Energy efficiency based on passive design solutions in UAE.

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Abstract

Energy consumption in the building sector accounts for over 30% of global final energy consumption. This figure is much higher in developed countries like the UAE, where energy consumption by the built sector can reach up to 80%. Thus, developing appropriate future energy and climate change strategies requires alternative methods for the reduction of energy consumption in buildings. Passive design techniques, such as shading devices and courtyards, are used in sustainable architecture to create structures that harness sunlight and wind for lighting and ventilation while keeping away heat gain and glare. This research aims to investigate and create a comparison between the effects of two passive design solutions on a villa housing project in Sharjah, United Arab Emirates, through the use of Revit software. The study concluded that courtyards significantly outperformed shading devices in reducing energy costs, providing a greater overall impact on energy consumption. In this research, a comparative study was done between three building types in the same area: a villa without any passive design solution, a villa with the introduction of shading devices, and a villa with a courtyard. The research shows that courtyards, by enhancing natural ventilation and air circulation, lowered HVAC costs to approximately 14.69 AED/m2 per year, compared to 33.06 AED/m2 per year for louvers. While louvers improved lighting efficiency and reduced lighting needs, they led to slightly higher costs for window shades. Overall, courtyards achieved a cost reduction of 24.24 AED/m2 per year versus 6.61 AED/m2 per year for shading devices, emphasizing the importance of integrating passive design strategies for sustainable building practices and climate change mitigation.

***Keywords*:** Energy consumption, Passive design, Courtyards, Shading devices, Heat gain, Ventilation, Revit software.

1- Introduction

Traditional design principles, particularly passive design methods, are foundational to both vernacular and sustainable architecture, aiming to improve interior temperature conditions while minimizing energy use (Thaleia Konstantinou, 2018). These methods remain relevant today, especially in the face of global warming and rapid urban development. The UAE's rapid urban growth, coupled with its hot-arid climate, has prioritized construction quantity over energy efficiency, exacerbated by inadequate building codes and low energy costs, leading to a high environmental footprint.

This research compares two traditional passive design techniques - courtyards and shading devices - in UAE based homes to demonstrate their potential in reducing energy consumption. The study analyzes these techniques to identify the optimal solution for enhancing energy efficiency, reducing heat gain, and improving thermal comfort, aiming to find sustainable approaches that benefit the built environment and occupants.

2- Literature review

2.1 Courtyards

The world is worried about the ongoing urbanization that goes hand in hand with global warming. Incorporating passive sustainable solutions into design has become of utmost importance. Muna Salameh (2022) finds that traditional urban districts perform better in terms of heat than modern urban districts as they have passive design solutions like courtyards.

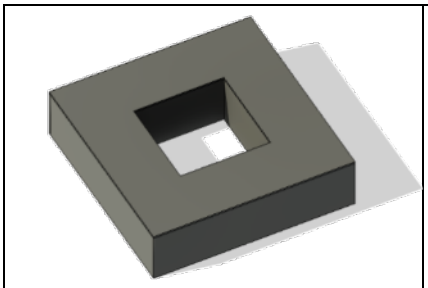
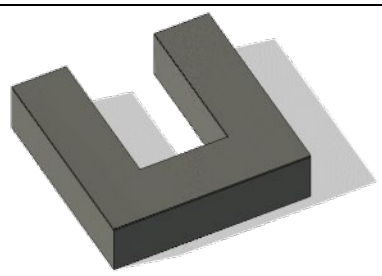
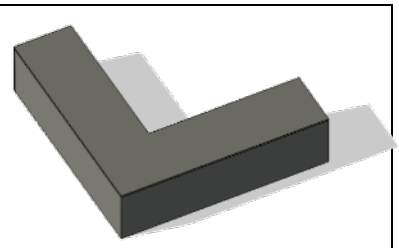
Courtyards are private open spaces surrounded by a building wall on their sides. A courtyard's shape might be square, rectangular, or round. The majority of courtyard designs from the past were square or rectangular. Figure 1. illustrates the three typical courtyard design types: semi-opened, semi-closed, and closed.

Since it offers great privacy, good ventilation and lighting, the closed courtyards are found frequently in deep layouts. Conversely, a semi-private courtyard is typically formed between buildings and is said to provide a shaded area. Finally, semi-opened courtyard has the least degree of privacy, but it also offers the building easy access, ventilation, and natural light.

Furthermore, it has been discovered that courtyards in the UAE, especially in Sharjah, are advantageous for social interaction and energy efficiency, according to IA Ibrahim (2018).

Figure 1.

Courtyard types.

		
A- Closed Courtyard	B- Semi-Closed Courtyard	C- Semi-Opened Courtyard

2.2 Shading Devices

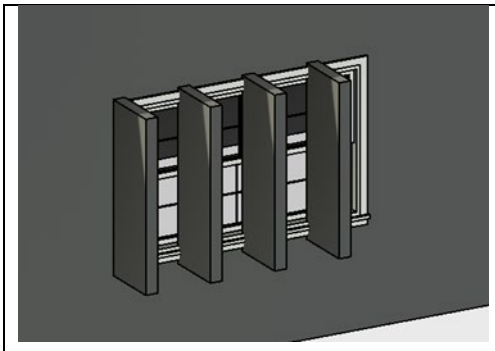
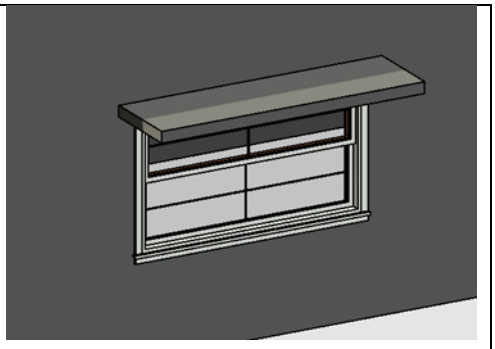
Shading devices are external projections that shield a building's glazed areas from direct sunlight, and they can be horizontal or vertical. The choice and type of shading device depend on the building's orientation. Fixed louvers are ideal for south-facing facades due to direct sunlight during peak hours, while operable louvers are more suitable for east and west facades. Shading devices are unnecessary for north-facing facades in the UAE, as this direction does not receive direct sunlight.

According to studies conducted in the United Arab Emirates, shading devices can dramatically lower a building's energy usage. According to Reem Ali Talib Alothman, 2024 horizontal shading elements can save 0.5% to 30.8% of energy in multi-story residential buildings, depending on orientation and depth. Figure 2. highlights the types of shading devices.

Finally, the shading devices can be installed at any given time, even for existing buildings. Shading devices are an affordable way to cut carbon emissions and energy use, according to research conducted regularly in the United Arab Emirates. Though kinetic shading devices have potential, fixed shading devices still have a bigger potential for energy savings, according to Byungyun Lee (2019).

Figure 2.

Types of Louvers

	
A- Vertical Louvers	B- Horizontal Louvers

2.3 Autodesk Revit Architecture

Autodesk Revit Architecture, developed by Autodesk, is a powerful software program for architects and other construction professionals. It features tools for energy analysis, solar radiation analysis, and thermal analysis, which are utilized in this research. Revit, known for its Building Information Modeling (BIM) capabilities, enables the creation of a parametric 3D model with information about building and design that is both geometric and non-geometric. This research aims to demonstrate how passive design solutions, supported by Revit's features, can enhance energy efficiency. The objectives are as follows:

1. Model three case studies with two different passive design solutions.
2. Use Revit to generate results regarding energy use and cost.
3. Compare and contrast the results to draw conclusions about the benefits or drawbacks of passive design.

Passive design solutions take time to show significant results and are not quick to reflect drastic changes. This research, using Revit analysis, will generate annual results on cost and efficiency. Additionally, this research explores two case studies to demonstrate how passive design solutions can be applied either before, during, or after construction.

3- Methodology

This research will use a qualitative approach that relies on comparative analysis for a case study following computer simulation using Revit; the case study will be a villa located in Sharjah, United Arab Emirates. The case study will be divided into two parts: one is collecting data through computer stimulation, and the other is analyzing the information found.

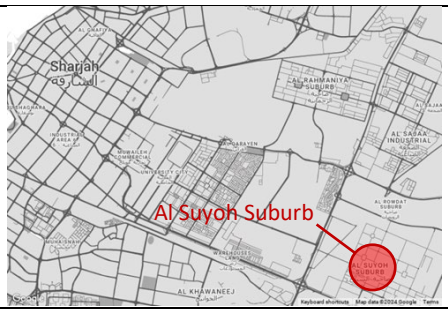
3.1 Location and criteria of the case study

To evaluate the efficiency of passive design techniques, a villa in Al Suyoh Suburb, Sharjah, was selected for the study. This location is ideal for understanding how the UAE's climate impacts building design. The villa, oriented northwest, follows a modern architectural style and has a total built-up area of 10,115.77 m² across two stories, including a ground floor, first floor, and a staircase room on the roof. The ground floor features public spaces such as a majlis, dining area, guest bedroom, and kitchen, while the first floor contains private bedrooms, each with an attached bath and a dressing area, along with balconies. The villa's design lacks specific passive design techniques to reduce heat gain or glare, aside from the orientation of the openings. The numerous and large openings could increase energy consumption, as more cooling is needed to counteract the heat gain.

Figure 3.

The Location of Case Study

A- United Arab Emirates



B- Al Suyoh Suburb in Sharjah
25°14'05"N 55°37'45"E

C- Front Elevation of the Villa

3.2 Use of Revit as Research Software

The potential of Revit, a Building Information Modeling (BIM) platform, is to enhance sustainability analysis in building design has been shown in recent research.

1. İbrahim Bektaş, Aysun Özköse (2022). *Investigation of Housing Projects for Rural Areas in Terms of Sustainability Criteria with Revit* used Revit to analyze rural housing projects, finding that while they were advantageous in terms of energy consumption, they were disadvantaged in solar orientation and daylight benefit.
2. JP Carvalho, L Bragança, R Mateus (2021). *Analyzing the feasibility of BIM platforms to support practical building sustainability assessment,* conducted more research on the viability of BIM platforms, such as Revit, in the context of practical building sustainability assessment. The findings indicate that Revit can facilitate the automated and expedited assessment of sustainability criteria.
3. Sudhakar Mogili, Vamsi Krishna Appecharla, Harsha Vardhan Avvari (2022). *Energy Consumption Analysis of Residential Buildings Using* Autodesk Revit to predict energy usage in a residential building, achieving a 31.3% reduction in consumption and a 30% reduction in cost.

3.3 Stimulation Criteria and Stages

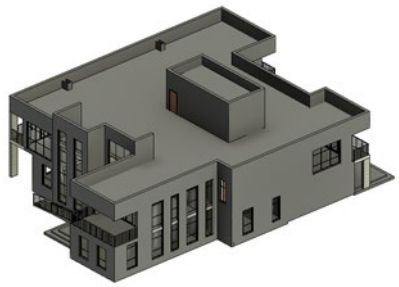
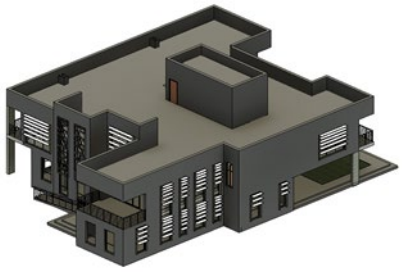
The research investigated two passive design solutions on the existing case study apart from the original villa (Figure 4), as follows:

1. Basic case (BC).

2. The integration of shading devices (SBC).
3. Integrating the courtyard for further analysis for future design prototypes of the villa (CBC)

Figure 4.

The different case studies.

		
A- Basic Case study (BC).	B- Integrating Shading Devices (SBC).	C- With Courtyard (CBC)

3.4 Revit Analysis Procedure

Autodesk's Revit software utilizes its energy analysis features to determine annual energy expenditures by creating a detailed 3D model of a building, including architectural elements and mechanical systems. Revit specifies parameters such as location, climate data, occupancy schedules, and HVAC details to conduct a dynamic thermal simulation. This simulation calculates hourly energy consumption, including equipment loads, lighting usage, and HVAC energy needs. Revit then aggregates this data to compute annual energy costs, presenting the results through reports, graphs, and visualizations. Additionally, daylighting analysis in Revit uses the project's specific solar conditions to measure "illuminance" and "luminance," helping architects optimize building performance and energy efficiency.

3.5 Unified Stimulation Conditions

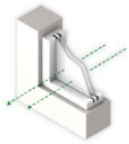
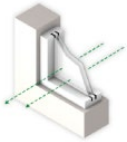
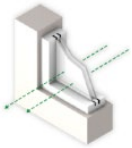
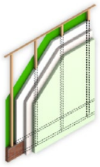
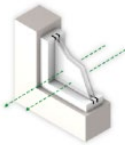
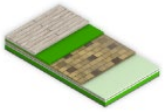
The research used Revit to undergo an energy analysis of the building envelope. This version of the villa does not have any passive design solutions. The villa has large windows and multiple openings. Table 1. shows the detailed analysis for this case.

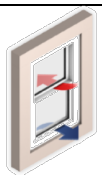
All materials and some design parameters were defined in the three scenarios for the stimulation to highlight only the effect of the two integrated passive design solutions.

Table 1.

Unified Design Approaches

Unified Design Approaches

1. Orientation of the Building	Rotates a structure in a clockwise direction starting at 0 degrees. For example, turning a building 90 degrees causes the north side to face east. Current Setting: 270 - 135 	2. West Window Glass	Along with other considerations, glass qualities regulate how much daylight, heat transfer, and solar heat gain enter the building. Current Setting: Sgl Clr - Trp LoE 
3. WWR - Southern Walls	The relationship between window attributes and window-wall ratio (glazing area/gross wall area) affects heating, cooling, and daylighting. Current Setting: 95% - 0% 	4. WWR- Eastern Walls	The relationship between window characteristics and window-wall ratio affects heating, cooling, and daylighting. Current Setting: 95% - 0% 
5. Window Glass-South	Along with other considerations, glass qualities regulate how much daylight, heat transfer, and solar heat gain enter the building. Current Setting: Sgl Clr - Trp LoE 	6. Window Glass-East	Along with other considerations, glass qualities regulate how much daylight, heat transfer, and solar heat gain enter the building. Current Setting: Sgl Clr - Trp LoE 
7. WWR-Northern Walls	The relationship between window characteristics and window-wall ratio affects heating, cooling, and daylighting. Current Setting: 95% - 0% 	8. Wall Construction	Represents the total resistance to heat gains and losses of wall structures. Current Setting: R13 Wood - 12.25-inch SIP 
9. Window Glass- North	Along with other considerations, glass qualities regulate how much daylight, heat transfer, and solar heat gain enter the building. Current Setting: Sgl Clr - Trp LoE 	10. Roof Construction	Represents the total resistance to heat gains and losses of wall structures. Current Setting: Uninsulated - R60 
11. WWR-Western Walls	The relationship between window characteristics and window-wall ratio affects heating, cooling, and	12. Infiltration	Air escaping into or out of conditioned compartments without effort; frequently caused by gaps in the building envelope.

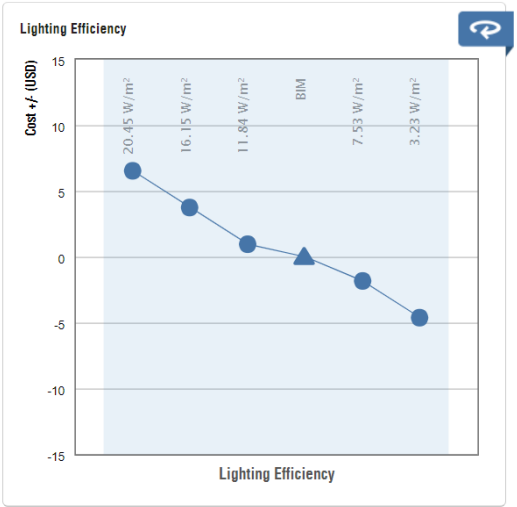
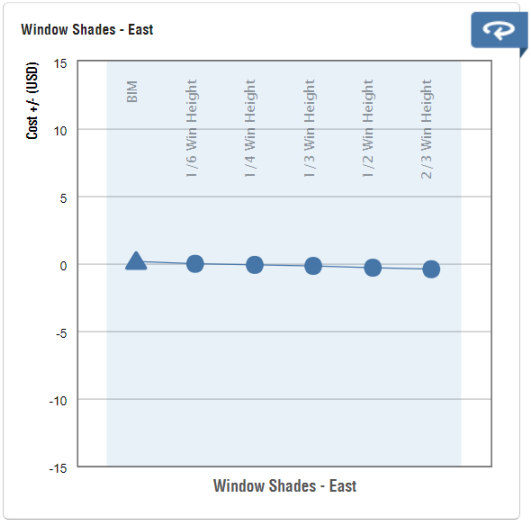
	daylighting. Current Setting: 95% - 0% 		Current Setting: 2.0 ACH - 0.17 ACH 

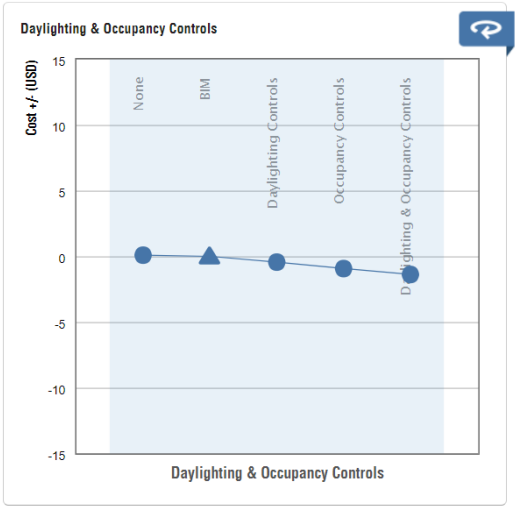
3.6 Integrated Shading Devices

For the first passive design case, the research will introduce shading devices to see how they affect energy consumption in a villa (Table 2.). Shading devices can dramatically lower a building's energy use, according to research conducted in the United Arab Emirates.

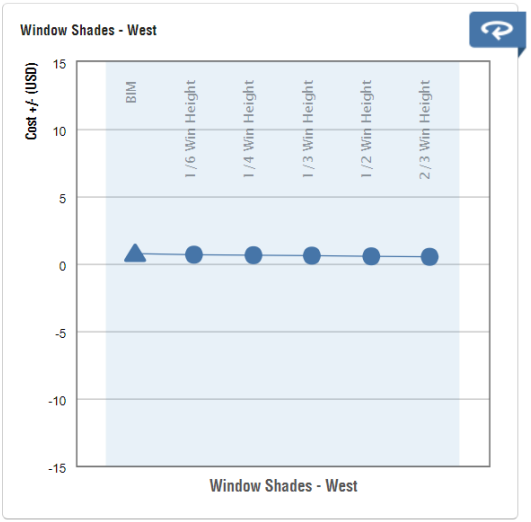
Table 2.

Scenario two, Shading Devices

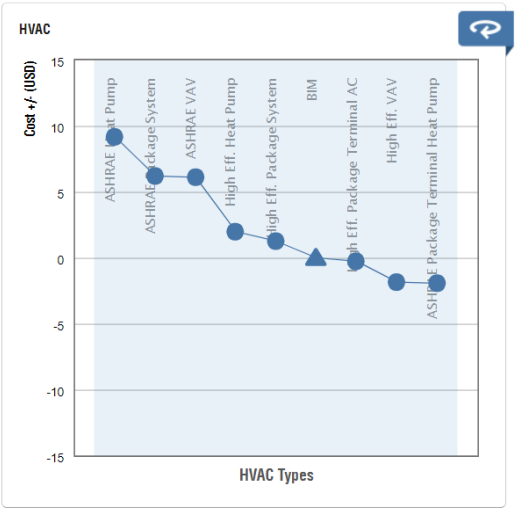
SBC	
	
Lighting Efficiency	Window shades - East



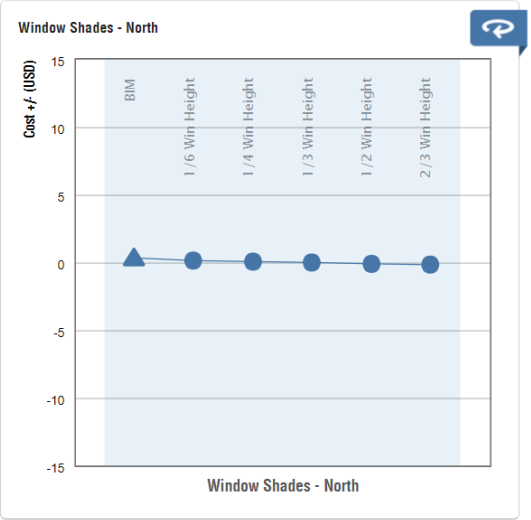
Daylighting and occupancy control



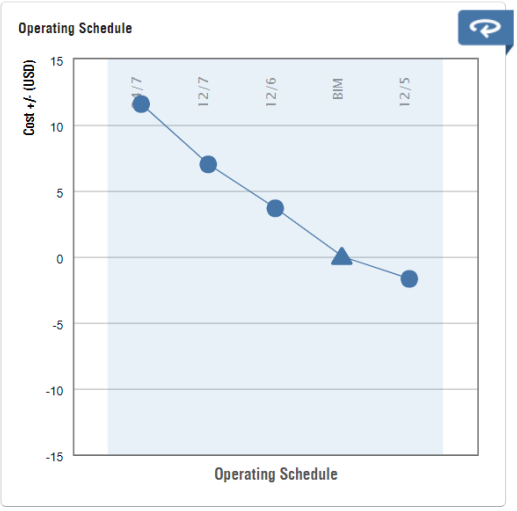
Window shade - West



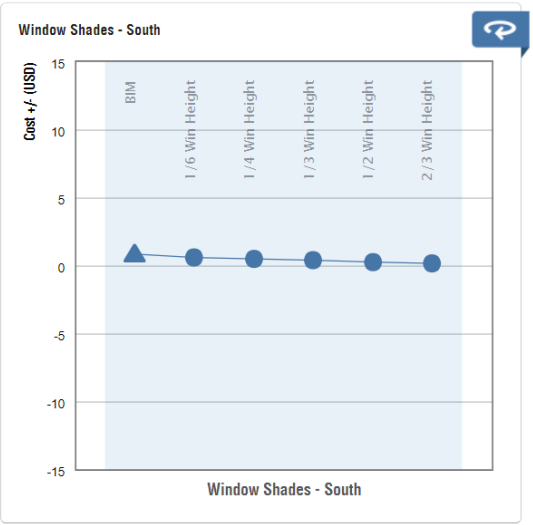
HVAC



Window Shade – North



Operating schedule



Window shade - South

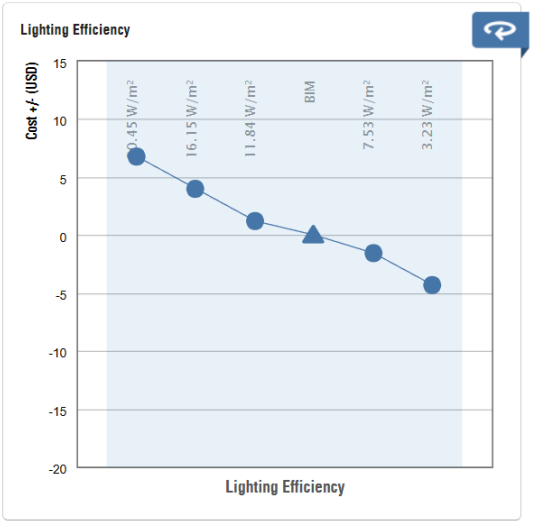
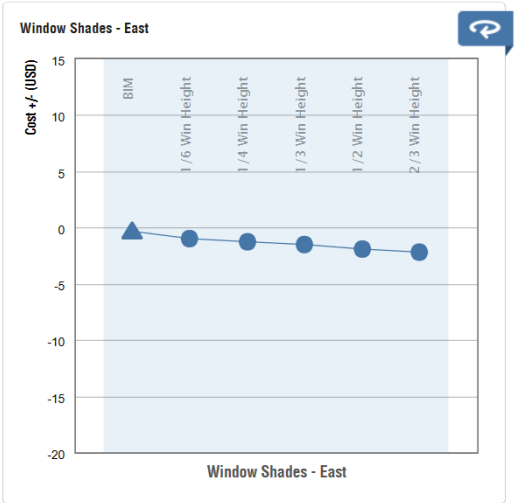
3.7 Integrated Hypothetical Courtyard

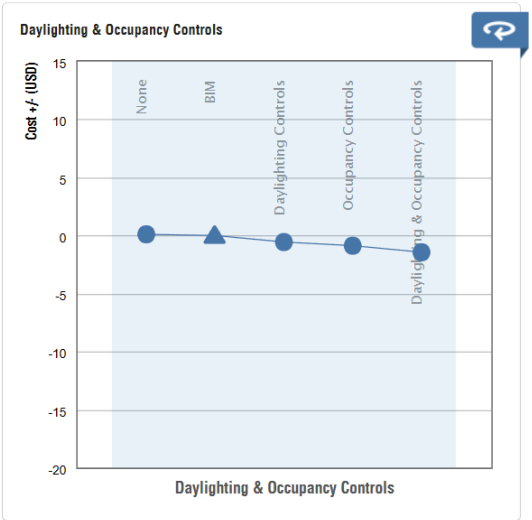
The second passive design solution applied in the villa is the introduction of a courtyard as a prototype for future designs (Table 3.). The courtyard type used is the semi-closed courtyard. Many studies have been conducted on the social and environmental benefits of courtyards found in villas in the United Arab Emirates. Both IAS Ibrahim, 2018, and HM Taleb, 2020, emphasize how courtyards can improve thermal performance and sustainability.

IAS Taleb, 2020, goes so far as to say that the most efficient courtyard arrangement is u-shaped, the same is applied in this scenario.

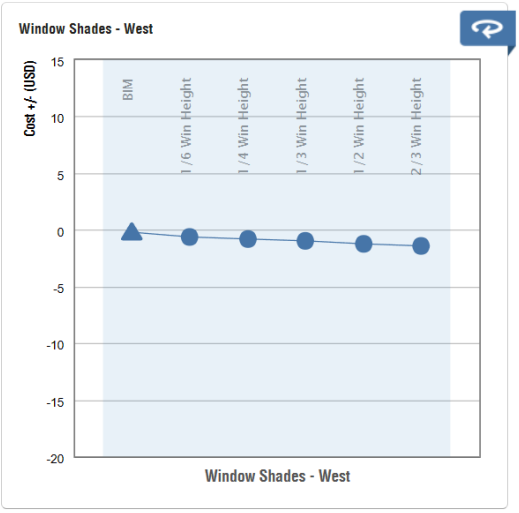
Table 3.

Special Design Parameters for scenario three, courtyard

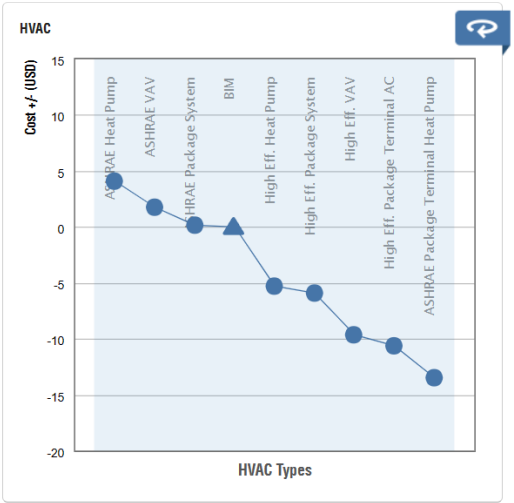
CBC	
	
Lighting Efficiency	Window shades - East



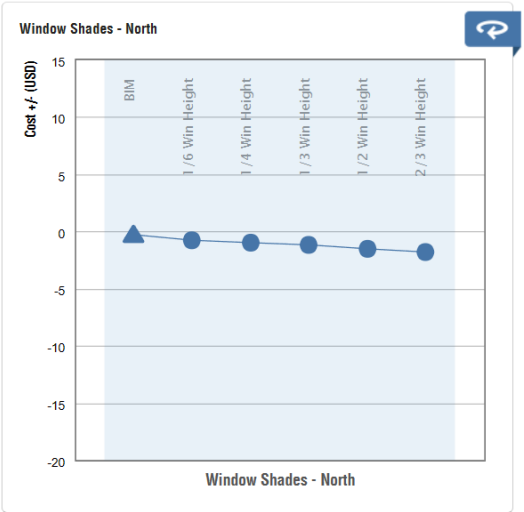
Daylighting and occupancy control



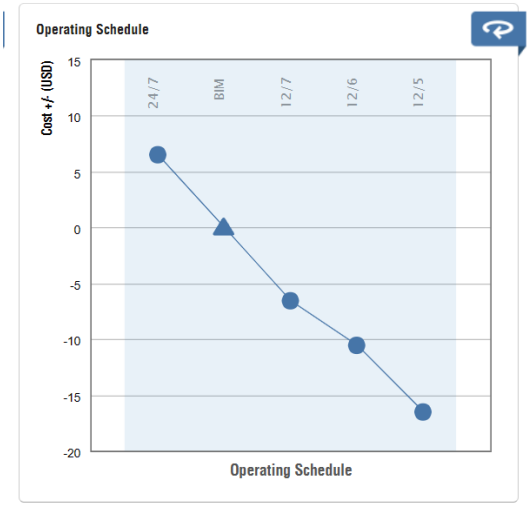
Window shade - West



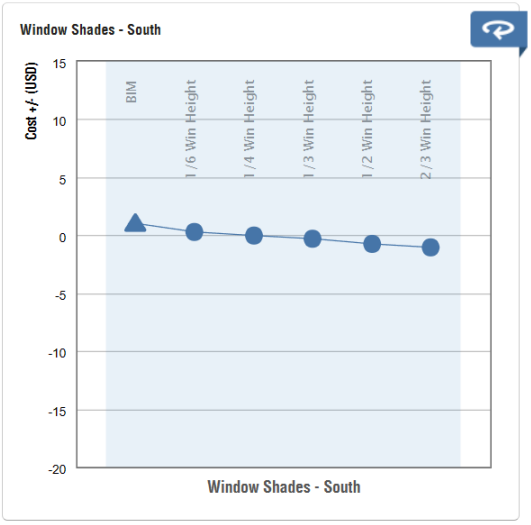
HVAC



Window Shade – North



Operating schedule



Window shade - South

3- Discussion and results.

The villa with a built-up area of 10115.77 m2 located in Sharjah, United Arab Emirates, was modeled and stimulated on Revit to understand its energy consumption on a yearly basis. The stimulation output revealed variations in its light efficiency, energy costs, HVAC, etc.

The research, as shown in Table 4, indicates minor differences in lighting efficiency, HVAC, and window shading across different scenarios, which, although not significant, do impact the overall energy consumption of the villa. After simulations, it was found that lighting efficiency improved the most with the use of louver shading elements, as they effectively filter and control natural light. Louvers also optimize daylight while reducing heat gain, leading to energy savings. However, the use of window shades on all sides incurs a slightly higher cost, around 3.67 AED per square meter per year, according to Revit's findings.

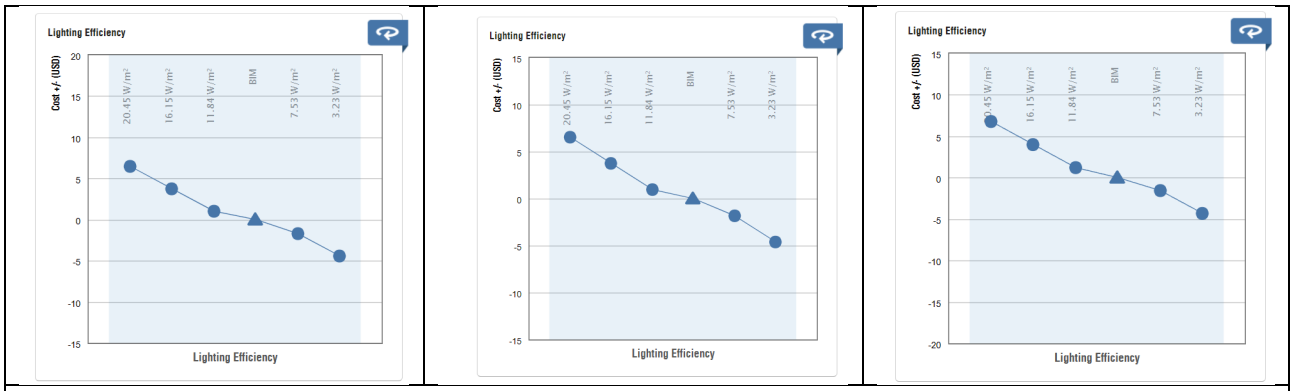
Moreover, the discrepancy in HVAC costs between using louvers and incorporating a courtyard primarily stems from differences in thermal regulation and passive cooling effectiveness. Louvers, while effective in controlling natural light and reducing solar heat gain, may not provide the same level of thermal comfort as a courtyard. Despite their ability to mitigate some of the heat entering a building, they might still necessitate more intensive HVAC usage to maintain comfortable indoor temperatures, especially in hotter climates or during peak sunlight hours. Consequently, HVAC operational costs remain relatively higher at 33.06 AED/M2/y. On the other hand, courtyards offer significant passive cooling benefits. They create natural ventilation, facilitate air circulation, and provide shaded areas, effectively reducing the overall cooling load on HVAC systems. This results in lower energy consumption and decreasing HVAC operational costs, which are reflected in an approximate 14.69 AED/m2/y, as shown in figure 5.

This study delves into leveraging passive design strategies to mitigate climate change by curbing energy consumption. As part of a multifaceted approach, the research examines the efficiency of integrating louvers and utilizing courtyards for potential prototypes. Notably, the findings reveal that, courtyard integration outperformed shading devices, yielding a significant reduction in energy costs at 24.24 AED/m2/yearly compared to the 6.61 AED/m2/yearly reduction achieved with shading devices. However, while shading devices contributed to decreased lighting needs, the overall impact on energy consumption was less pronounced than that of courtyards. This underscores the importance of strategic design choices in optimizing energy efficiency within architectural frameworks. Moreover, the study highlights the potential of courtyards as a versatile solution with broader implications for sustainable building practices. By prioritizing passive design solutions like courtyards, architects and urban planners can have a role in addressing the pressing challenges of climate mitigation.

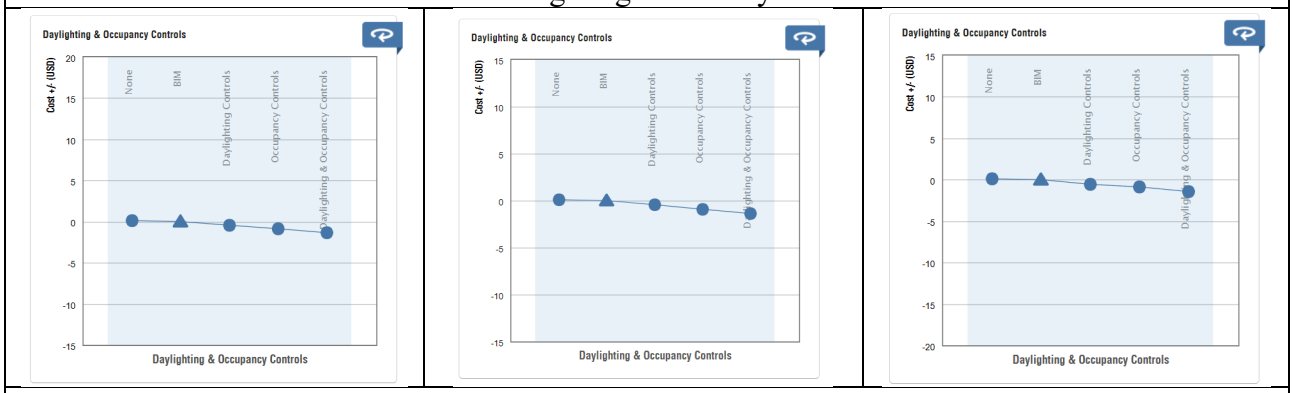
Table 4.

Comparative Study between the three cases according to design parameters

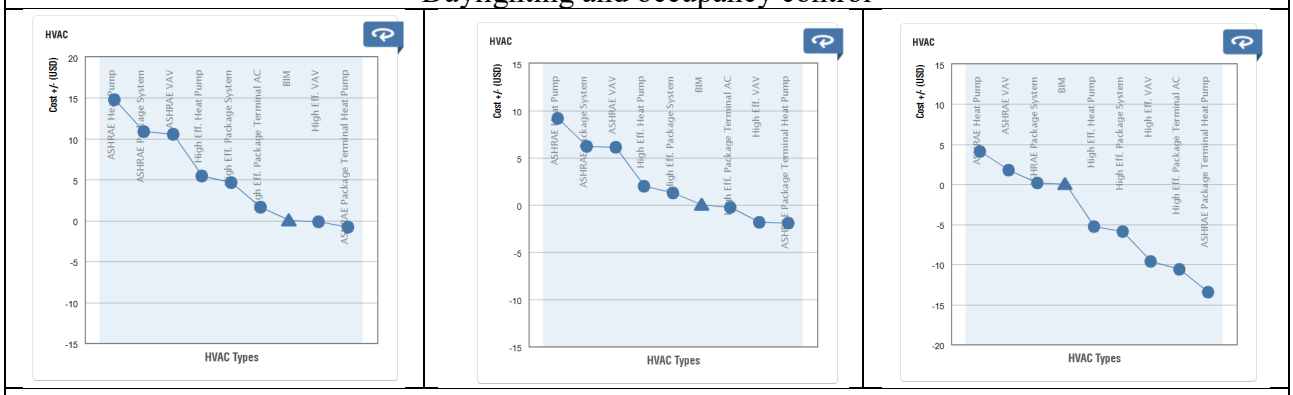
Basic Case (BC)	SBC	CBC



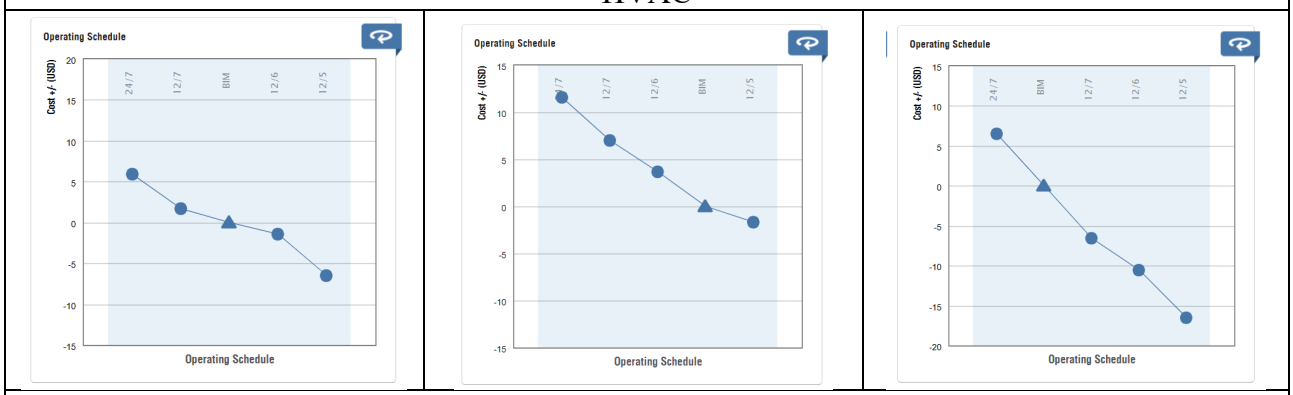
Lighting Efficiency



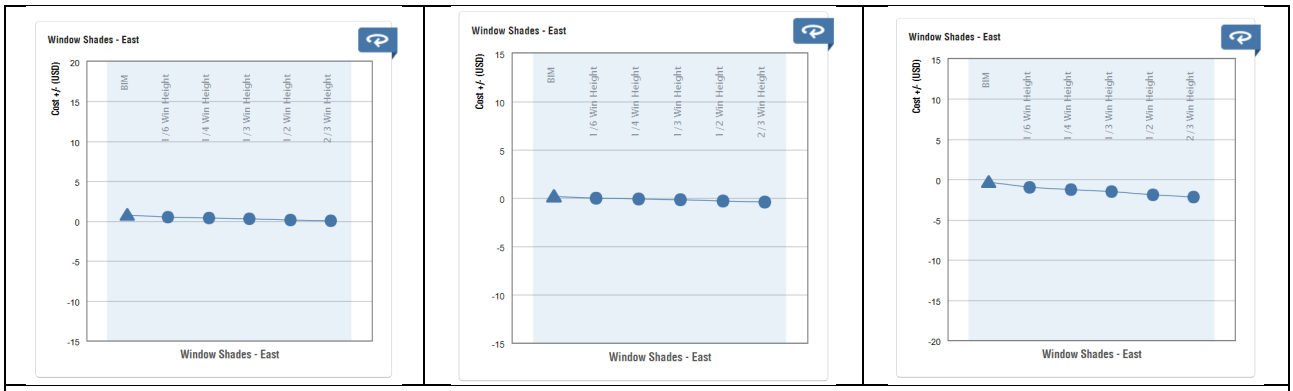
Daylighting and occupancy control



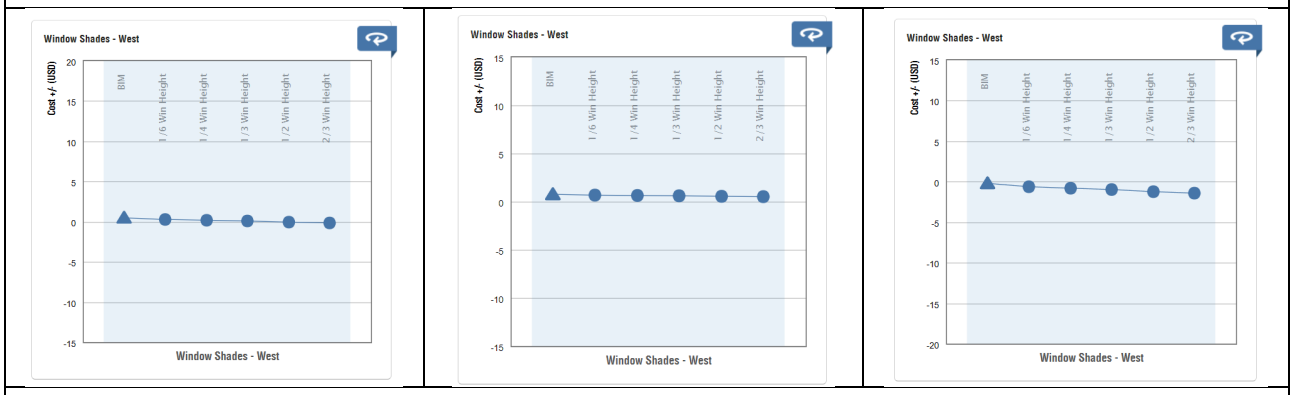
HVAC



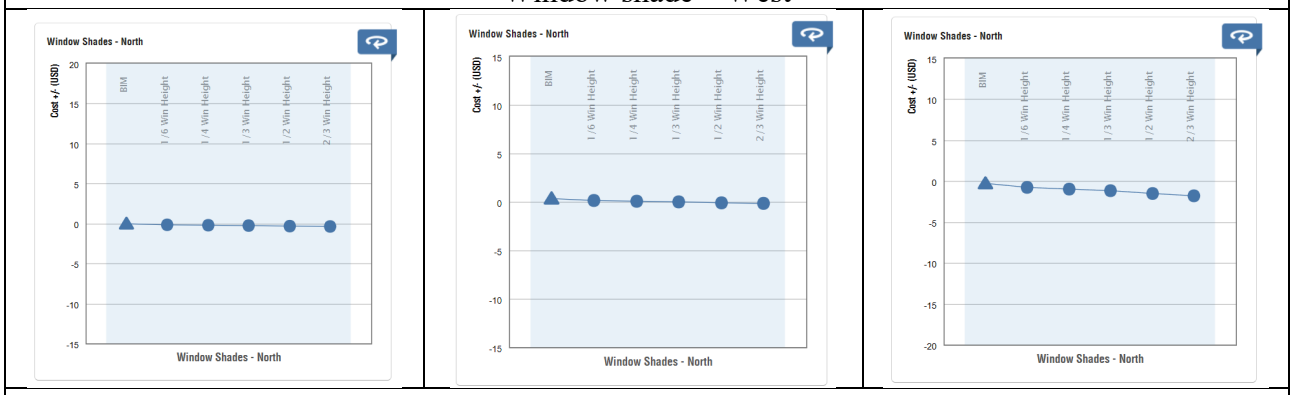
Operating schedule



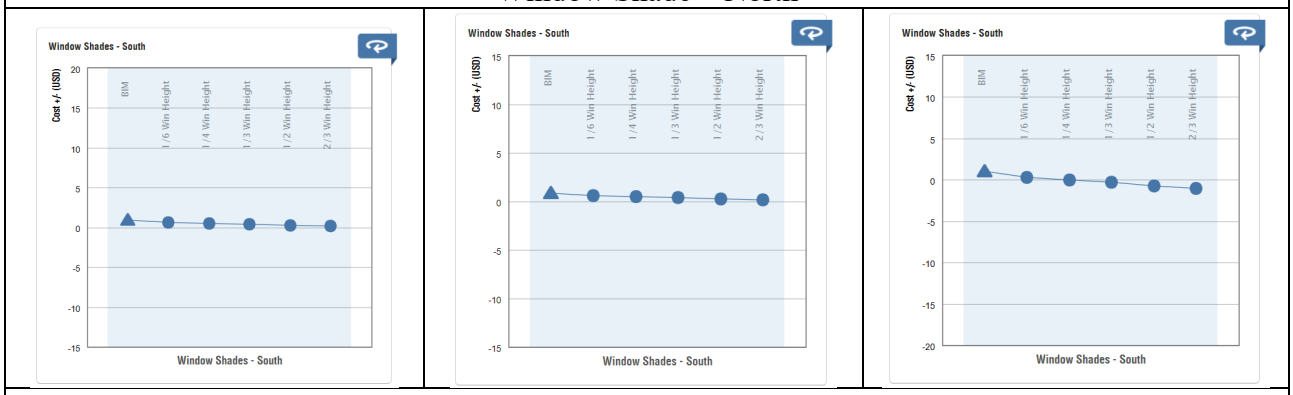
Window shades – East



Window shade – West



Window Shade – North



Window shade – South

Table 5.

Charts showing the ranges of different criteria for the three scenarios

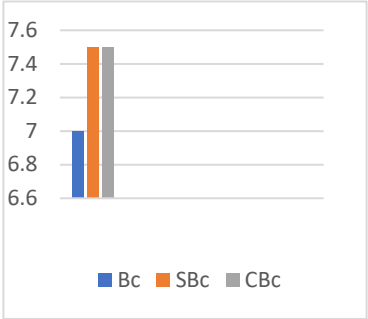
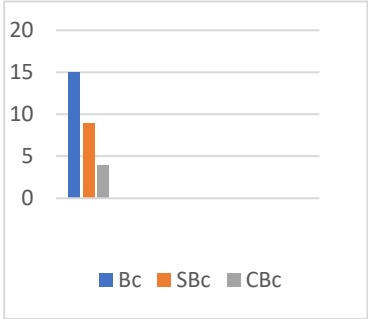
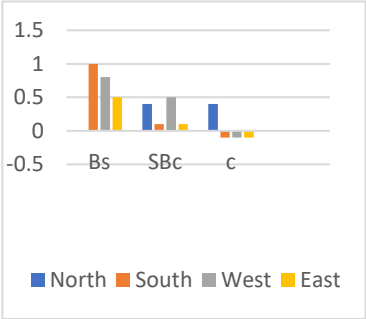
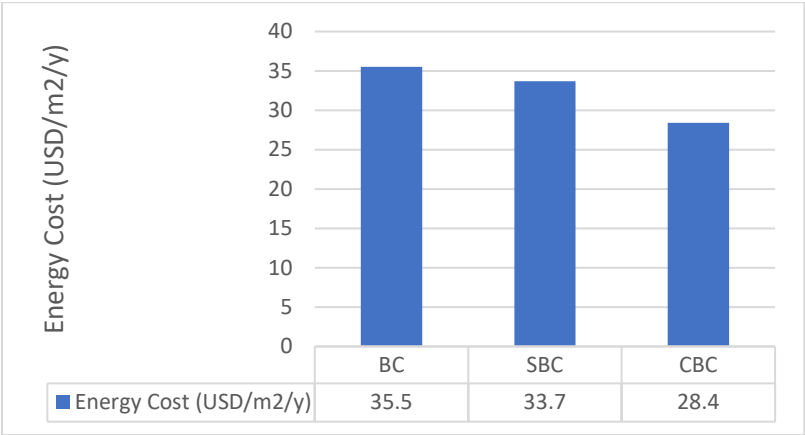
		
Daylighting Efficiency	HVAC	Window shade – Four sides

Figure 5.

Energy Costs in Different Scenarios



4- Conclusion

This research, using Revit software, assessed the impact of two passive design techniques- shading devices and courtyards- on energy efficiency. Shading devices can be implemented during construction or after occupancy, while courtyards must be incorporated from the initial design stage. The findings are applicable to the design of villas or similar residential complexes in the future.

The results indicated that louver shading elements improved lighting efficiency by filtering and controlling natural light effectively, though they led to slightly higher costs of about 3.67 AED/m2 yearly for window shades. HVAC costs with louvers were higher at 33.06 AED/m2/year due to their less effective thermal regulation compared to courtyards.

Courtyards, by enhancing natural ventilation and air circulation, significantly reduced HVAC costs to approximately 14.69 AED/m2/year. Overall, courtyards provided a greater reduction in energy costs (24.24 AED/m2/year) compared to shading devices (6.61 AED/m2/year). While shading devices reduced lighting needs, courtyards had a more substantial impact on overall energy consumption, highlighting their effectiveness in passive design strategies for sustainable building practices and climate change mitigation.

By analyzing and comparing the two passive design solutions- shading devices and courtyards- and creating a stimulation that shows their effects on energy consumption in a villa located in Sharjah, United Arab Emirates, using Revit software, this research helps in the advancement of the subject of sustainable architecture as well as the use of passive design solutions.

Contributions:

1. The research provides a comprehensive analysis of the ways in which courtyards and shading devices impact energy use, including lighting efficiency, HVAC costs, and total energy consumption. Architects and planners can gain useful insights into the efficiency of these passive design techniques from this qualitative investigation.
2. With a focus on Sharjah, United Arab Emirates, the research discusses the unique opportunities and limitations of passive architecture in hot, arid climates. By placing the findings in a geographical context, the study can provide specific recommendations for sustainable building methods across the globe with similar climates.
3. The study offers architects and developers clear information on the best ways to design energy-efficient buildings by comparing and indicating that courtyards reduce HVAC operating costs and overall energy consumption more effectively than shading devices. This shows how early courtyard integration can have positive effects for the economy and ecology.

Significance:

1. The results of this research highlight how passive design techniques are important in lowering energy use, especially with the help of courtyards. This does not only help in lowering costs but also supports sustainable development and international initiatives to reduce the emissions of greenhouse gases through clean building practices.
2. This study quantifies the cost-effectiveness of passive design solutions and indicates how courtyards result in long-term savings in energy and HVAC operation costs even with greater initial investment.
3. The research's conclusions are valuable for teaching and learning sustainable design concepts. Additionally, building laws and regulations can be updated to encourage the implementation of such design solutions on a larger scale for a more sustainable built environment.

References

Abbass, Jasim Hashim and Hanan M. Taleb. (2015). *Applying passive design strategies: case*

study of an art gallery.

Alothman, Ahmed Reda Abdin and A H Mahmoud. (2024). *The Effect of Using Horizontal Shading Elements on the Energy Efficiency of Multistory Residential Buildings*

Drach, J. Karam-Filho. (2014). *Increasing Ventilation by Passive Strategies: Analysis of Indoor Air Circulation Changes through the Utilization of Microclimate Elements.*

Friess, Kambiz Rakhshan. (2017). *A review of passive envelope measures for improved building energy efficiency in the UAE, Renewable and Sustainable Energy Reviews,Volume 72*.

Giovannini and Valerio Roberto Maria Lo Verso and Boris Karamata and Marilyne Andersen. (2015). *Lighting and Energy Performance of an Adaptive Shading and Daylighting System for Arid Climates*.

Ibrahim. (2018). *Eco-Architecture VII: Harmonization between Architecture and Nature.*

Konstantinou, Alejandro Ignacio Prieto Hoces and Thaleia Konstantinou and Nata. (2018). *Environmental Design Principles for the Building Envelope and More: Passive and Active Measures*

Lee. (2019). *Heating, Cooling, and Lighting Energy Demand Simulation Analysis of Kinetic Shading Devices with Automatic Dimming Control for Asian Countries.*

Mesloub and Aritra Ghosh and Mabrouk Touahmia and Ghazy Abdullah Albaqawy and Emad Noaime and Badr M. Alsolami. (2020). *Performance Analysis of Photovoltaic Integrated Shading Devices (PVSDs) and Semi-Transparent Photovoltaic (STPV) Devices Retrofitted to a Prototype Office Building in a Hot Desert Climate*.

Salameh and Basim Touqan. (2022). *Traditional Passive Design Solutions as a Key Factor for Sustainable Modern Urban Designs in the Hot, Arid Climate of the United Arab Emirates.*

Taleb and Lama AbuMoeilak. (2020*). An assessment of different courtyard configurations in urban communities in the United Arab Emirates*.