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**ENHANCING THERMAL COMFORT OF
RESIDENTIAL BUILDINGS IN HUMID HOT
REGIONS ADOPTING PASSIVE DESIGN
STRATEGIES**

Joodi ASAAD

Master's Thesis

Supervisor

Asst. Prof. Dr. Erinc ONBAY

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The thesis titled ENHANCING THERMAL COMFORT OF RESIDENTIAL BUILDINGS IN HUMID HOT REGIONS ADOPTING PASSIVE COOLING DESIGN prepared by Joodi ASAAD and submitted on 03/10/2024 has been **accepted unanimously** for the degree of Master of Science in Architecture.

Asst. Prof. Dr. Erinc ONBAY
Supervisor

Thesis Defense Committee Members:

Asst. Prof. Dr. Erinc ONBAY

Department of Interior
Architecture and
Environmental Design,

Altinbas University

Asst. Prof. Dr. Can UZUN

Department of Architecture,

Altinbas University

Asst. Prof. Dr. Hasan POLAT

Department of Architecture,

Firat University

I hereby declare that this thesis/dissertation meets all format and submission requirements for a Master's thesis.

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Joodi ASAAD

Signature

XXXXXXXXXX

DEDICATION

Working, studying, traveling and passing hard time during my studying, it will be passed once I feel the moment of successful.

I want to extend my thanks to my family, friends, and everyone who support and encourage me even in one word to proceed and finish my study.



ABSTRACT

ENHANCING THERMAL COMFORT OF RESIDENTIAL BUILDINGS IN HUMID HOT REGIONS ADOPTING PASSIVE COOLING DESIGN

ASAAD, Joodi,

M.Sc., Architecture, Altınbaş University,

Supervisor: Asst. Prof. Dr. Erinc ONBAY

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Most buildings in humid hot regions require a huge energy consumption due to using air conditioning devices and result in waste in energy .Consequently , this research aims to study passive cooling strategies in hot humid regions in the Emirates to achieve thermal comfort and reduce energy demand . To conduct the study, a broad and intensive literature review was initially conducted on passive cooling strategies, especially in hot humid regions. All traditional passive cooling strategies in hot humid regions were studied, and all modern innovations to improve the performance of passive cooling strategies were mentioned. After conducting the extensive literature review, a questionnaire targeting the population was conducted to evaluate the thermal comfort in residential buildings in Abu Dhabi.

A field study was also conducted that included 30 buildings to verify the extent of the application of passive cooling strategies that were identified based on the literature review that was conducted. After noting the shortcomings in the application of passive cooling strategies in hot humid regions, a residential villa was selected as a case study and temperature readings were taken inside and outside the building to verify the ineffectiveness of the current applied strategies. Based on the temperature measurements inside and outside the building that were recorded using a thermometer and the extensive literature review of passive cooling strategies, traditional passive cooling strategies were proposed and the suggestion design strategies were carried out using AutoCAD 3d Max and Lumion Software to enhance thermal comfort indoor the building .In addition , This study could establish guidelines using comprehensive literature review conducted and these guidelines comprise passive cooling strategies in humid hot region in terms of natural ventilation types, roofs,

walls and courtyards facades, insulation and building materials. Moreover, this study introduces recent innovated strategies of passive cooling design in humid hot regions.

Keywords: Hot Region, Thermal Comfort, Architectural Design, Humid Climate, Passive Cooling.



ÖZET

PASİF SOĞUTMA TASARIMI İLE NEMLİ SICAK BÖLGELERDEKİ KONUT BİNALARININ ISI KONFORUNU ARTIRMAK

ASAAD, Joodi,

Yüksek Lisans, Mimarlık, Altınbaş University,

Danışman: Dr. Öğr. Üyesi Erinç ONBAY

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Nemli sıcak bölgelerdeki çoğu bina, klima cihazlarının kullanılması nedeniyle büyük bir enerji tüketimi gerektirir ve enerji israfına neden olur. Sonuç olarak bu araştırma, termal konforu sağlamak ve enerji talebini azaltmak için Emirlikler'deki sıcak nemli bölgelerde pasif soğutma stratejilerini incelemeyi amaçlamaktadır. Çalışmayı yürütmek için öncelikle sıcak nemli bölgelerde pasif soğutma stratejileri üzerine geniş ve yoğun bir literatür taraması yapıldı. Sıcak nemli bölgelerdeki tüm geleneksel pasif soğutma stratejileri incelenmiş ve pasif soğutma stratejilerinin performansını artıracak tüm modern yeniliklere değinilmiştir. Kapsamlı literatür taramasının ardından Abu Dabi'deki konut binalarında termal konforu değerlendirmek için nüfusu hedef alan bir anket uygulandı.

Yapılan literatür taramasına dayanarak belirlenen pasif soğutma stratejilerinin uygulama kapsamını doğrulamak amacıyla 30 binayı kapsayan bir saha çalışması da yapıldı. Sıcak nemli bölgelerde pasif soğutma stratejilerinin uygulanmasındaki eksikliklerin fark edilmesinin ardından örnek çalışma olarak bir konut villası seçilmiş ve mevcut uygulanan stratejilerin etkisizliğini doğrulamak için binanın içinde ve dışında sıcaklık okumaları yapılmıştır. Bir termometre kullanılarak kaydedilen bina içi ve dışındaki sıcaklık ölçümlerine ve pasif soğutma stratejilerine ilişkin kapsamlı literatür taramasına dayanarak, geleneksel pasif soğutma stratejileri önerildi ve öneri tasarım stratejileri, termal iyileştirme için AutoCAD 3d Max ve Lumion Yazılımı kullanılarak gerçekleştirildi. Ayrıca bu çalışma, yapılan kapsamlı literatür taramasını kullanarak, nemli sıcak bölgelerdeki pasif soğutma

stratejilerini doğal havalandırma türleri, çatılar, duvarlar ve avlu cepheleri, yalıtım ve yapı malzemeleri açısından kapsayan kılavuzlar oluşturabilir. Ayrıca, bu çalışma nemli sıcak bölgelerde pasif soğutma tasarımına yönelik son yenilikçi stratejileri tanıtmaktadır.

Anahtar Kelimeler: Sıcak Bölge, Isıl Konfor, Mimari Tasarım, Nemli İklim, Pasif Soğutma.



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1. INTRODUCTION

1.1 DEFINITION OF PASSIVE COOLING DESIGN

Asian structures and facilities use a lot of energy to cool and dehumidify due to their hot and humid climates. Global warming raises building cooling loads. Lee, Trihamdania, and Kubota evaluate land-use changes and global warming to 2030s temperature increases. At most 71% of urban temperature rise in the 2030s will be caused by global warming (Han et al., 2017). Doan and Kusaka forecast a 0.5 °C warming in newly urbanised places like Ho Chi Minh City in Southeast Asia in the 2050s, accounting for 20–30% of global warming (Van et al., 2018). Given the ongoing urbanisation and climate change in Asia, passive design cooling solutions should be used as much as feasible to lower indoor temperatures and cooling loads (Chen et al., 2021). Many research have examined passive design strategies for residential thermal comfort in hot and humid climates. These methods concentrate on envelope, microclimate, ventilation, daylighting, orientation, thermal insulation, shading, construction materials, and other aspects of architectural design in hot and humid climates (Chen et al., 2021).

Buildings with passive cooling save energy. These architectural designs can reduce fossil fuel usage, incorporate renewable energy, and lower building energy demand (Amirifard et al., 2019). Architectural passive cooling systems minimise cooling loads and improve thermal comfort (Bhamare et al., 2019).

Passive cooling has been studied in many climates. In hot-dry Iran, passive methods like green roofs, roof ponds, wind catchers, and underground houses reduce temperature and improve thermal comfort (Goudarzi et al., 2017).

Passive cooling methods include daytime ventilation in naturally ventilated buildings to increase thermal comfort or lower indoor temperatures when air temperatures are high (Sakiyama et al., 2020). Calculating the length of outdoor air flow into a building to remove interior heat can identify ventilation (Shakya et al., 2021).

Night ventilation allows cold exterior air to enter a structure at night to extract heat and lower daytime indoor temperatures (Panchabikesan et al., 2009). Water evaporation lowers

temperature and raises humidity (Panchabikesan et al., 2017). Assessing the building's climate is essential to studying passive cooling design (Putra et al.,2022).

1.2 CHALLENGES FACING RESIDENTIAL BUILDINGS IN UAE

The United Arab Emirates, especially in cities such as Sharjah, Dubai and Abu Dhabi, are hot and humid areas, where the summer temperature reaches 46 degrees Celsius, and humidity rates in coastal areas range between (75-85)% (Almario, 2023).

And in light of these environmental conditions that the United Arab Emirates suffers from, represented by humidity and heat, energy consumption has become increasing in light of the population increase, as the rate of energy consumption increases in the Emirates, especially for residential buildings, as shown in Figure 1.1 (Karlsson et al ,2015)

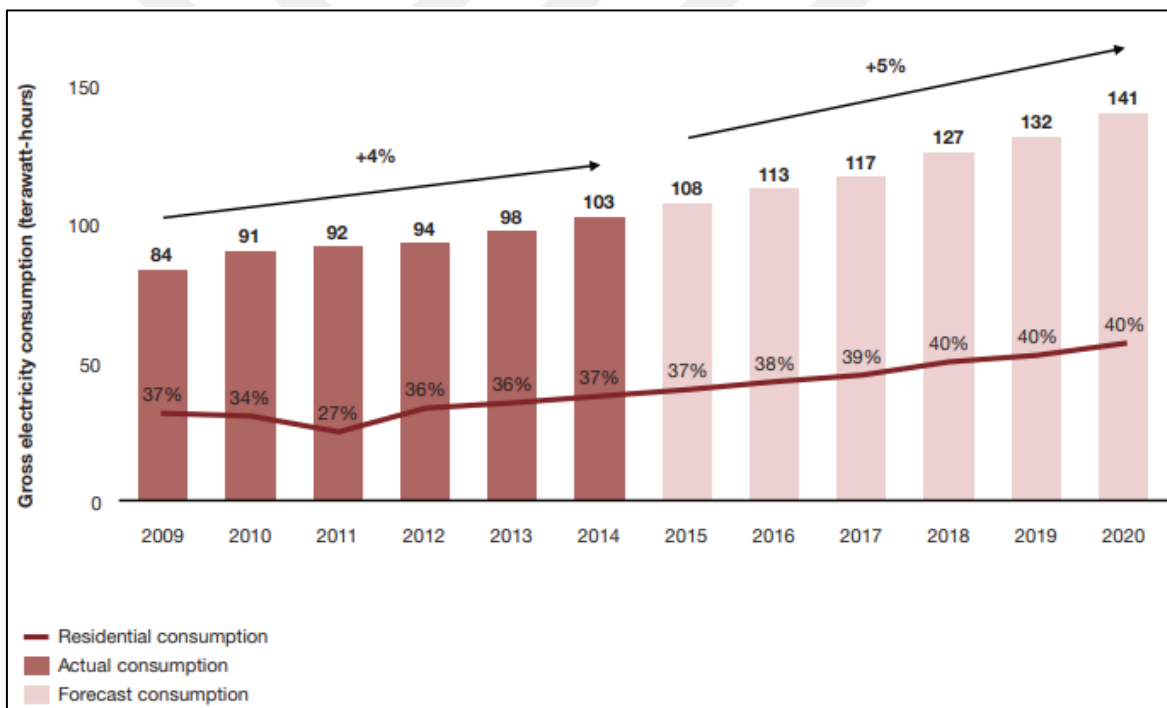


Figure 1.1: Electricity Consumption Rate From 2009 to 2020 (Karlsson et al ,2015).

UAE also faces climate change-related issues such greenhouse gas emissions from fossil fuel use to generate electricity, rising energy demand, and water scarcity. In addition to funding renewable energy generation, the UAE government has implemented many effective strategies to reduce water consumption and energy consumption, such as desalinating sea water, reusing irrigation water, and using solar energy (U.AE,2023). In UAE, passive design

cooling for residential buildings is relatively rare, resulting in high energy and water use and greenhouse gas emissions.

(Salama, & Salama,2017) mentioned the issues facing implementing residential buildings in emirates represented by lack of awareness in passive cooling design strategies and proper architectural design principles in Humid hot regions . According to a study conducted by (Ramani & García de Soto,2021), code used to provide natural techniques to cool the buildings in Emirates that named, The pearl Rating System for Estidama,2010 is considered limited comparing to other codes that considers passive cooling design .

This research focusses on passive cooling design solutions for Abu Dhabi residential structures, especially in hot and humid environments. To improve thermal comfort in Abu Dhabi's near-coastal areas, investigate traditional and innovative passive cooling design solutions.

1.3 SIGNIFICANCE OF APPLYING PASSIVE COOLING DESIGN

The significance of this study comes from the fact that it deals with the full study of the difficulties facing residential buildings in the coastal areas and near the coast, as they are exposed to extreme temperatures and high humidity, especially in the summer, and then searches for the most effective strategies for implementing residential buildings that contribute to ensuring thermal comfort for residents and reducing humidity in addition to improving indoor air quality.

1.4 OBJECTIVES OF APPLYING PASSIVE COOLING DESIGN

The Major objective of the research is to enhance the thermal comfort in residential buildings in Abu Dhabi, Also identify the traditional and innovated Passive cooling Design techniques can be used to achieve thermal comfort of these residential buildings. some of minor objectives as follows:

- a. Conducting a comprehensive literature review about the traditional and modern solution in Passive cooling Design strategies to achieve thermal comfortable and reduce humidity in humid hot regions and these strategies include all passive design strategies (insulation, shading, glazier, green roofs, shading, ventilation , etc..).

- b. Evaluate the current passive cooling design strategies in Abu Dhabi near coastal regions during months of summer adopting cases studies of residential buildings.
- c. Determine the challenges and limitations in the current Passive cooling Design techniques specially issues related to thermal comfort and humidity.
- d. Establish a framework with traditional and innovated Passive cooling Design techniques of residential buildings in hot and Humid climate .

1.5 RESEARCH QUESTIONS

This study answers the following questions:

- a. What is current condition of thermal comfort of residential buildings in Abu Dhabi?
- b. What are the traditional passive cooling design strategies can be adopted to enhance thermal comfort of residential buildings near coastal regions in Abu Dhabi?
- c. What are the innovated passive cooling design strategies can be adopted to enhance thermal comfort of residential buildings near coastal regions in Abu Dhabi?

1.6 RESEARCH METHODOLOGY

This study uses passive architectural design principles in humid hot conditions to improve residential building thermal comfort. This requires a literature review to synthesise current knowledge and provide passive design framework. Qualitative research will also use this framework to ask questions and give solutions.

In order to achieve the objective of the study to , several procedure have been adopted :

The first step based on adopting qualitative method by conducting extensive and comprehensive literature review via reviewing all papers, publications ,dissertations and journals of the traditional and innovated passive cooling design in humid hot regions according to the following sections: ventilation, shading ,materials, roofs, courtyards, walls ..etc.

The qualitative method included data collection, figures and tables in the relevant topic. This step assists to develop framework can be a beneficial contribution of architectural design of residential buildings in humid hot regions.

The second step addressed quantitative analysis using survey questionnaire targeted residents of Abu Dhabi that are considered a city located along the coastal line. The purpose of the survey questionnaire is to develop is to investigate whether the residents in residential buildings of Abu Dhabi feels thermal comfort or not.

The following procedures based on field study of 30 residential buildings located in different regions of Abu Dhabi. The field study comprised checking process whether passive cooling strategies that are reviewed in the literature are implemented or not.

After conducting a checklist of passive cooling strategies in the residential buildings selected, a villa in Abu Dhabi will be chosen as a case study and temperature measured indoors and outdoors to determine how well the architectural design achieves thermal comfort.

Based on temperature data measurements, check list of the passive cooling strategies and extensive literature review of traditional and innovated passive cooling design, design strategies using passive cooling design will be suggested using Autocad 3D Max and Lumion software in order to enhance thermal comfort.

1.6.1 Literature Review and Theoretical Framework

Literature Review: An integrated literature review on passive design cooling principles in residential buildings and application of passive cooling strategies in residential buildings will be executed. This will require collecting relevant scholarly articles, books, and reports from academic databases. Key themes and concepts will be defined to develop a framework.

Theoretical framework: The Theoretical framework will provide architectural engineers and designers with traditional and innovated passive design cooling of residential buildings in humid hot regions.

Also, case study as residential building in Abu Dhabi will be used to evaluate the present condition of climatic conditions of residential buildings in Abu Dhabi using taking

measurements of temperature and humidity in addition to conduct survey questionnaire targets residents in Abu Dhabi to evaluate thermal comfort.

1.6.2 Qualitative Method

The qualitative method will be conducted by comparative analysis by Incorporation of Visual Documentation and photographs to enhance understanding and illustrate critical findings. This method will be employed to establish theoretical framework of passive cooling design in humid hot regions related to courtyards, ventilation techniques, roof design, wall design, shading system, walls and other traditional and innovated strategies.

The research process, including data collection procedures and analysis techniques, will be thoroughly documented.

Qualitative findings will be presented using tables, figures, and visual materials to support interpretation and enhance readability.

2. RESEARCH CONTRIBUTIONS IN PASSIVE COOLING DESIGN

2.1 BENEFICIAL CONTRIBUTIONS IN ACHIEVING THERMAL COMFORT

The chapter provides a comprehensive literature review comprising all techniques, methods, strategies, and materials used in architectural design to achieve residential buildings naturally cooled in humid, hot regions. Also, the chapter will review all passive strategies and techniques to achieve thermal comfort and reduce humidity naturally without energy consumption. Moreover, the chapter will introduce the beneficial contributions of academics and scholars in upgrading sustainability in residential buildings and achieving thermal comfort.

Bakhtiari, et al. (2020) investigated a typical old office building's cooling needs and mechanical night ventilation's effect on thermal comfort. The IDA-ICE simulation program examined how night ventilation cooling could improve thermal comfort and power use. External climates, flow rates, cooling system performance coefficient, and ventilation unit fan power values were parametrically analysed. Also examined was how door designs affect workplace temperature comfort (Figure 2.1). Despite being in a cold zone, night ventilation cannot cool the building, hence active cooling is essential. By 33% and 40%, night ventilation can reduce workplace exceedance hours and cooling electricity. Higher night ventilation saves power. Over a certain maximum beneficial ventilation rate, fan electricity use surpasses cooling machine electricity. Building thermal mass capacity, cooling system performance, design ventilation rate, and night ventilation cooling potential determine it.



Figure 2.1: The Building of the City Hall of G, Bakhtiari, et al. (2020).

Darmanis, et al. (2020). Conduct a study how urbanization and rising global temperatures have demanded natural cooled building methods, especially in humid hot countries. High temperatures and humidity make residential building design and operation problematic in the United of Emirates. Living in thermal comfort in such conditions requires novel climate change mitigation and excellent quality of life. A survey examines passive cooling architecture for residential structures in the humid, hot Emirates. The work is to identify and promote novel methods that reduce these buildings' cooling load requirement, decreasing energy consumption and environmental effect (a temperature data showed in Figure 2.2). The work uses modern architectural and engineering methods to create a more Thermal comfort in the future where residents can live comfortably while reducing their environmental impact.

Passive cooling technologies are continuously being studied. Their major goal is to increase thermal comfort while reducing energy expenses. In Givoni's passive cooling systems, "passive" means rejecting heat from a building using natural cooling resources and assuring a cost-effective heat transfer system for cooling system collaboration.

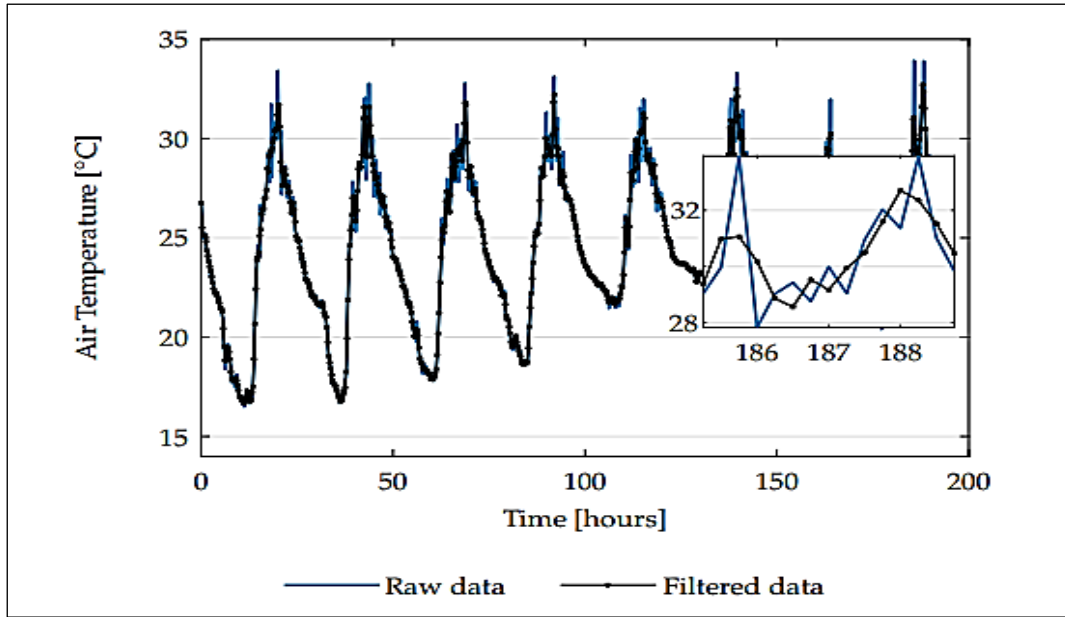


Figure 2.2: Raw and Filtered Temperature Data, (Darmanis, et al., 2020).

2.1.1 Principles of Passive Cooling Design

Passive cooling design is a method that prioritizes reducing human effects on the natural environment without sacrificing human comfort or convenience. To combat the effects of the climate and ensure long-term environmental and social sustainability, passive cooling design concepts are crucial for residential structures in hot, humid places like the Emirates . Eman & Harputlugil, (2019) published a manuscript on sustainable architecture, which is based on the premise of minimizing all types of waste. Waste prevention and resource conservation are fundamental tenets of the approach, which applies to all phases of a building's existence. Hot, humid conditions highlight the importance of efficient resource utilization in areas where these are limited or expensive. Long-term sustainability in tropical climates requires climate-responsive design. We use passive design methods including natural ventilation, solar shading, and thermal mass. Building heating is efficient with climate-responsive architecture (Hu et al., 2023).

Alagamy, (2023) published a manuscript on long term architecture, which is based on the premise of avoiding waste of all kinds. The air quality is particularly important to consider while researching the health benefits of green architecture. The health of the user, the user's ability to handle stress, and the user's overall quality of life are all improved by clean air. Is because the various environmental stimuli that physically interact with the users are

responsible for the resulting consequences on health. There is mounting evidence that exposing people to more natural light, providing them with a view, and encouraging them to spend time outside all contribute to improved health and happiness. The level of pleasure with lighting and air quality is higher than that with thermal and acoustic factors, according to the research (shown in Figure 2.3). Because discomfort negatively affects occupants' quality of life, it must be reduced as much as possible.

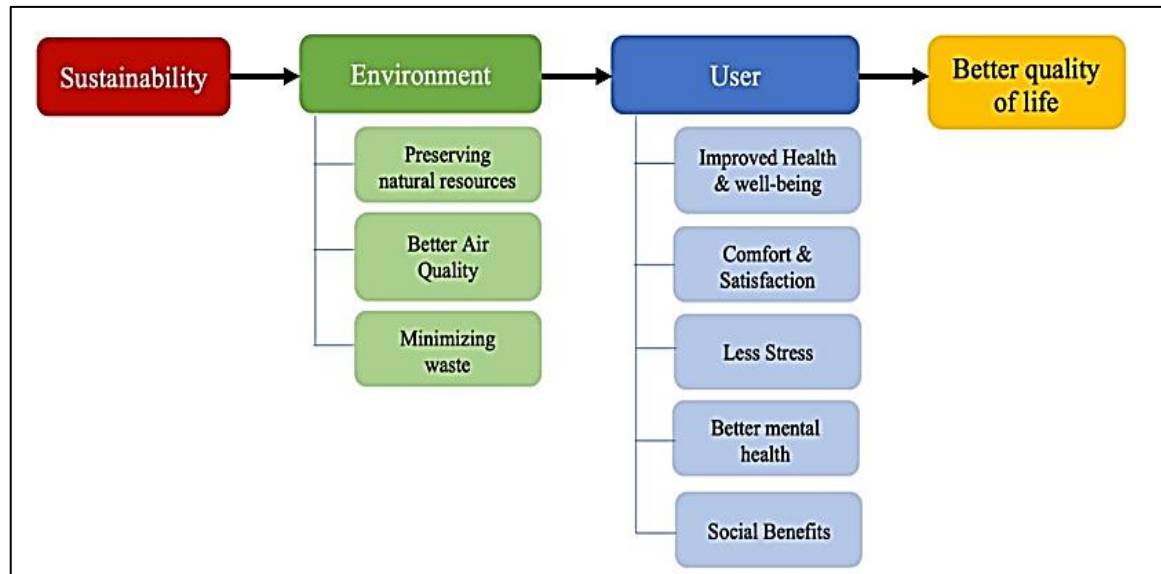


Figure 2.3: A Diagram of the Relation Between Sustainability, Environment and user (Alagamy, 2023).

Gou & Xie (2017) published a manuscript which is based on the premise of minimizing all forms of waste. Green spaces, renewable energy, and eco-friendly building materials are all promoted under guiding philosophy. Waste minimization, recycling, and incorporating natural elements into man-made structures are all a part of concept. Bio-sustainability aims to make the world a better place by striking a balance between people's wants and the preservation of natural resources.

Ghoulem et al. (2019) researched Health and Happiness in buildings characterize thermal comfort, the well-being of the occupants is prioritized. Increasing airflow, installing more windows to let in natural light, and creating serene spaces can make home healthier for body and mind. Environmentally friendly buildings in hot and humid locations use natural circulation to reduce cooling needs and improve indoor air quality.

2.1.2 Importance of Passive Cooling Design in Residential Buildings

Residential passive cooling design in hot and humid places like the Emirates is a solution to global environmental challenges, not a trend. Multiple views promote green homebuilding. Mohammadi et al. explored change resilience in 2018. Hot and humid locations are especially vulnerable to climate change's extreme weather. Using climate-responsive technologies, passive cooling design reinforces structures against extreme weather. Flexibility is needed by heat-wave residents.

Ideal Health and Happiness: Indoor air quality, natural ventilation, and window location affect building occupants' health and happiness. These considerations are at the forefront of home design, which aims to create wholesome environments for people to live in. Residents' health and happiness benefit from increased sunshine hours and cleaner air.

Zhang et al. (2019) studied resilience and environmental adaption. Rising temperatures and extreme weather occurrences are especially noticeable in hot and humid regions (Figure 2.4). Indoor air quality is crucial to health and happiness. Interior environment improvements have been related to better health in various studies.

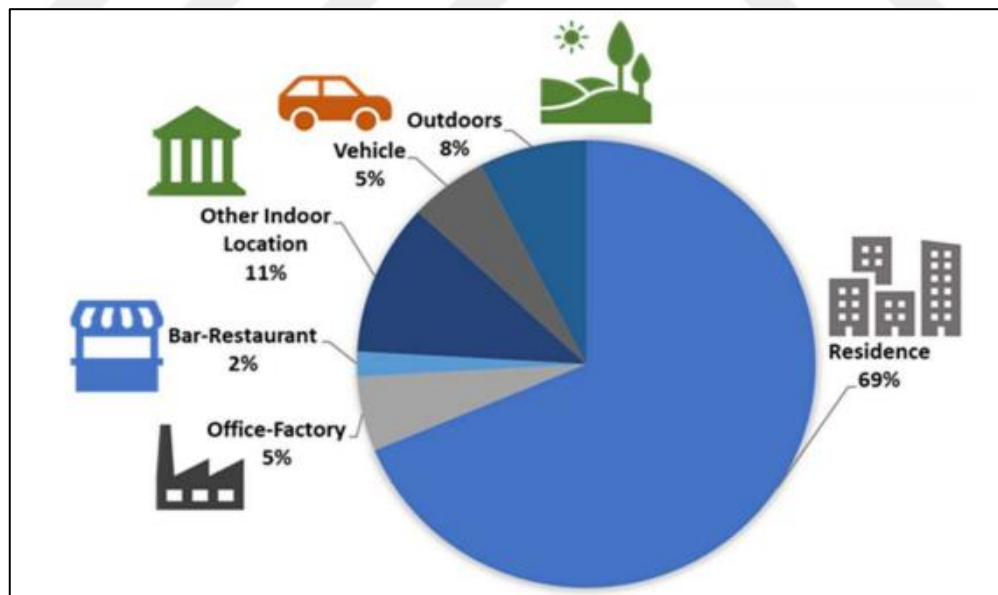


Figure 2.4: A Breakdown of How Much Time was Spent Inside Versus Outside.

The US Environmental Protection Agency's National Human Activity Pattern Database provided these numbers. The survey included 9196 participants, 87% of whom spent time

inside (in homes, workplaces, restaurants, hotels, shopping centres, schools, churches, public buildings, spas, gyms, garages, car repair shops, and laundry mats). (Zhang et al. 2019)

Mohammadi et al. (2018) studied resilience and adaptation to changing settings. Hot and humid areas are especially vulnerable to climate change's rising temperatures and harsh weather. It should stimulate long-term development efforts abroad as a powerful symbol. The UAE's green home development concept inspires the area and helps make the world greener.

Eladham et al. (2021) found that homeowners are becoming more conscious of the importance of passive cooled home design in meeting the challenges of climate change, dwindling natural resources, and the need for greater energy efficiency. Using energy-efficient technologies and ecologically friendly building methods, the strategy aims to lessen impacts on the environment and the health of residents. Passive cooling design reduces environmental strain by minimizing waste of valuable resources like water and electricity. It also encourages the use of recycled or locally sourced materials, which helps reduce emissions from both transportation and manufacturing shown in Figure 2.5.



Figure 2.5: Stone Used in Pedestrian Paths in Madinaty (Eladham et al., 2021).

2.1.3 Global Context: Passive Cooling Design in Hot and Humid Regions

As elsewhere in the world with high temperatures and humidity, passive cooling design in the Emirates is difficult. Passive cooling design in these places must be understood globally

as the globe fights climate change. Recent research assesses the present state of passive cooling design options for tropical locations and the biggest challenges to their general adoption. Eco-friendly construction methods are quickly becoming more crucial in tropical regions. The city's architecture gives top billing to effective land utilization, and it incorporates guidelines for optimal sun orientation and building massing. Parking garages, lots, and roadways in the area have had their capacities increased to accommodate the building's occupants (as illustrated in Figure 2.6), and similar measures have been taken in front of schools and mosques (Khattab, 2015).



Figure 2.6: Green and Walkable District Design.

Source: <https://ipgegypt.com/en/properties/1151-special-apart ment-with-garden-90-m2-for-sale-at-ordinary>.

Feng et al., (2019) said that because it's hard to establish standards internationally, the National Renewable Energy Laboratory (NREL) offers multiple "net zero energy" criteria and encourages builders to adopt them. Indicators that work well for specific applications can be chosen by users, developers, and other interested parties. The work does not provide a single definition of NZEB but rather suggests ways to approach the concept more systematically. According to the Department of Energy's definition, a Net Zero Energy

Building (NZEB) is one in which "the actual annual supplied energy is less than or equal to the on-site renewable exported energy."

NZEBs by renewable energy generation site are A, B, C, and D in Fig. 2.7. Consider whether renewable energy is generated on-site or purchased. Types A and B NZEBs generate all renewable energy on-site, while C and D use largely renewables elsewhere.

Type A NZEBs generate all of their electricity from renewable sources located entirely inside their building footprint, while Type B NZEBs generate electricity from renewable sources located entirely within their building footprint and/or on their site.

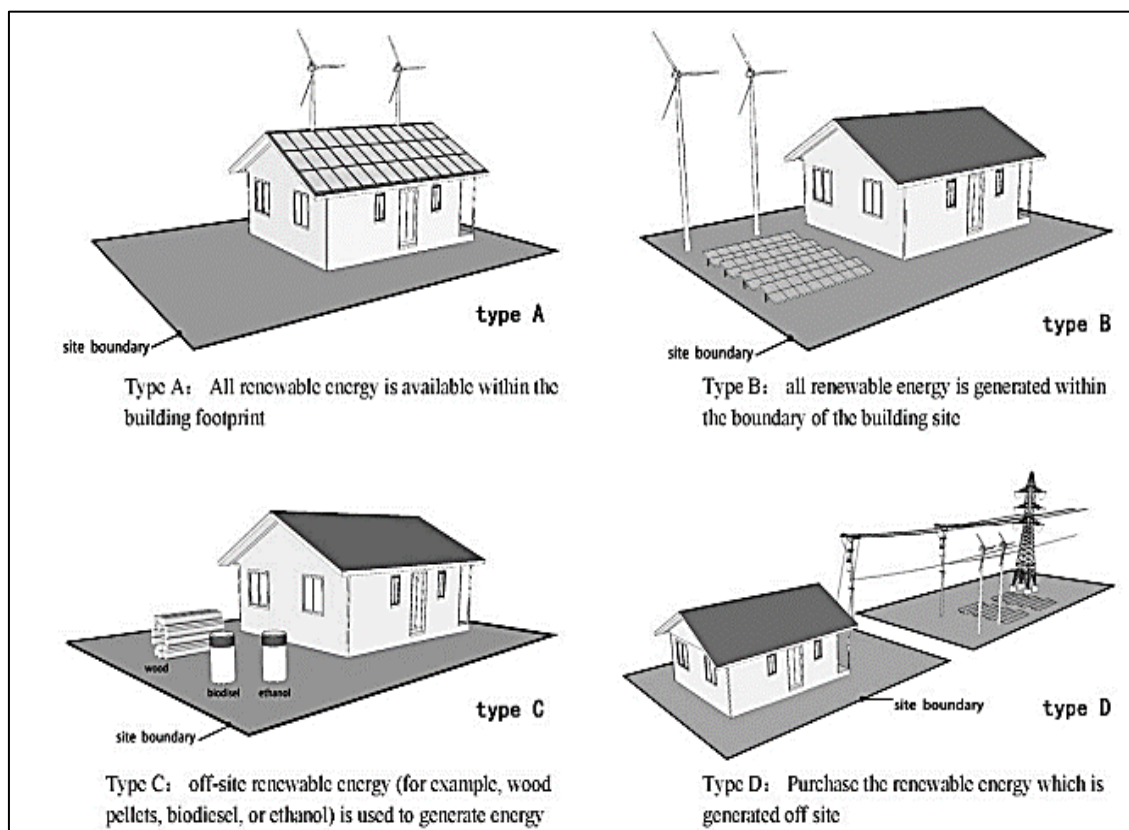


Figure 2.7: Four Types of NZEBs: A, B, C and D, (Feng et al., 2019).

2.2 ENVIRONMENTAL CHALLENGES IN HUMID HOT REGIONS

2.2.1 Climate Change and Its Impact on Humid Hot Regions

The UAE, like many Middle Eastern countries, has a hot, humid environment, rendering it sensitive to climate change. Climate change is most evident in rising global temperatures,

weather patterns, and sea levels. In humid, hot climates, climate change affects residential structures, which is why passive cooling design is recommended.

Climate change frequently alters normal precipitation patterns, leading to wet and dry periods that are hard to forecast. Unpredictable precipitation can cause both droughts and flash floods in warm, humid climates. The water supply, agricultural output, and city development as a whole are all impacted by the degree of uncertainty (Salameh & Touqan, 2022).

Satola et al., (2020) showed a study about how climate change is making extreme weather events like hurricanes and tropical storms happen more often. Extreme damage, including to homes, can be caused by these natural disasters, which occur more frequently in hot and humid settings. Communities in danger face the risks of displacement and economic losses

Higher temperatures increase the need for cooling (shown in Figure 2.8), which in turn increases the energy demand. Moreover, shifts in rainfall patterns put a burden on the water supply. It is becoming increasingly important, particularly in the context of residential projects, to strike a balance between meeting the energy demands of a growing population and guaranteeing water security. (Sudhakar et al., 2019).

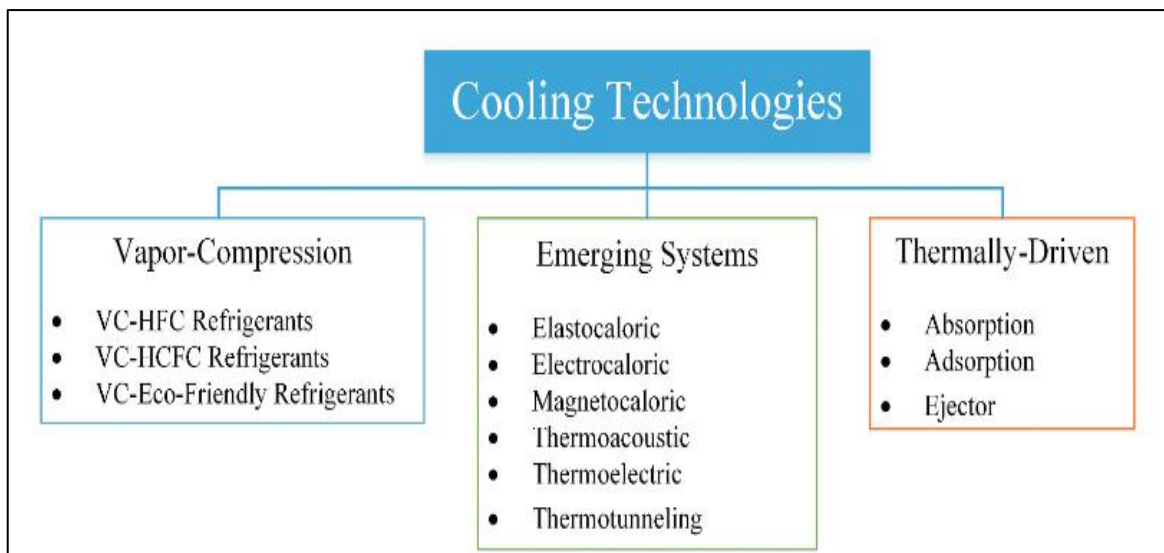


Figure 2.8: Examined Cooling Systems (Satola et al., 2020).

Residential building design and construction in humid, hot nations like the UAE must be done fast and wisely due to climate change. Combating climate change requires climate-

responsive architecture, energy-efficient technologies, and water conservation. Climate resilience in residential buildings is essential for community well-being and sustainability in hot, humid countries like the UAE, where urbanization is rapid.

2.2.2 Specific Environmental Challenges in Emirates

The United Arab Emirates (UAE)'s hot and arid climate requires regionally appropriate house design cooled naturally. When constructing eco-friendly communities in the Emirates, architects, urban planners, and policymakers must consider these obstacles. Salameh & Touqan (2022) spoke about UAE buildings that could overheat due to hot weather and bright sunlight. Thus, typical building materials and design methods fail to reduce heat, requiring expensive, energy-intensive cooling systems. Development of Urban Infrastructure: Rapid urbanization in the UAE spurs construction and infrastructure development. Unsustainable management of these activities can cause habitat loss, pollution, and ecosystem disruption.

Tayar et al. (2015) spoke about United Arab Emirates buildings that could overheat due to hot weather and bright sunshine. The environmental impact of new home construction can be minimized through effective waste management, recycling programs, and the use of eco-friendly building materials. Passive cooling design innovations are needed to meet these difficulties. The Emirates' passive cooling designs incorporate solar-reflective materials, natural airflow, green spaces, water-efficient technology, and energy-efficient appliances. The study employs a Sharjah commercial office block as its case study. Location of the office building: 25°160' north, 55°190' west. Figure 2.9 demonstrates that June and December have the highest and lowest solar insolation. The rest of the building's electrical energy comes from cooling, lighting, and appliances (Salameh, et al., 2023).

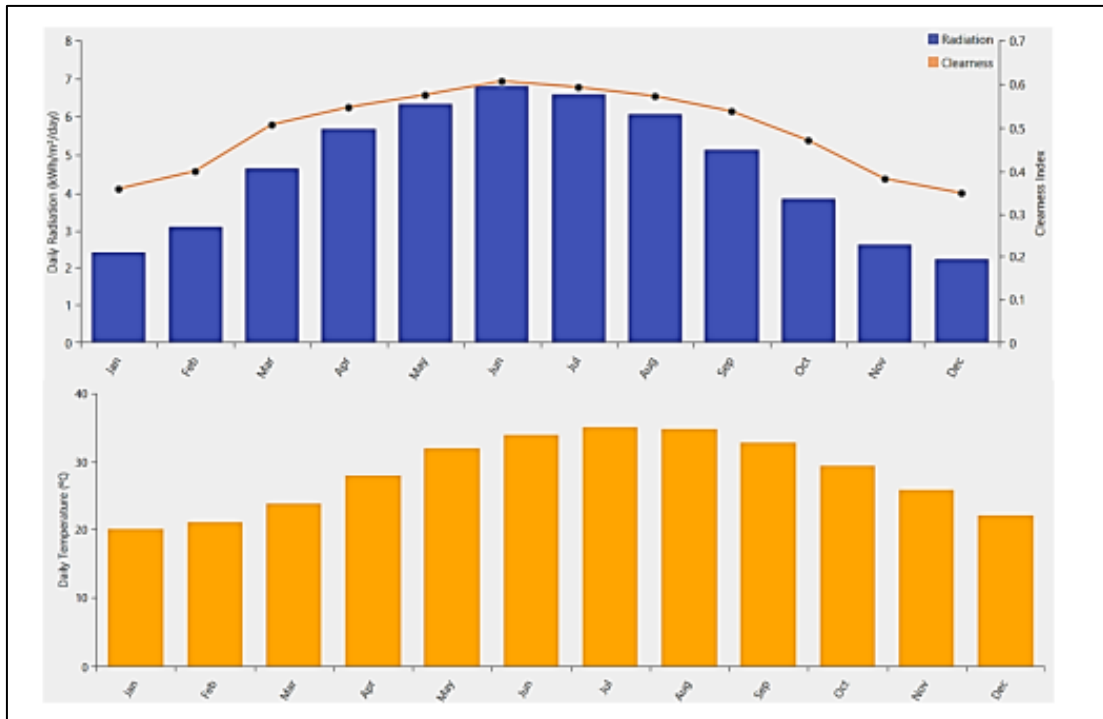


Figure 2.9: The Metrological Data for Sharjah City in UAE (Salameh, et al. 2021).

Figure 2.10 depicts the three-dimensional (3D) geometry of the commercial office structure in Sharjah.

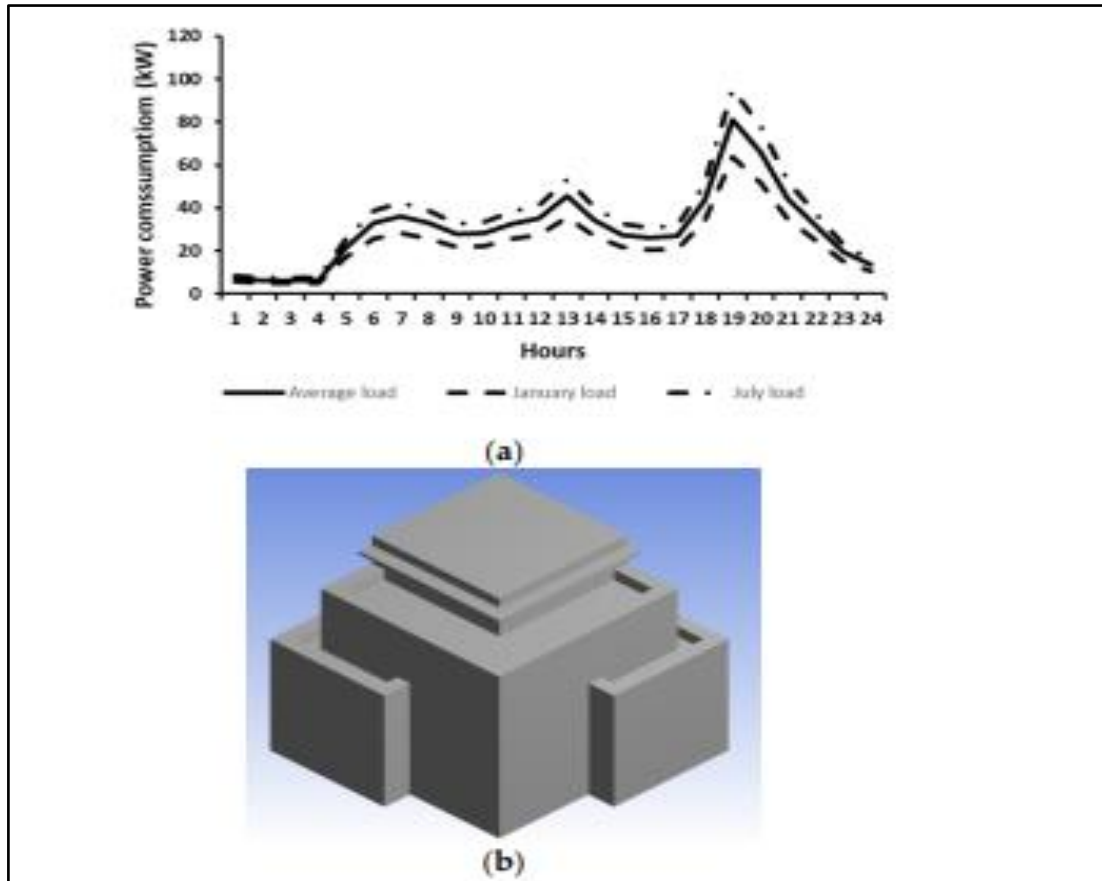


Figure 2.10: (a) The Hourly Load Profile of the Building and (b) the Commercial Office Building in Sharjah Emirate. (Salameh, et al. 2021).

In conclusion, the Emirates' specific environmental concerns call for locally appropriate passive cooling design responses. By carefully responding to these issues, the Emirates can help its citizens live in safe, thermal comfort, and pleasant environments while also contributing to international efforts to prevent climate change.

2.3 EFFICIENT SOLUTIONS ENHANCE THERMAL COMFORT IN HOUSING DEVELOPMENTS

Bande et al. (2021) mentioned that the last forty years have seen a rapid increase in urban development in the (UAE). The local government has started a plan to construct 7270 homes by 2021. Various municipal sustainability policies were being put into effect, such as Abu Dhabi's Public Realm Manual. Those regional recommendations were designed to take into account the UAE's hot and dry climate in addition to the materials used, the addition of vegetation, shading devices, etc. Cities like Abu Dhabi, Al Ain, and Dubai have mandated

the use of these rules. Furthermore, the recently created housing initiatives align with the official plan. For each city, more research was required to determine how these design plans affect outdoor thermal comfort (OTC). Detached villas were the most commonly constructed prototype, resulting in untreated waste areas devoid of vegetation or shade. Arabic buildings were built adjacent to each other in the traditional local communities in order to optimize shade and facilitate pedestrian walking. The purpose of their study was to investigate the districts in which housing initiatives are implemented and to ascertain the best approach for reducing outdoor air heating and improving walkability. The district assessments of the buildings and the externally deployed materials, microclimate sites measurements, ENVI-met (the primary program utilized), models of both present and potential scenarios, results, and recommendations were all implemented in the following order by the approach. Because of the microclimate and other factors, the tactics have distinct effects in both cities. Figure 2.11 illustrates the shading device reference that was used to ENVI-met models in a previous study.

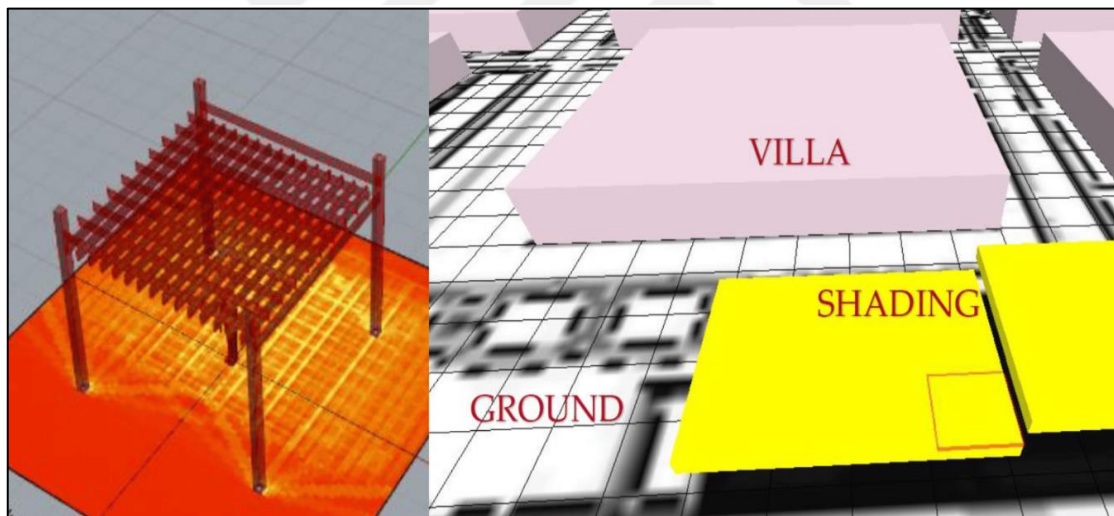


Figure 2.11: Reference Shading Device Employed in an Earlier Work and Implemented in ENVI-met Simulations (Bande et al., 2021).

2.3.1 Innovation in Insulating

Insulated concrete blocks (ICB) were one of the most popular UAE building materials, according to Taleb & AlShuhail (2021). Insulating inserts and a particular block design made this block energy efficient. Their article examined this block's thermal performance in different climates. This block was used to build a Sharjah testing structure. A year was spent

examining its thermal behaviour using the Continuous Method (CM) and Infrared Technique. Time Lag, Decrement Factor, and Temperature Difference Rating were the main thermal measurements. Seasonal and directional effects on the ICB were found. According to the data, ICB would function best in the autumn, with a mean TDR of 0.56 and DF of 0.23. With a value of 14.85 hours, Spring has the highest Tg. Variations in wind could also impact these three characteristics. Rain, in addition to wind, has an impact on the ICB's thermal performance. There will be a discussion of calibration among the CM and IR approaches, and a thorough analysis will be given. Figure 2.12 shows the Daily average temperature at certain locations via a concrete wall.

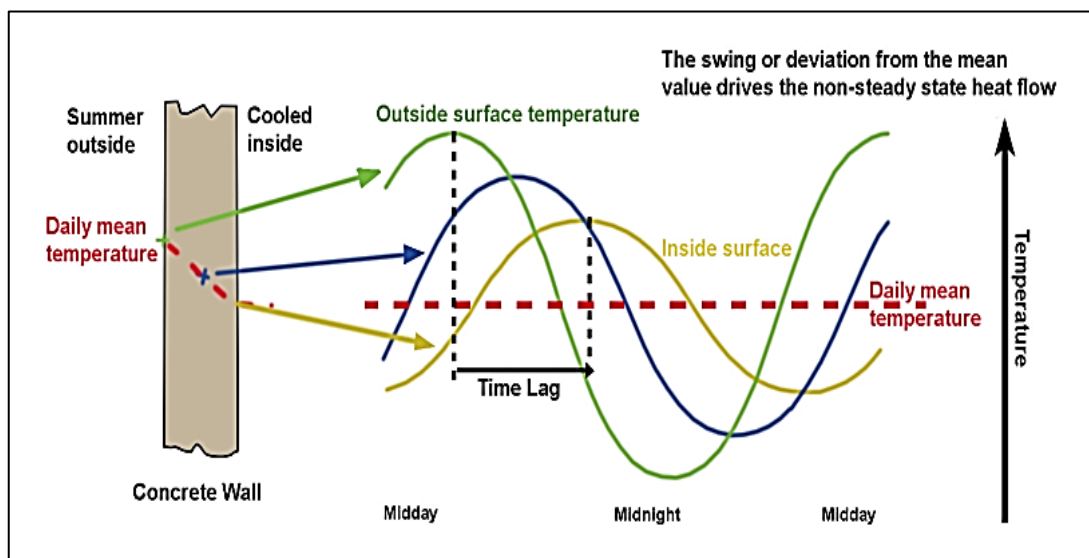


Figure 2.12: Data Gathered from a Concrete Wall Over the Duration of a day (Taleb & AlShuhail, 2021).

Khoukhi et al. (2020) revealed how residential building insulating layer transient thermal conductivity influences cooling and energy performance. Expanded polystyrene (EPS) insulation was evaluated at three moisture content values (10%, 20%, and 30%) in the hot UAE climate compared to dry low density (LD) insulation. Thermal wall resistance was measured using an enthalpy-based conjugate heat-transfer model. We used e-quest to evaluate building energy and compare variable and non-variable thermal conductivity in expanded polystyrene to determine cooling demand and capacity with time. They discovered that predicting the λ value as a function of operational temperature significantly impacts daytime temperature. Heat resistance is lowest in LD expanded polystyrene-insulated walls.

With the lowest heat resistance, 30% humidity causes the biggest cooling requirement and capacity variations of 6.5% and 8.9%.

2.3.2 Alternatives for Shading

Early on, daylight and thermal comfort were vital (Awad & Abd-Rabo, 2020). As climate change or intangible cultural patrimony, the building envelope mediates between its environment and the building. Desert nations like the UAE were ignoring climate change and embracing totally glazed development standards. Inefficient construction causes identity crises. Thus, sun exposure was minimised and solar availability maximised. Sustainable development reduced CO₂ emissions and building energy utilisation, resulting in environmental adaption and resident pleasure. They assessed daylight performance using case studies. Performance modelling and parametric generic method software (Revit - Insight 360 plugin) were used to optimise lighting and energy utilisation in hot-arid environments at Ajman University, UAE. (1) Evaluate case-study light and energy efficiency, (2) compare to hot-arid climate, and (3) choose the best solutions and recommendations. Using climate-related design options and understanding the relationship between layout demands and daylight effectiveness metrics, their innovative building optimisation performance method helps architects predict optimal energy consumption and daylight techniques to improve the environment.

Alhuwayil et al. (2019) determined passive design solutions to be the most cost-effective and viable energy and thermal control options for conceptual buildings. Despite substantial external shading studies, self-shading envelopes have not been examined. In hot-humid Saudi Arabia, multi-story hotels experimented outside shading systems with self-shading envelopes for energy savings and economics. Energy modelling and calculations were done by DesignBuilder (4.5.0.148). The structure's base-design geometry determined shade options for the south, north-west, north, north-east, south-west, and south-east faces. The Saudi Building Code-601 mandated double-glazed windows and roof and wall fibreglass insulation. The shading method created a self-shading envelope, saved energy, and added space affordably. Instead of the simple example, the shade might save 20.5% building energy. Another passive shading investment should pay off in 2 years. Another baseline insulation and glazing solution (polyurethane roof and walls and triple low-e glazed

windows without shading) saved 5% of annual energy use but had an unacceptable 84-year payback.

2.3.3 The impact of Glaziers

Their research (Taleb & Antony, 2020) examined glazing styles to optimise illumination. An authentic Dubai workplace was used for the case study. The modelling application Integrated Environmental Solutions (IES) was validated by comparing real air temperature and light intensity data to forecasted values. Krypton, PV, xenon gas-filled double glazing, reflecting coated glazing, 400 mm projection shade, insect-eye, begonia, human-eye, mirrored begonia, Mashrabiya, and white powder glazing were simulated. The results were intriguing. Single glazing with 300–500 lux was acceptable in the UAE. Mashrabiya glass cut cooling burden 23%. UAE commercial buildings with xenon or krypton windows have higher lux and lower U-value. The results may inspire UAE architects and designs and others in similar climates.

Abdou et al. (2022) said office buildings require a lot of electricity and wide glazing for light. The UAE's sweltering desert demands window or fenestration configuration to facilitate daylighting without solar heat gain. They studied an evidence-based west façade retrofitting option for UAE office buildings to reduce cooling energy load and improve indoor environmental quality at UAEU's HE office. A comprehensive exploratory study that included indoor quality of environment monitoring and occupant satisfaction polls produced an evidence-based retrofitting option. DesignBuilder replicates single- and multiparameter sensitivity testing for window-to-wall proportion, outside shading, and glazing type to reduce annual cooling load and solar heat gain while maintaining internal daylight illuminance. Window-to-wall ratio primarily impacts daylighting and energy use. The west façade should have 20–30% WWR, per data. High-performance windows and outdoor shading save energy with a larger WWR. Double Low E tinted windows, 0.4 projected shading overhanging, and side fin save energy use 14%. The final retrofitting features and design standards validated window performance in a hot, arid environment, allowing architects and stakeholders to apply passive factors to reduce energy consumption and office building occupant comfort.

It can be inferred how different types of windows affect building energy use (a) and daylight illuminance (b); in Figure 2.13, the dotted box indicates optimal performance.

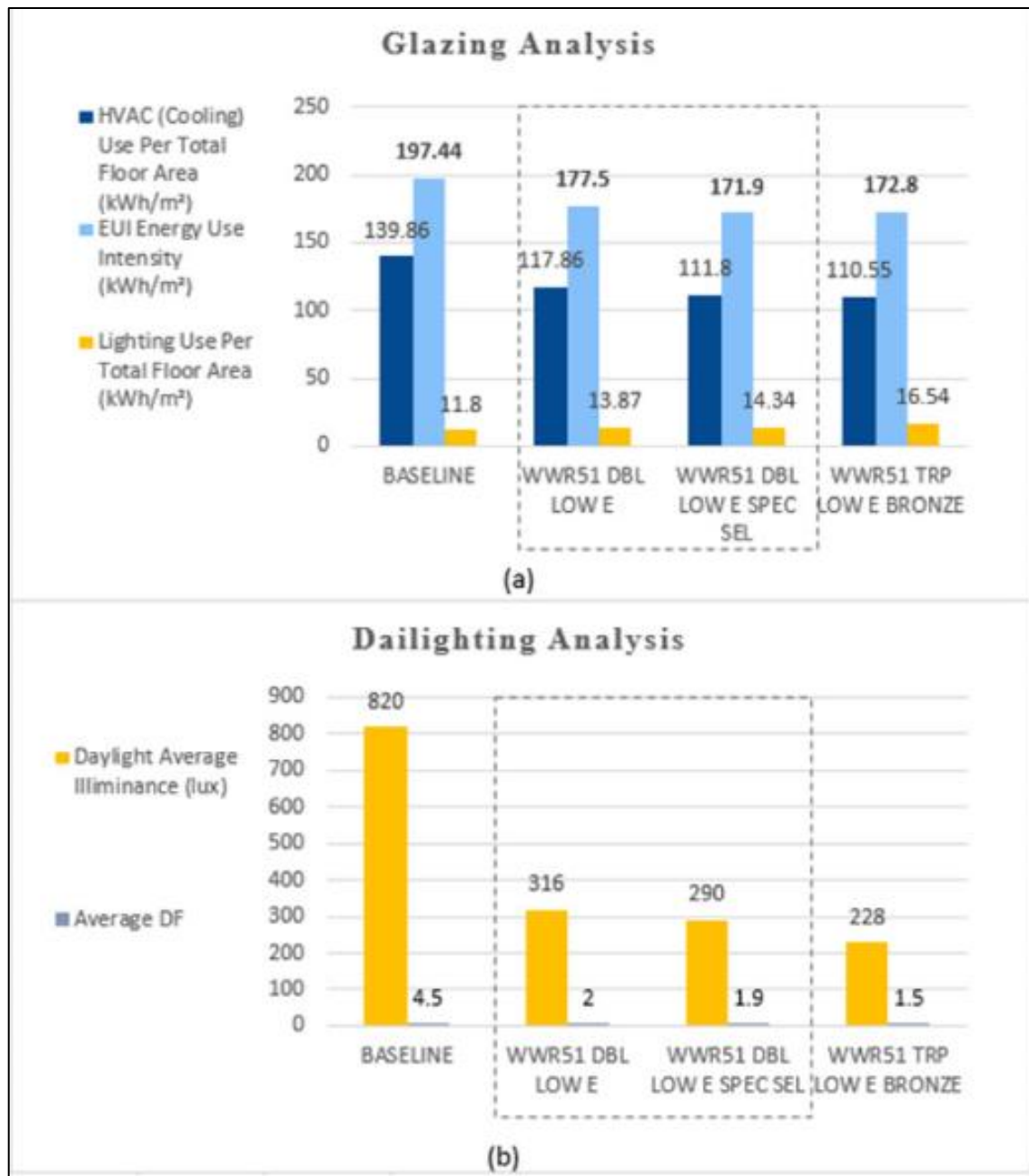


Figure 2.13: Impact of Glazing Style on Daylight Illumination (b) and Building Energy Consumption (a); the Dotted box Indicates Optimal Performance (Abdou et al., 2022).

2.3.4 Constructions with Green Roofs

Green walls, rooftops, and urban farming have been adopted in several nations to reduce heat-related city problems owing to extreme climate change (Aboulnaga & Fouad, 2022). Speedy urbanisation and population growth in megacities enhance the urban heat island effect (UHIE) and induce climate change. Thus, urban green covers may reduce CO₂ emissions and increase air pollution in major cities. National and municipal green roof planning and building laws were reviewed. North America, Europe, South America, Australia, MENA, and Asia's green roof policies were also discussed. Presentations and discussions covered urban farming, green walls, and green roofs.

In future decades, as the world's population grows, there will be greater urbanization, according to (Susca, 2019), which would raise building energy consumption and cause an increase in urban climate, which in turn would impact building energy demand. The building industry plays a major role in the world's energy use; hence, improving this industry is vital to achieving climate stabilization. Published research supports the idea that green roofs are a universally applicable solution by demonstrating how they impact building energy use both directly and indirectly. However, climatic conditions and the particular design of the roofs affect how effective their deployment is.

It can be obvious in Figure 2.14 what the count of scholarly articles pertaining to green roofs that were released between 2013 and 2018.

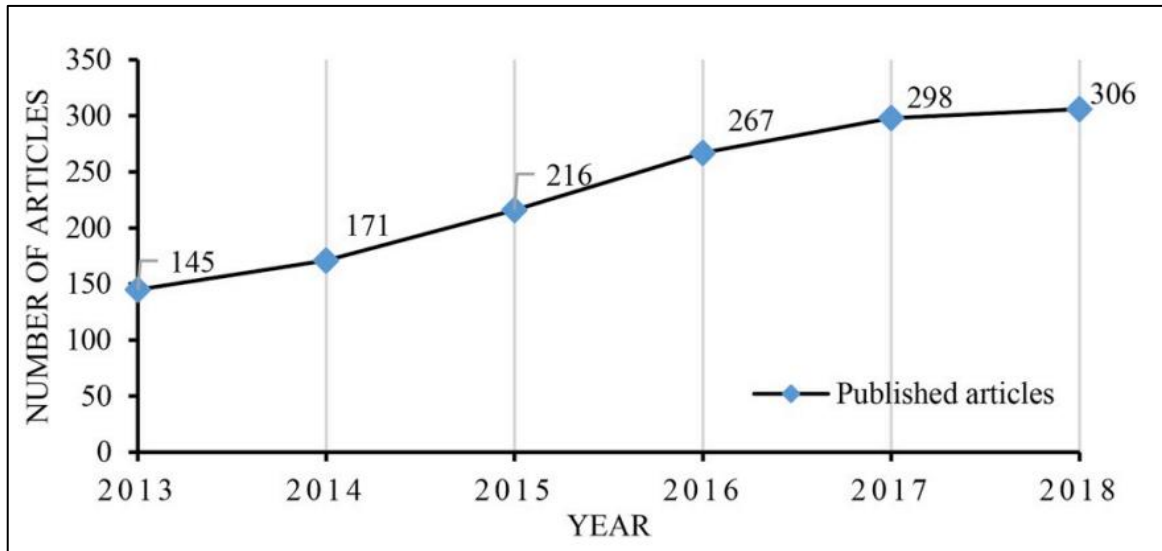


Figure 2.14: Quantity of Scientific Articles Published (2013-2018) Concerning Green Roofs (Susca, 2019).

2.3.5 The Competence of Ventilation

Energy savings and indoor comfort can arise from natural ventilation (Aldawoud & Salameh, 2020). DesignBuilder/ANSYS CFD Fluent program assessed energy performance and indoor air temperatures of Dubai school buildings to reduce cooling energy use. Several schools were created based on opening size, orientation, and sun shading. Natural ventilation couldn't cool summers due to high air temperatures and little breeze. It could be a building comfort backup system. Window inlets and exits can lower interior temperatures by 5–7 degrees Celsius depending on size and wind orientation. Ventilation variations Windows settings are in Figure 2.15.

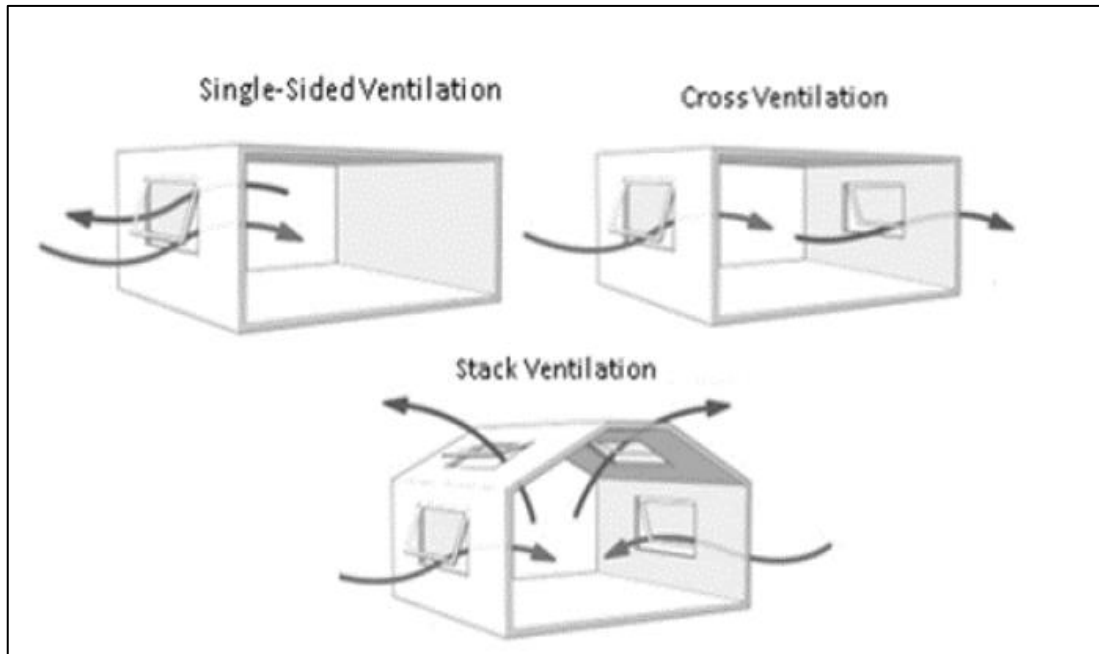


Figure 2.15: Organizing Windows for Various Ventilation Setups (Aldawoud & Salameh, 2020).

Early in the design process, the energy efficiency of buildings must be considered (Belpoliti et al., 2021). Buildings in the UAE relied largely on air conditioning due to a disregard for regional typologies and methods. Particularly tall buildings that, in contrast to conventional typologies, were frequently created just to be iconic. Despite Dubai's five months of excellent weather, natural ventilation was seldom utilized by very many towers, despite its potential to improve IEQ and initiate passive cooling measures. In their work, they used CFD, parametric/generative design, and advanced computer-aided design to develop a passive-cooled, energy-efficient tower that optimises natural ventilation and reduces air conditioner running. (1) CFD was used to analyse sites with different urban fabrics, densities, and typologies to choose a poorly ventilated area for the project site and demonstrate the new tower concept's benefits; and (2) parametric modelling optimised the structure's shape to reduce solar radiation and increase wind flow. Analysis of flat spaces to increase inside natural ventilation and parametric façade layout of the optimal tower-shape were the next research steps.

2.3.6 Approaches for Thermally Comfortable Indoor Lighting

Mahmoud et al. (2023) stated that energy consumption and carbon emissions reduction from quantitative lighting analysis were well-known in the UAE, but well-being was not. Their article examined the context, analyzes UAE home interior lighting, and proposes interior space planning. The technique examined home interiors' functionality, human well-being, and inventive lighting. The analysis results were; due to interior space functions, the site and floor plan must be established in the planning phase, local context matters. Second, install the necessary lighting fittings and bulbs. The residential project's many interior zones needed appropriate lighting arrangements. Interior architects supply lists and material for healthy lighting and space. Their study would provide essential data for UAE housing interiors. It would also aid future studies in decision-making for design standards and operational plans. Their study presented and simulated daylight diversity through the day to deal with the circadian cycle for both mental and physical health in Dubai, UAE, using trends, creativity, and national efforts as the backdrop.

People spend over 90% of their time indoors as mentioned by (Al Ghaithi, 2022). Indoor environment quality affects user efficiency and energy consumption. Absenteeism and medical costs would decrease if tenants work in a pleasant indoor setting. A comfortable workplace boosts productivity by ten to fifteen percent and decreases absenteeism by 2.5%. According to the IPCC's recent climatic report, UAE citizens were facing rising temperatures and rougher weather. Previous studies found that people are more likely to be exposed to harmful settings the longer they stay inside buildings. Sick Building Syndrome and other physical and psychological issues would increase, overtime within buildings increases energy needs.

2.4 NATURAL AND BUILDING COMPONENTS FOR LOWERING MOISTURE, HIGH TEMPERATURES AND ENERGY

Retrofitting a building was often cheaper than building new according to (Khoukhi et al., 2022). Since buildings use a lot of energy, especially for cooling and heating, and existing buildings make up the majority of the built environment, energy conservation retrofits were necessary to lower energy use and lighting costs. Energy conservation was not the primary motivation to modify buildings. A high-performance building should be created by using a

combined, whole-building design approach to the project during planning to meet all important design objectives. Their work gave a real-world example of energy-efficient building retrofiting. Indeed, most UAE structures were unsuited for the region's harsh environment, which generates large cooling demands and use of energy due to proper construction criteria. A recurring computer model of Sharjah office building energy use was run under UAE weather. The building orientation, HVAC system, outside shading, window-to-wall ratio, and wall and roof U-values were improved to save energy. The simulation showed that the optimal scenario was 41.7% more effective and 30.6% better than the basic situation. The roof component saved 8.49% of energy, followed by the AC system by 8.34% if selected using the base scenario. The new roof structure cut energy use by 38%, the most of the five components. After a 37% energy savings from a new HVAC system, an insulated wall type saved 20%.

Salam et al. (2020) examined energy use and costs for a UAE corporate office building in a hot, dry, humid climate with a high cooling load. A basic case without PV and standard glass windows (a) and a BIPV façade design with clear PV windows (b) were simulated. Both buildings have the same dimensions, form, orientation, and size/space layout. The PVSYST algorithm calculated the best BIPV façade system orientation to reduce cooling demand and maximise electricity generation. Combining weather data for the Sharjah, UAE, building site with silicon amorphous thin film (b). The building's interior cooling demand and expenses were examined in all situations. BIPV façade system cases reduced cooling system electrical demand by 26.79% and energy expenses by \$2084 in hot, dry, and humid environments. A study like that would give climate data needed for Sharjah's system's design and execution. Figure 2.16 shows curtain wall-solar path alignment.

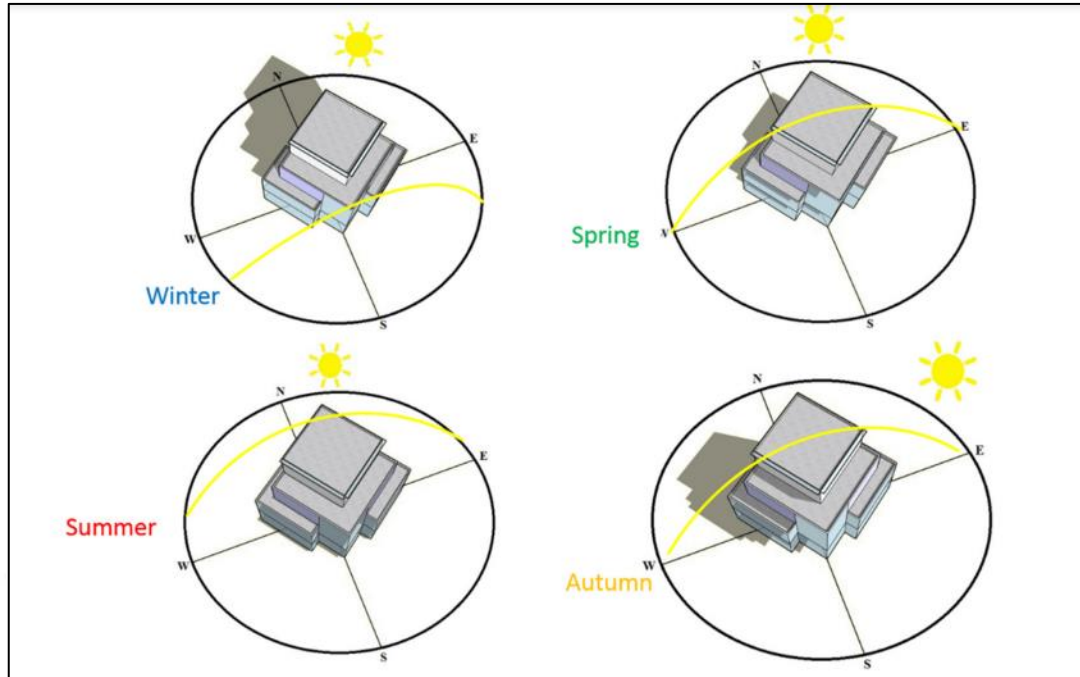


Figure 2.16: Orientation of the Solar Path and Curtain Walls (Salameh et al., 2020).

Over the past decade, phase-changing materials (PCM) have been extensively integrated into architectural elements to minimize air-conditioning needs for thermal comfort in the house (Rashid et al., 2019). Latent heat was absorbed and released by the PCM in a small temperature range. Summer experiments showed energy savings and lower indoor temperatures. The UAE, with substantial heat flux year-round, has little studies on the topic. PCM integration in UAE buildings for thermal comfort inside and energy savings was covered in their work. The report revealed BIPV issues such efficiency decline. The importance of PCM in construction and its research need were underscored by reporting all prior discoveries, including PCM in glass, concrete, and BIPV.

Maatouk Khoukhi & Abdelbaqi (2019) changed the insulating layer thermal conductivity to study home cooling. The simulation compared dry insulation material for LD to polystyrene (EPS) in highly hot Al Ain (UAE) circumstances at four densities (12 kg/m³, 20 kg/m³, 30 kg/m³, and 35 kg/m³) and three moisture levels (10%, 20%, and 30%). Different temperatures and moisture content have been employed to examine EPS thermal conductivity. An enthalpy-based conjugate heat exchange model measured thermal wall resistance. We compared a building with a λ -value to a constant one by analysing cooling demand and storage capacity over time using e-quest, a building energy analysis tool.

Modelling the λ -value has a substantial impact on the temperature profile of polystyrene (EPS) insulation during the day compared to keeping it constant. EPS with different densities and moisture levels showed a comparable wall section temperature trend. The LD sample's fluctuating thermal conductivity raises the building's monthly cooling energy. Polystyrene with fixed and variable thermal conductivity increases space cooling capability and is needed annually as moisture content rises. The largest cooling demand and capacity changes were 6.5% and 8.8% at 30% moisture.



3. ARCHITECTURAL PASSIVE COOLING STRATEGIES IN HUMID HOT REGIONS

3.1 NATURAL VENTILATION

Natural ventilation is a common way for hot, humid residential buildings to offer thermal comfort and save energy. Traditional building in these regions uses simple yet effective ventilation methods.

With the development of technology, more efficient innovative solutions have emerged based on airflow simulation studies and intelligent systems. In this chapter, we will discuss both traditional and innovative natural ventilation strategies in hot humid regions, with a focus on recent research that has worked to develop traditional ventilation design strategies.

3.1.1 Traditional Natural Ventilation Strategies for Residential Buildings in Hot And Humid Regions

3.1.1.1 Courtyard design function

Historically, the courtyard was a key architectural element in traditional homes in hot, humid regions. The courtyard helped improve airflow through the “heat chimney effect,” drawing hot air upward and allowing cooler air to enter through lower openings. This technique was popular in regions such as the Middle East and India (Baharuddin & Ibrahim, 2019).

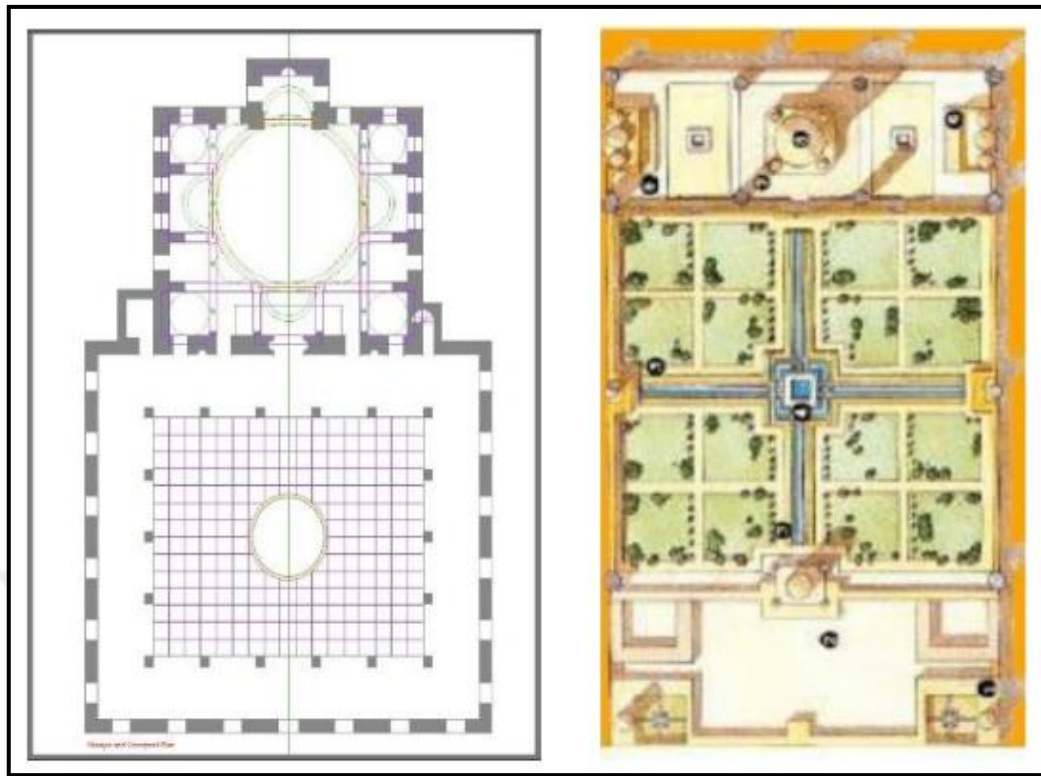


Figure 3.1: A Mosque Plan With two Internal Courtyards (Shah and Margee, 2022).

Table 3.1 displays a literature evaluation of traditional courtyard design ideas in humid hot locations.

Table 3.1: Overview of Traditional Design Principles of Courtyards in Humid hot Regions.

Design principle	Description	Example	Authors
shape	Square courtyards or courtyards with a low length-to-width ratio help achieve a better balance between ventilation and shading. On the other hand, rectangular courtyards oriented with the longest axis east-west show a greater ability to reduce solar heat gain than other shapes.	 (Fay,2020)	(Zhu et al.,2023); (Khastar, S., & Taleghani, 2024); (Toris-Guitron et al.,2022), (Buluset al.,2017), (Rodríguez et al.,2018), (Almahmoud et al., 2024)
shading	-Courtyards rely on reducing the exposure of buildings to direct sunlight by using high walls or tree branches, which contributes to reducing the heat entering the building. - Increasing the courtyard's H/W ratio considerably reduces solar heat gain.	 (Daily Arch,2019)	(Li et al.,2018),(Hong & Lin, 2015),(Liu, et al.,2018),(RIDHA, 2022),(Bagasi et al.,2021)

Table 3.1: Overview of Traditional Design Principles of Courtyards in Humid hot Regions (Table Continued.)

Water	Adding natural elements such as water to courtyards works as an effective traditional solution to cool the surrounding air and increase thermal comfort. water features help reduce heat through evaporation.	 (home designing,2008)	(Barone,2022),(Bagasi et al.,2021),(Sun et al.,2024),(Li et al.,2022),(Gao et al.,2020)
plant	Adding natural elements such as plants to courtyards works as an effective traditional solution to cool the surrounding air and increase thermal comfort. Plants provide natural shading and cool the air.	 (Arch Daily,2024)	(Han et al.,2021),(Darvish et al.,2021),(ElHussieny et al.,2023),(Gomaa et al.,2024)

3.1.1.2 Role of ventilation types in design

Using cross-ventilation windows is another common strategy in traditional design. These windows allow air to enter from one side and exit from the other, creating a natural air movement that promotes the cooling of interior spaces. This method reduces humidity and prevents the accumulation of hot air inside buildings (Bay et al, 2022).

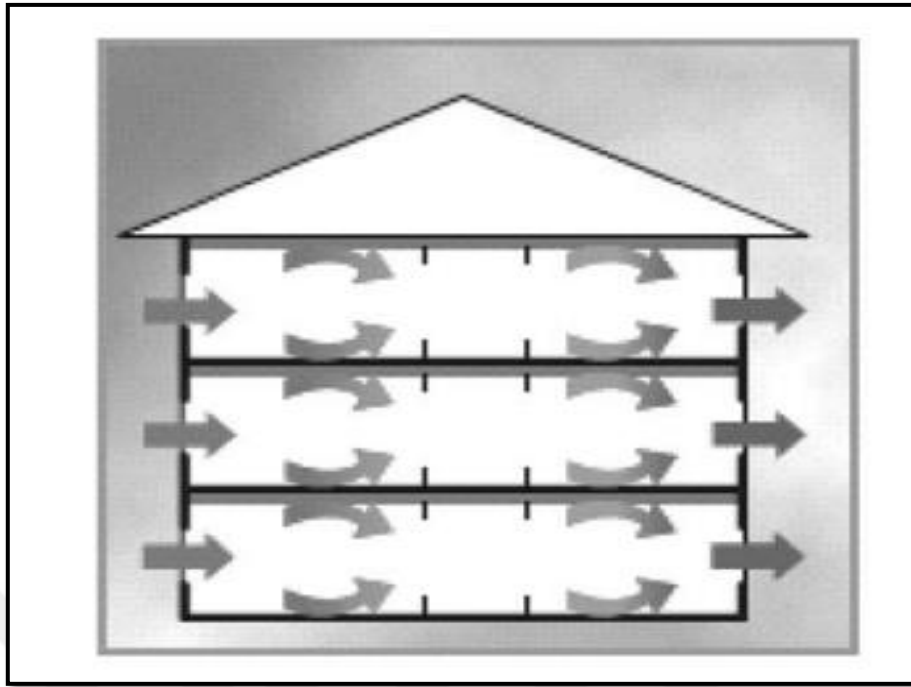


Figure 3.2: Cross Ventilation (Ohba & Lun,2010).

As for traditional evaporative ventilation strategies , courtyard water features were used to cool the surrounding air through evaporation, as in Islamic architecture (Kljuno, 2022). In addition to improving the indoor climate, they contribute to enhancing the aesthetic aspect.

Modern courtyards incorporate evaporative cooling. Baker and Steemers (2000) found that courtyard fountains and small ponds boost evaporative cooling by lowering air temperature. Courtyards also use natural wind movement to draw cool air in and discharge hot air via top openings, improving ventilation without air conditioning.



Umayyad Mosque in Aleppo



Ulu Cami in Turkey

Figure 3.3: Water Courtyards (Mavink,2022).

Also, another traditional evaporative ventilation strategies are Water Walls, this method relies on cooling the indoor air by passing it through surfaces wet with water (Givoni, 1994). This system is effective in reducing temperatures, but requires continuous maintenance to ensure the cleanliness of the water.

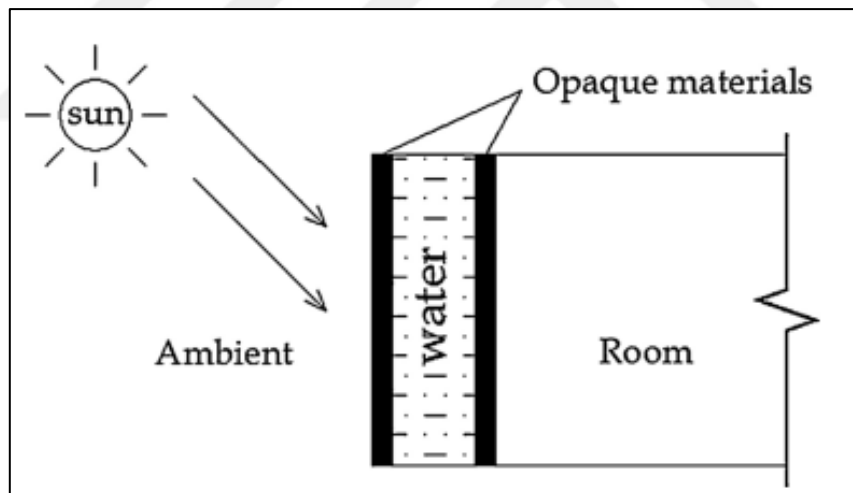


Figure 3.4: Water Wall System (Wu & Lei, 2016).

Local materials like clay and stone were employed in construction in hot, humid locations to create thermal comfort due to their natural insulation. These materials allow air to move and reduce heat absorption during the day, cooling the building at night (Samuel et al., 2017).

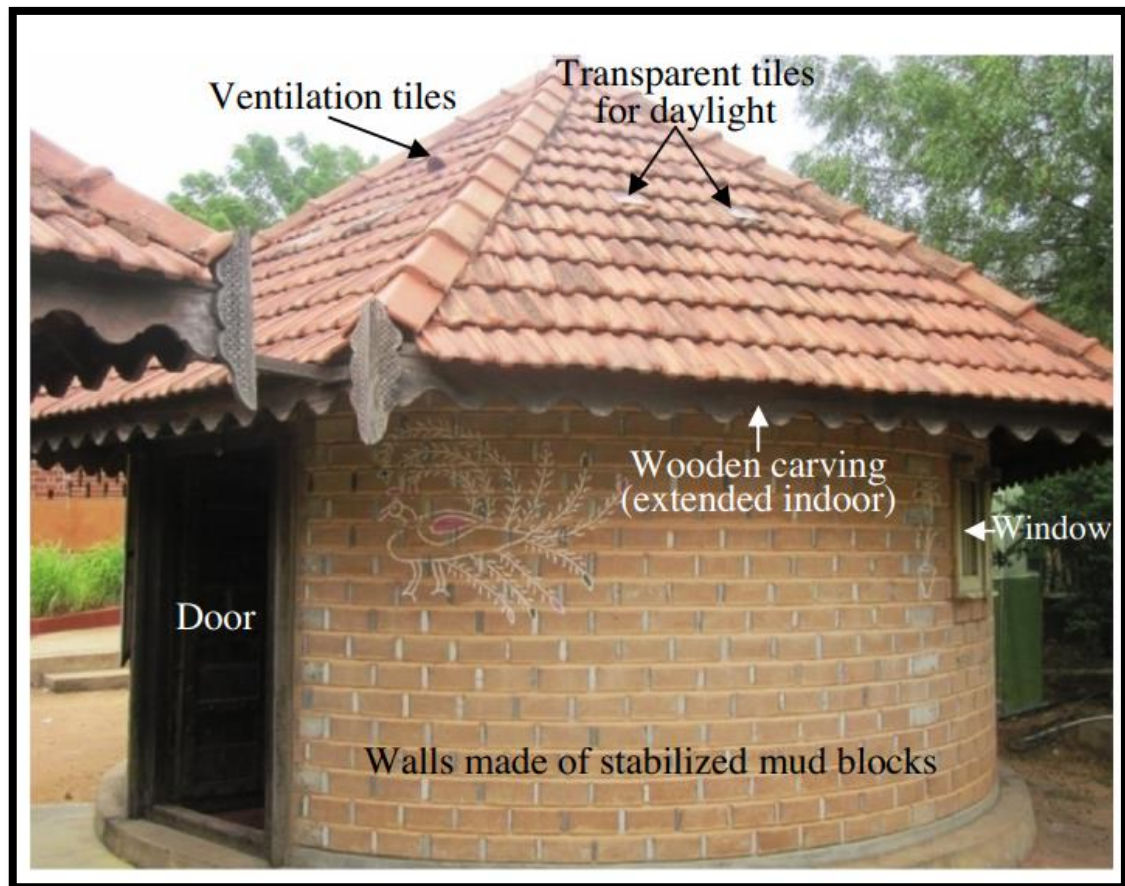


Figure 3.5: Thermal Comfort Using Mud Buildings (Samuel et al.,2017).

Table 3.2 shows literature review of the Traditional architecture design principles of courtyards in Humid hot regions

Table 3.2: Overview of Traditional Design Principles of Ventilation in Humid Hot Regions.

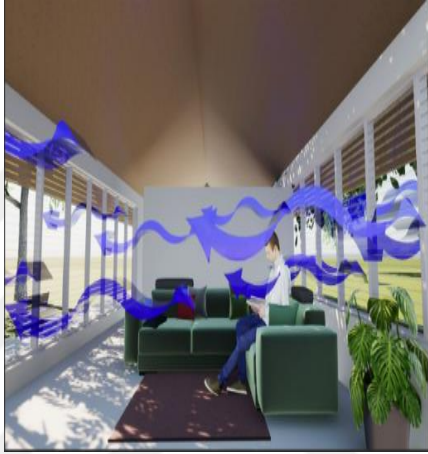
Ventilation Type	Design Principle	Description	Example	Authors
Cross Ventilations	Window locations and distribution	-To achieve maximum cross ventilation effectiveness, windows should be placed on opposite or adjacent walls at angles close to 180 degrees. - Windows on the side facing the prevailing wind should be open to allow cool air in, while the opposite windows act as exit vents.	 (Architropics,2024)	(Jiang et al.,2023),(Zaki & Sharma2023),(Chohan & Awad, 2022),(Nejat et al.,2021),(Hetebrij,2021).

Table 3.2: Overview of Traditional Design Principles of Ventilation in Humid Hot Regions (Table Continued.)

	Window proportions and height	- Window area should be about 40% of floor area to achieve effective ventilation in hot, humid areas. - Windows are placed at an average height close to seating level (about 0.9 to 1.2 metres above the floor), so that cold air enters at this level, which contributes to cooling people directly.		(Schiavon et al.,2010),(Zomorodian & Tahsildoost,2017),
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Table 3.2: Overview of Traditional Design Principles of Ventilation in Humid Hot Regions (Table Continued.)

	Window orientation	- In hot, humid areas, prevailing winds are often from the east or southeast. A study of local winds may be required to determine the optimum orientation. - Trees or tall buildings can obstruct the natural flow of wind. Therefore, windows should be positioned in a direction that allows direct wind to enter without obstruction.		(Stasi et al.,2024),(Daemei et al.,2018),(Chohan & Awad,2022),(Swarno et al.,2024)
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Table 3.2: Overview of Traditional Design Principles of Ventilation in Humid Hot Regions (Table Continued.)

Stack Ventilation	Window locations and distribution	-Openings in the ceilings or upper walls: Overhead openings (such as skylights or chimneys) should be placed in the ceiling or high up in the walls to drain hot air. -Opening lower windows: Lower openings should be placed at a low height to allow cool air to enter. Openings located at foot level (about 0.3 m from the floor) are preferred.	(Wang et al.,2024),(Togno & Zarrella, 2024),(Tognon & Zarrella,2024)
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Table 3.2: Overview of Traditional Design Principles of Ventilation in Humid Hot Regions (Table Continued.)

	Window proportions and height	The upper and lower vents should be proportionate. The upper vents are usually slightly larger than the lower ones to allow more hot air to be released that has accumulated in the upper part of the room.	 (Everbgy.Gov,nd)	(Sorgato et al.,2016),(Fitzgerald & Woods,2004)
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Table 3.2: Overview of Traditional Design Principles of Ventilation in Humid Hot Regions (Table Continued.)

	Window orientation	-It is preferable for the upper openings to be directed towards areas where the greatest heating occurs (such as kitchens or areas of direct sun). -Wind and thermal flues: When designing ventilation flues, the upper openings should be positioned in a way that allows for the greatest benefit from strong winds that help draw the hot air out.		(Hamed,2021),(Osaro et al.,2022),(Mumovic et al.,2018),(Chenari et al.,2016),(Zhang, 2023),(Jacobs et al.,2020),
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Table 3.2: Overview of Traditional Design Principles of Ventilation in Humid Hot Regions (Table Continued.)

		-Additional considerations Use of rotating or variable vents: Rotating or controllable vents can be used in the roof to increase the efficiency of vertical ventilation by controlling the flow of incoming and outgoing air according to climatic conditions.		
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Table 3.2: Overview of Traditional Design Principles of Ventilation in Humid Hot Regions (Table Continued.)

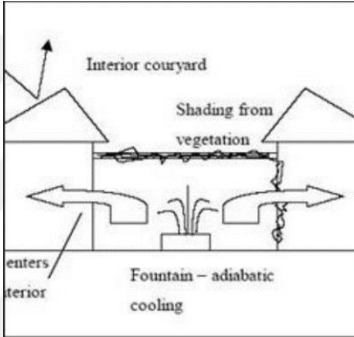
Evaporative cooling	Locations and distribution of water bodies	-Placing water bodies such as ponds and fountains near areas where air enters the building, so that air passes through these bodies and the water evaporates from it, which cools the air before it enters. - Aquatic plants or green walls are used as a natural source of evaporation around the building or in interior courtyards.	 (Akande, 2010)	(Kharrufa & Noori,2022),(Hamdy et al.,2023),(Arbabzadeh et al.,2020)
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Table 3.2: Overview of Traditional Design Principles of Ventilation in Humid Hot Regions (Table Continued.)

	Percentage of openings compared to water bodies	Openings facing water bodies should be large enough to allow adequate intake of cooled air.		(Krajčik et al.,2021),(Aste et al.,2020).
	Orientation of openings	Openings and windows should be oriented towards prevailing winds passing over water bodies or aquatic plants to get cool air. Flowing water surfaces (such as water walls) can be used next to openings to effectively cool the passing air.		(Hopkins & Goodwin,2011),(Imani & Vale, 2022)

3.1.1.3 Barjeel (wind towers)

Barjeel is one of the oldest traditional architectural solutions used in hot, humid regions, such as the Arabian Gulf. These towers direct outside air into the building through upper openings, which helps cool the air inside the house. Studies have shown that Barjeel can reduce indoor temperatures by up to 5° C (Baharuddin & Ibrahim, 2019).



Figure 3.6: (a) Traditional Barjeel in Dubai (b) Traditional Barjeel in Sharjah (Awad and Boudiaf,2020).

3.1.1.4 High ceilings, domes and vaulted roofs

High ceilings or domes are common features in traditional architecture in hot regions, such as Islamic and ancient Egyptian architecture. These ceilings allow hot air to rise upwards,

reducing heat build up in lower areas of the building. Domes create aerodynamic effects that help in escaping hot air and replacing it with cooler air (Al-Jawadi,2010).



Figure 3.7: (a) Traditional Domes in Sharjah (b) Traditional Domes in Ajman(Awad and Boudiaf,2020).

Vaulted roofs direct heated air upward into the interior, where it can escape through roof or upper window openings. This method lowers building temperatures in hot climates.

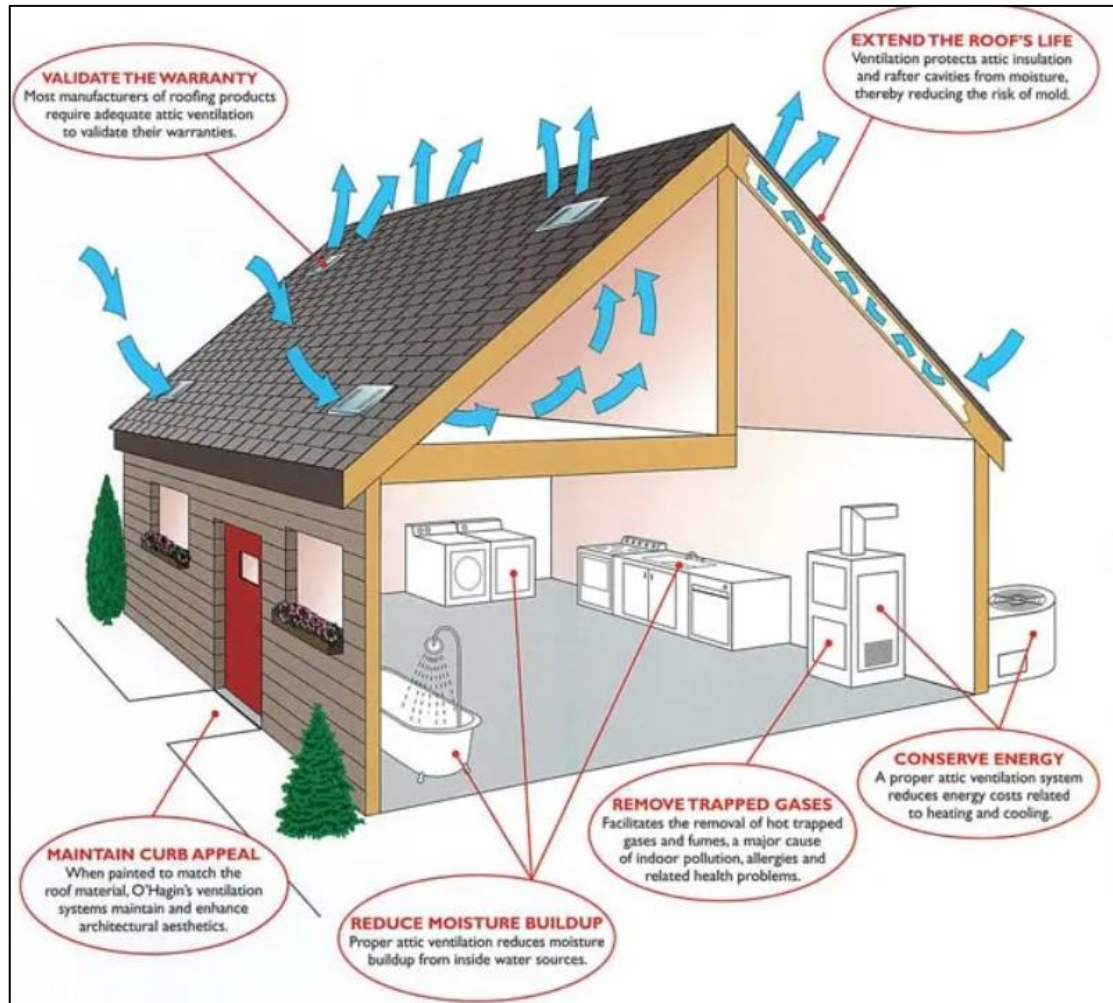


Figure 3.8: Vaulted Roofs (Mavink,2022).

Table 3.3 shows literature review of the Traditional architecture design principles of high roofs in Humid hot regions

Table 3.3: Overview of Traditional Design Principles of High Roofs in Humid hot Regions.

	Design principle	Description	Example	Authors
Ventilation	Ceiling height ratio	The ideal ceiling height in hot humid areas should be between 3.5 and 4.5 meters. This height ensures the vertical cooling effect and creates enough space for effective ventilation through the upper openings.	 (Zillow ,nd)	Olgyay,(2015)

Table 3.3: Overview of Traditional Design Principles of High Roofs in Humid hot Regions.(Table Continued.)

	Distribution of ventilation openings	To make the most of high ceilings, overhead vents or skylights should be designed to release hot, collected air. These vents can be adjustable to make it easier to control airflow as needed.		Givoni,(1998)
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Table 3.3: Overview of Traditional Design Principles of High Roofs in Humid hot Regions.(Table Continued.)

	Correct orientation of the openings	The upper openings should be directed towards the prevailing winds to benefit from natural ventilation. The large lower openings should be positioned to receive cool air and push hot air upward.		Givoni,(1998)
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Table 3.3: Overview of Traditional Design Principles of High Roofs in Humid hot Regions.(Table Continued.)

shading	Reflective surfaces and shadings	The effectiveness of high ceilings in achieving thermal comfort can be improved by using reflective surfaces or coverings that prevent heat absorption. Light-coloured surfaces reflect sunlight rather than absorbing it, reducing roof heating.	Yuan et al,2024
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Table 3.3: Overview of Traditional Design Principles of High Roofs in Humid hot Regions.(Table Continued.)

	Use of eaves and balconies: To reduce the direct effect of sunlight on the roof and external walls, wide eaves and balconies should be added that cast shade on the building. This external shading reduces heat gain and improves ventilation performance.	 (Tarp hire Australia,no date)	(Jayaweera et al.,2024),(Nwalusi et al,2022),(Yalaz, & Dişli, 2024),(Njunge & Erçin,2021),(Khei et al.,2024).
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Table 3.3: Overview of Traditional Design Principles of High Roofs in Humid hot Regions.(Table Continued.)

Evaporative cooling	Merge water bodies	The cooling effect of high ceilings can be enhanced by incorporating water features into the building's exterior design. Water evaporating from ponds or fountains around the building can help cool the air before it enters the building, reducing interior heat.	 (Asktheman,nd)	(Krajčík et al.,2021),(Aste et al.,2020).
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Table 3.3: Overview of Traditional Design Principles of High Roofs in Humid hot Regions.(Table Continued.)

	Interior courtyard design	In hot, humid areas, interior courtyards can be designed with aquatic plants or small bodies of water that contribute to improving air quality and cooling it before it is distributed inside the building.		(Li et al.,2023)
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3.1.1.5 Mashrabiya

Mashrabiya are decorative architectural elements in traditional Islamic architecture, used to control the entry of air and sunlight into buildings. Mashrabiya regulate the movement of air through small, decorated windows, allowing the air to cool before it enters the building. They also improve privacy, in addition to their role in thermal control (Sabea, 2018).

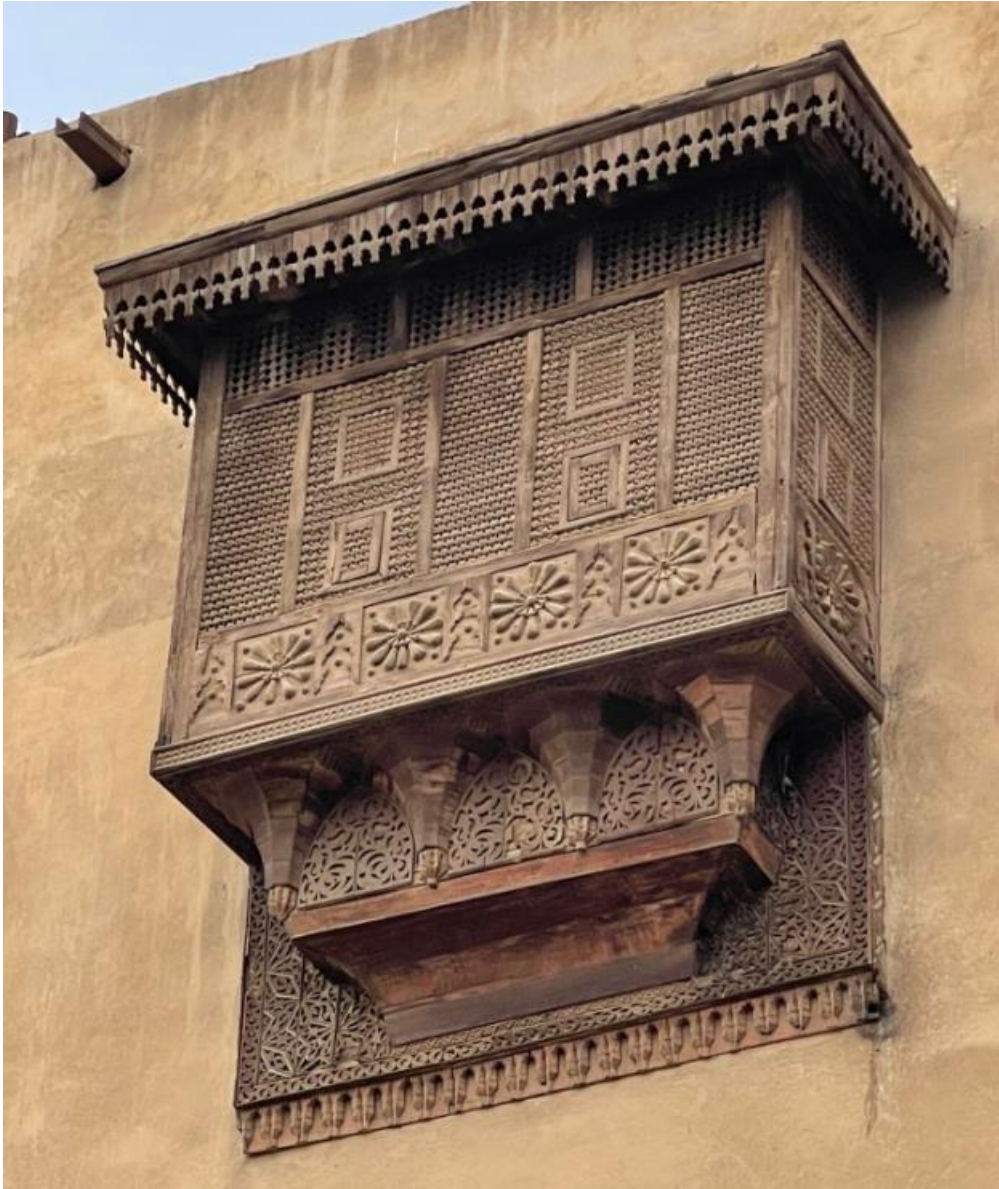


Figure 3.9: Traditional Mashrabiya (Museum for Art in wood,2022).

3.1.2 Innovated Natural Ventilation Strategies for Residential Buildings in Hot and Humid Regions

3.1.2.1 Smart ventilation facades

Recent advancements like smart facades use integrated ventilation systems to automatically adjust air flow. A 2022 study found that these facades improved thermal comfort and reduced energy usage by 40% compared to standard approaches (Chen & Zhang). Smart Ventilation Facades have double-layer glass, solar shading, PV integration, etc. In smart facades, where intensity, period, and solar radiation type affect transmission qualities, transparency is correlated to light reaching the glass surface (Figure 3.10). Glass darkens as global sun energy strikes it. Fabrication methods affect the system's sensitivity to global solar radiation (Brunoro, & Frighi, 2024).



Figure 3.10: Examples of Smart Facades (Brunoro & Frighi,2024).

3.1.2.2 Green roof design

Green roofs are an innovative technology that aims to improve thermal comfort in hot, humid buildings. Plants on roofs provide natural cooling and reduce indoor temperatures (Mihalakakou et al., 2023).



Figure 3.11: Green Roof Design (Korol & Shushunova ,2021).

Design of green roofs and walls has improved to reduce energy use and increase thermal comfort. Green roofs are an innovative urban heat island solution. In Seoul, covering roofs with green spaces lowered summer temperatures by 1°C and energy usage by 8% (Adilkhanova et al., 2024; Santamouris et al., 2024). This technique relies on evaporation from plants, which reduces reliance on mechanical air conditioning systems (Adilkhanova et al., 2024). In addition, green walls, especially those integrated with ventilation and air conditioning systems, offer the advantage of improving indoor air quality by removing pollutants such as volatile organic compounds. These systems, known as bio-walls, reduce the need for outdoor air exchange, saving energy costs for heating or cooling (Moseley et al., 2013; Velazquez, 2024).

Layer Design

Green roofs and walls consist of several layers that play a key role in improving thermal performance, including:

Waterproofing layer: Protects the roof or wall from water seepage.

Root protection layer: Prevents plant roots from penetrating the building structure.

Drainage layer: Ensures drainage of excess water and prevents its accumulation.

Growth layer or planting medium: The soil that supports plant growth and retains the water needed by plants.

Plants: The main component of the system, and species that can withstand local climatic conditions must be selected to maximize evaporation and shading (Living Architecture Monitor, 2024; UNSW, 2024).

3.1.2.3 Modern wind towers with new technologies

In innovative designs, the wind towers principle has been improved to become more combined with novel techniques. Conventional wind towers are combined with mechanical ventilation regimes to achieve effective air distribution indoor buildings. (Li & Wang, 2021) revealed that utilizing modern wind towers that depends on power came from solar radiation to move air aims to minimizing energy depletion by 25%

Masdar City has moderate wind, however the designers placed the windcatcher near the Institute of Science and Technology Public Square to reach more people. The massive public metropolitan wind tower uses proven technologies. Figure 3.12 shows thermal performance. Stage performances below the wind tower. Automatic ventilation is regulated via wind tower sensors.

These sensors track wind direction and alter ventilation holes to direct wind beneath the tower. The tower uses a high-temperature mist jet to humidify air and chill the ground floor (Nessim et al., 2023).

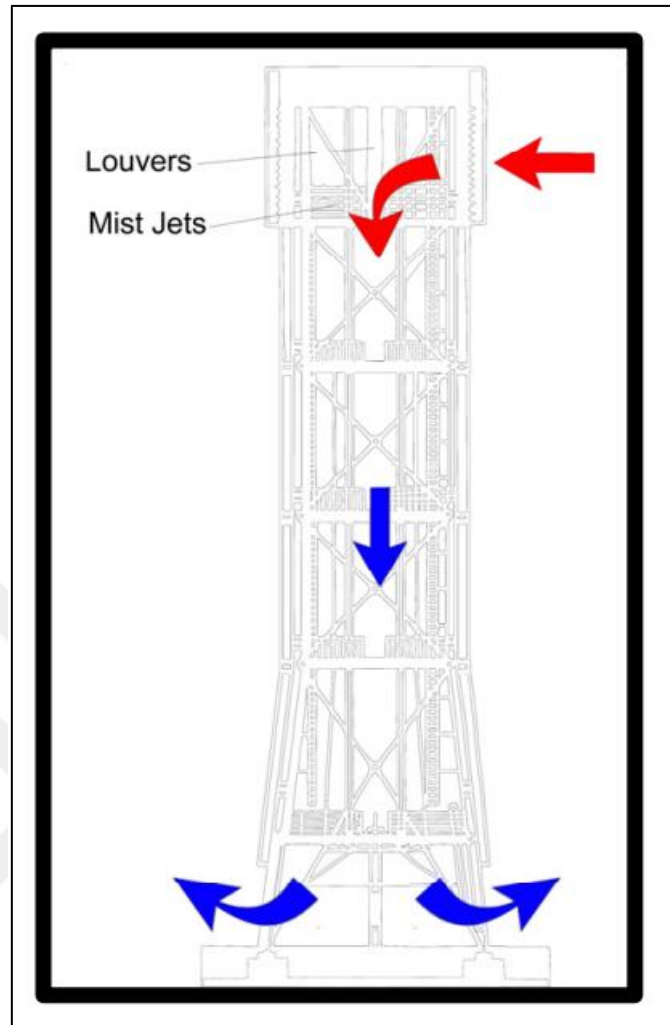


Figure 3.12: A Sketch via the Windcatcher that Illustrate its Performance, the red Arrow Indicates hot air, Whereas the Blue Ones Demonstrates that the air has Been Cooled (Nessim et al., 2023).

Qatar's 2022 FIFA World Cup Khalifa Stadium cools via windcatchers. Over 1 kilometre from the stadium, cooling towers house fans' regime. Pumping tower-cooled water into the stadium.



Figure 3.13: Wind Tower at Khalifa International Stadium (Nessim et al.,2023).

Khalifa International Stadium is the world's largest chilled outdoor stadium. In this building, an energy-saving technology was used. Urban refrigeration keeps players and spectators comfortable.

Energy centres one kilometre from the stadium allow this. A tube brings chilled water to this centre. Cooling water is pumped towards the stadium middle, playing field and sitting areas to reach 500 stand vents. Dense cool air blocks warm air near the ground (FanTR Khalifa Stadium,2023).Masdar City and Khalifa Stadium in Qatar use breakthrough wind tower technology to cool outdoor spaces in the Gulf, where wind is scarce and climate is harsh (Nessim et al.,2023).

3.1.2.4 Smart courtyards

Smart courtyards are an evolution of traditional courtyards, where airflow and light are controlled through smart sensor technologies. These technologies allow the courtyard openings to be adjusted according to climatic conditions to improve ventilation. (Agha, 2019).

Advances in material technology have contributed to improving the design of courtyards, as modern architecture relies on the use of innovative materials that are characterized by their ability to insulate, store heat, and then release it gradually. According to Bahadori (2018), materials such as thermal bricks as illustrated in Figure 3.14 and treated and sustainable wood are used to reduce heat absorption during the day and provide natural insulation at night.



Figure 3.14: Integrating Traditional Insulating Materials in Courtyard Design in Humid Hot Regions (Thomas Linger, 2014).

Double-glazed heat-insulating glass has also been developed, which reduces solar energy absorption, keeping the courtyard temperature stable (Bangre et al.,2023). One of the recent innovations in courtyard design is the integration of “green walls” and planted surfaces into the architectural design.



Figure 3.15: Integrating Green Walls into Courtyard Design (Biotechture, 2024).

Bandehali et al,(2021) indicate that plants used in green walls act as a natural insulator against heat and contribute to improving indoor air quality by reducing pollution and increasing humidity. The use of plants also helps cool the surrounding air through the process of evaporation, which reduces the high temperatures that characterize hot and humid areas.

Natural lighting plays an important role in the design of modern courtyards. Courtyards are designed to allow sunlight to enter the building but in a thoughtful way that protects against overheating.



Figure 3.16: Using Insulating Glass in Courtyard Design (Vkshomedecor, 2020).

With the development of engineering software, designers can now use advanced environmental simulation programs to evaluate the thermal performance of courtyards before they are built. Baker and Steemers (2019) indicate that modern simulation programs allow architects to analyze air movement, light distribution, and temperatures within the courtyard, which helps them improve the design to ensure maximum comfort for residents.

Recently introduced courtyard design in hot and humid climates combines technology with environmental sustainability. Smart control technology, natural cooling, and sustainable materials increase courtyards' environmental and thermal efficiency, reducing energy use and improving user comfort.

These innovations make courtyards an important part of contemporary architecture in hot and humid regions, where architectural design interacts with nature to provide a comfortable and sustainable living environment.

Tablada et al. (2005) evaluated two courtyard geometries' wind flow characteristics and indoor air speed using validated CFD calculations and wind tunnel observations and found that tropical courtyards are predominantly employed for ventilation.

Because simulations were isothermal, only wind drove them. Rao & Dua (2021) pointed to passive cooling methods for decreasing building heat gain, including courtyard ventilation. Two courtyards with W/H ratios of 0.33 and 0.66 are 9 m high by 3 m wide and 9 m by 6 m.

Three lines up to 2 meters within courtyard-facing rooms with open windows measured the average internal air speed. This average takes room occupancy into account. Figure 3.17 shows airflow in the two courtyards with differing aspect ratios.

Open windows in the tiny courtyard produce vortices that match the number of storeys. In the second courtyard, open windows have little effect on cavity airflow. The courtyard's core vortex remains unchanged. Figure 3.17 shows that room air speed values vary greatly between floors and rooms (Mishra & Kumar,2021).

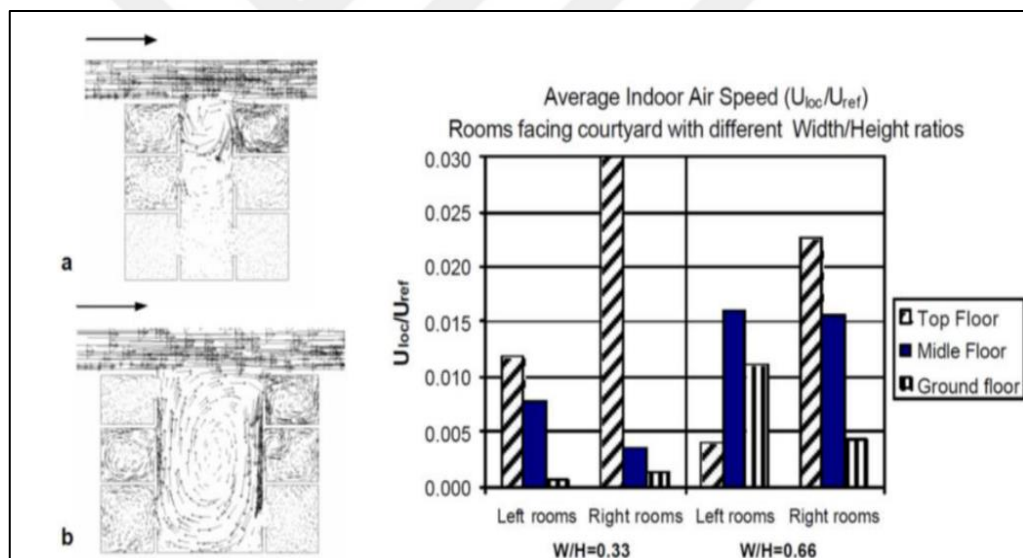


Figure 3.17: Average Indoor air Speed Given as U_{loc}/U_{ref} . U_{loc} = local air speed, U_{ref} = Reference air Speed at 10m height. The Values are Given for both Cavities Ratios, on the left: W/H = 0.33, on the right: W/H = 0.66 (Tablada et al.,2005).

The findings show that courtyard constructions, because to their flexibility, can passively maximise natural variables like sunlight and wind. In other climates, the amount of facade apertures affects interior ventilation.

3.1.2.5 Modern mashrabiya

Smart mashrabiya are an evolution of the traditional element, incorporating automated control techniques into the movement of decorative panels to adjust airflow according to the movement of the sun and temperatures. (El Semary et al., 2017).

Innovative mashrabiya with high-tech responsive systems are popular in modern architecture. Thus, many 21st-century mashrabiya are innovative. See several mashrabiya below:

In 1987, Jean Nouvel finished Paris' Institut Monde Arabe. The massive "mashrabiya" facade, 30m long and 80m wide, wonderfully blends modernity, technology, and Arabian architecture. Figures (3.18) show how these façades change daily and hourly to reflect changing conditions and demands.

In Figure 3.18, the institution describes radical high-tech walls with mechanical vents that narrow to reduce sun exposure or dilate to let daylight in (El Semary et al., 2017).

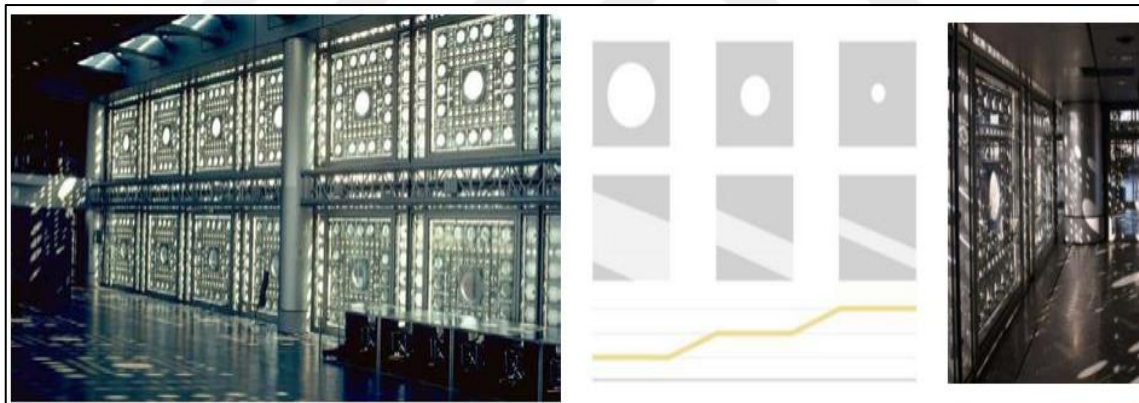


Figure 3.18: Mashrabiya of Institut du Monde Arabe Façade (El Semary et al., 2017).

Dynamic solar shading of the Kolding Campus responds to climate and user modes to maximise lighting and thermal comfort along the façade.



Figure 3.19: Mashrabya Façade of SDU Kolding Campus (El Semary et al., 2017).

Innovated mashrabya with high-tech daylight reactive regimes present an intelligent resolution for numerous ecological & aesthetic considerations. Future researchers should begin concentrating on the innovated mashrabya.

Mashrabya influences hot-climate building interiors, Bagasi & Calauti (2020) found. The Baeshen House, Jeddah's oldest Mashrabiya, is used in this study. In two identical rooms (one open Mashrabiya and one close) in the building, we measured air temperature, relative humidity, globe temperature, and air velocity in typical hot summer conditions when the afternoon outdoor temperature was 40-41.6 °C.

The Mashrabiya used thermal mass, water pots, water spray, and cloth for passive/evaporative cooling. The results showed that the closed Mashrabiya reduced afternoon hot air flow into rooms, maintaining 35.4-35.8 °C indoor temperatures.



Figure 3.20: Different Model Configurations of Passive Cooling Strategies with the Mashrabiya.

Bagasi & Calauti (2020) examined Mashrabiya's interior effects in a hot-region traditional dwelling. A Mashrabiya-filled Saudi house block is an example. The building's two identical rooms—one open Mashrabiya and one close—were monitored for internal temperature, humidity, outside temperature, and air velocity during typical hot summer circumstances when the afternoon outdoor temperature was 40-41.6 degrees. Mashrabiya cooled evaporatively with thermal mass, water pots, spray, and cloth. Mashrabiya shutters kept inside temperatures at 35.4-35.8 ° C in the afternoon.

It was revealed that the most efficient technique was the utilization of wetted cloth beside the Mashrabiya inlet to reduce air temperature indoor.

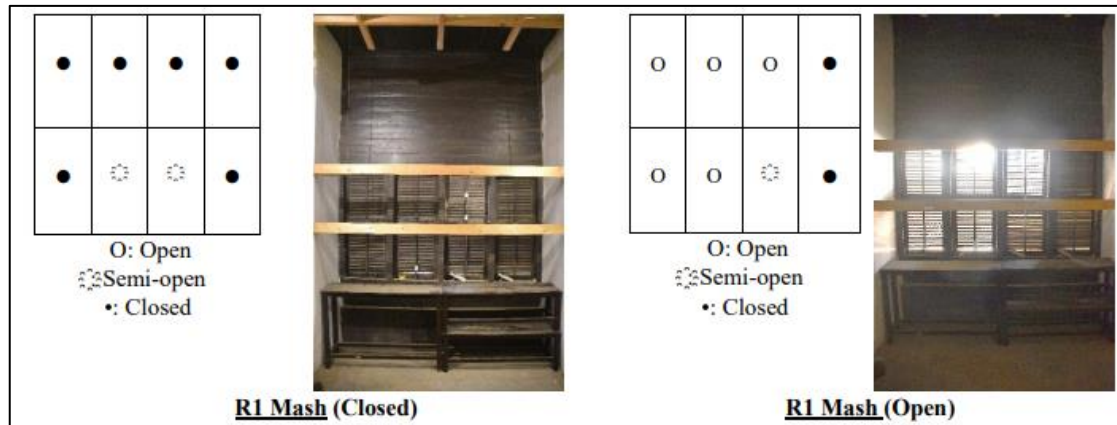


Figure 3.21: Integrating evaporative cooling with mashrabya (Bagasi, & Calauti, 2020).

3.1.2.6 Innovated water wall

This technology relies on the use of smart electric pumps to improve water distribution and provide more effective cooling (Santamouris, 2016). This innovation enhances cooling performance but increases the complexity and maintenance of the system.

Sunspace and water wall are direct and indirect attain regimes, respectively. In a single-story residential building, Yadav and Tiwari (1988) performed a transient analysis of an opaque water wall between the sunspace and living space. The living room temperature decreased significantly when the water wall was integrated with the sunspace and as water wall thickness increased.

Four models in two containers were examined by Sánchez-Ostiz et al. (2014) to estimate the thermal performance of a sunspace with water for thermal energy storage TES sunspaces with water boosted the adjacent room's thermal comfort in winter and summer. Experimental results validated TRNSYS numerical model. Wu & Lei (2016) found TRNSYS numerical model matched experimental data.

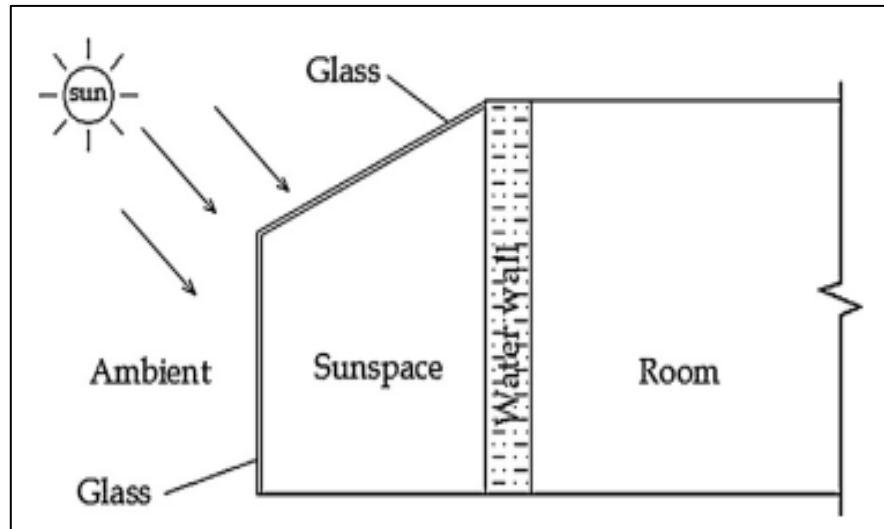


Figure 3.22: Integration Water wall with Sunspace (Wu & Lei, 2016).

Solar chimney passively improves stack-driven ventilation (buoyancy, 2011). A water wall (Figure 21) should increase nighttime ventilation in the solar chimney.

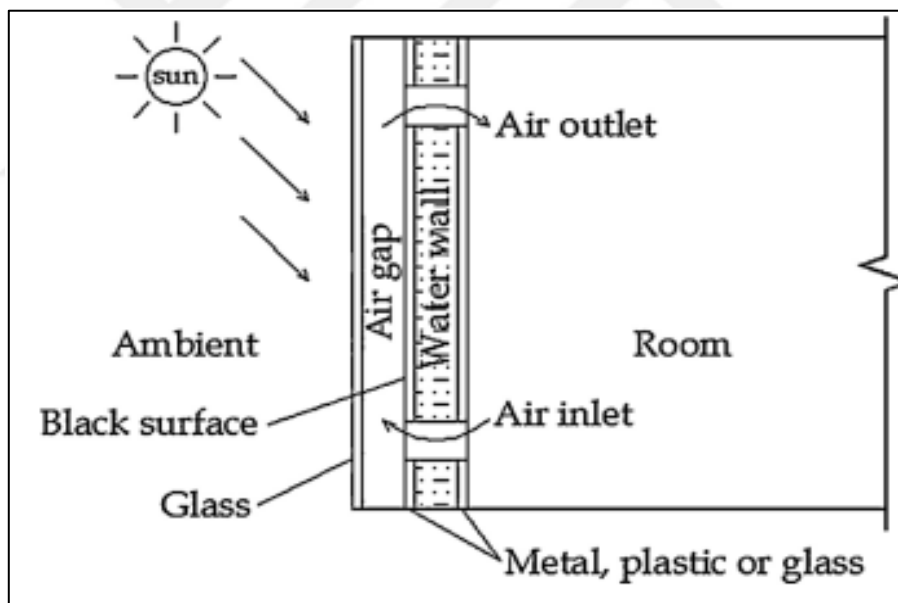


Figure 3.23: Sketch of a Water wall with Solar (Wu & Lei, 2016).

Water walls and natural ventilation reduce heating and cooling. Passive systems can lower indoor temperatures by 4°C in summer and raise them by 3°C in winter compared to massless walls (Wu & Lei, 2016).

3.1.2.7 Stepped roof design

This strategy is based on designing roofs in the form of multi-level steps or platforms. This type of design allows hot air to be directed upwards and out easily, creating a natural air flow and reducing indoor temperatures. The stepped roof design is an architectural innovation that combines aesthetics and ventilation efficiency (Mahmoud & Ismaeel, 2019).



Figure 3.24: Stepped Roof Design (Vroque, 2024).

This design is characterized by the use of ventilation openings distributed at different heights inside the building. These openings help achieve vertical air flow, as cold air enters from the lower openings and hot air exits from the upper openings. This innovation helps enhance air flow and reduce temperature without the need for air conditioning (Wahab et al., 2016)

3.1.2.8 Double skin facades

Modern architectural design advancements include this strategy. The design uses two exterior and internal faces with an air-flow area between them. Allowing air to circulate freely and reducing external heat impact improves building ventilation. Indoor air quality and heat reduction are greatly improved by double walls (Wang et al., 2020).

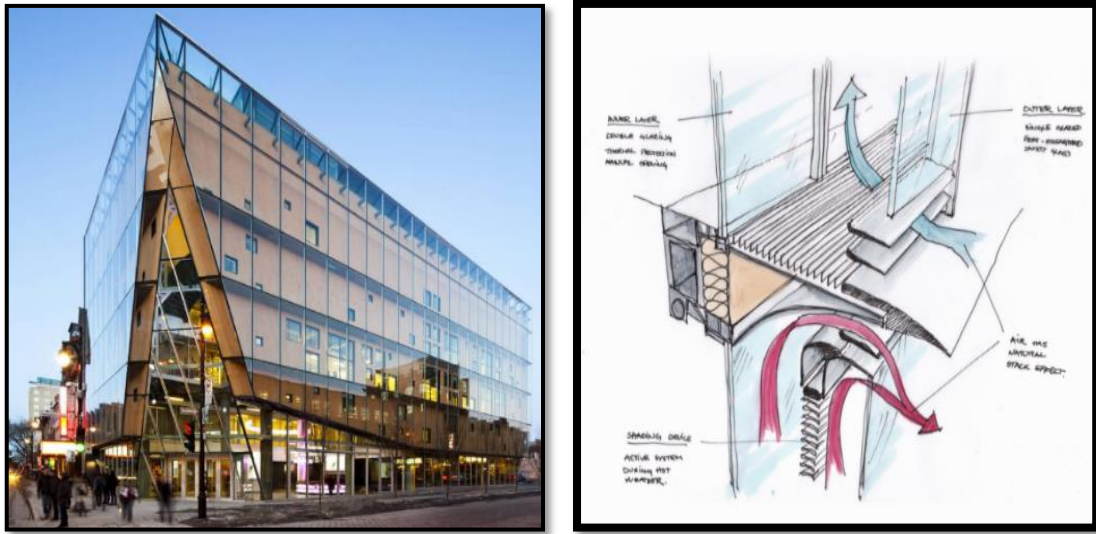


Figure 3.25: Double Skin Façade Greg (2022).

3.2 SHADING SYSTEMS

3.2.1 Traditional Shading Strategies for Residential Buildings in Hot and Humid Regions

- a. Interior courtyards: Traditional building designs in hot, humid regions rely on open courtyards that provide shade and direct air towards the interior areas, which contributes to reducing indoor temperatures and enhancing thermal comfort (Halawa et al., 2018).
- b. Mashrabiya: Mashrabiya are a popular traditional system that provides shade and allows natural ventilation without exposure to direct sunlight, thus contributing to reducing heat gain inside buildings (Radhi, Sharples & Fikiry, 2013).
- c. Trees and plants: Trees and plants surrounding buildings are used to provide shade and mitigate the effect of heat through the evaporation process, which improves thermal comfort in homes (Qahtan, 2019).
- d. Arches & Balconies: Arches provide additional shading and reduce exposure of walls to direct sunlight, while balconies help protect windows from the sun (Halawa et al., 2018).

3.2.2 Innovated Shading Strategies for Residential Buildings in Hot and Humid Regions

Double facade systems rely on separating the building facade with two layers of glass, between which there is an air gap that reduces heat transfer to the interior, reducing reliance on mechanical air conditioning (Ghaffarian hoseini et al., 2016). This system provides dynamic control over airflow and light quantity, which enhances energy efficiency (Kim et al., 2009).



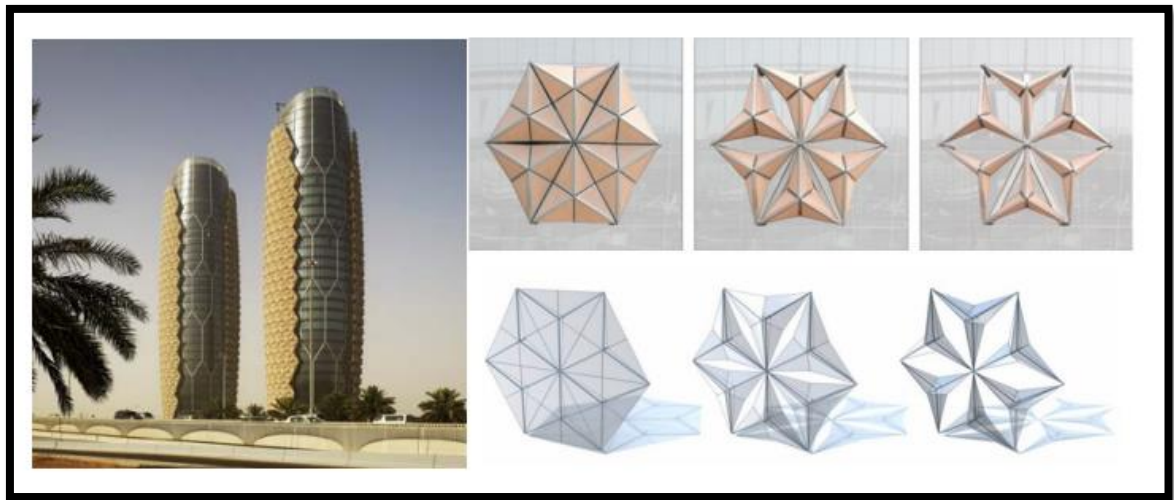
Figure 3.26: Double Facades (Arch Daily, nd).

Smart blinds use sensors to adjust shading based on the angle of the sun's incidence, reducing unwanted heat gain and maintaining comfortable temperatures inside buildings (Shameri et al., 2013).



Figure 3.27: Smart Blinds (GEEKS,nd).

The UAE has been able to use a very modern shading technique, as it has used the movable decorative mashrabiya that surrounds the building in the presence of solar radiation and is removed according to a dynamic mechanism in the absence of solar radiation. It has also been able to integrate traditional heat-insulating materials such as clay into the design of the mashrabiya to act as a shading and heat-insulating device at the same time, in addition to the aesthetic aspect.



(a) Mashrabiya Tower



(b) Terracotta Mashrabiya

Figure 3.28: Mashrabiya Tower in Abu Dhabi (Akçay & Alotman,2017).

3.3 MATERIALS

3.3.1 Traditional Cladding Materials to Achieve Thermal Comfort

In hot and humid regions, traditional materials adapted to harsh climatic conditions are used to achieve thermal comfort, such as clay, stone and wood. Clay, for example, is widely used because of its high ability to absorb heat during the day and cool the air at night, reducing the impact of high temperatures on the interior. Stone, on the other hand, acts as a natural insulator due to its high density, reducing heat absorption during the day and increasing thermal sustainability at night. Also, white and smooth surfaces reduce the absorption of

direct sunlight, while wood is often used to cover windows or external walls to prevent the flow of hot air (Toris-Guitron et al.,2022),(Shaeri et al.,2018)



Figure 3.29: Traditional Materials in Architecture to Achieve Thermal Comfort (clay works, nd).

3.3.2 Modern Cladding Materials to Achieve Thermal Comfort

Modern materials use advanced technologies to improve thermal insulation and limit heat transfer. Insulating materials like polystyrene minimise interior-exterior heat exchange. Double or reflective glass minimises solar radiation absorption, reducing air conditioning needs. Green roofs (planted roofs) absorb solar radiation and transform it into plant evaporation, cooling buildings and boosting thermal comfort. Solar panels and smart energy management systems store solar energy to power air conditioning systems, reducing cooling energy use. Multi-layer insulating materials with air-tight technology improve building thermal sustainability and maintain appropriate temperatures.(2019, Lotfabadi & Hançer).

3.4 COMPARATIVE STUDY BETWEEN INNOVATED AND TRADITIONAL PASSIVE COOLING STRATEGIES FOR RESIDENTIAL BUILDINGS IN HOT AND HUMID REGIONS

After the literature review conducted that addressed traditional and innovated passive design cooling in hot humid regions, Table 3.4 have been developed to shows Comparison Between Innovated and traditional passive cooling strategies in humid hot Regions

Table 3.4: Comparison Between Innovated and Traditional Passive Cooling Strategies in Humid hot Regions.

Strategy	-Traditional Technique	Innovated technique
Shading	-Use large balconies and umbrellas. - Use light colors to reflect sunlight. -using eaves and balconies -high trees -using wooden mashrabya	- Movable shading systems that can be adjusted according to the sun angle.. -integrating mashrabya with isolation materials or sensors adjusted with sun light -double reflective glazing
Cross Ventilation	Opposite vents to facilitate airflow through the building.	Adjustable windows for better airflow.
Stack Ventilation	- Use open spaces with high ceilings to encourage the rise of hot air.	- Vertical air extractors to extract hot air. - Natural ventilation systems combined with simple mechanical technology to improve efficiency. -using inclined roofs or stepped roofs with multiple upper openings in addition to lower openings

Table 3.4: Comparison Between Innovated and Traditional Passive Cooling Strategies in Humid hot Regions (Table Continued).

Evaporative cooling	- Relying on water bodies such as fountains and swimming pools to cool the surrounding air.	Integrating vegetation with water bodies and using aquatic plants to improve evaporative cooling Integrating vegetation with water bodies and using aquatic plants to improve evaporative cooling - Integrated evaporation systems in facades and natural ventilation -water walls
Facades	Use of traditional dense building materials to provide thermal insulation such as bricks, stones and clay.	- Use of double facades with air gap for thermal insulation and improved ventilation. -use of mashrabiyas and reflective colored glass adjusted with climatic conditions using sensors -adopting dynamic mashrabya with sensors according to the sun light
Roofs	- High ceilings that enhance the upward movement of hot air or domes - Using white ceilings to reflect sunlight	-High ceilings integrated with upper and lower vent openings applying cross and stack ventilation. - Green roofs covered with plants to provide natural thermal insulation. - Using modern reflective materials that improve the thermal performance of roofs while preserving the environment
walls	-Thick brick or stone walls to provide thermal insulation.	- Use of modern insulating building materials such as sandwich panels and double walls. -water walls -green walls

Table 3.4: Comparison Between Innovated and Traditional Passive Cooling Strategies in Humid hot Regions (Table Continued).

Interior courtyard	-An open interior courtyard promotes natural ventilation and reduces the impact of heat.	-integrating interior courtyard with ponds ,vegetations, and water plants -integrating reflective glazing, high roofs ,multiple openings -using trees -using green walls in court yards -using water walls -using traditional materials as mud and stones -adopting high roofs with natural ventilation facades
Mashrabya	Wooden mashrabya used as shading device	-integrating traditional mashrabya with sensors that open and close according solar radiant -using traditional materials in Mashrabya design for thermal insulation in addition to shading - integrating evaporative cooling with mashrabya using wet blinds
Water wall	the traditional wall is covered with opaque materials	-Wall with sun space and glazing : integrating water wall with the sunspace and glazing lead to great minimization of the temperature in the living room and the temperature reduces while increasing water wall thickness. - integrating water wall with solar chimney that adopts air gap between glazing layer facing the sun and water wall with natural ventilation using upper and lower \ openings

4. PROGRESSION OF ARCHITECTURAL DESIGN of RESIDENTIAL BUILDINGS IN ABU DHABI

4.1 ARCHITECTURAL DESIGN PROGRESSION OF RESIDENTIAL BUILDINGS IN ABU DHABI (FROM OIL DISCOVERY PERIOD UNTIL PRESENT)

Since the second half of the 20th century, Abu Dhabi's residential architecture has developed rapidly due to economic, social, environmental, and climatic concerns. We discuss residential building design stages, focussing on thermal comfort and sustainability.

4.1.1 The Traditional Stage Before the Discovery Of Oil

In the early twentieth century and until the discovery of oil in the 1950s, residential buildings in Abu Dhabi relied on the traditional architectural style, which aimed to withstand harsh environmental conditions. The materials used were local materials such as clay, plaster and coral stone, and the construction took into account natural ventilation and thermal insulation using elements such as courtyards, thick walls, and small doors and windows to reduce the buildings' exposure to high temperatures.

Traditional building designs also aimed to provide spaces for social interaction inside the home while maintaining privacy (Abu Dhabi Culture, 2023).

4.1.2 The post-oil Discovery Stage (1960s and 1970s)

After the discovery of oil in the 1950s, the pace of urban change in Abu Dhabi accelerated, as the city began to transform from a small coastal village into a modern capital. The urban plans overseen by Sheikh Zayed bin Sultan Al Nahyan aimed to achieve rapid architectural development to suit the population expansion. During this period, modern residential buildings emerged using materials such as reinforced concrete and glass.

Residential building designs during this period were larger and more comfortable, with air conditioning systems being an essential part of the design to provide thermal comfort in the hot, humid climate. Examples of this period include housing projects targeting local families in new neighborhoods that were built in a modern style away from traditionalism (Elsheshtawy, 2004).

4.1.3 The Shift to Postmodern Architecture (1990s - 2000s)

In the 1990s, Abu Dhabi witnessed a greater shift towards skyscrapers and luxury residential complexes. This was part of the city's vision to enhance its global status, as residential building designs began to combine modern aesthetics with functionality.

The use of glass, steel, and distinctive visual elements were prominent features of this period, with large residential towers, such as the Etihad Towers, becoming a symbol of Abu Dhabi's economic growth and modern power (Elsheshtawy, 2019).



Figure 4.1: Etihad Tower (Bayut, nd).

4.1.4 Sustainable Design and Thermal Comfort (2010-present)

With the onset of the 21st century, Abu Dhabi began to adopt sustainable architectural strategies, especially in the field of residential buildings. The trend towards environmental

sustainability was a result of global concern for the environment, as well as the climate challenges in the region.

The architectural design of residential buildings in Abu Dhabi has witnessed a remarkable development since 2010 until now, driven by the urban renaissance and technological developments in the Emirates.

The architectural design revolved around mega projects oriented towards luxury, such as the Marina Towers, using modern technologies and increasing heights to meet the growing demand for housing.

The designs focused on a modern appearance, relying on glass and steel to create modern facades and provide panoramic views. Residential buildings that partially take the environment into account have also emerged, applying sustainability standards to reduce energy consumption.

The importance of sustainability in architectural designs has also increased, driven by Abu Dhabi Vision 2030, which seeks to transform the emirate into a smart and sustainable city.

The use of sustainable architectural designs has spread, such as solar energy systems. Many residential communities have been designed that focus on improving the quality of life through open green spaces, and interest in providing services close to residents. After 2020, the importance of smart design has increased with the emergence of the concept of smart homes and the reliance on Internet of Things technologies to provide integrated and modern residential environments.

After the Corona pandemic, new designs focused on flexibility, taking into account work spaces from home, in addition to wider and more ventilated living spaces.

More sustainable concepts such as highly water and energy efficient buildings have been incorporated, providing environmentally friendly urban solutions that meet the needs of population growth.

A prominent example from this period is the Masdar City project, which is a model for sustainability in the Arab world. This project focuses on residential buildings that rely on solar energy and natural cooling technology. Modern residential buildings in Abu Dhabi are

now designed to achieve thermal comfort adopting thermal insulation systems and natural ventilation techniques (Boussabaine, 2019) in addition to electrical air conditioning.



Figure 4.2: Residential Buildings in Masdar city (Building design and construction, 2015).

4.2 THE CURRENT EVALUATION OF THERMAL COMFORT OF RESIDENTIAL BUILDINGS IN ABU DHABI

In order to evaluate the current climatic conditions and thermal comfort of residential buildings in Abu Dhabi, survey questionnaire has been developed targeting 100 residents from different areas in Abu Dhabi. Also, the surveying study contains information of that can give perception of how extent resident in Abu Dhabi feels during months of summer and whether their residential buildings achieves thermal comfort during summer

When residents in the buildings selected through the survey were asked about thermal comfort inside their buildings in the summer, all residents responded that they suffer from heat in the summer, especially in the summer months of July, August, and September, as they cannot feel thermal comfort without operating the electric air conditioner in which all residents evaluated thermal comfort sensation indoor their buildings that is hot.

Also, the surveying study comprised evaluation the condition of Humidity during summer season and most of residents affirmed that they are suffering from very humid weather since

the residential buildings live in are located very near from coast. The results of questionnaire are illustrated as the following:

The first part of questionnaire included asking the respondents on their age and the Residential area

Figure 4.3 shows the percentages of respondents according to their age .It can be noted that the residents of ABU Dhabi from different ages.

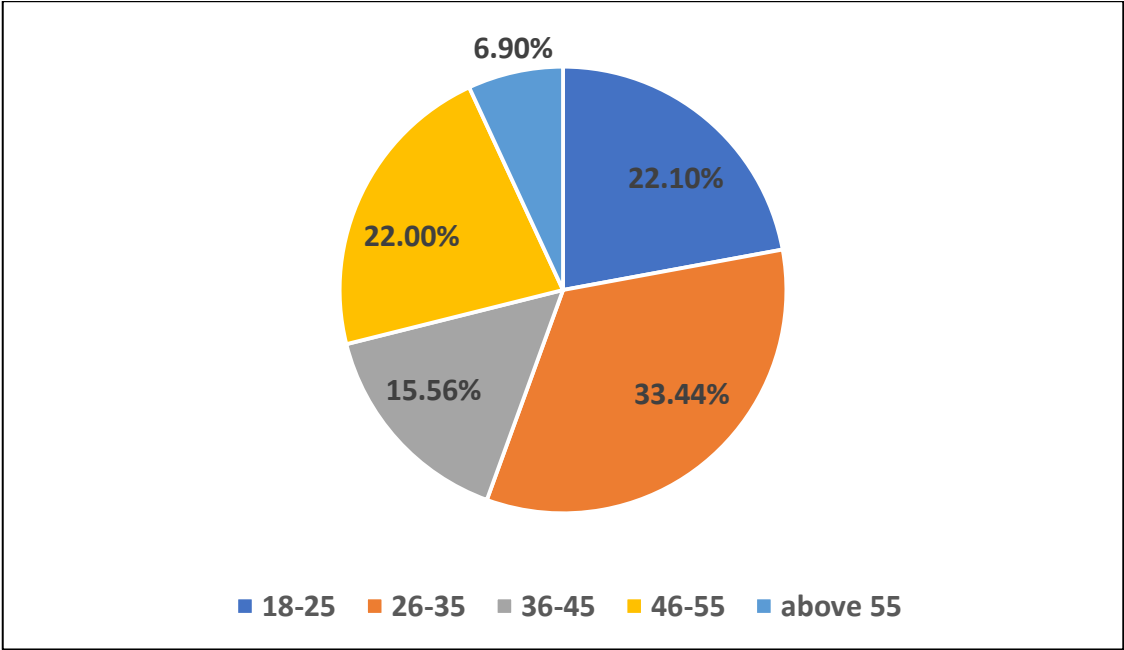


Figure 4.3: Percentages of Respondents According to Their Age.

Figure 4.4 displays the percentages of respondents according to their residential area .It can be noted that respondents targeted lives in different regions near coast line, these residential areas in Summer are considered humid hot regions

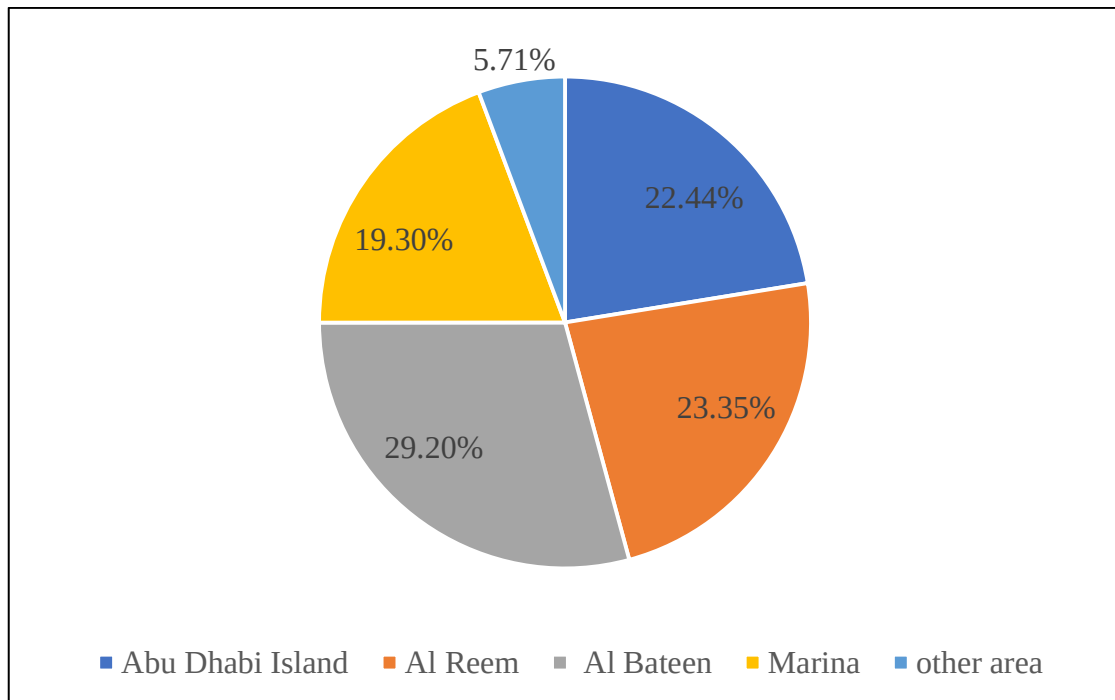


Figure 4.4: Percentages of Respondents According to Their Residential.

The second part of questionnaire includes characteristics of the residential building. Figure 4.5 shows type of accommodation. It can be noted that 52.2% of respondents live in villa and 23.4% lives in detached house while 15% lives in an Apartment.

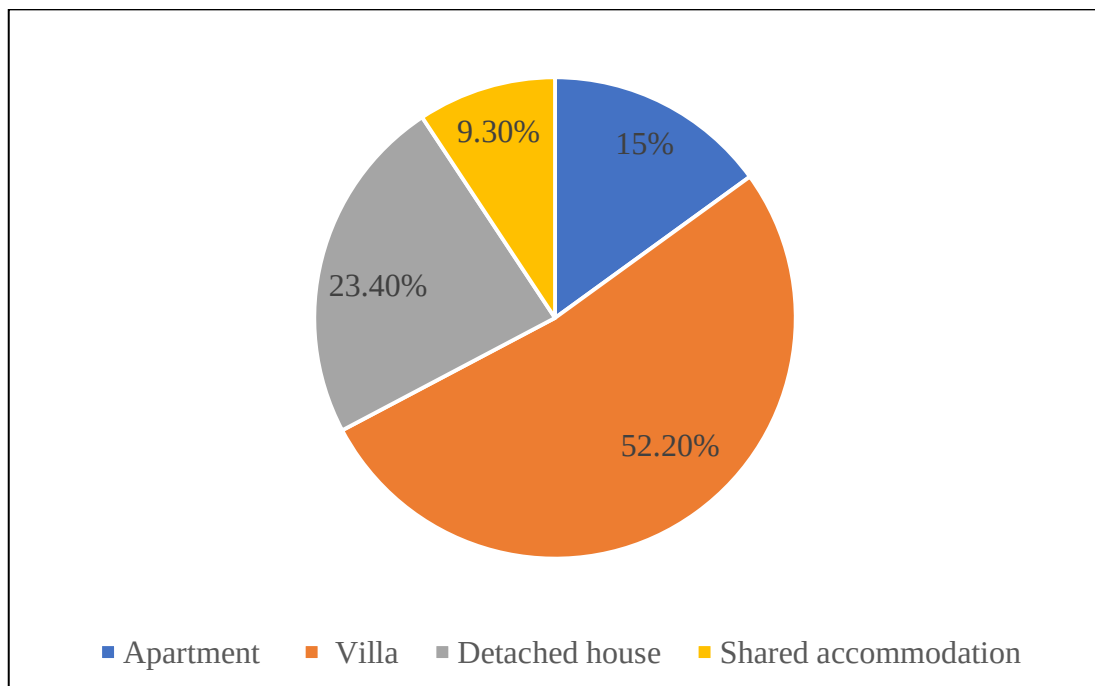


Figure 4.5: Percentages of Respondents According to the Type of Accommodation.

Figure 4.6 illustrates whether residential buildings contain air conditioning or not. Figure 4.6 depicts that 95.2% of respondents use electrical air conditioning in the accommodation.

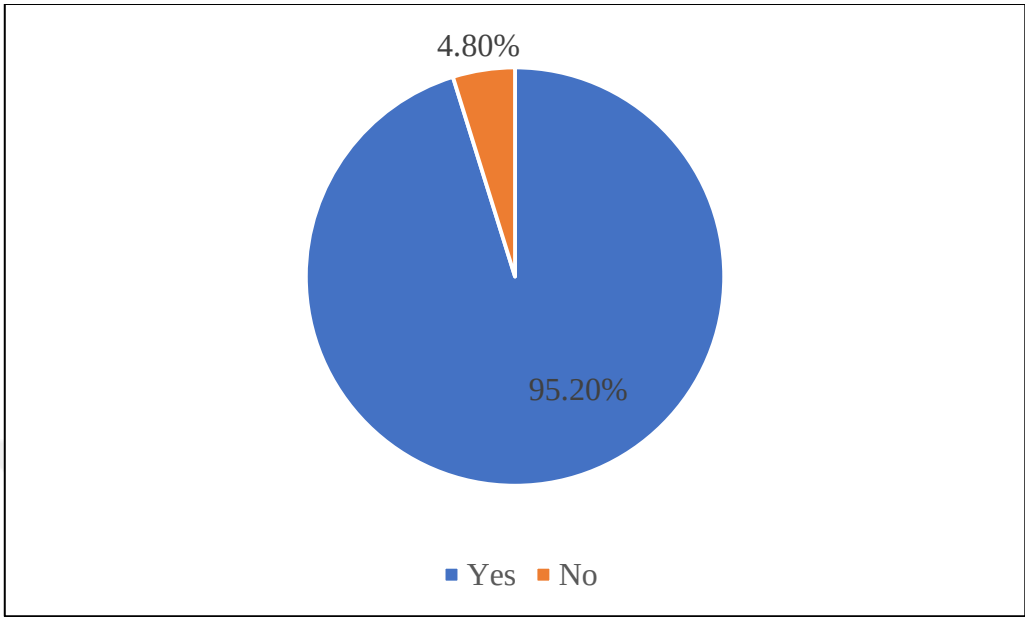


Figure 4.6: Percentages of Respondent of Using Electrical air Conditioning.

Figure 4.7 depicts whether residential buildings contain air natural ventilation. Figure 4.7 depicts that 52.3% of respondents says that their residential buildings have adequate natural ventilation while 31.4% says that their buildings have openings and windows to some extent

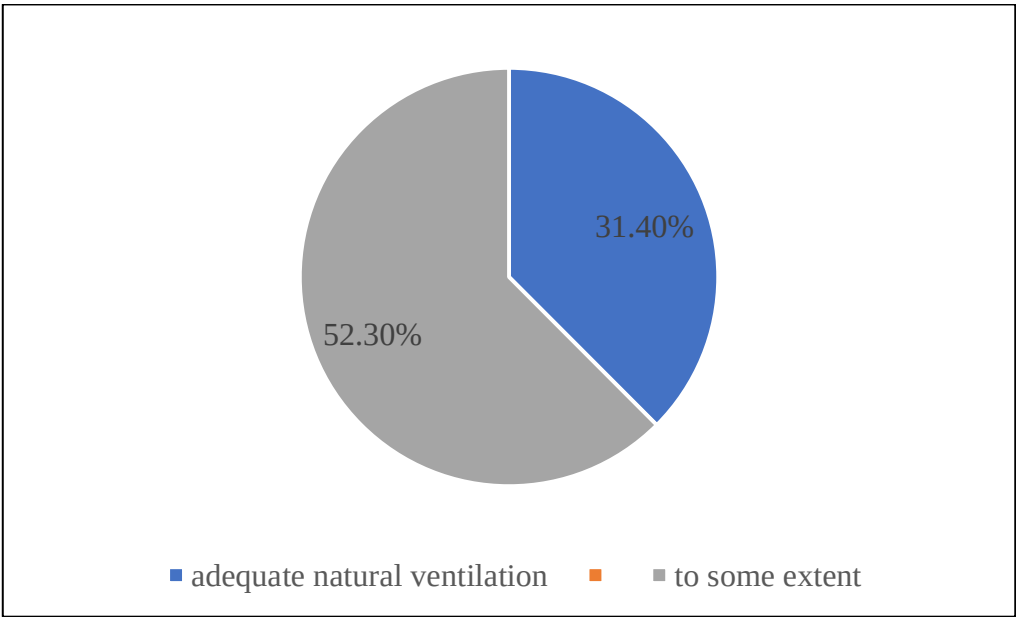


Figure 4.7: Percentages of Buildings that Contains Natural Ventilation.

The results of survey questionnaire reveals that the residents in Abu Dhabi don't receive thermal comfort in their residential buildings and most of them complains from humidity .Also, most respondent feels very hot indoor their buildings during day in summer and feel slightly hot during night .In addition huge percentages of respondents uses electrical air conditioning to achieve thermal comfort which leads to energy consumption and high costs.

In order to investigate causes behind a huge humidity and lack of thermal comfort indoor residential Buildings, surveying study had been conducted to evaluate how extent the passive cooling design strategies are applied in residential buildings of Abu Dhabi .30 villas have been selected for evaluation process .the villas selected are situated in different areas in Abu Dhabi. Thermal comfort assessment is addressed in part three where the respondent were asked the level of thermal comfort in their accommodation during the summer without operating air conditioning as illustrated in Figure 4.8.It can be noted that 75% of respondent feels very uncomfortable in their residential buildings due to elevated temperatures and 22.3% feel uncomfortable .

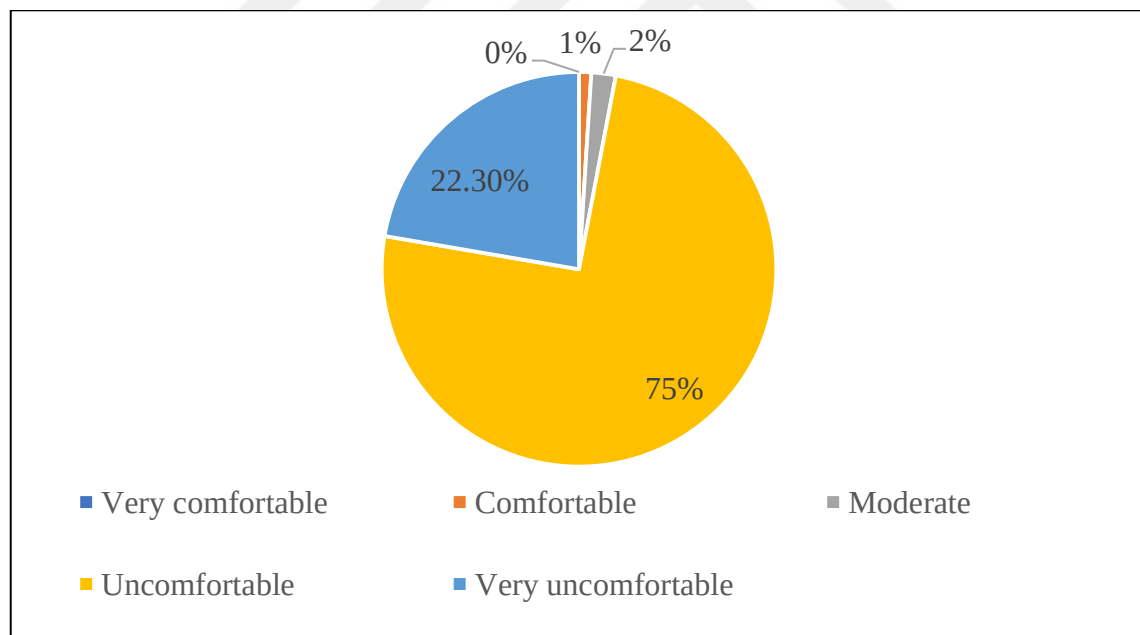


Figure 4.8: Thermal Comfort Assessment.

Figure 4.9 displays how respondents feel the temperature inside their homes during the day in the summer without operating air conditioning. It can be noted the respondents suffer from elevated temperature indoor the building in which the respondents almost feel very hot during a day .

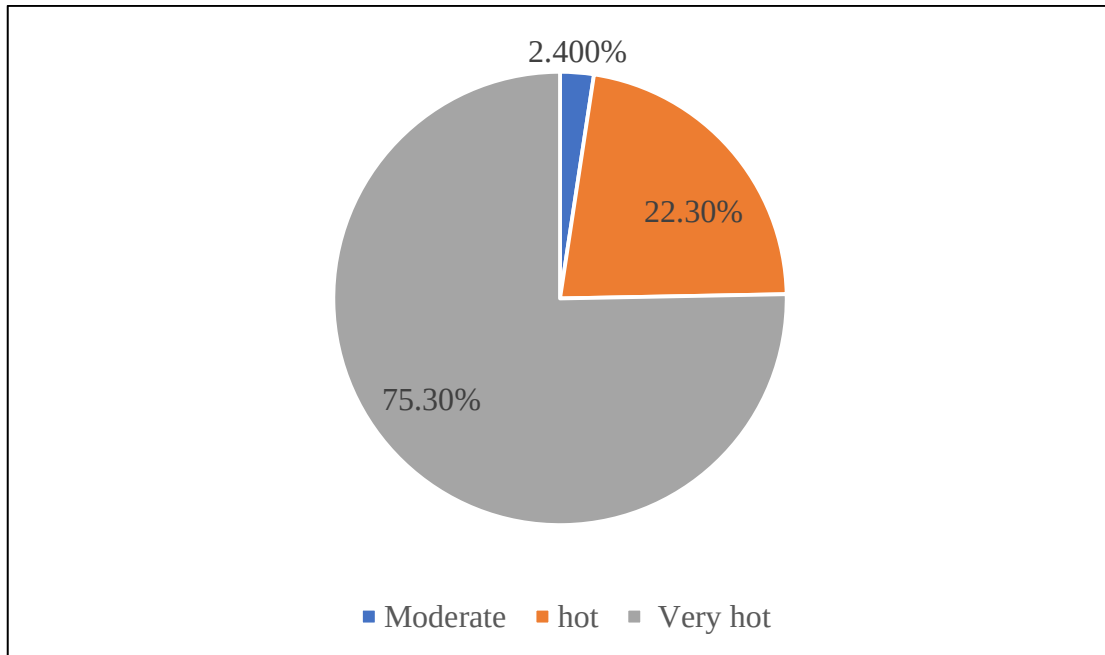


Figure 4.9: The Temperature Inside Respondents' Homes During the day in the Summer.

Figure 4.10 shows how respondents feel the temperature inside their homes during the night in the summer without operating air conditioning. It can be noted the respondents suffer from elevated temperature indoor the building in which the respondents who feel a slightly hot during a night are 79.3 % while the respondents who feel a hot during a night are 19.7 %

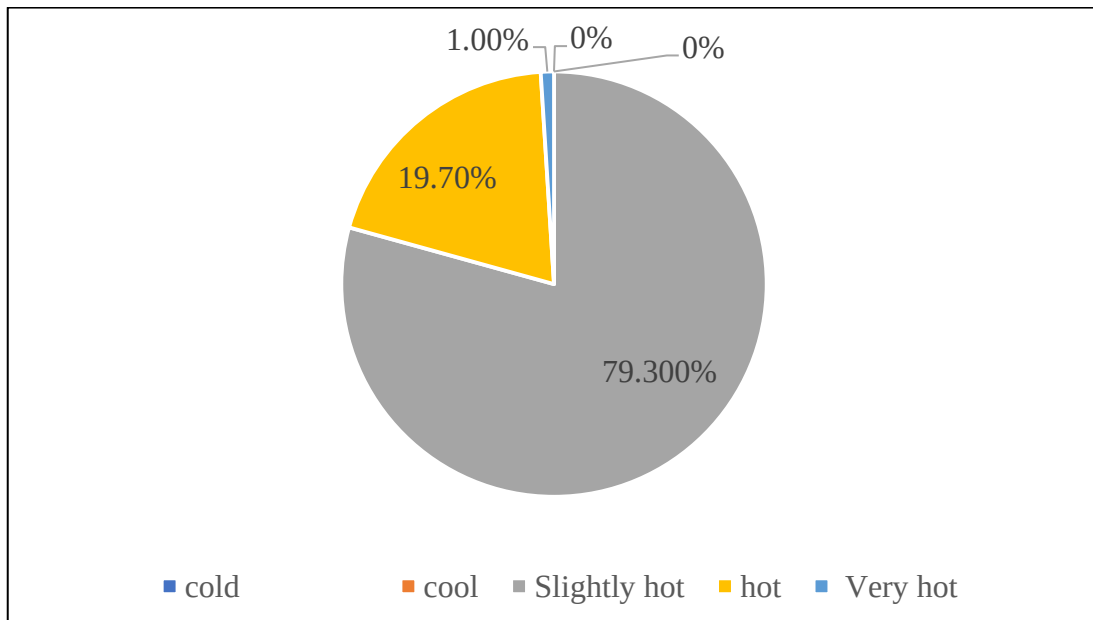


Figure 4.10: The Temperature Inside Respondent's Homes During the Night in the Summerpart four of Questionnaire Comprise Humidity Assessment of Residential Buildings in Abu Dhabi.

Figure 4.11 Evaluates humidity level of residential buildings in Humid Hot regions.

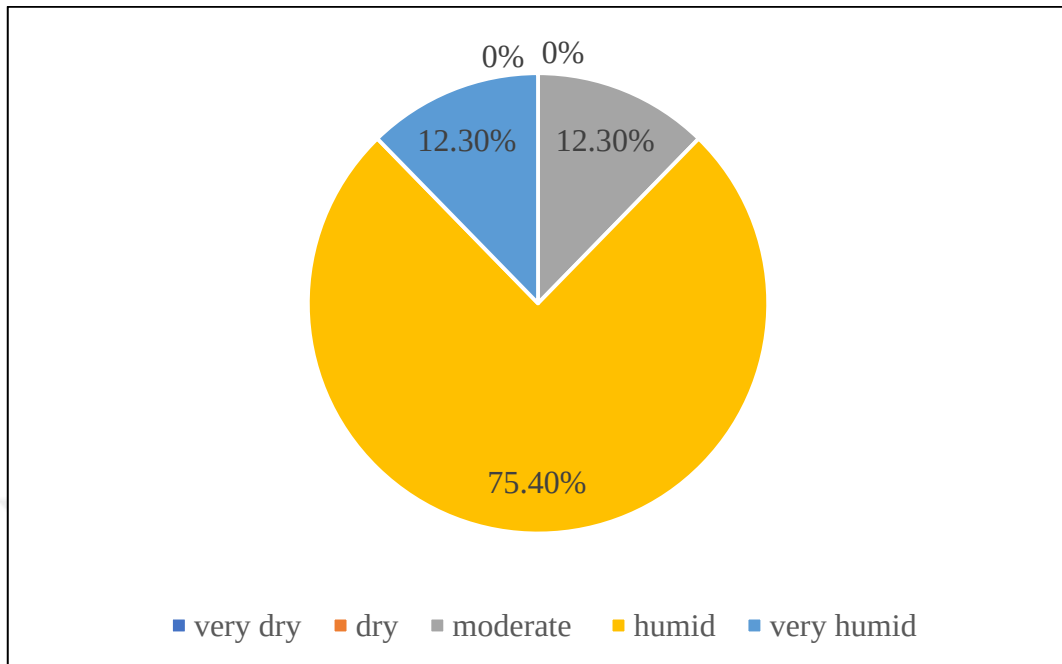


Figure 4.11: Humidity Level of Residential Buildings in Humid Hot Regions.

It can be noted that 75.4% of respondents suffer from humidity in humid hot regions which indicated that there is a significant humidity inside the residential buildings.

4.3 INVESTIGATION PROCESS OF PASSIVE COOLING DESIGN STRATEGIES IN ABU DHABI

Table 4.1: Definition 30 Residential Buildings in ABU DHABI According to Passive Cooling Design.

P a s s i v e c o o l i n g s t r a t e g y	o p t i o n s	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
R o o f t y p e	- g r e e n r o o f - c o o l r o o f w i t h l i g h t p a i n t	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	S P F	
I n t e r c o u r t y a r d	- p l a n t - p o n d	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
E v a p o r a t i v e c o o l i n g	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table 4.2: Definition 30 Residential Buildings in ABU DHABI According to Passive Cooling Design (Table Continued).

Cross ventilation	opposite windows large openings	√	√	√	√	√	√	√	x	x	x	x	x	x	x	x	√	√	√	x	x	x	x	√	√	√	√	√	√	√
Stack ventilation	- inclined roof with openings - stepped roofs with openings	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Construction materials	- mud-stone	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cladding materials	- reflective paint - brick - wood - stone - reflective glazing - smart blinds	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
walls	- mud walls - green walls - double skin walls	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table 4.3: Definition 30 Residential Buildings in ABU DHABI According to Passive Cooling Design (Table Continued).

[illegible]

Table 4.1 shows that there is a lack in adopting passive cooling design strategies in humid hot regions .Via the conducting a site visits for these buildings , it was noted that the construction material used are concrete and hollow concrete blocks and these materials aren't efficient for thermal insulation .As for shadings, it wasn't notices any traditional or innovated shading devices as eaves, arches, trees ,balconies , mashrabyas or any smart shading .As for glazing all buildings studied equipped with double glazing that is efficient to reduce temperature indoor. Cladding materials used aren't efficient to achieve thermal comfort or to reduce temperature .As for roof for all buildings investigated, it is reinforced concrete slab isolated with SPF and painted with white paint.Walls are double skin of hollow concrete isolate with polyetheren and air gap.As for natural ventilation , only cross ventilation and one sided ventilation had been noticed .It wasn't noticed courtyard indoor the building equipped by pond and water plant. Also, the courtyards outdoor the buildings are free of land escaping, trees, waterbodies and water plants.

According to the investigation process of the selected building , the following chapter will adopt case study in order to measure the indoor and outdoor temperature of the building and then shows the lack and limitation in applying passive cooling strategies and suggest traditional and innovated passive cooling strategies to enhance thermal comfort indoor the building

5. ENHANCING PASSIVE COOLING DESIGN OF RESIDENTIAL BUILDINGS

5.1 LOCATION OF THE CASE STUDY SELECTED

case study presents residential building in Khalifa city in Abu Dhabi , that are located along the coastal line that is characterize in humid hot climate in which Figure 5.1 indicates the location of khalifa city using Google earth and Figure 5.2 illustrates the distance of Khalifa city from the coast line .



Figure 5.1: Location of Selected Case Study.

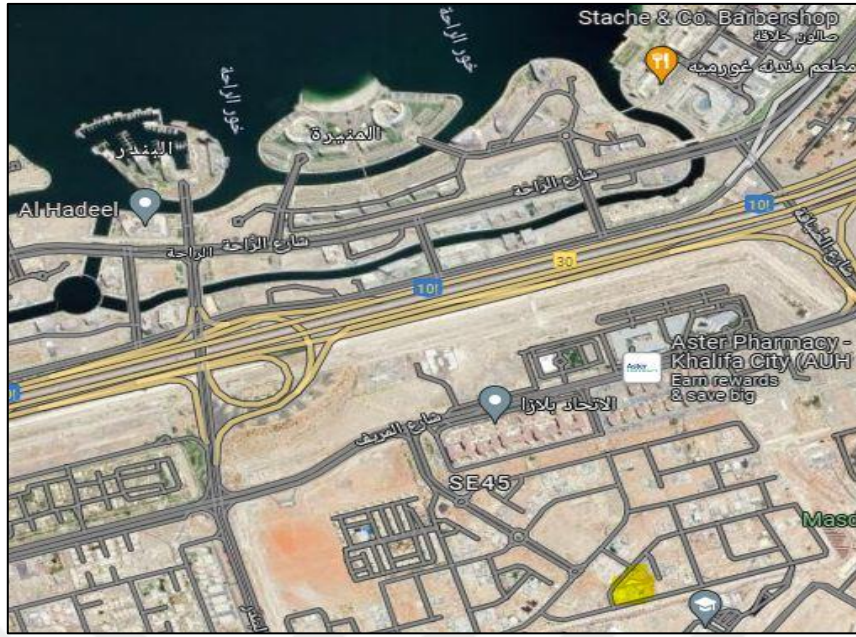


Figure 5.2: Location of the Selected Case Study in Relation to the Coast.

Abu Dhabi residential structures were built and rehabilitated according to Estidamah code, although passive cooling measures must be studied to lower summer warmth and humidity. So, this study investigates whether current passive cooling solutions are effective for thermal comfort. This study also identifies residential building strategy weaknesses. This study also proposes the most effective thermal comfort measures to lower temperature and humidity in residential structures. A good research approach is needed to analyse such a condition and discover such issues through the selected case study. It's easy to spot the study gap by observing what makes present residential buildings thermally uncomfortable. The research purpose, knowledge concerns, researcher practice standards, and other useful contributions on the topic determine the main study approach (Buchanan & Bryman, 2007).

5.2 STUDY METHOD

The utilization of both qualitative and quantitative methods is integrated in this research. The quantitative methodologies are utilized to compute the indoor temperature, outdoor temperature and survey questionnaire, humidity while qualitative analysis using literature review based on tables, figures, web sites, journals and publications was utilized to identify efficiency of suggested thermal comfort strategies in addition qualitative study approach utilized to gather more data as literature study to enhance design strategies of the current

UAE residential building, to gather residents' views over the thermal comfort experience with their residential building. It motivates the integration of quantitative and qualitative methods to detect the set of facts that may be verified utilizing several kinds of investigations, while also approving and considering all findings on the critical factors for the information occurrence (Clark, 1998). The qualitative study will assist to explain the correlation between the variables of the research. However, the quantitative methodology assists in understanding the entire range of the study issue. To accomplish the first purpose, the study uses a thermometer to quantify the temperature difference between interior and outside buildings. The main experimental tool for measuring interior and exterior wall temperatures every two hours is a thermometer. This examination will compare the temperature to the ceiling and wall surfaces to determine how the building envelope affects indoor and outdoor thermal comfort.

The maximum and minimum internal and external surface temperature values selected case study will be assessed. To study the second objective, suggesting passive cooling design strategies in the selected case study area will be introduced. Autocad 3d Max and Lumion software will be selected for this purpose. The enhancement process in passive cooling strategies will be conducted based on literature review conducted in chapter two and chapter three.

5.3 DATA COLLECTION

Both primary and secondary data sources were utilized for data collection. The study adopted using various tools, comprising questionnaires, and monitor guides, major data for the study was collected. Journals, articles, dissertations, maps were considered as secondary data resources.

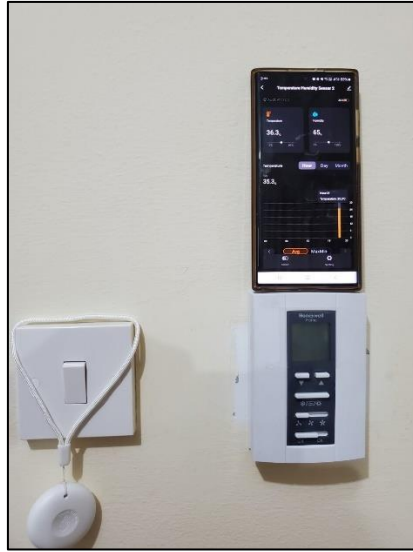
5.3.1 Study Indicator Selection

To achieve the research goal, numerous indicators should be taken into account in the field that immediately influences the performance building in terms of the thermal comfort. The factor that influences the thermal comfort performance comprises design parameters as orientation, the ventilation of the building, shading, insulation, and other parameters mentioned in the literature review. Performance of thermal comfort influences by climatic

variables -as solar irradiation, moisture, rainfall, air temperature, operation directly influence in building's thermal performance.

5.3.2 Air Temperature Measurement of Residential Building

To analyse residential building thermal comfort performance. Selected UAE case study will be analysed to determine summer target. A thermometer is needed to measure room temperature, including exterior and indoor temperatures and relative humidity. To compute maximum air temperature of summer season, residential building was chosen and room thermometer was utilized for 15 days regularly i.e. (August 1st- August 15th) at middle of selected building as case study. The data records of air temperature and humidity were taken at 7 times a day i.e., morning 7Am, 9 Am, 11Am, 1 pm, 3 pm, 5 pm 7pm to compute the maximum air temperature of summer season. One thermometer was located outdoor the building to record the external temperature as illustrated in Figure 5.4, while other placements indoor the building were utilized to observe the internal temperature as illustrated in Figure 5.3. The thermometer utilized is connected to application on laptop or smart phone via application shows the measurements of humidity and temperature as illustrated in Figure 5.5. BIGTHREE Bluetooth Temperature Humidity Monitor Sensor, 300FT Indoor Thermometer for home room freezer with free data storage and Export, Remote Wireless Thermometer Hygrometer is used.



(a) Temperature measurement indoor



(b) Temperature measurement indoor

Figure 5.3: Temperature and Humidity Data Record Indoor and Outdoor the Building.

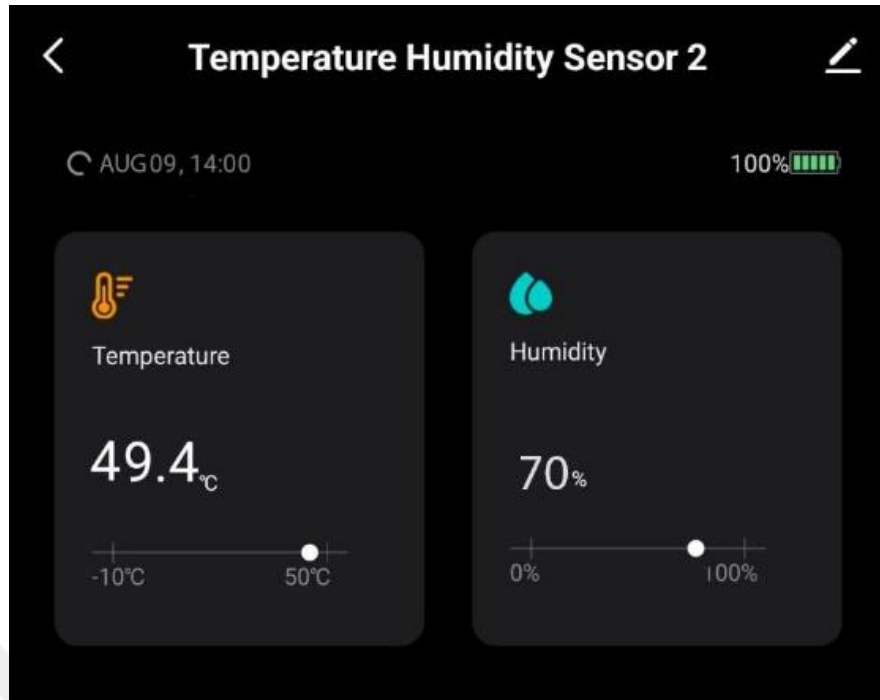


Figure 5.4: Application used to Illustrate the Measurements of Humidity and Temperature.

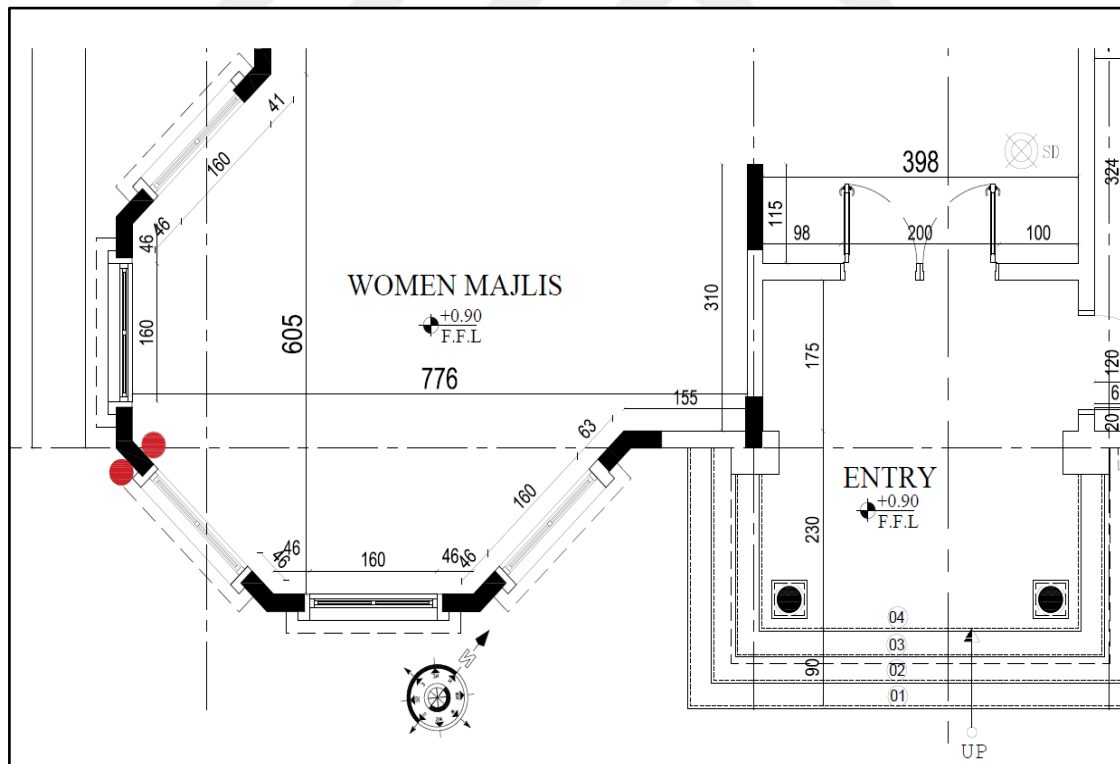


Figure 5.5: Thermometer Location Indoor and Outdoor Building (red point).

5.4 THERMAL COMFORT IN-DEPTH INVESTIGATION OF THE SELECTED CASE STUDY RESIDENTIAL BUILDING

A residential building was chosen in Khalifa City illustrated in Figure 5.6, which is considered a hot and humid area. The area of the residential building is $721m^2$, the Ground floor consisting of one room while the first floor contains of 5 rooms.

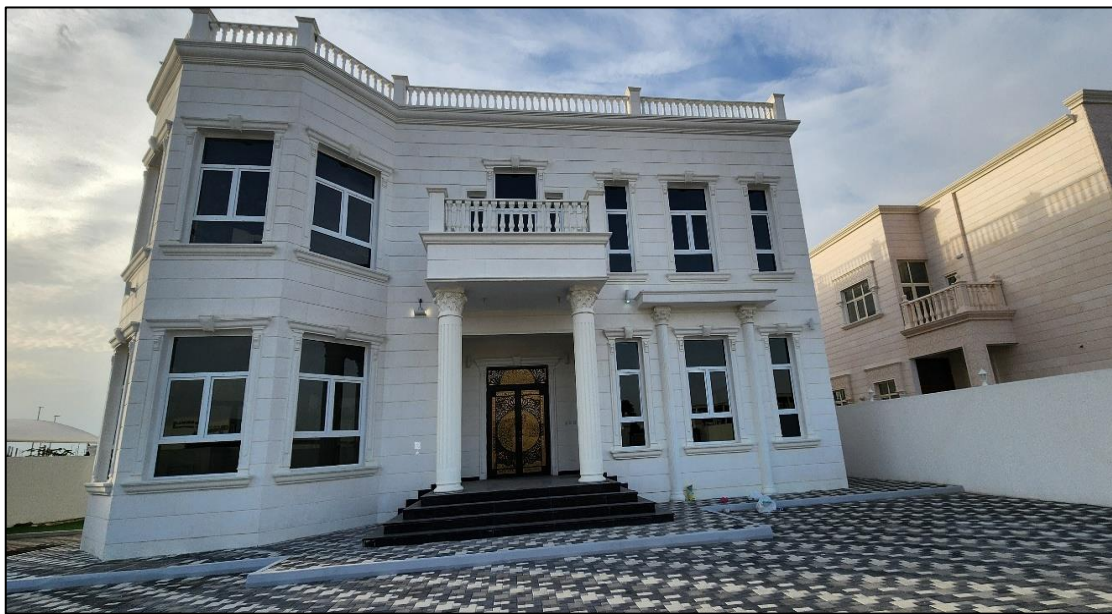


Figure 5.6: Selected case Study in Khalifa City.

Building internal and exterior air temperatures are shown in Figure 5.7. First, the thermometer tool recorded indoor and outdoor building air temperatures from 7:AM to 7:PM. Figure 4.2 illustrates that the case study residential building's techniques barely affect air temperature and cannot provide thermal comfort. Starting, peak, and ending indoor and outdoor temperatures can be determined by taking multiple temperature observations throughout the day. Taking multiple temperature observations throughout the day helps identify the starting, peak, and ending temperatures inside and outside the building and evaluate thermal comfort.

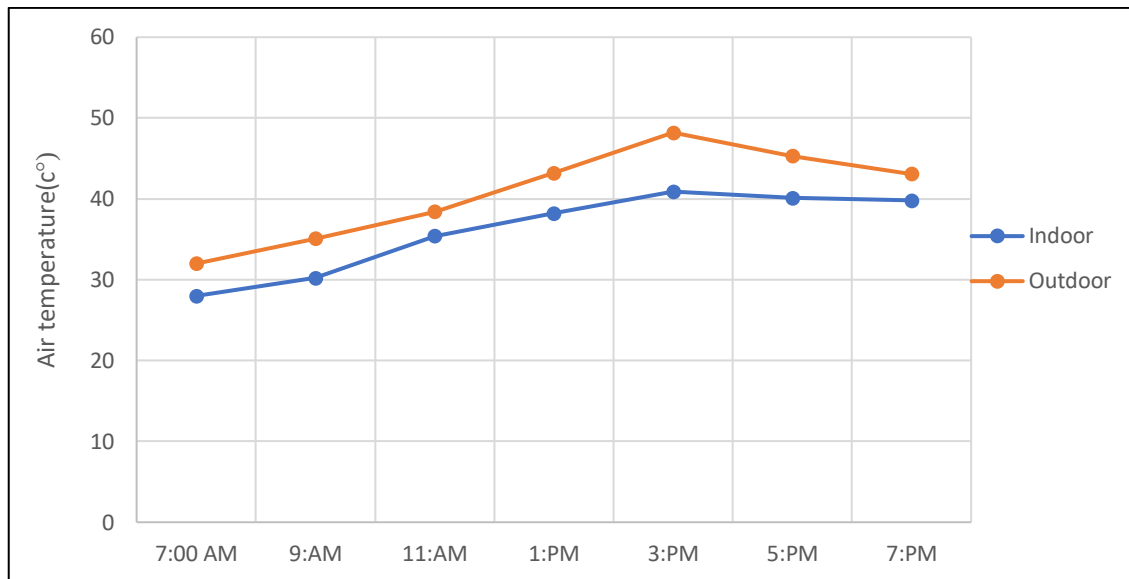
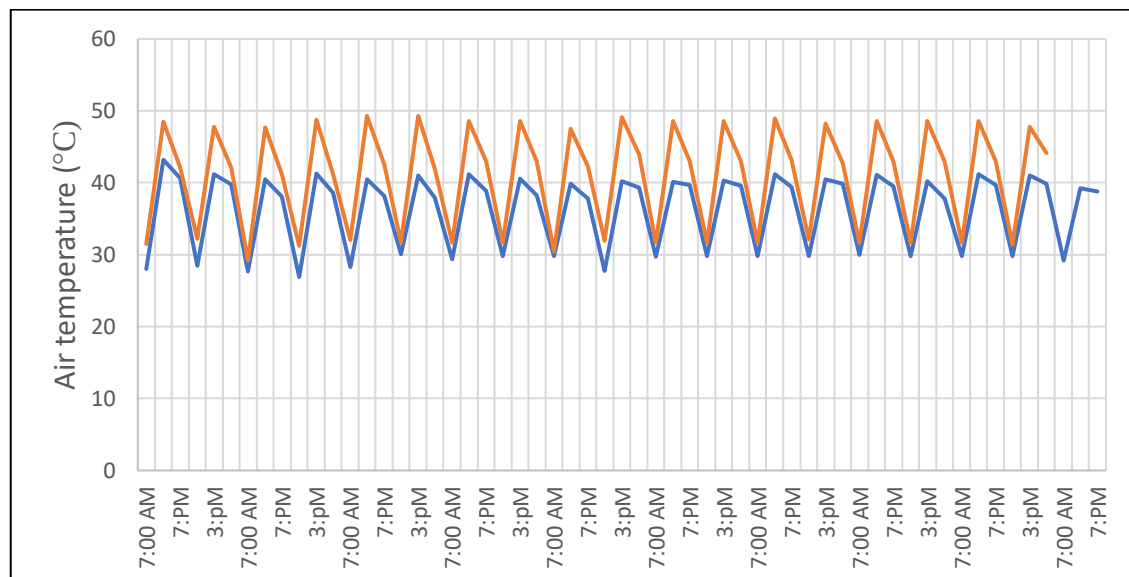


Figure 5.8 was drawn, which shows the temperature changes during 15 days starting From August 1 to August 15, the month of August was chosen because it is one of the summer months in which residents feel the most thermal discomfort. Figure 5.8 shows that Khalifa City witnesses a significant rise in temperatures during the month of August, reaching more than 49 °C outside the building and up to 40 °C inside the building



After evaluating the thermal comfort in the case study residential building that selected, the slight measurements variations of air temperature between indoor and outdoor building affirmed the views of residents in which the residential building in Abu Dhabi can't achieve thermal comfort. The selected case residential building showed very limitations in sustainable design to achieve thermal comfort. After investigating the causes of lack of efficiency of sustainable design it was noted several reasons: The roof design of the selected residential building is flat roofs is illustrated in Figure 5.9.



Figure 5.9: The Roof Type in the Selected Residential Building.

These types of ceilings are not considered preferable for achieving thermal comfort. Rather, it is preferable to design using inclined roof because they contribute to the flow of a larger amount of air, which contributes to moving the air current and thus reducing temperature levels. Also, the roofs is isolation technique is illustrated in Figure 5.10. The construction firm that implemented the case study project equipped the researcher the thermal isolation technique used that is spray applied polyurethane foam

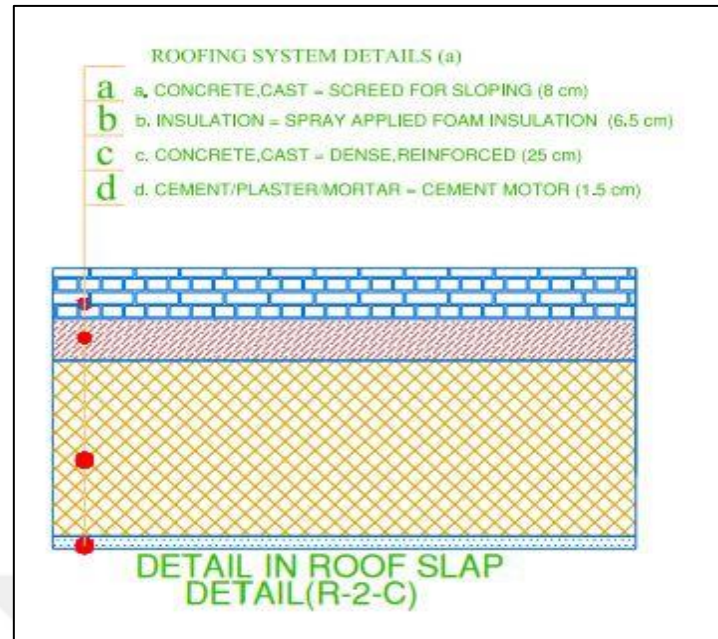


Figure 5.10: The Roof Isolation Technique Used in the Selected Case Study.

Construction material utilized in wall design as illustrated in Figure 5.11 are solid concrete blocks indoor and outdoor the building. wall insulation technique utilized is expanded polystyrene in addition the building is constructed using modern materials represented by concrete that have constrains to prevent thermal transfer indoor the building.

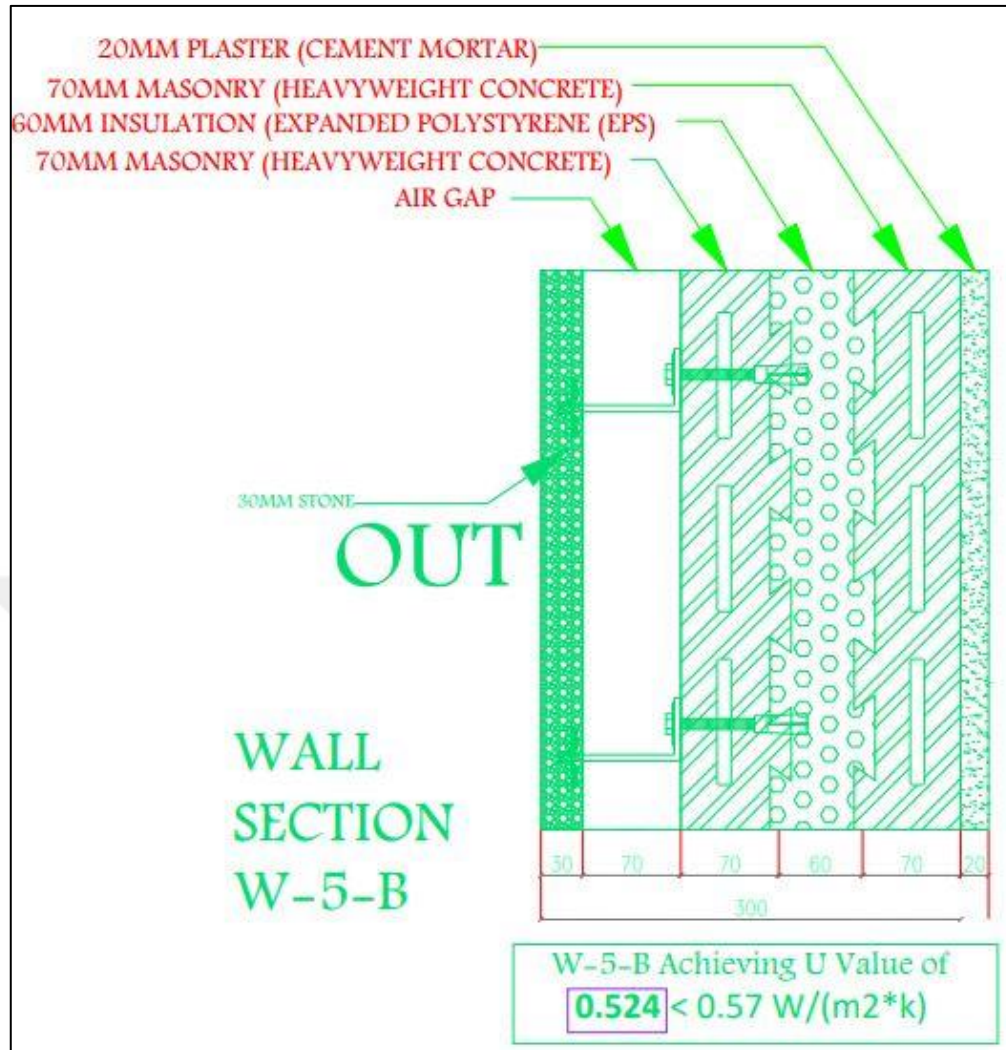


Figure 5.11: Interior and Exterior Wall Design.

No vegetation was observed in or around the building. Orientation of the building wasn't considered into account to receive air current or avoiding the direct sunlight. It wasn't noted any shading strategies to reduce heat transfer indoor the building. the glazing used for windows is double glazing and it characterize efficiency to prevent heat transfer and achieve the sustainable specifications. The evaluation process showed limitations to achieve thermal comfort presented by issues in orientations, ventilation, construction materials, insulation and other passive design strategies.

5.5 ENHANCING CURRENT CONDITION OF PASSIVE COOLING STRATEGIES OF THE CASE STUDY BUILDING

Based on literature review of passive cooling strategies of residential buildings in humid hot regions that executing and with adopting Autocad 3d Max and Lumion software, the following traditional and innovated passive cooling design strategies have been suggested:

As for roof, the present roof in reinforces concrete slab insulated with spray applied foam insulation and layer of concrete with thickness 8cm to protect insulation and the roof is illustrated in Figure 5.12



Figure 5.12: Thermal Insulated Roof With Reinforcement Concrete Slab.

The suggested solution had been designed using Autocad 3d Max and Lumion software to enhance passive cooling strategy by adopting green roof as illustrated in Figure 5.13

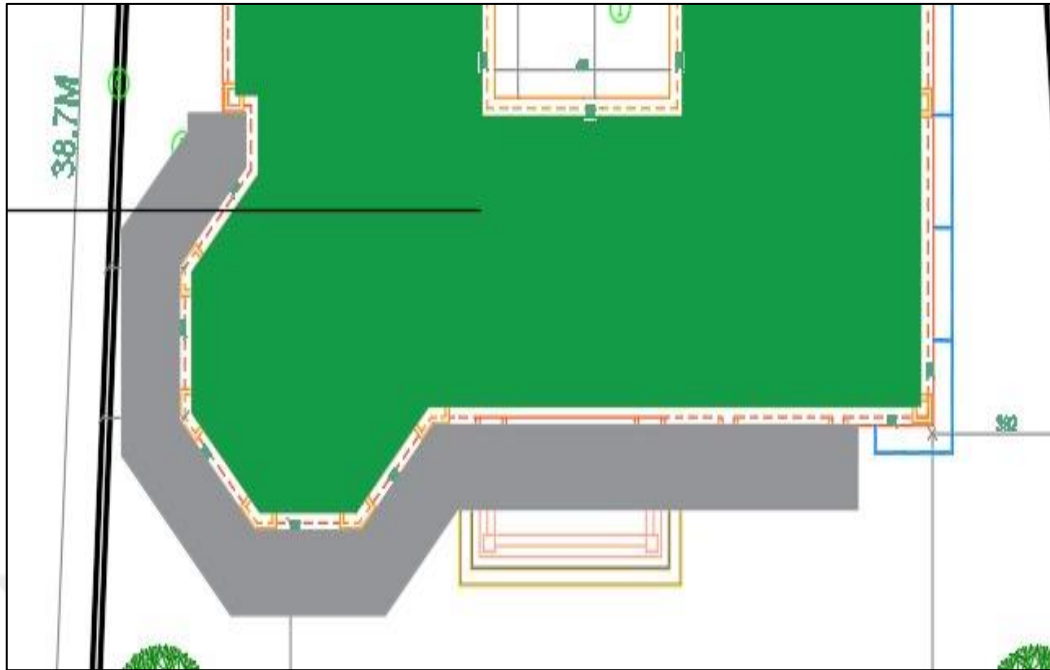


Figure 5.13: Green Roof Suggested for the Building.

Green roof had been suggested as efficient solutions to enhance thermal comfort since several recent studies proves green roof's efficiency to prevent heat transfer indoor the building due to their efficiency in evaporative cooling (wang et al.,2022),(Coma et al.,2018),(Morakinyo et al.,2017)

Green roofs and walls consist of several layers that play a key role in improving thermal performance, including:

Waterproofing layer: Protects the roof or wall from water seepage.

Root protection layer: Prevents plant roots from penetrating the building structure.

Drainage layer: Ensures drainage of excess water and prevents its accumulation.

Growth layer or planting medium: The soil that supports plant growth and retains the water needed by plants.

Plants: The main component of the system, and species that can withstand local climatic conditions must be selected to maximize evaporation and shading (Living Architecture Monitor, 2024; UNSW, 2024).

This type of roof design had been selected as design suggestion according to the following reasons:

Thermal insulation: The plants and soil used in green roofs act as an insulating layer, reducing the transfer of heat into the building. This helps maintain a lower internal temperature compared to traditional roofs.

Evaporation and transpiration: Plants release moisture into the air through the process of evaporation and transpiration, which helps lower the temperature surrounding the roof and improve the overall atmosphere around the building.

Solar absorption: Green roofs absorb less sunlight than traditional roofs such as asphalt or concrete, reducing the “Urban Heat Island Effect” that increases the heat of urban areas.

Improved air quality: Green roofs purify the air by absorbing carbon dioxide and producing oxygen, which helps improve air quality in hot, humid areas that may suffer from pollution. (wang et al.,2022),(Coma et al.,2018),(Morakinyo et al.,2017)

Also, the case study building with no shading devices, no balconies, no eaves no, arches, no trees. Consequently, the shading system suggested is to integrate reflective double glazing. inclined eaves with A 1.5-meter-and-a-half protrusion was placed to reduce the visibility of the windows on the eastern, southern, and southwestern sides. at the top roof. and eaves shading device for each windows as illustrated in Figure 5.14

Several studies proves that the efficiency of eaves shading devices increases while increasing both of inclination and protrusion of eaves (Olawale et al.,2021),(Qian et al.,2024).

Choosing an oblique projection above windows as a shading technique depends on several important reasons and functions aimed at energy efficiency and providing thermal comfort inside buildings, including:

Blocking direct sunlight: The oblique projection allows blocking high sunlight in the summer, especially when the sun is at a high angle. This reduces the entry of heat into the building, which reduces the need for air conditioning and improves thermal efficiency.

Allowing natural light to enter: In the winter or when the sun is at a low angle, the oblique projection allows natural light and heat to enter the building, which enhances natural lighting and contributes to heating the interior spaces.

Improving shade distribution: The oblique design helps distribute shade effectively on windows and glass surfaces throughout the day, which reduces glare and maintains a more moderate temperature inside the building.

Preserving external visibility: The oblique projection of windows allows residents to benefit from natural lighting without significantly affecting external visibility. It allows good shading while maintaining visual contact with the external environment.

Reducing energy consumption: By reducing the effect of solar heat, the overhang reduces the need for artificial cooling, thus contributing to reducing energy consumption in residential and commercial buildings

Control of thermal comfort: Thanks to its ability to regulate the amount of heat and light entering the building, the sloping overhang contributes to improving the thermal comfort of residents throughout the day and different seasons(Olawale et al.,2021),(Qian et al.,2024).



(a) Before designing eaves for roof and windows



(b) After designing eaves for roof and windows

Figure 5.14: Shading device Adopting Inclined Eaves for Roof and Windows.

In addition ,very high trees on the east, southeast and southwest sides to provide shade. round the building have been used as illustrated in Figure 5.15



Figure 5.15: Surrounding the Building With High Long Trees.

Using tall trees for shade in hot, humid areas provides several environmental and functional benefits that contribute to improving thermal comfort and reducing the impact of heat. The most prominent of these benefits are:

Providing natural shading: Tall trees provide extensive shade for buildings and surrounding spaces, reducing exposure of surfaces to direct sunlight and lowering the temperature in areas surrounding the building.

Cooling the surrounding air: Trees transpire, which is the evaporation of water from leaves, which contributes to humidifying and cooling the air. This effect reduces the temperature of the surrounding atmosphere, which is especially important in hot, humid areas.

Reducing the urban heat island effect: In urban areas, hard surfaces such as concrete and asphalt retain heat and increase the temperature of the surrounding environment. The presence of tall trees reduces this effect by providing shade and reducing heat absorption.

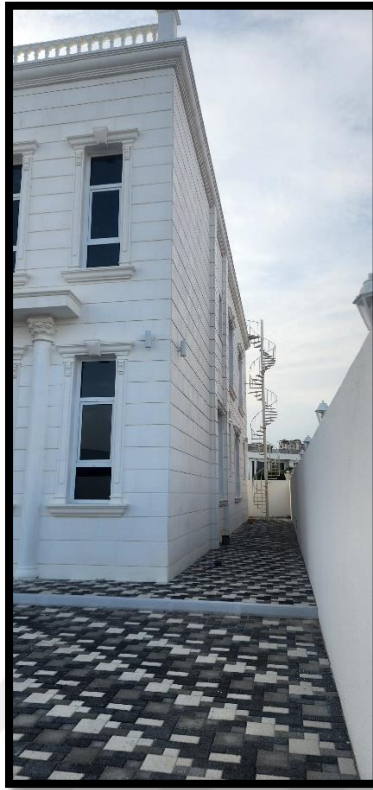
Improving air quality: Tall trees absorb carbon dioxide and release oxygen, which contributes to improving air quality in hot, humid areas that may suffer from high levels of pollution.

Providing a comfortable natural environment: Tall trees provide a green and attractive space, enhancing the comfort of residents and providing a cool, shaded environment that helps in relaxation and relieving stress.

Moreover, Mashrabyas had been designed around windows .Figure5.16a shows the villa before designing shading device suggested while Figure 5.16b illustrated shading system suggested to be used as passive cooling design in humid hot regions.Mashrabya s considers efficient traditional passive cooling and this strategy had been innovated by integrated it with evaporative cooling system (Bagasi et al,2020),(Bagasi, 2021),

The clay mashrabiya was chosen for the facade most exposed to the sun to contribute to achieving the greatest possible degree of thermal insulation, ventilation and shading. The mashrabiya was not used on the front facade to preserve the aesthetics of the design, and other methods were used to protect the facade from the sun's rays.

The main windows of the rooms were surrounded by mashrabiya s to protect them from the eastern side, while the service windows, such as the bathrooms, were left without mashrabiya s.



(a) Before Designing Mashrabya



(a) After Designing Mashrabya

Figure 5.16: Using Mashrabya as Shading Device.

In order to provide evaporative cooling , The water pond was designed in the northern and northwestern facades near the windows to help cool the air flowing into the windows as depicted in Figure 5.17 (Yao et al.,2023),



(a) North-west Façade without evaporative cooling techniques



(b) Adding water bodies ,vegetation and water plant

Figure 5.17: Evaporative Cooling Strategy.

Aquatic plants were also placed to contribute to the evaporation process, in addition to surrounding the building with vegetation that contributes to the cooling process (Noroozi,2020)

Also, Figure 5.17 shows that the fence sewn into the building is designed as a green wall to be used as passive cooling strategy to cool surrounding the building , several studies proved the efficiency of green walls in natural ventilation and providing thermal comfort (Li,et al.,2022),(Assimakopoulos et al.,2020),(Assimakopoulos et al,2020),(Freewan et al.,2022).

Using a green wall for a fence in the yard offers a range of environmental, aesthetic and functional benefits, especially in hot and humid areas. Among these benefits:

Shading and heat reduction: The green wall covers the fence with plants that absorb sunlight and reduce ambient temperatures. This helps reduce the effect of solid walls that retain heat, which contributes to providing a cooler atmosphere in the yard.

Improving air quality: Plants on the green wall absorb carbon dioxide and release oxygen, which contributes to purifying the air and improving its quality.

These passive cooling strategies techniques according to an extensive and comprehensive literature review can be an efficient strategies in order to enhance thermal comfort of residential buildings in Abu Dhabi.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

Passive cooling in hot, humid Emirates is studied. The study began with a literature review of passive cooling methods for hot, humid areas. We studied all classic passive cooling techniques in hot, humid conditions and highlighted modern improvements. After extensive literature review, a population-based questionnaire analysed Abu Dhabi household thermal comfort.

A field investigation of 30 buildings confirmed the literature review's passive cooling solutions. After discovering the ineffectiveness of passive cooling methods in hot, humid climates, a private villa was used as a case study and temperature readings were taken inside and outdoors. Traditional passive cooling strategies were presented and created in AutoCAD 3d Max and Lumion based on thermometer temperature measurements inside and outside the building and a thorough literature review.

6.2 CONCLUSION

The main goal of the research is to improve thermal comfort in Abu Dhabi residential buildings and identify traditional and innovative passive cooling design techniques. To achieve this goal, the study should answer the following questions:

a. What is current condition of thermal comfort of residential buildings in Abu Dhabi?

The surveying study using questionnaire that targeted 100 residents in different areas of Abu Dhabi showed that resident feels uncomfortable in their homes without using electrical air conditioning and this result had been proved when taking temperature measurements indoor and outdoor the building and the difference between indoor and outdoor temperature was extremely slight and that affirms that the passive cooling strategies executed in the residential buildings in Abu Dhabi are in need of investigation .

b. What are the traditional passive cooling design strategies can be adopted to enhance thermal comfort of residential buildings near coastal regions in Abu Dhabi?

Comprehensive literature review developed framework of the passive cooling strategies comprised developing framework of courtyard design in humid hot regions and the importance of integrating plants and ponds in the interior courtyard. The literature research also found that square or rectangular courtyards are optimal in humid hot climates. Increased courtyard height to width (H/W) reduces solar heat gain. The study also produced a framework of ventilation types and design principles for natural ventilation (cross ventilation, stack ventilation, evaporative cooling) in terms of vent orientation, distribution, size, and location.

Moreover, design principles of high ceiling in humid hot regions to achieve thermal comfort have been detailed and the result found the significance of vaulted roofs or stepped roof with multi vents adopting upper and lower openings in achieving thermal comfort.

The review found that in hot and humid regions, traditional materials adapted to harsh climatic conditions are used to achieve thermal comfort, such as clay, stone and wood.

Also, the study reviewed all traditional shading systems can be adopted in residential buildings to achieve thermal comfort comprise: trees, arches, balconies, mashrabya and eaves and found that the inclined eaves give high efficiency to prevent sunlight.

c. What are the innovated passive cooling design strategies can be adopted to enhance thermal comfort of residential buildings near coastal regions in Abu Dhabi?

Several innovations have emerged in the field of passive design strategies in hot and humid regions, including:

- a. Smart glass facades that reflect sunlight and change color to adapt to weather conditions using sensors.
- b. Green walls, especially those integrated with ventilation and air conditioning systems, offer the advantage of improving indoor air quality.
- c. Mashrabya facades that are integrated with sensors with dynamic movement according the climatic conditions.
- d. Mashrabya facades that are integrated with passive cooling systems as wet blinds or near body water.
- e. Green roofs that achieves evaporative cooling and offer efficient thermal insulation

f. Double skin facades that are recently became innovated design to achieve thermal comfort. The design is based on building two external and internal facades with a space between them that allows air to flow. This space contributes to improving the ventilation of the building by allowing air to flow freely and reducing the impact of external heat on the interior. this technique integrates multiple shading techniques as glazing, mashrabya, solar panels. etc.

g. Innovated water wall in which this technique relies on the use of smart electric pumps to improve water distribution and provide more effective cooling. This innovation enhances cooling performance but increases the complexity and maintenance of the system.

h. Smart blinds use sensors to adjust shading based on the angle of the sun's incidence, reducing unwanted heat gain and maintaining comfortable temperatures inside buildings.

Also, based on the comprehensive literature review conducted for passive cooling design , the study introduced suggestions to enhance thermal comfort of residential building s in Abu Dhabi and these suggestion are as follows :

- a. Replacing the thermal insulation using foam with innovated green roof
- b. Adopt shading system using inclined eaves for all windows and roof with sufficient projection.
- c. Adopting vegetations in windows and in the courtyard
- d. Surrounding the building with tall trees to provide a view of the building
- e. Adopt mashrabiya for windows that are not used frequently.
- f. Using water bodies integrated with water plants and vegetation in the courtyard to achieve evaporative cooling

6.3 RECOMMENDATIONS

According to the results revealed in this study, the following recommendations can be introduced:

In the Design Field: It is recommended to adopt passive cooling design to reduce energy consumption and achieve thermal comfort

Its is advised to keep on date on the latest innovations in passive design cooling in humid hot regions

In the Research Field: It is recommended to do experimental and thermal simulation models to address passive design cooling and determine accurately how extent is their efficiency to achieve thermal comfort

It is recommended to search innovated solution can be integrated with passive cooling designs to get optimum results



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SURVEY QUESTIONNERIA

- a. Apartment b. Villa
- c. Detached house d. Shared accommodation

2. Does the building have air conditioning systems?

- a. Yes b. No

3. Does the building have natural ventilation systems (such as large windows or vents)?

- a. adequate natural ventilation b. to some extent

Part Three: Thermal comfort assessment

1. How would you describe the level of thermal comfort in your home during the summer?

- a. Very comfortable b. Comfortable
- c. Moderate d. Uncomfortable
- e. Very uncomfortable

2. How do you feel the temperature inside your home during the day in the summer?

- a. Very cold b. Cold
- c. Moderate d. hot
- e. Very hot

3. How do you feel the temperature inside your home at night in the summer?

- a. cold b. cool
- c. Slightly hot d. hot
- e. Very hot

Part 4: Humidity and ventilation assessment

1. How would you describe the humidity level in your home during the summer?

- a. Very dry b. Dry
- b. Moderate d. Humid
- e. Very humid