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Article

Towards Sustainable Saudi Housing: Balancing Modernity with Traditional Architectural Practices

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Abstract: This paper investigates the impact of integrating traditional and modern architectural practices to enhance energy efficiency and cultural compatibility in Saudi residential buildings. A comparative analysis was conducted between contemporary detached houses and traditional courtyard houses in the Eastern Province of Saudi Arabia. A representative modern house was selected and evaluated using data from architectural consultants. This study highlights the high cooling loads in contemporary designs, which amount to 37,166,250 watt-hours annually, with peak loads in July and August. The reliance on air conditioning is driven by the design's failure to incorporate effective passive cooling strategies. The research proposes modifications to incorporate culturally and climatically effective shading elements. For instance, adding a shading element that allows for cross ventilation while maintaining privacy reduced the cooling load to 29,707,751 watt-hours annually. This represents a reduction of approximately 8 million watt-hours, demonstrating the efficacy of such interventions. The traditional courtyard house design, characterized by its central open courtyard and thick insulative walls, provided superior climatic adaptability, significantly reducing the need for mechanical cooling. These findings suggest that modern Saudi homes can benefit from integrating traditional design elements, such as vertical and bridging shading elements. These strategies not only enhance natural ventilation and thermal comfort but also align with cultural preferences for privacy. This study underscores the importance of revisiting traditional architectural wisdom to address contemporary environmental challenges, advocating for a balanced approach to sustainable housing design in Saudi Arabia.

Keywords: Saudi housing design; passive solar control; climatic adaptation; energy efficiency; cultural considerations

1. Introduction

Saudi Arabia has undergone substantial transformations in its social, economic, and environmental sectors, driven by robust economic growth linked to the expansion of oil production, rising exports, and elevated oil prices relative to Gross Domestic Product (GDP) (Alshuwaikhat and Mohammed, 2017; Yusuf and Lytras, 2023). Al-Ibrahim's analysis encapsulates this metamorphosis: "…in less than half a century, these countries have been transformed from a nomadic and subsistence farming economy into a modern urban/industrial society with per capita incomes that are among the highest in the world" (Mahmoud, 2019; Baumann, 2019). This shift is particularly evident in the evolution of Saudi Arabia's built environment (Moser, Swain and Alkhabbaz, 2015). Over the past five decades, contemporary gridiron urban plans have predominantly replaced the traditional urban fabric (Babsail and Al-Qawasmi, 2014). Traditional houses, once climatically and culturally attuned to their environments and constructed from locally sourced materials, have been demolished, resulting in the disappearance of the historic clustered city structure (Samir, Klingmann and Mohamed, 2018; Hobbs, 2017). As a rult, the urban and residential imagery of the country has been significantly transformed (Alqurashi and Kumar, 2016; Alqurashi, Kumar and Sinha, 2016).

Saudi Arabia has adopted advanced construction methods and materials to accommodate modern residences, such as reinforced concrete structures and cement block walls (Almulhim, Hunt and Rogers, 2020; Mohamed, Klingmann and Samir, 2019). While these innovations have facilitated rapid urbanization, they have concurrently contributed to increased energy consumption—a trend reflected globally (Almulhim and Cobbinah, 2023; Al-Douri, Waheeb and Voon, 2019). The rapid economic and population growth in developing countries has further intensified energy consumption, particularly in the housing sector (Alshehry and Belloumi, 2015; Mezghani and Haddad, 2017; Mahalik et al., 2017). In Saudi Arabia, this issue is compounded by the low cost of electricity, which has led to elevated consumption levels, resulting in an annual power demand increase of approximately 6%, primarily driven by domestic usage (Mikayilov et al., 2020). The nation's per capita energy consumption currently stands at 6.8 tons of oil equivalent (TOE), significantly surpassing the global average of 1.8 TOE (Malik et al., 2019; Parkinson et al., 2016). This highlights the urgency of decoupling economic and infrastructural development from oil dependence to avoid potential economic instability (Bradshaw, Van de Graaf and Connolly, 2019; Gasim et al., 2023).

In this context, modern Saudi homes remain heavily reliant on oil-powered electricity (Dannreuther, 2015). Therefore, future urban and residential developments must adapt to new energy consumption paradigms by redesigning residential buildings (Ajlan and Al Abed, 2023). Notably, residential buildings in Saudi Arabia allocate nearly 70% of their electricity use to air conditioning, which is entirely fueled by fossil energy sources (Almutairi et al., 2015; Felimban et al., 2019). Alarmingly, projections suggest that these fossil fuel reserves may be depleted by 2038, with alternative energy sources not yet sufficiently developed (Salam and Khan, 2018). Consequently, both individuals and the government must invest in renewable energy sources—such as solar, wind, or nuclear power—to reduce dependence on fossil fuels for residential air conditioning (Howarth et al., 2020; Amran et al., 2020).

This strategic transition is not merely a response to the looming exhaustion of fossil fuels but also aligns with broader global efforts to mitigate climate change (Mani and Goniewicz, 2023). The Saudi Vision 2030 initiative articulates the nation's commitment to diversifying its energy portfolio and promoting sustainability (Al-Gahtani, 2024). Integrating renewable energy systems, enhancing building energy efficiency, and encouraging technological innovation are essential for realizing a more sustainable and resilient energy future (Ali, 2023; Attoye, Tabet Aoul and Hassan, 2022). This paper contends that through investment in alternative energy and sustainable construction practices, Saudi Arabia can reduce its carbon emissions, ensure long-term energy security, and cultivate a resilient built environment for future generations.

2. Materials and Methods

A comparative analysis has been conducted between contemporary Saudi houses and traditional courtyard houses. This study analyzes the composite climate of a typical detached Saudi house design in the Eastern Province of Saudi Arabia. A representative house was selected and examined based on interviews with consultant architectural offices in the Eastern Province. Subsequently, this contemporary house was compared to the traditional house form's sustainable socio-cultural and climatic qualities to identify potential solutions for current design practices.

2.1. Traditional House of the Eastern Province

The traditional house in the Eastern Province of Saudi Arabia, particularly in the oasis regions of Alhasa and Qatif, was predominantly a courtyard house (Awad et al., 2022; Mahmoud, El Samanoudy and Jung, 2023). These attached coral stone courtyard houses formed dense, clustered settlements (Jung, Awad and Al Qassimi, 2021). These houses were characterized by a climatic hierarchy comprising various ventilated, shaded, and open spaces that influenced their physical form (Jung et al., 2022).

Firstly, the central open courtyard, exposed to the sky, was open for weather conditions. Secondly, semi-open spaces provided partial shade and shelter, featuring colonnaded passages in front of the rooms. Finally, enclosed spaces offered full shade and adapted to weather conditions by strategically opening and closing windows and doors to achieve internal comfort (Figure 1) (Arar and Jung, 2022; Asfour, 2020). This design allowed occupants to enhance their comfort while respecting cultural norms by maintaining family privacy, allowing control of the micro-climate without affecting neighbors' privacy (Qahtan, 2019). These interior rooms, deeply embedded in the plan and surrounded by shading, were enclosed by thick, insulative walls, making them the coolest zones in the houses (Alnaim, 2024). This spatial organization allowed occupants to adjust to varying weather conditions (Aldersoni et al., 2022).

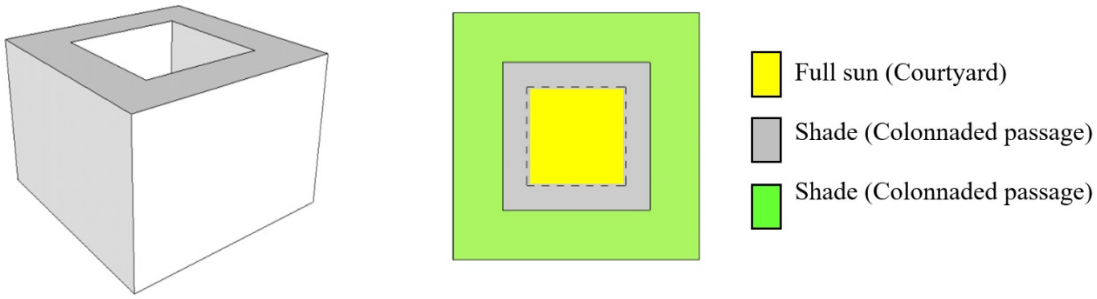


Figure 1. A courtyard surrounded by rooms is the basic form of traditional houses in the Eastern Province (**Left**); order of spaces from full sun to full shade gave occupants options to tolerate the weather (**Right**).

Another critical aspect of the traditional house was the protection of exterior walls from direct solar radiation, achieved either by attachment to neighboring houses or through shaded underpasses known as *sabats*, which were vital common urban spaces in the region (Figure 2) (Raji et al., 2016). The *sabat*, a shaded street beneath a bridge room, remained cool throughout the year. The temperature differential between shaded and unshaded streets generated breezes in the *sabats* (Alnaim, 2020). Locals described these areas as the coolest external domestic spaces, where they socialized and their children played during hot summer days.

Figure 2. Shaded streets sabat under bridged room between houses contributed to the thermal efficiency of the traditional house.

2.2. Typical Modern House of the Eastern Province

A typical modern Saudi house is a single detached dwelling on a plot of at least 500 square meters (Alrashed, Asif and Burek, 2017). This structure commonly comprises three levels: a ground floor, a first floor, and a roof, each covering an approximate area of 250 square meters (Abdul Salam et al., 2014). The house is centrally positioned within the plot, adhering to building regulations that mandate a setback of 2 meters on three sides and 6 meters at the front.

The front façade of these modern houses is typically fully glazed (Figure 3), incorporating extensive use of double-glazed reflective glass (Jung and Mahmoud, 2022). This design choice is prevalent across all rooms, featuring at least one large window to facilitate natural light penetration (Figure 4) (Jung, Mahmoud and Alqassimi, 2022). The utilization of double-glazed reflective glass enhances energy efficiency by reducing heat transfer and glare, aligning with contemporary architectural trends that prioritize both aesthetic appeal and functional performance (Arar and Jung, 2022; Al-Mohannadi and Furlan, 2022).

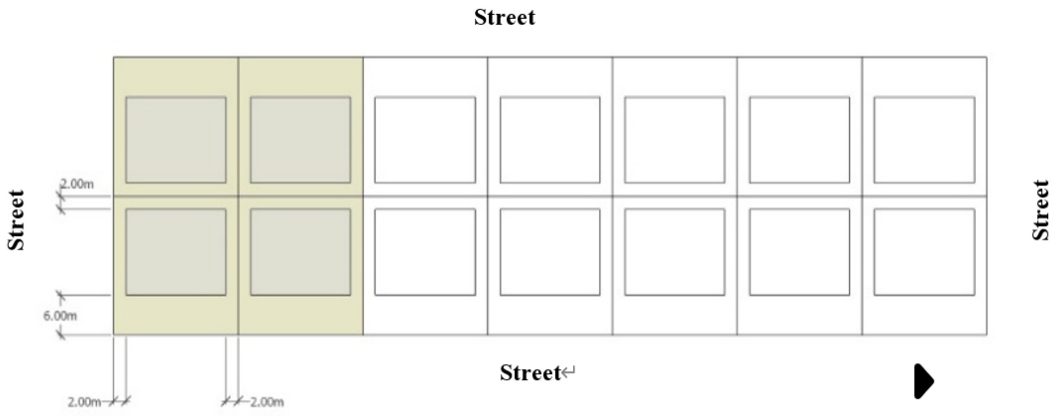


Figure 3. The common block design in the current suburbs in the Eastern Province.

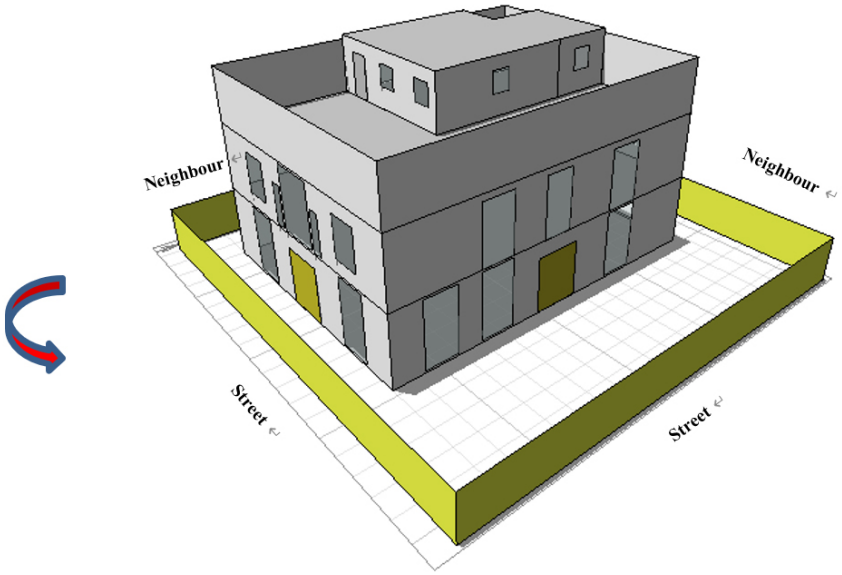


Figure 4. Large glazed unshaded facades of a typical Saudi modern house (The southern façade with large glazed area is the most exposed façade to solar radiation).

2.3. Sustainable Measures of the Current Design

The current design of the box-like detached house in Saudi Arabia presents numerous challenges related to climatic and socio-cultural considerations (Alqahtany and Aravindakshan, 2022). These contemporary architectural forms have led to cultural conflicts that have impeded the houses' passive performance (Giddings, Almehrej and Cresciani, 2023).

First, the detached box-like structure allows windows to be placed on exterior walls, introducing significant socio-cultural issues. In this context, window placement on house facades has led to privacy conflicts, as neighboring windows face each other, resulting in visual intrusion and compromising family privacy (Alnaim et al., 2023). The rigid and inflexible form of the detached house exacerbates these issues. In contrast to traditional designs, the separation of houses and the pattern of subdivision contradict the main climatic and cultural objectives of windows (Almushaikah and Almasri, 2021). Modern windows no longer facilitate cross ventilation and fail to address visual intrusion effectively. Largely glazed facades have become a distinctive feature of contemporary Saudi houses. In the Eastern Province, it is common for the main front facades facing the street to feature full-height, unshaded, and visually unprotected windows (Figure 5) (Bayoumi, 2017).

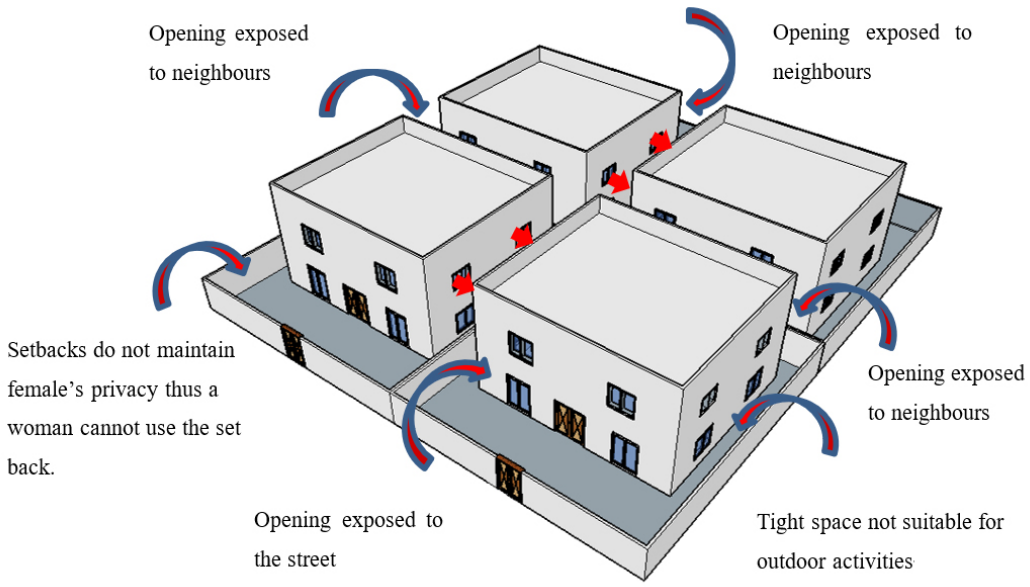


Figure 5. Large glazed unshaded facades of a typical Saudi modern house.

Second, the modern subdivision layout in Saudi Arabia exposes houses to extreme weather conditions. Due to the spacing imposed by building regulations, detached houses are subjected to maximum solar exposure, with no effective shading from neighboring structures (Almushaikah and Almasri, 2021). Facades, especially those facing south and west, experience intensive solar radiation, particularly during summer (Bayoumi, 2017). Southern facades are exposed to sunlight throughout the day. In contrast, western facades receive substantial sunlight in the afternoon, and eastern facades face the sun in the morning and are shaded in the afternoon (Mesloub, Albaqawy and Kandar, 2020; Alwetaishi et al., 2021).

Furthermore, the ratio of building height to street width (H/W) fails to create adequate shade during thermally critical times in summer (Abd Elraouf et al., 2022). The wide streets prevent facades from benefiting from shading, and the required 2-meter setback from three sides of the house minimizes the shading effect from neighboring buildings (Asfour, 2022). The house height-to-setback ratio indicates that the shade will primarily fall on the setback area rather than providing mutual shading between neighboring houses (Asfour, Mohsen and Al-Qawasmi, 2023). Consequently, the mandated spacing between houses is ineffective in offering beneficial shade during peak sun exposure in the early afternoon when the sun is directly overhead (Edrees, 2016).

These observations highlight the need to reconsider current housing designs and urban planning regulations to address climatic and socio-cultural needs effectively (Klingmann, 2023). By integrating these considerations, future housing developments can enhance comfort, privacy, and energy efficiency.

3. Results

Based on the data collected in this research, a simplified model of a representative local house form was developed to evaluate the impact of neglecting cultural considerations and climatic factors in the design of a Saudi house in the Eastern Province's climatic region. The model assumes that windows remain closed throughout the year due to cultural concerns, restricting their opening.

The analysis indicates that the cooling loads are significantly high throughout the year, with a total of 37,166,250 watt-hours required to maintain indoor temperatures between 18–26 °C (Figures 6 and 7).

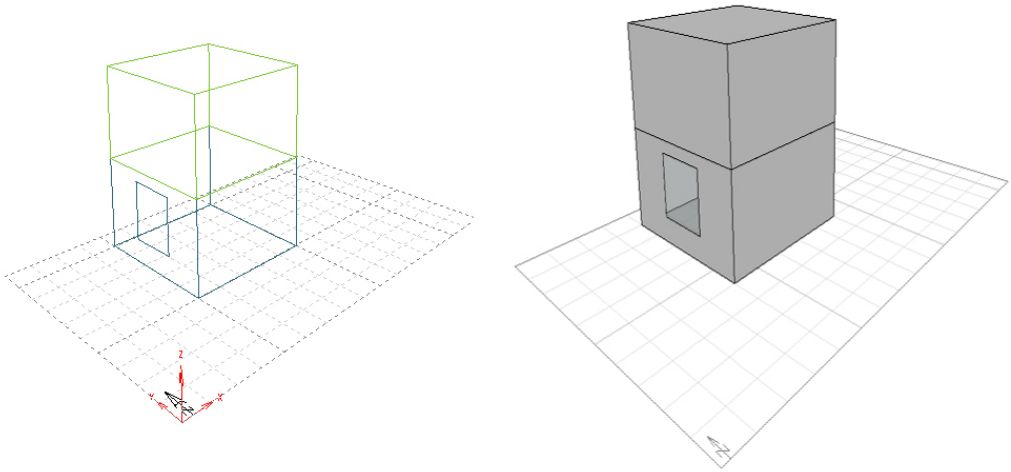


Figure 6. Cooling loads Ecotect test model with unshaded window in the climatic region Eastern Province.

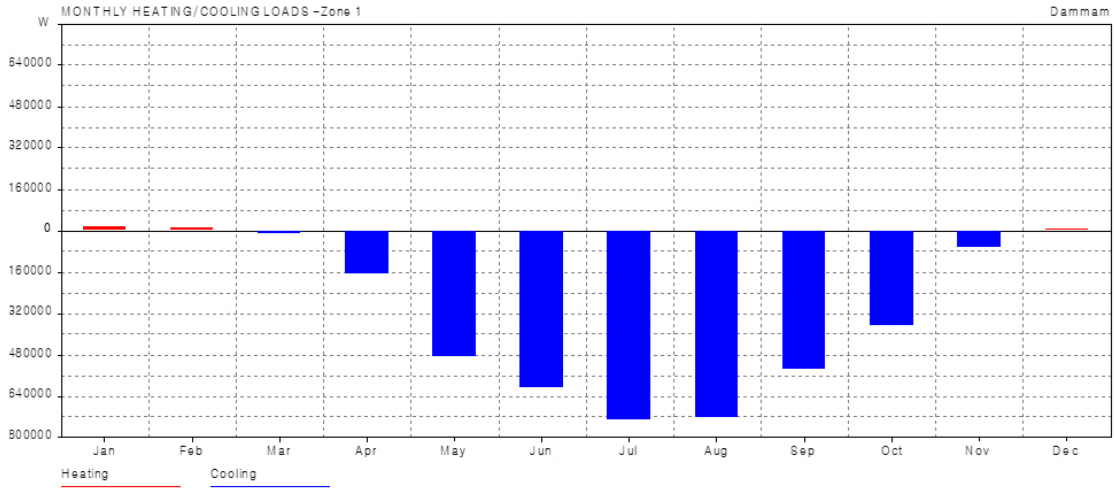


Figure 7. Heating and cooling loads for the ground floor for the test model with unshaded window.

The study also highlights that the cooling loads are highest during the hot season from May to October, with July and August recording the peak values. An active cooling system is particularly critical during these months due to elevated humidity levels (Figure 8).

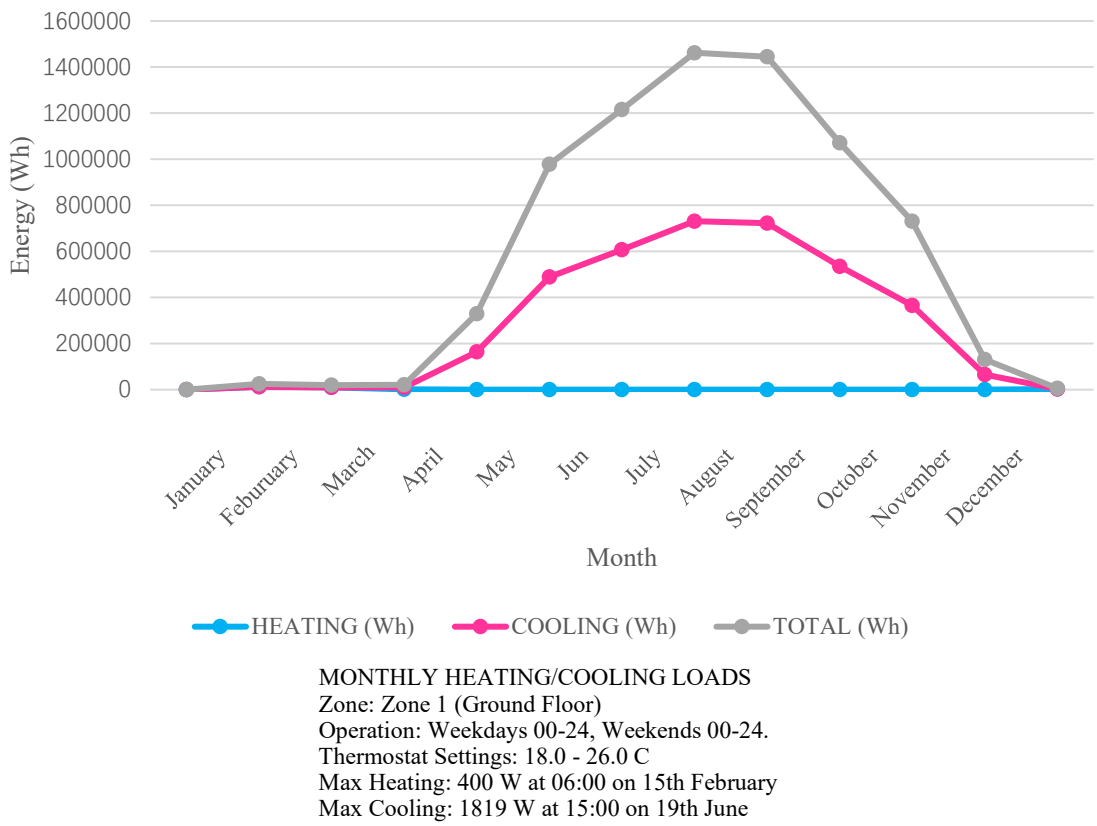


Figure 8. Cooling loads for a simplified model that does not respect climatic and cultural factors.

A notable reduction in cooling loads was observed when culturally and climatically effective shading of openings was implemented. For the same test model, the researcher added a shading element that facilitates cross ventilation by allowing window openings while ensuring complete privacy for the family inside the house (Figure 9).

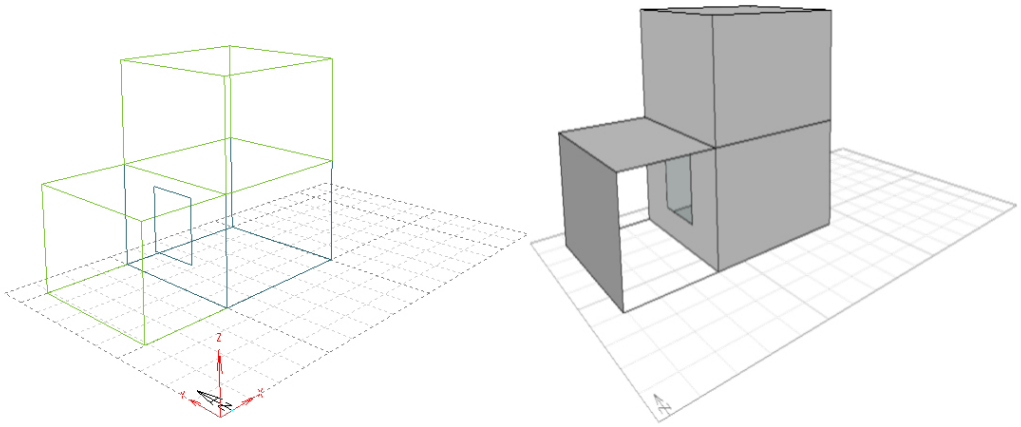


Figure 9. Heating and cooling loads for the ground floor for the test model with unshaded window.

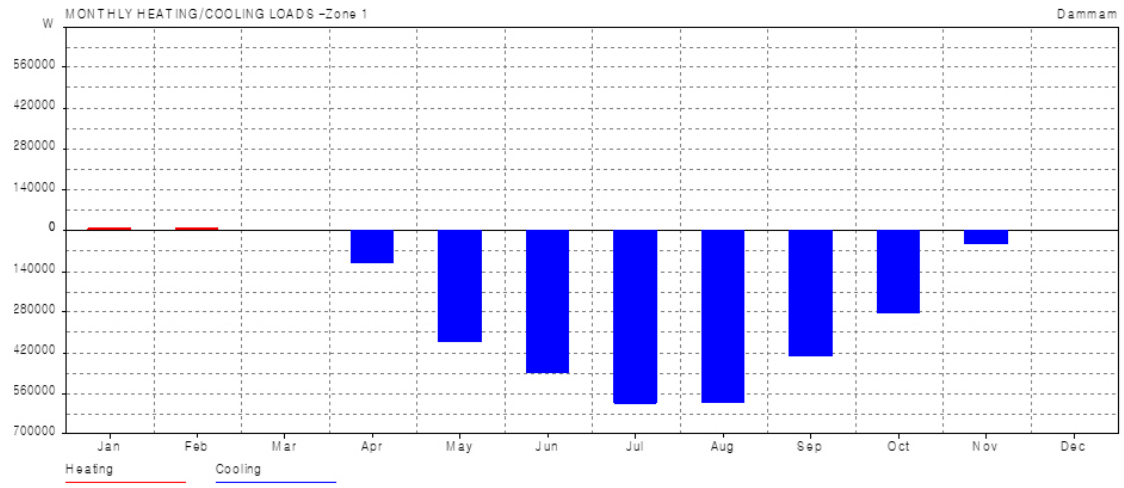
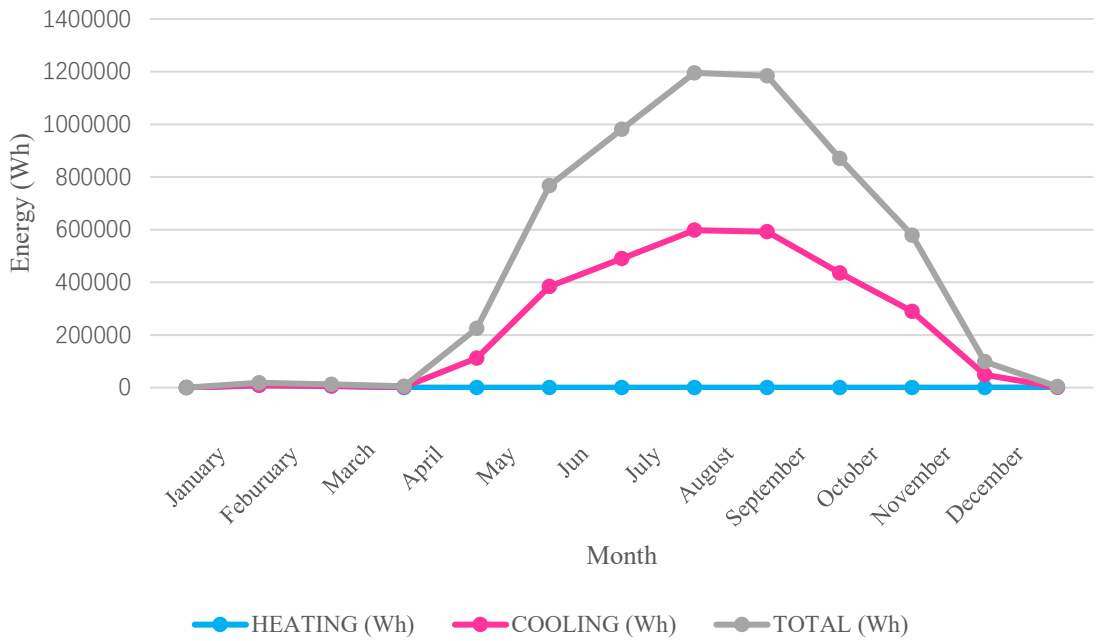


Figure 10. Heating and cooling loads for the ground floor for the test model.

This modification significantly enhanced the occupants' ability to open and close windows. The subsequent analysis revealed that the cooling loads for the modified house decreased from 37,166,250 watt-hours to 29,707,751 watt-hours annually (Figure 10). This represents a reduction of approximately 8 million watt-hours, achieved through culturally and climatically effective shade structures (Figure 11).



MONTHLY HEATING/COOLING LOADS
Zone: Zone 1 (Ground Floor)
Operation: Weekdays 00-24, Weekends 00-24.
Thermostat Settings: 18.0 - 26.0 C
Max Heating: 324 W at 06:00 on 15th February
Max Cooling: 1369 W at 16:00 on 21st July

Figure 11. Cooling loads for a simplified model that respects climatic and cultural factors.

These findings demonstrate that incorporating simple shading elements with cultural and climatic considerations can substantially enhance natural ventilation, reduce cooling loads, and lower energy consumption. The study underscores the importance of integrating cultural norms and climatic responsiveness in architectural design to improve energy efficiency and occupant comfort in Saudi residential buildings.

4. Discussion

Shade is recognized as one of the most effective passive solar control strategies, a principle extensively applied in traditional towns and houses (Al Dakheel and Tabet Aoul, 2017). In the composite climatic region of Saudi Arabia, the requirement for shade supersedes the need for evaporative cooling provided by prevailing winds (Friess and Rakhshan, 2017). This is primarily due to the ineffectiveness of the wind for evaporative cooling for most of the year (Zhang et al., 2015). Furthermore, the orientation of existing houses cannot be easily adjusted to benefit from prevailing winds at this stage of urban development. Therefore, to enhance the current design of Saudi houses, it is crucial to incorporate shade as the primary climatic responsive element within the built environment. Protecting house façades from solar heat through appropriate shading devices is essential (Evangelisti et al., 2020). Additionally, like traditional openings, these shading elements should enable occupants to maintain control over windows, allowing them to open windows to take advantage of prevailing winds when necessary (Premier, 2019). Implementing such modifications can significantly improve the climatic performance of contemporary house designs.

Contemporary Saudi residents have become accustomed to the comfort provided by air-conditioned environments (Elnaklah et al., 2021). There are periods during the year when it may be challenging for residents, used to a certain comfort level, to forgo air-conditioning. However, the reliance on air-conditioning can be significantly reduced during certain months. The following proposed treatments do not seek to eliminate mechanical cooling use but offer occupants additional options to manage weather conditions passively (Oropeza-Perez and Østergaard, 2018). This is a step towards reducing dependence on mechanical cooling systems, a vital objective of this paper. The modifications aim to preserve culturally appropriate privacy while enhancing window control to facilitate passive cooling when needed. The current extroverted detached box form of contemporary domestic buildings limits the ability to open windows freely due to cultural concerns regarding women's privacy (Jung, Awad and Chohan, 2021).

A viable solution must provide privacy while increasing control over window operations to manage comfort levels and promote air circulation. The proposed treatments are classified into two main categories: first-floor and ground-floor treatments, achievable through the following approaches (Jung, Awad and Al Qassimi, 2021).

The proposed modifications to incorporate traditional architectural elements into modern Saudi housing have several potential challenges that may impact their practical application. Cultural acceptance and behavioral shifts present a significant hurdle, as residents accustomed to the continuous comfort of air conditioning might find it difficult to adjust to passive cooling methods, particularly during peak summer months. Awareness campaigns and educational efforts could support this transition. Additionally, regulatory constraints may arise, as elements like mashrabiya or bridged shading could conflict with existing building codes and setback requirements, necessitating collaboration with urban planning authorities to allow these adaptations in contemporary developments. Economic feasibility also plays a role, as retrofitting or redesigning homes to incorporate these architectural features may involve considerable initial costs, particularly for middle- to low-income households. Financial incentives or subsidies could help address these economic barriers. Finally, the availability of appropriate materials and skilled craftsmanship could affect the scalability of these design modifications, requiring partnerships with local artisans or manufacturers to ensure effective implementation. Strategic planning and active stakeholder engagement can manage these challenges, enhancing the feasibility and acceptance of the proposed modifications across Saudi housing developments.

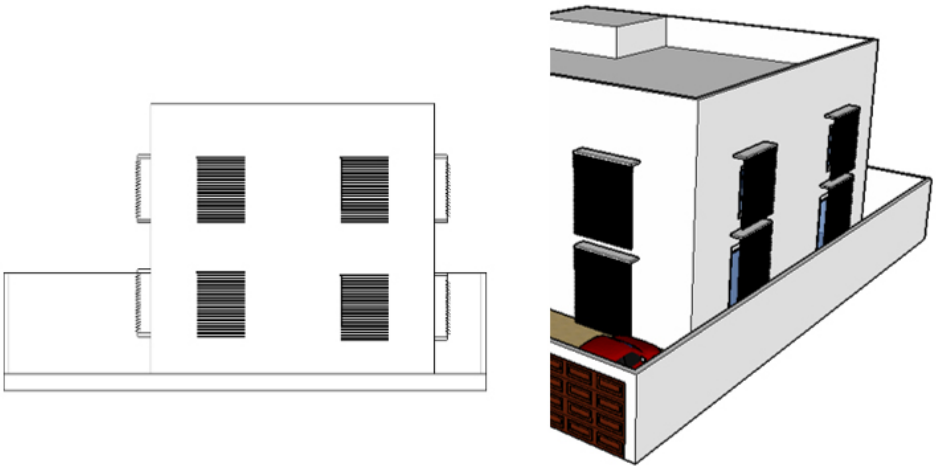


Figure 11. Vertical windows shade that give privacy and shade and allow complete control over windows so occupants can open the window for natural ventilation. This treatment effectively prevents afternoon solar radiation, especially for the western windows.

One optimal solution for extroverted forms in similar cultural contexts is screening openings, functionally equivalent to the traditional *mashrabiya* (Bagasi, Calautit and Karban, 2021). These screened openings efficiently provide privacy and shade and encourage air circulation by allowing windows to be opened while screening the occupants. Historically, *mashrabiya* was widely used in the facades of traditional houses in the western region of Saudi Arabia for aesthetic and functional purposes (Abdelkader and Park, 2018). Modern architecture can adapt this concept to achieve the same cultural and environmental benefits. Contemporary equivalents of *mashrabiya* can be installed as projections on first-floor facades integrated with existing openings (Figure 11). For better weather control, sliding window glass may be retained. With full-height windows, *mashrabiya* can also serve as a seating area (Figure 12).

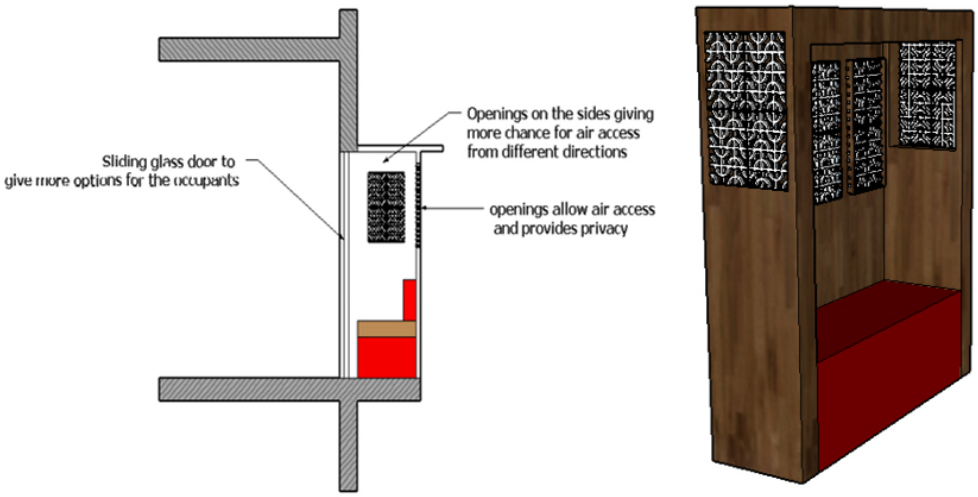


Figure 12. Retrofitting to current window: Mashrabiya with glass sliding door that provides privacy and gives more options to the occupants.

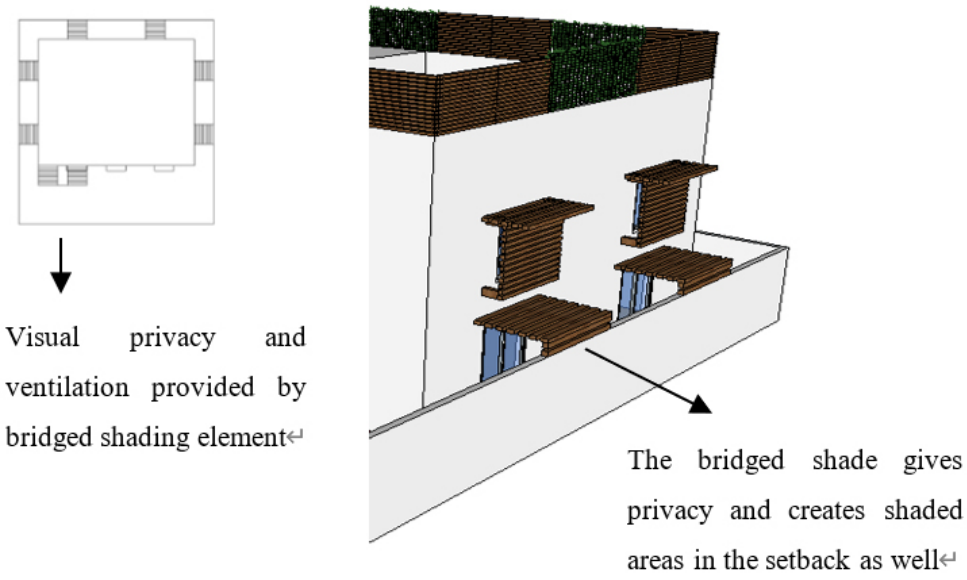


Figure 13. Adding bridged shading above windows on the ground floor in an existing condition. The shading element has to provide privacy and should allow breeze.

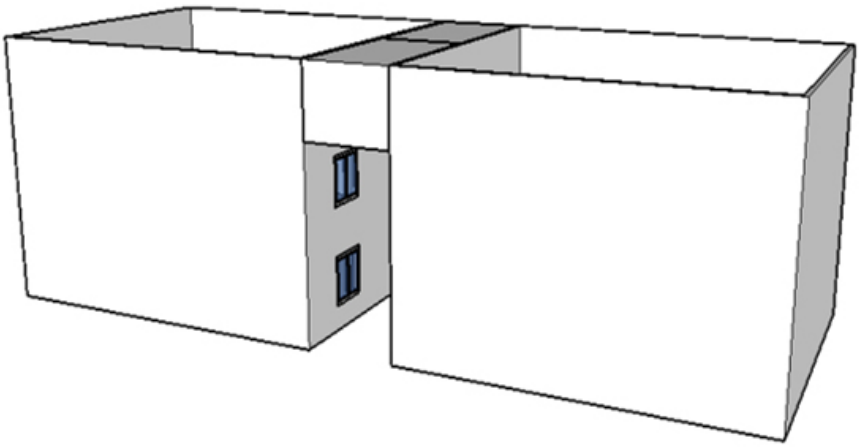


Figure 14. Two bridged rooms may be built to connect the two houses. This treatment can reduce setbacks, and the rooms may be used for the family.

Inspired by the traditional *sabat*, the bridging shading element can be implemented in several ways (Smail et al., 2024). A horizontal shading element can be installed for ground floor openings, extending from above the opening to the fence, thereby providing effective shading (Freewan, 2014). A bridging shading element can extend from above the window to the opposing neighbor's window for first-floor openings. These elements can be controlled manually or electrically, extending or retracting them based on weather conditions. This strategy also provides the benefit of shading the setback area (Figure 13). Another approach involves creating a bridged room that connects two houses, with each house sharing a wall with the neighboring house (Figure 14). Implementing this type of treatment would require addressing property boundary regulations. In the current residential areas of the Eastern Province, a bridged room could shade part of the setback used privately by the family, unlike the shaded public street created by traditional bridged rooms.

Incorporating culturally and climatically effective shading elements in the design of modern Saudi houses can substantially enhance natural ventilation, reduce cooling loads, and lower energy consumption (Taki and Kumari, 2023). These strategies honor traditional architectural wisdom while addressing contemporary environmental and cultural needs, offering a balanced approach to sustainable housing design in the Eastern Province of Saudi Arabia.

While the proposed modifications for integrating traditional architectural elements into modern Saudi housing demonstrate substantial potential benefits, several challenges could impact their implementation. Practical barriers such as regulatory constraints, economic feasibility, appropriate materials and skilled labor availability may hinder widespread adoption. Additionally, cultural adaptation may pose a challenge, as residents accustomed to air-conditioned comfort could initially resist a shift to passive cooling solutions. Addressing these challenges will require collaborative efforts among policymakers, architects, and residents, supported by awareness campaigns and possible financial incentives. By acknowledging these barriers, the paper provides a balanced perspective on the feasibility of the proposed design modifications, equipping stakeholders with insights into real-world applications.

5. Conclusions

Incorporating culturally and climatically effective shading elements in the design of modern Saudi houses can substantially enhance natural ventilation, reduce cooling loads, and lower energy consumption. This study demonstrates the significant benefits of integrating traditional architectural wisdom into contemporary housing designs to address environmental and cultural challenges.

The analysis of a typical modern detached house in the Eastern Province of Saudi Arabia revealed that current designs lack effective passive cooling strategies and result in high annual cooling loads of 37,166,250 watt-hours. This high energy demand is exacerbated during the peak summer months of July and August, emphasizing the inadequacies of modern design in mitigating extreme climatic conditions. Implementing shading elements that facilitate cross ventilation while maintaining privacy reduced the cooling load to 29,707,751 watt-hours annually. This approximately 8 million watt-hours reduction highlights the potential energy savings achievable through simple architectural modifications.

Traditional courtyard houses, characterized by their central open courtyards, semi-open spaces, and thick insulative walls, provided superior climatic adaptability and thermal comfort. These designs allowed for natural ventilation and effective shading, significantly reducing the reliance on mechanical cooling systems. The spatial organization of these traditional houses offered flexibility in adjusting to varying weather conditions, respecting cultural norms, and ensuring family privacy. Adapting such elements into modern designs can help reconcile the need for privacy with improved energy efficiency and thermal comfort. Using vertical and bridging shading elements inspired by the traditional mashrabiya and sabat can create a balance between aesthetic appeal and functional performance. These strategies not only enhance the passive cooling capabilities of modern houses but also align with the cultural expectations of Saudi residents.

Moreover, the study underscores the importance of re-evaluating current housing designs and urban planning regulations. Integrating climatic and socio-cultural considerations into these frameworks can lead to the development of more sustainable and resilient housing solutions. This approach is particularly relevant in Saudi Arabia's Vision 2030 initiative, which aims to diversify the energy portfolio and promote sustainability. By revisiting traditional architectural practices and adapting them to contemporary needs, Saudi Arabia can significantly reduce its carbon footprint and ensure energy security. Such an approach can foster a more sustainable built environment that is both culturally sensitive and environmentally responsive. Future housing developments incorporating these principles will enhance occupant comfort and contribute to global efforts to mitigate climate change.

The findings of this study advocate for a balanced approach to housing design, where modern innovations are harmoniously blended with traditional architectural wisdom. This strategy offers a viable path toward sustainable urban development, ensuring Saudi Arabia can meet its energy and environmental goals while preserving its rich cultural heritage. Future research could explore the long-term impacts of the proposed modifications on energy consumption and occupant comfort in Saudi housing. A longitudinal study would be particularly valuable in assessing the durability and effectiveness of traditional architectural elements, such as mashrabiya and bridged shading, in reducing cooling loads over time. Further investigation into occupant behavior and adaptability to passive cooling methods would provide insights into cultural and practical acceptance. Additionally, examining the potential scalability of these design modifications across various climates and housing types in Saudi Arabia would contribute to developing adaptable and resilient housing solutions. By pursuing these research directions, future studies can deepen our understanding of sustainable housing practices in Saudi Arabia, offering stakeholders data-driven insights for continued improvement and innovation.

Author Contributions
Conceptualization, S.A. and C.J.; methodology, S.A.; software, S.A.; validation, C.J. and S.A.; formal analysis, S.A.; investigation, C.J.; resources, S.A.; data curation, C.J.; writing—original draft preparation, S.A.; writing—review and editing, C.J.; visualization, S.A.; supervision, C.J.; project administration, C.J. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest
The authors declare no conflict of interest.

Data Availability Statement
New data were created or analyzed in this study. Data will be shared upon request and consideration of the authors.

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