 Recommendations

- Integrating wind absorbers/solar chimneys into the design of new mosques and developing legislation for them in the initial design stage.
- We recommend further research to explore the possibility of combining passive cooling systems based on minarets with other sustainable technologies and to study mosques with two minarets in terms of air intake and exhaust.
- An inventory of existing mosques, a study of their authorized locations, and the possibility of linking them to the prayer hall.
- Study the structural condition of the minarets and the possibility of making ventilation openings for the prayer hall in the event that it does not exist.
- Study other sustainable solutions to reuse minarets, such as placing wind turbines inside the minarets or air turbines at the tops of the minarets, or using them for the purposes of solar cells or rainwater collectors.

In conclusion, the idea of reusing mosque minarets as passive cooling elements is a promising solution to reduce energy consumption in mosques and promote sustainability in the UAE while also preserving the region's rich architectural heritage. It paves the way for the vision of the United Arab Emirates to become a global leader in the field of sustainability and heritage preservation.

References

- Abed Wahid Jassim, J. AL. (2018). *A New Design of the Minaret of as a Two-Sides Wind Catcher. Journal of Engineering Science and Technology.*
- Ahmed, T., Kumar, P. & Mottet, L. (2021). Natural ventilation in warm climates: The challenges of thermal comfort, heatwave resilience and indoor air quality. *Renewable and Sustainable Energy Reviews.* Elsevier Ltd.
- Al-Ruzouq, R., Shanableh, A., Khalil, M. A., Zeiada, W., Hamad, K., Dabous, S. A., Gibril, M. B. A., Al-Khayyat, G., Kaloush, K. E., Al-Mansoori, S. & Jena, R. (2022). Spatial and Temporal Inversion of Land Surface Temperature along Coastal Cities in Arid Regions. *Remote Sensing.* MDPI, vol. 14(8).
- Al-Safat. (2020), p. 2020.
- Al, J. A., Jassim, W. & Sudany, A. (2015). *International Journal of Current Engineering and Technology Employment Minarets Wind-catcher Natural Ventilation and Passive Cooling in the Mosques of Baghdad.* 3186| *International Journal of Current Engineering and Technology* [online]. Available at: <http://inpressco.com/category/ijcet>.
- AlAli, M., Mattar, Y., Alzaim, M. A. & Beheiry, S. (2023). Analysis of Electricity and Water Consumption in Existing Mosque Buildings in the UAE. *Buildings.* MDPI, vol. 13(4).
- Alkhateeb, E. & Abu-Hijleh, B. (2019). Potential for retrofitting a federal building in the UAE to net zero electricity building (nZEB). *Heliyon.* Elsevier Ltd, vol. 5(6), p. e01971.
- Alzaed, A. & Balabel, A. (2017). *A new modern Design of four-sided Windcatcher for Natural Ventilation in Residential Building in Saudi Arabia.* *International Journal of Applied Environmental Sciences* [online]. Available at: <http://www.ripublication.com>.
- ASHRAE Standard 55. (2017). ASHRAE Standard 55 - version 2017, vol. 2017.

- Awad, J. (2021). The current trends in mosque architecture in the northern cities of the United Arab Emirates (UAE). *Archnet-IJAR*. Emerald Publishing, vol. 15(3), pp. 854–871.
- Bagasi, A. A., Calautit, J. K. & Karban, A. S. (2021). Evaluation of the integration of the traditional architectural element mashrabiya into the ventilation strategy for buildings in hot climates. *Energies*, vol. 14(3).
- Bloom, J. (Jonathan M. . & Blair, S. (2009). The Grove encyclopedia of Islamic art and architecture. Oxford University Press.
- Chohan, A. H. & 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 (Switzerland)*. MDPI.
- Dahlan, A., Eissa, M., Sadik Dahlan, A. & Ahmad Eissa, M. (2019). '*Improving the Thermal Performance of Mosque Buildings with the Assistance of Passive Cooling Systems*' [online]. Available at: <https://www.researchgate.net/publication/336238704>.
- Dina Ejlali Vachin. (2017). Iranian Windcatchers.
- Dolatabad garden's wind-catcher in Yazd. | Download Scientific Diagram.* (2023) [online]. [Accessed 22 December 2023]. Available at: https://www.researchgate.net/figure/Dolatabad-gardens-wind-catcher-in-Yazd_fig2_233759939.
- dubai building code. (2021).
- Elzaidabi, A. A. M. (2008). *Low Energy, Wind Catcher Assisted Indirect-Evaporative Cooling System for Building Applications*.
- Environment, V. (2023). IES VE Vista User Guide 6.0 [online]. Available at: <http://www.iesve.com/downloads/help/Thermal/Vista.pdf>.
- Erica Solomon. (2023). *Energy-Efficiency for a 'Smart' Mosque - Khalifa University*

[online]. [Accessed 2 October 2023]. Available at: <https://www.ku.ac.ae/energy-efficiency-for-a-smart-mosque/>.

General Authority of Islamic Affairs & Endowments (General Authority of Islamic Affairs & Endowments Sharjah), L. S. C. (2023). *Number of Mosques & Eid Mosques by Emirate*.

Google. (2023). *GoogleEarth*.

Gottheil, R. J. (1910). The Origin and History of the Minaret Author (s): Richard J . H .
Gottheil Source : Journal of the American Oriental Society , Vol . 30 , No . 2 (Mar . , 1910), pp . 132-154 Published by : American Oriental Society Stable URL :
<https://www.jstor.org/st.> *Journal of the American Oriental Society*, vol. 30(2), pp. 132–154.

<https://uaeeasy.com/>. (2023) [online]. [Accessed 1 December 2023]. Available at:
<https://uaeeasy.com/2023/01/24/الكارن-بين-أسعار-الكهرباء-في-الإمارات/>.

IESve. (2023). No Title.

Jomehzadeh, F., Hussien, H. M., Calautit, J. K., Nejat, P. & Ferwati, M. S. (2020). Natural ventilation by windcatcher (Badgir): A review on the impacts of geometry, microclimate and macroclimate. *Energy and Buildings*. Elsevier Ltd.

Lotfi Saleh, Shawkat Al-Qadi, E. M. (2018). The development of minarets architecture in Yemen and Egypt.

Maarof, S. (2014). *Roof Designs And Affecting Thermal Comfort Factors In A Typical Naturally Ventilated Malaysian Mosque*.

Maleki, B. A. & Shabestari, A. F. (2015). Optimization of ‘Badgir (wind tower)’ in Iranian Hot-Arid Region Architecture. *Conference On Technology & Sustainability in the Built Environment*, pp. 445–456 [online]. Available at:
https://cap.ksu.edu.sa/sites/cap.ksu.edu.sa/files/attach/tsbe_2_e_05.pdf.

- Mazraeh, H. M. & Pazhouhanfar, M. (2020). Functionalism of wind renewable energy in vernacular elements of wind catcher and moshabak (Case study: Qeshm island). *Journal of Urban and Environmental Engineering*. Universidade Federal da Paraiba, vol. 14(1), pp. 161–172.
- Milano, P. D. I. (2021). Use Of Energy Modelling Software (Ies Ve) For Hvac Sizing , A Comparison With Old Practices Abstract, (926941), pp. 1–65.
- Mohamed, M. & Mohammed, M. F. M. (2018). Investigating the environmental performance of the wind catcher in Jeddah. *WIT Transactions on the Built Environment*. WITPress, pp. 15–26.
- Nejat, P. (2018). Windcatcher as a Persian Sustainable Solution for Passive Cooling. *Civil Engineering Research Journal*. Juniper Publishers, vol. 6(1).
- Nejat, P., Jomehzadeh, F., Abd Majid, M. Z. Bin, Mohd Yusof, M. B. & Zeynali, I. (2019). Windcatcher as sustainable passive cooling solution for natural ventilation in hot humid climate of Malaysia. *IOP Conference Series: Materials Science and Engineering*. Institute of Physics Publishing.
- OpenStreetMap. (2023) [online]. [Accessed 27 October 2023]. Available at: <https://www.openstreetmap.org/#map=7/24.371/53.982>.
- Oxford Encyclopedia of the Modern World. (2008). *Oxford Encyclopedia of the Modern World*. Oxford University Press.
- Pirhayati, M., Ainechi, S., Torkjazi, M. & Ashrafi, E. (2013). Ancient Iran, the Origin Land of Wind Catcher in the World. *Research Journal of Environmental and Earth Sciences*, vol. 5(8), pp. 433–439.
- Prima, Y. (2019). Wind Catcher and Solar Chimney Integrated As An Alternative Ventilation For Urban Dense Settlements In Tropical Climate. *International Journal of Architecture and Urbanism*, vol. 03(01), pp. 51–68.

- Robert, B. & Brown, E. B. (2015). *Heating, Cooling, Lighting: Sustainable Design Methods for Architects*. Fourth.
- Sangdeh, P. K. & Nasrollahi, N. (2022). Windcatchers and their applications in contemporary architecture. *Energy and Built Environment*. KeAi Communications Co., pp. 56–72.
- Sharjah Department of Planning & Survey. (2023). Drawings.
- Sivakumar, V., Visagavel, K., Selvakumar, A. & Jayavel, C. (2018). An explicit approach of natural ventilation for various orientation of wind catcher openings using CFD. *Journal of Applied Fluid Mechanics*. Isfahan University of Technology, vol. 11(Specialissue), pp. 103–105.
- Spentzou, E., Cook, M. & Emmitt, S. (2014). *Assessing Natural Cooling Strategies In Apartment Buildings Using De-Coupled Internal-External Airflow Simulations*.
- Al Suliman, D. (2014). Wind Catchers and Sustainable Architecture in the Arab World, vol. 6(12) [online]. Available at: www.iiste.org.
- Tan, F. & Shojaei, S. (2019). Past to Present: Solar Chimney Power Technologies. *El-Cezeri Journal of Science and Engineering*. TUBITAK, vol. 6(1), pp. 220–235.
- Tavakolinia, F. (2011). *Wind-Chimney Integrating the Principles of a Wind-Catcher and a Solar-Chimney to Provide Natural Ventilation*.
- UAE Ministry of Climate Change and Environment (MOCCAE). (2015). The UAE Green Agenda Programs (2015-2030). *Moccae*, pp. 2–4 [online]. Available at: <https://www.moccae.gov.ae/assets/download/dbcb99d6/The UAE Green Agenda Programs - English.pdf.aspx>.
- Valibeig, N., Nasekhian, S. & Tavakoli, S. (2014). The role of wind catchers in improving people's comfort. *WIT Transactions on the Built Environment*. WITPress, pp. 93–102.

Ventusky - Wind, Rain and Temperature Maps. (2023) [online]. [Accessed 27 October 2023]. Available at: <https://www.ventusky.com/>.

Zafarmandi, S. & Mahdavinejad, M. (2021). The Technology of Modern Windcatchers: A Review †. *International Journal of Architectural Engineering & Urban Planning*, vol. 31(3), p. 2021.