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The Impact of Passive Strategies on the Overall Energy Performance of Traditional Houses in the Kingdom of Saudi Arabia

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Abstract: Communities in nations all over the world must work to address the problem of energy consumption, which has emerged in modern times. Given that domestic consumers account for roughly 49% of the total electricity used annually by all sectors, buildings can be seen as a key player in this conundrum. The architecture field can therefore play a vital role in saving energy, not only through building design but also through the materials used. To minimize architectural programmes' negative impact on the environment, sustainable design that saves energy is being employed today in traditional Saudi Arabian buildings. This study examined whether current housing designs can effectively integrate four key passive energy-saving strategies: outdoor green area, thermal mass wall, window-to-wall ratio and shading device. This study analysed two types of traditional houses from two different cities in Saudi Arabia's Najd region, Riyadh and Hail, examining the four passive strategies. Using traditional house designs, this paper created four simulation models for each house, and compared the simulation results with the base case model to determine how well these strategies could affect the energy consumption for residential buildings in Saudi Arabia (KSA). The results indicate that the selected strategies can play an important role in saving energy in residential buildings in the KSA.

Keywords: traditional house; passive strategies; energy consumption; thermal mass; window-to-wall ratio (WWR)

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Citation: Aldersoni, A.; Albaker, A.; Alturki, M.; Said, M.A. The Impact of Passive Strategies on the Overall Energy Performance of Traditional Houses in the Kingdom of Saudi Arabia. *Buildings* **2022**, *12*, 1837. https://doi.org/10.3390/buildings12111837

Academic Editors: Gerardo Maria Mauro and Costantino Menna

Received: 26 September 2022
Accepted: 27 October 2022
Published: 1 November 2022

1. Introduction

The global trend to reduce the consumption of energy includes a broad range of fields, including the domestic, industrial, commercial, government, and agricultural sectors. Among these, the domestic sector is known as the highest consumer of energy. Domestic consumption constituted 47.58 percent of all power consumed in 2020, with industrial use making up 20.0 percent, followed by commercial use (14.2 percent), preceded by government use (12.51 percent), and then other uses (25.7 percent) [1]. This situation can be improved by reducing the negative impact on the environment produced by implementing architectural programmes and integrating sustainable design. However, these ideas and objectives are not new to the field of architectural design, since vernacular architecture is frequently directed towards the successful integration of buildings into the surrounding natural environment. In Saudi Arabia, almost all traditional houses in each area are constructed based on the local environment and the surrounding structures [2] by segregating among themselves through elements such as form, scale, and measurements of the buildings, the types of materials used, and homogeneity with the surrounding environment. Therefore, traditional buildings in Saudi Arabia are a good example of traditional architecture today that can participate in saving energy [3].

Traditional houses in Saudi Arabia are noteworthy examples of vernacular architecture today. For example, houses in the Najd region are designed according to the culture and traditions surrounding central Saudi Arabia. Despite many common characteristics, Saudi houses in each region have been developed based on the local climate and geography, and are thus differentiated from each other through the form, scale, and size of the building, as well as by the materials used and the surrounding environment. Saudi Arabia is a huge country extending from the south to the north, which means there are several climatic zones and diverse topographic features. Therefore, different parts of Saudi Arabia have different climatic conditions, although the desert encompasses approximately 90% of the overall area of the country [4]. The present research identified the most significant geographical areas in Saudi Arabia that have hosted many Arabic civilizations. There are four provinces in present-day Saudi Arabia, the largest of which is the Najd Plateau; this area is almost the size of France, with a surface area of about 700,000 square kilometres, accounting for about a third of Saudi Arabia's total territory [5]. Despite the diversity of desert architecture, Najd architecture may appear simple (see Figure 1); nevertheless, it is significantly differentiated by its focus on modifying the severe desert conditions [6]. Historically, Najd Houses represented the practical wisdom and spirituality of the locals. Najd houses were originally built in two areas with a courtyard in the middle. Besides providing shelter from the weather, they also enrich safety. The courtyard houses of the Najd region comprised square or rectangular dwelling spaces with two or more floors and also had other rooms that could be used for public or private purposes [6]. The courtyard was not only a type of shelter but was also considered to be a spatially responsive geographical area since it provided a contemporary blend for long-lasting urban development [7]. Courtyards in urban areas may include gardens on the inner side, which Akbar [8] indicated usually included simple trees or plants.

Figure 1. Sample of a traditional house in the Najd region.

Traditional Najd houses reflect people's response to the area's hot, arid environment using sustainable thinking. The plans are influenced by factors such as economics, the environment and thermal comfort; it was especially effective to use the 50 cm thermal walls on the ground floor for indoor cooling during summer [6]. Meanwhile, Najd houses are built with sun-dried mud bricks, while mud block samples that contain ash have a lower thermal conductivity compared to other modern block forms. For every degree of temperature (represented in watts per meter kelvin, W/mk), thermal conductivity is the time it takes to keep a constant heat flow (in watts) through a meter square unit area (M2) in a direction at right angles to an isothermal outside [9]. Moreover, in Najd housing design, blocks of houses were set apart from one another to shield them from the heat, while adjacent buildings provided protection when only a few walls were unprotected.

From above, this solid urban form was evident, with light wells elevated above the ground, as well as narrow streets [10]. In places with significant daily temperature fluctuations, incorporating thermal mass in buildings can be one of the most efficient strategies to reduce structural heating and cooling loads. The building's employment of thermal mass lowers temperature fluctuations and absorbs energy surges from solar and internal heat gains. Thermal mass incorporated in the building reduces temperature swings and absorbs energy surpluses both from solar gains and internal heat gains. Furthermore, substantial building envelope elements retard and flatten thermal waves brought on by variations in exterior temperature [11]. In addition, a substantial proportion of research has been carried out on how thermal mass affects the energy performance of buildings that have been under extreme conditions in Saudi Arabia. The effect of thermal mass on energy utilization was also examined in the study by Aladross. In order to determine whether the thermal mass had any discernible impact on the villa's overall energy consumption, the thickness of the outer concrete walls of the villa was altered from 5 cm to 40 cm. The results, according to the researcher, were to be expected since the greatest advantage from the thermal mass is attained in climatic zones with a high diurnal temperature range, which is defined as a significant temperature difference between day and night to allow for the storage and release of heat during a day cycle. This tactic can reduce overall cooling and heating use by 15% [12]. The primary aim of the study was to examine how thermal mass influences the energy demand for cooling and heating.

Stone was scarce in the Najd region, so mud was used to construct the sun-dried bricks expended in the houses. Mud was also used as a plaster for the outer and inner parts of the walls since it was suitable for the sandy environments [13]. The primary building materials in Najd construction were mud (known as Libin), cut stones for the basement, palm tree trunks for the roof, and straw (see Figure 2). This was carried out by master builder Al-Moualem and his family, neighbours, and relatives [6].

Cut Stones Mud Bricks Tree Trunks

Figure 2. Construction materials used for traditional houses in the Najd Area.

The ratio of windows to exterior walls, or the exterior window-to-wall surface, is referred to as the Window-to-Wall Ratio (WWR). There are many ways that WWR can influence building attributes, such as the size of windows impelling their physical and visual relationship with the outside. The use of materials in vernacular architecture also influences the environment [14]. The vernacular architecture uses exterior walls that lack windows to prevent direct vision from the outside and restrict dusty wind from entering the space [14]. Window-to-Wall Ratio, also known as WWR, is the area of glass panels to the exterior wall from floor to floor. Research on WWR and its correlation to energy performance has been more prevalent in recent years [15]. Awetaishi stresses the benefits of adopting thermal insulation and WWR diminution in terms of a building's energy conservation. The author indicated that significant energy savings can be made in both the demand for cooling and heating, particularly in the north-facing zone, which uses roughly 400 W of energy for heating in the winter between 3 a.m. and 11 a.m. One can see that a 50% reduction in WWR has led to a 15% overall reduction in energy usage [16]. In traditional Najd courtyard houses, shading devices are also crucial to reducing heat gain and regulating indoor temperatures. The sun's rays are diverted from entering the house, which is the chief purpose of opposing excessive heat gain. One panel radiator could produce the heat resulting from each square meter of a building that is exposed to direct sunlight [17]. Numerous studies examine the effects of the WWR and shading devices on the energy efficiency of residential buildings [18–20]. Ossen analyzes the impact of shading devices on energy performance and the possibility that they could lower the amount of daylight, which would elevate the need for the utilization of artificial lighting. To lower the direct sun radiation impingement on a windowpane by more than 80%, the author's research revealed that the east and west orientations necessitated larger horizontal overhang ratios. Maximum shading from direct solar radiation for north and south orientations can be attained with overhang ratios of 0.6 and 0.8, respectively. When compared to the total incoming solar radiation on the window surface, the naked window initially showed a heat gain reduction of between 23.9 and 29.3 percent on the east, west, north, and south orientations. According to the author, as the overhang ratio grew, energy savings for cooling increased gradually, and the most economical energy savings of 31%, 26%, 19%, and 22% were found at overhang ratios of 1.4, 1.3, and 1.2 on east-west and north-south orientations, respectively [21]. In another study, the temperatures in Saudi Arabia were used to examine how building-integrated photovoltaics (BIPVs) can be used as shading devices in hot environments. According to the author, a case of horizontal BIPV shading devices with a 45-degree tilt angle received the utmost annual total insolation (104 kWh/m^2) and propounded effective window shading for, on average, 96 percent of the total window area in summer [22].

As new technologies advance, buildings begin to lose these useful tactics. However, many researchers have designed passive ways of employing emerging innovations, and they agree with their value and importance. The contribution of this research supports the use of the architectural solution in the Najd region's vernacular homes by examining the impact of passive methods on the energy performance of the vernacular homes that could be implemented in the production of prospective home interiors. The risk of high energy consumption, which is linked to several hazards, will be directly impacted by this research. Additionally, by employing the principles of vernacular architecture, the research will inspire designers to incorporate the architectural identity of Saudi houses into new iterations of contemporary homes.

2. Materials and Methods

In a hot and dry climate, traditional architecture is composed of many resolutions that adapt to the climate for human comfort, particularly during the hot summer months. These solutions include a green outdoor area, thermal mass, WWR and shading device strategies, as described previously. To understand the influence of the four chosen passive strategies on the energy performance of the traditional house, this study adopted three analyse.

First, this paper analysed two traditional Saudi houses built in two different climatic zones in the Najd region. These houses in the cities of Riyadh and Hail (Case 1 and Case 2) were analyzed according to two key criteria, the surrounding environment, and traditional architectural techniques. This stage involved a field trip to the two traditional houses to implement a monitoring strategy to evaluate the performance of the current building envelope. The field trip collected 45 days of weather data in the summer of 2018, which was an appropriate time to access the buildings during the most challenging weather conditions. Between 20 July and 5 September 2018, the local weather data were gathered.

The researchers also collected official architectural and construction details, while routine site visits ensured that initial design drawings and pre-approval conditions were met. It was also identified that broken windows in older, more traditional buildings could compromise their validity, so the researchers undertook a walkthrough of both buildings and conducted a survey to determine whether these factors were present.

The second stage of the research methodology was to validate the collected data to create a base case model that could be used to assess the performance of the selected case studies. When choosing the right monitoring tools for mapping, several crucial factors were taken into account. Batteries, parameters, accuracy, sampling rates, sensitivity, and sensitivity are all essential factors that were included in this study. As a result, the research's collection of interior weather data was done using iButton Data Loggers (DS1922L-F5). Two advanced weather stations (HP 1000 Professional Weather Station) that provided several climatic details, including solar radiation, wind speed and direction, humidity, and temperature, were also used to accomplish the research objectives.

The information on internal weather conditions was gathered for a variety of locations with distinct uses and, consequently, unique architectural elements. Three rooms on the first level and three rooms on the second floor each had an internal temperature logger. Additionally, the loggers were positioned away from the entrance in the middle of the room's ceilings. Despite this, the logger's data were impacted by open windows and doors since the air change exhibited hourly oscillations. To ensure open access to climatic influences, weather stations were also erected on the building's roof and placed on uniquely engineered platforms, lifting the weather station above the surface of the roof to allow for the uninterrupted collection of weather data. To record the sun's movements, solar radiation sensors were positioned south. This paper used Design Builder software to display architectural and construction details. In the summer of 2020, real data were used to validate the temperature calibrations. This validation was a first step towards understanding passive strategies for the future analyses of traditional houses in the cities of Riyadh and Hail, which was the main motivation for using these models. As seen in Figure 3, regarding the software temperature calibration, the measurements and the validation model results in Riyadh city were almost identical, with a 3.16 per cent difference on average between the measured and model results. Similarly, Figure 4 shows the simulation results for the traditional house model in Hail city, indicating an average difference of 0.84 per cent between the measured temperature and that predicted by the simulation.

Lastly, this paper analysed the impact of the four selected passive strategies on the energy performance of the traditional house by comparing the real data with the computational program investigation. The influence of the green area was studied by comparing the measured outdoor weather data of two different cases in Hail city (Case 2 and Case 3); the first of these was a traditional house partly protected by trees, while the other was a contemporary house that stands alone with no green areas or trees to protect from the harsh weather. For the two study locations in Case 2 and Case 3, the researchers analyzed hourly measured outdoor weather data for August 2020. Meanwhile, the Design Builder simulation software program was used to understand the influence of the green area on energy performance during the summer period. Therefore, the researcher revised the weather file of Case 2 to adapt to the weather characteristics of Case 3.

The simulation created by the Design Builder software program was used to analyse the other three traditional passive strategies identified previously. During this stage, the research examined the functionality of traditional passive strategies by implementing the design strategies of Saudi contemporary houses into the traditional house design. The results of the research were then compared to the base case model.

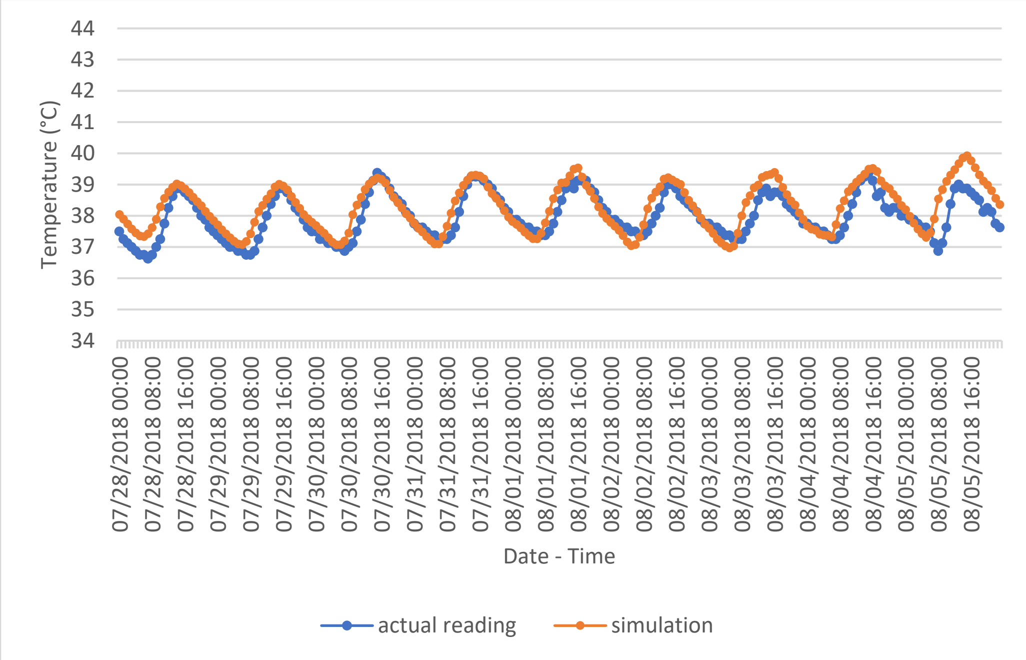


Figure 3. Temperature calibration of the simulation results for bedroom 1 in the traditional house in Riyadh City.

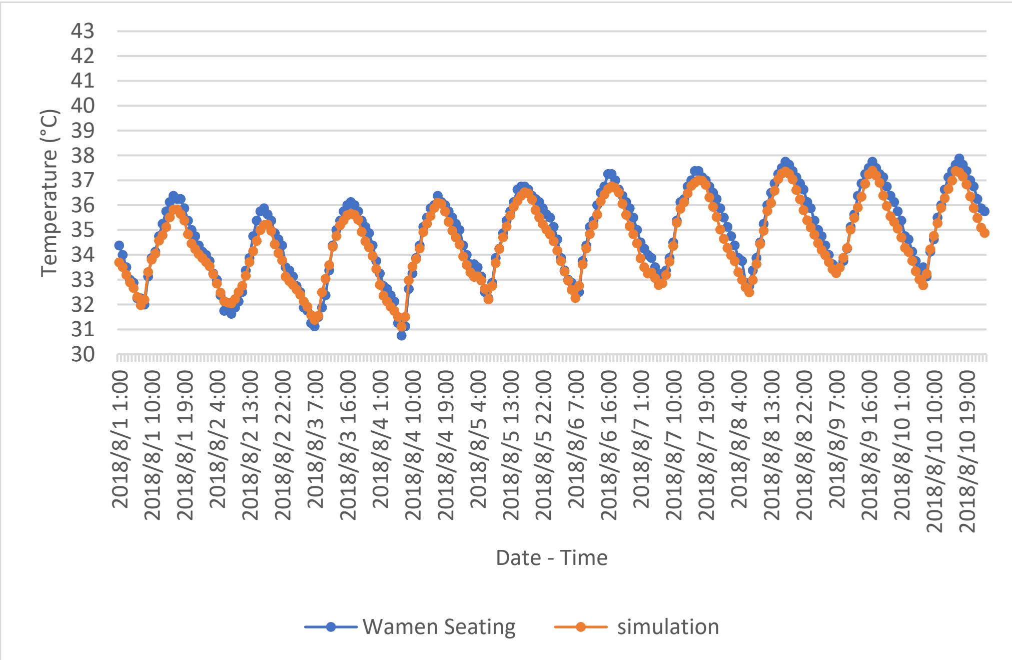


Figure 4. Temperature calibration of the simulation results for the family seating area in the traditional house in Hail City.

Regarding the traditional building material of mud or clay blocks, these are not currently produced in modern Saudi Arabia and do not appear on the Saudi Building Code's list of approved materials. Therefore, the study compared the thermal properties of clay blocks and insulated concrete blocks, which imitate the exterior wall structure of contemporary houses. Table 1 illustrates the differences between the external wall structures of traditional and contemporary designs based on previous studies, as well as the Design Builder library.

Table 1. Exterior wall structure and thermal propriety for traditional and contemporary houses.

Exterior Wall Thermal Priorities for the Contemporary Houses						
Categories	**Elements N.**		**Density (kg/m^2)**	**Specific Heat (J/kgK)**	**Thickness (mm)**	**Conductivity (W/mk)**
Exterior walls	Cement Plaster		1760	840	25	0.72
	Insulated Concrete block	Concrete block	1400	1000	100	0.51
		Expanded polystyrene	10	1400	30	0.046
		Concrete block	1400	1000	70	0.51
	Cement plaster		1760	840	25	0.72
U-value	0.82 W/m^{2}k					
Exterior Wall Thermal Priorities for the Traditional Houses						
Categories	Elements N.		Density (kg/m^2)	Specific heat (J/kgK)	Thickness (mm)	Conductivity (W/mk)
Exterior walls	Clay plaster		1790	2085	60	0.406
	Mud block		1253	880	450	0.215
	Clay plaster		1790	2085	60	0.406
U-value	0.391 W/m^{2}k					

The present research also modified the characteristics of the WWR of a contemporary house to assume how it affects energy efficiency in traditional houses. In Cases 1 and 2, Tables 2 and 3 illustrate these modifications in context with the WWR of a traditional house.

Table 2. The modification of WWR in traditional house in Riyadh city Case 1.

	WWR Guest Room (NW)			**WWR Guest Room (SE)**			**WWR Dining Room**		
	Wall Area m^2	**Window Area m^2**	**WWR %**	**Wall Area m^2**	**Window Area m^2**	**WWR %**	**Wall Area m^2**	**Window Area m^2**	**WWR %**
Traditional Base Case (T B.c)	11.6	0.11	0.9	15.5	0.25	1.6	10.2	0.25	2.5
Contemporary Base Case (C B.c)	13.2	1.5	11.4	19.8	1.5	7.6	16.5	1.5	9.1
WWR Modification (WWR. M)	11.6	1.1	9.5	15.5	1.5	9.5	10.2	0.9	9.1
	WWR Living Room			WWR Kitchen Room			Bedroom 1		
	Wall Area m^2	Window Area m^2	WWR %	Wall Area m^2	Window Area m^2	WWR %	Wall Area m^2	Window Area m^2	WWR %
(T B.c)	13	0	0	14.5	0	0	12.6	0.25	2.0
(C B.c %)	16.2	1.5	10.8	9.9	1.5	15.2	15.8	1.5	10.5
(WWR. M)	13	1.4	10.8%	14.5	2.2	15.2%	12.6	1.3	10.5%

Table 2. *Cont.*

	WWR Guest Room (NW)			**WWR Guest Room (SE)**			**WWR Dining Room**		
	Wall Area m²	**Window Area m²**	**WWR %**	**Wall Area m²**	**Window Area m²**	**WWR %**	**Wall Area m²**	**Window Area m²**	**WWR %**
	Bedroom 2			Family Room (NW)			Family Room (SE)		
	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %
(T B.c)	13.1	0.25	1.9	13.6	0.25	1.8	17.9	0.5	2.8
(C B.c %)	15.8	1.5	10.5	16.5	1.5	9.1	-	-	-
(WWR. M)	13.1	1.4	1.5%	13.6	1.2	9.1%	17.9	1.6	9.1%
	Bedroom 3			Bedroom 4			Bedroom 5		
	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %
(T B.c)	11.5	0.25	2.2	27.1	0.6	2.2	16.6	0	0
(C B.c %)	15.8	1.5	10.5	15.8	1.5	10.5	15.8	1.5	10.5
(WWR. M)	11.5	1.2	10.5%	27.1	2.8	10.5%	16.6	1.7	10.5%
	Bedroom 6								
	Wall Area m²	Window Area m²	WWR %						
(T B.c)	14.8	0.5	3.4						
(C B.c %)	15.8	1.5	10.5						
(WWR. M)	14.8	1.6	10.5%						

Table 3. The modification of WWR in traditional house in Hail city Case 2.

	WWR Guest Room (NW)			**WWR Guest Room (SE)**			**WWR Family Room**		
	Wall Area m²	**Window Area m²**	**WWR %**	**Wall Area m²**	**Window Area m²**	**WWR %**	**Wall Area m²**	**Window Area m²**	**WWR %**
(T B.c)	11.6	0.11	0.9	-	-	-	36	1.1	3.1
(C B.c %)	13.2	1.5	11.4	19.8	1.5	7.6	16.5	1.5	9.1
(WWR. M)	11.6	1.1	9.5%	-	-	-	36	3.3	9.1%
	WWR Dining Room			Bedroom 1			Bedroom 2		
	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %
(T B.c)	31.5	2.2	7.0	17	0.25	1.5	13.1	0.25	1.9
(C B.c %)	16.5	1.5	9.1	15.8	1.5	10.5	15.8	1.5	10.5
(WWR. M)	31.5	2.8	9.1%	17	1.8	10.5%	13.1	1.4	10.5%
	Bedroom 3			Bedroom 4			Bedroom 5		
	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %
(T B.c)	9.6	0.25	2.6	13.3	0.25	1.9	14.1	0.25	1.8
(C B.c %)	15.8	1.5	10.5	15.8	1.5	10.5	15.8	1.5	10.5
(WWR. M)	9.6	1.0	10.5%	13.3	1.4	10.5%	14.1	1.5	10.5%

Table 3. *Cont.*

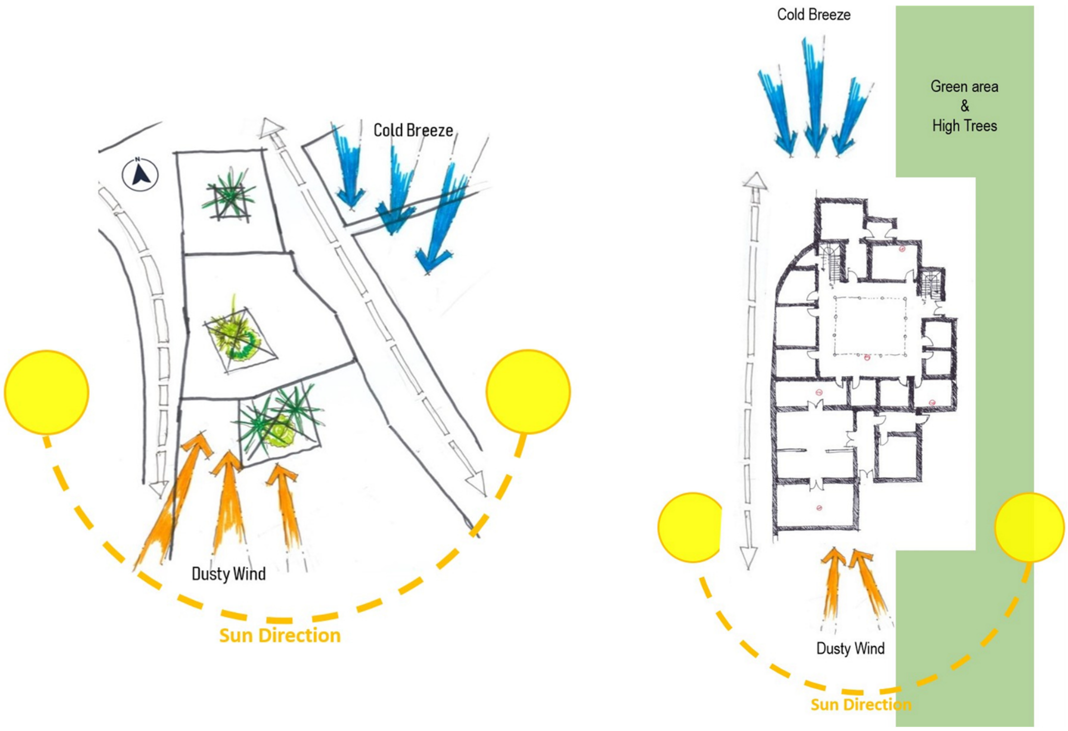
	WWR Guest Room (NW)			**WWR Guest Room (SE)**			**WWR Family Room**		
	Wall Area m²	**Window Area m²**	**WWR %**	**Wall Area m²**	**Window Area m²**	**WWR %**	**Wall Area m²**	**Window Area m²**	**WWR %**
	Bedroom 6			Bedroom 4			Bedroom 5		
	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %
(T B.c)	9.6	0.25	2.6	13.3	0.25	1.9	14.1	0.25	1.8
(C B.c %)	15.8	1.5	10.5	15.8	1.5	10.5	15.8	1.5	10.5
(WWR. M)	9.6	1.0	10.5%	13.3	1.4	10.5%	14.1	1.5	10.5%
	Bedroom 7			Bedroom 8			Bedroom 9		
	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %
(T B.c)	18.8	0	0	12.2	0.35	2.9	17.8	0	0
(C B.c %)	15.8	1.5	10.5	15.8	1.5	10.5	15.8	1.5	10.5
(WWR. M)	18.8	2.0	10.5%	12.2	1.3	10.5%	17.8	1.9	10.5%
	Bedroom 10			Bedroom 11 (North)			Bedroom 11 (South)		
	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %	Wall Area m²	Window Area m²	WWR %
(T B.c)	16.7	0.64	3.8	15.9	0.6	3.8	15.9	0.25	1.6
(C B.c %)	15.8	1.5	10.5	15.8	1.5	10.5	15.8	1.5	10.5
(WWR. M)	16.7	1.8	10.5%	15.9	1.7	10.5%	15.9	1.7	10.5%
	WWR Kitchen								
	Wall Area m²	Window Area m²	WWR %						
(T B.c)	30	0	0						
(C B.c %)	9.9	1.5	15.2						
(WWR. M)	30	4.6	15.2%						

3. Vernacular Architectural Analysis

Traditional architecture in hot, dry climates is characterized by a variety of climate-adaptive designs that offer a high overall level of occupant satisfaction, especially during the hot summer months. These include passive cooling strategies, the use of the appropriate thermal mass, natural ventilation, and shading techniques tailored to particular opening dimensions. According to research on vernacular architecture, passive techniques are a type of sustainability. To guarantee the refurbishment of interior spaces of vernacular architecture in response to the region's climatic circumstances, this literature has investigated techniques of analysis and energy recovery systems.

3.1. Site Analysis

An architectural site analysis was conducted to create design policies that incorporate harmonious design, and these are undertaken regularly to determine their potential impact on design conditions in the present and future [23]. In the present study, site analyses of traditional houses were used to ascertain how their architectural principles could be acclimated to contemporary house projects. These site visits provided useful information about the architectural features and environmental principles of vernacular construction in Najd. For a complete understanding of the site context, a range of factors should be considered: green areas, traffic conditions, zoning, size, topography, and building development. As part of the site analysis, this researcher identified and examined the wind direction and sunlight, while these factors were also included in the site drawings of Case 1 and Case 2 (see Figure 5a,b).



(**a**) (**b**)

Figure 5. (**a**) site analysis for traditional building in Riyadh city, KSA; and (**b**) site analysis for traditional building in Hail city, KSA.

Homes and roads were built to function as wind tunnels. Critical planning gaps are created by entries and gateways. They must be given special consideration as distinct bioclimatic zones. Considering that holes in a shelterbelt impair its effectiveness, due to the wind intensifying as it funnels through the gap within the shelterbelt, gaps potentially result in a rise in wind speed. Wind tunneling is a common name for this phenomenon. As a result, the position of entrances and gateways must be chosen based on the local climate. Small strips of shelter in front of the gap or the construction of an angled gap could very well be solutions for such gaps [24].

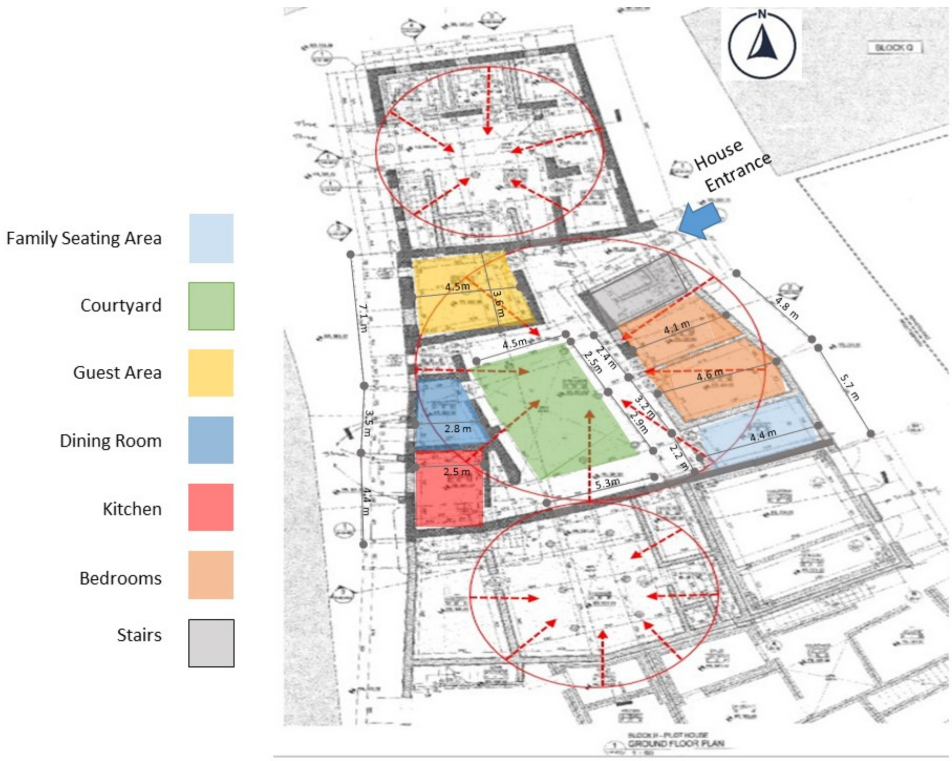
In traditional building design, wind direction is crucial. Most places have a dominant direction from which the wind tends to blow throughout the year and during various seasons, depending on the climate there. Considering traditional homes were made to be climatically adaptable, it is crucial to take into account the direction of the wind that can traverse through the interiors. The predominant summer wind is completely dry and blows out of the south. During winter, chilly, dry air blows from the north, and by the time they reach Najd, these winds lose the majority of their moisture However, depressions heading southeastward from the Mediterranean replace the northern wind in late winter, and these winds provide Najd's scant rainfall, including the most precious spring rains that drastically reanimate the desert [25].

Buildings are therefore designed to maximize their exposure to the north and south along an east-west axis. In order to benefit from the cold northern wind and indirect sunlight, the majority of windows are placed toward the north and south. Also, through regulating the microclimate, the dense grid of palm trees serves as a sort of protection. A palm oasis is undoubtedly better characterized by its ability to withstand temperature fluctuations, tolerate salty and alkaline soils, withstand drought, and raise the wind. The cooling effect brought on by vegetation and water is referred to as the "oasis effect" in climatology [24].

Additionally, the central courtyard concept offers an environmental solution for hot, dry climates, and it typically includes water features and canopy trees. In contrast to an open, hot area with considerable planting, this method created a comparatively cool contained air reservoir through an intense landscape. Furthermore, because of the differences in the properties of the land surface, vegetation prevents sand and dust from being carried away by the wind. Farzaneh, Mehdi and Amir investigated the impact of landscape on traditional courtyard houses in hot, dry climates, finding that green areas significantly reduced indoor temperatures [26]. The indoor climate is influenced by four factors related to landscape: (1) the landscape can block direct gains through windows, (2) the landscape blocks conduction gains through opaque surfaces, (3) landscapes shield buildings from the wind by reducing air pressure differences on their surfaces and (4) landscapes shade the surface of buildings, reducing the radiant heat gain through the envelope of a building [27].

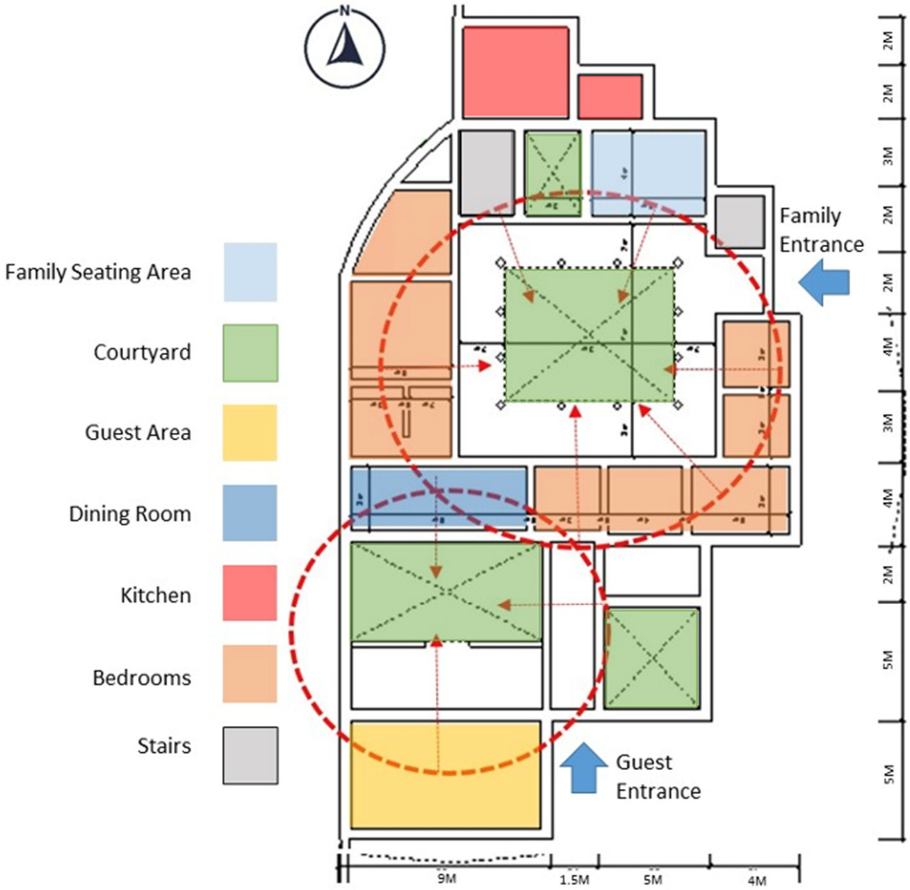
This paper examined the architectural elements of traditional buildings to gain a comprehensive understanding of the passive solutions used in their construction. It is important to take into account the cultural and social prospects of the Najd region while also following the principles of sustainable development [28]. Due to this, the building under study was a two-storey family house exhibiting central courtyards, allowing direct access to all other interior spaces (Figure 6a,b).

This research overlooked the concept of the courtyard for two reasons: (1) investments tend to be larger due to the increased demand for insulation materials for exterior building envelopes and (2) internal reorganization is required due to the addition of a courtyard. However, courtyard houses were distinguished by two conceptual characteristics that could be modified into residential building designs, the WWR and a solid projection shading device.



(**a**)

Figure 6. *Cont.*



(**b**)

Figure 6. (**a**) the design concept for traditional house in Riyadh city, KSA; and (**b**) the design concept for traditional house in Hail city, KSA.

3.2. Characteristics of Courtyards in Najd Houses

3.2.1. Window-to-Wall Ratio (WWR)

In vernacular architecture, the purpose of windowless exterior walls is to prevent direct vision from the outdoors to the interior, as well as to prevent dusty winds from entering the space. Moreover, how the WWR is positioned in each space is determined by the type and direction of openings within the building. As determined by the architectural analysis, three types of openings were used in Najd vernacular architecture:

1. A window is an opening in the wall that allows light, sound and air to enter the room. Typically, the height of the set window is between 0.8 m and 1.6 m above the ground (Figure 7a);
2. Passive ventilation openings and two-sided ventilation are examples of natural ventilation systems that provide both cross-ventilation and one-sided ventilation for indoor airflow. This type of opening is typically found in active rooms, such as family seating areas and guest bedrooms (Figure 7b);
3. Roof ventilation openings act as chimneys to remove toxic harmful exhaust gases and smoke produced by rooms with fireplaces, such as kitchens (Figure 7c).

(**a**) (**b**) (**c**)

Figure 7. (**a**) traditional house window; (**b**) traditional passive ventilation opening; and (**c**) traditional roof ventilation opening (chimney).

This includes all openings on the exterior walls, including windows and passive ventilation openings, as these are recognized as architectural openings in traditional houses in Riyadh and Hail (Tables 1 and 2). On the other hand, roof ventilation openings (chimneys) are not included in the tables because they are not visible on the exterior walls. There are major differences between traditional houses in Riyadh and Hail owing to the different climates. To inform readers, the research discusses various dissertations; however, this paper focused on the first type (window openings), which could be seen in the concept of a modern house design and is the most prevalent type of window employed in contemporary design.

3.2.2. Shading Device

During this study, shading devices used in vernacular buildings were identified as shading by volume [28]. In hot, arid climates, shading can be an essential tool to guard against high temperatures where the architectural concept may merely consist of a shadow that acts as an effective cooling source for the building space. Traditional houses in Riyadh and Hail city exhibited three different shading concepts that demonstrated shading by volume, as detailed below.

Shading through Courtyard Spaces

As well as reducing the temperature in the courtyard, courtyard shading devices can aid in maintaining relatively cool external walls in the courtyard [29]. As shown in Figure 8, this issue was treated by two elements of vernacular architecture, projection shading devices (corridors) and high walls; the shading projection length is affected by the height of the wall. The cantilever percentages of traditional buildings are shown in Table 4.

Figure 8. The courtyard shading techniques were used in traditional houses.

Table 4. Shading projection in traditional houses.

Direction	Traditional House in Riyadh City		Traditional House in Hail City	
	Projection % of Wall Height	M	Projection % of Wall Height	M
North	73.0%	2.4	48.9%	1.6
South	56.8%	1.9	0.0	0
West	54.1%	1.8	65.8%	2.2
East	59.5%	2.0	44.7%	1.5

Shading through the Space in Space Concept

The concept indicated here is an example of a house within a house, comprising two volumes, each of which has two distinct functions. The volume surrounding a cavity is a protective barrier against direct solar radiation, thus protecting against excessive heat [29]. Another form of shading was discernible in vernacular urban planning in Riyadh. The master plan for the Aldhoo neighbourhood in Riyadh city demonstrates this concept of traditional houses as vernacular urban content (Figure 9). This type of shading is not applicable presently as the Saudi Building Code requires a specific amount of offset between the existing houses.

Figure 9. The location of the traditional house for the vernacular urban content in Riyadh city.

Shading by Natural Elements

As plants absorb ultraviolet rays from the sun and store them in their leaves, not only does this provide a pleasant outdoor view, but it is also a highly effective way of filtering direct beam solar radiation. The leaves of plants are extremely efficient at storing biochemical energy from the direct beam of solar radiation emitted by the sun's direct beams. When placed a few meters away from buildings; vegetation like shrubs and trees provides the best shade for east and west-facing windows [29]. Large canopies on long palm trees can effectively provide shade for roofs and larger portions of a house structure, including driveways, pavements, and patios, resulting in heat being deflected away from the house (Figure 10). A comparison of this paper's two sites' measured weather data also confirms that trees have a direct influence on the outside weather. Regardless of the applicable statements, the research aimed to compare the measured outdoor weather data for the two different cases in Hail city (Case 2 and Case 3). Case 2 is a traditional house partially protected and surrounded by tall trees, while Case 3 concerns a freestanding contemporary house exposed to the harsh climate with no protection from vegetation or trees.

Figure 10. Long palm tree shaded the traditional house in Hail city.

3.2.3. Thermal Mass Walls

The construction systems of vernacular buildings should be analyzed to understand their contribution to climate control. Traditional building envelopes were affected by thermal mass systems, which are equivalent to heat capacities. Vernacular architecture in the Najd region employs thermal mass to minimize heat gains; it uses various strategies such as dense materials for roofing, floors, and walls, as well as increased external or cavity insulation. The walls of the house support the floors and also provide thermal mass for the house overall. Walls up to 450 mm thick can be built using unfired clay blocks and a mixture of clay and gypsum-based render (Figure 11).

Especially in climates such as Saudi Arabia, where high temperature fluctuations can be expected during the summer, thermally massed envelopes are particularly useful. The transfer of heat through the envelope is slower in buildings with larger thermal masses, meaning that indoor temperatures will be higher than those outdoors while outside temperatures will be lower. As a result, the thermal conditions within an indoor environment are at equilibrium [30].

According to Alaidroos [12], clay bricks in Saudi Arabia are the best choice when it comes to energy performance, capital investment, and operating costs; the energy consumption of clay bricks is 16% less than concrete blocks, 23% lower than lime bricks and 25% lower than prefabricated walls.

This paper made use of computer modelling to assess some passive strategies, which allowed the researchers to hypothesize what could happen in the real world. Furthermore, computational analysis can identify complications in the building design and conclude possible solutions.

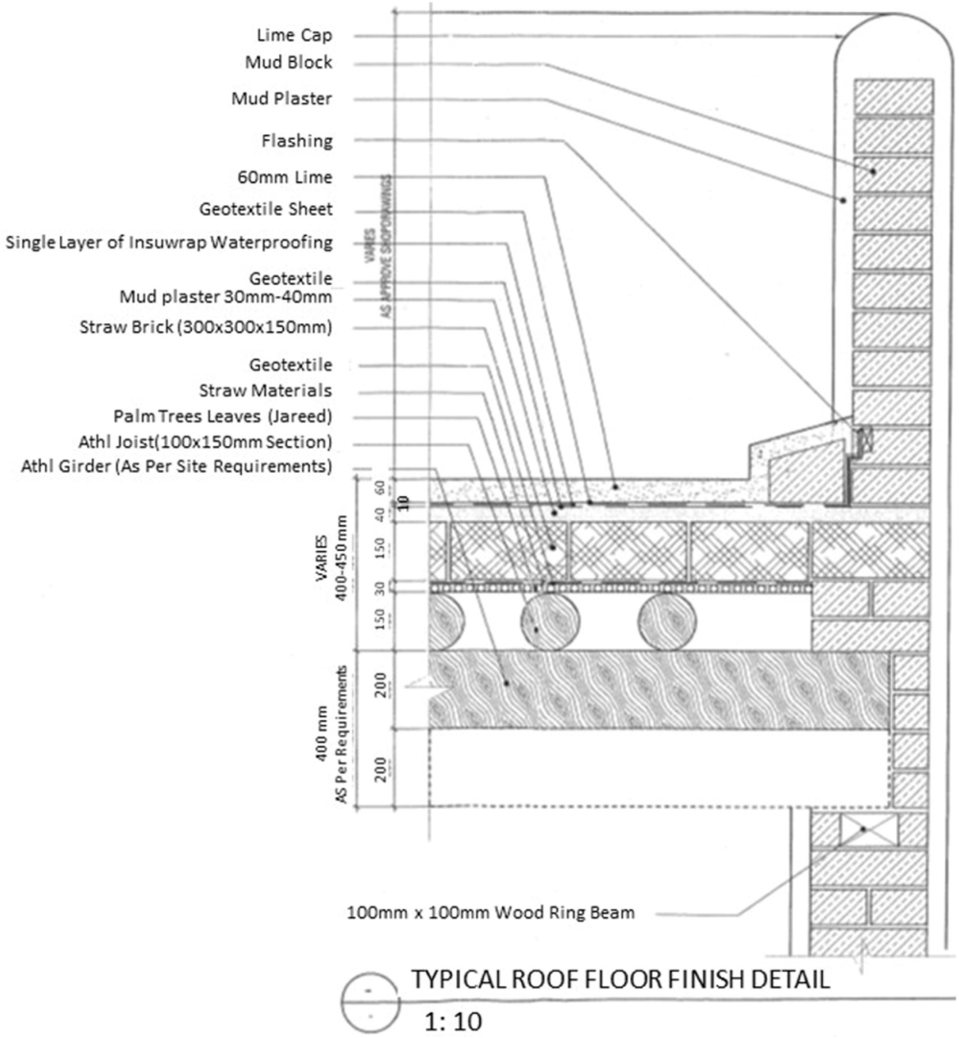


Figure 11. Long palm trees shaded the traditional house in Hail city.

4. Results

To determine the impact of selected passive strategies, various contemporary house design characteristics were incorporated into the traditional house designs.

4.1. Vernacular Architectural Analysis

Utilizing the Design Builder simulation software, the four conventional passive techniques that were identified in the research approach were examined. At this stage, the energy performance of the traditional homes in the Najd region of Saudi Arabia was examined concerning the consequences of implementing these traditional practices.

Investigation of the Impact of the Green Area on Vernacular Architecture

The researchers analyzed the hourly measured outdoor weather for two Case Studies 2 and 3, as shown in Figure 12. There were deviations in both outdoor relative humidity and outdoor temperature between observed and measured climate data.

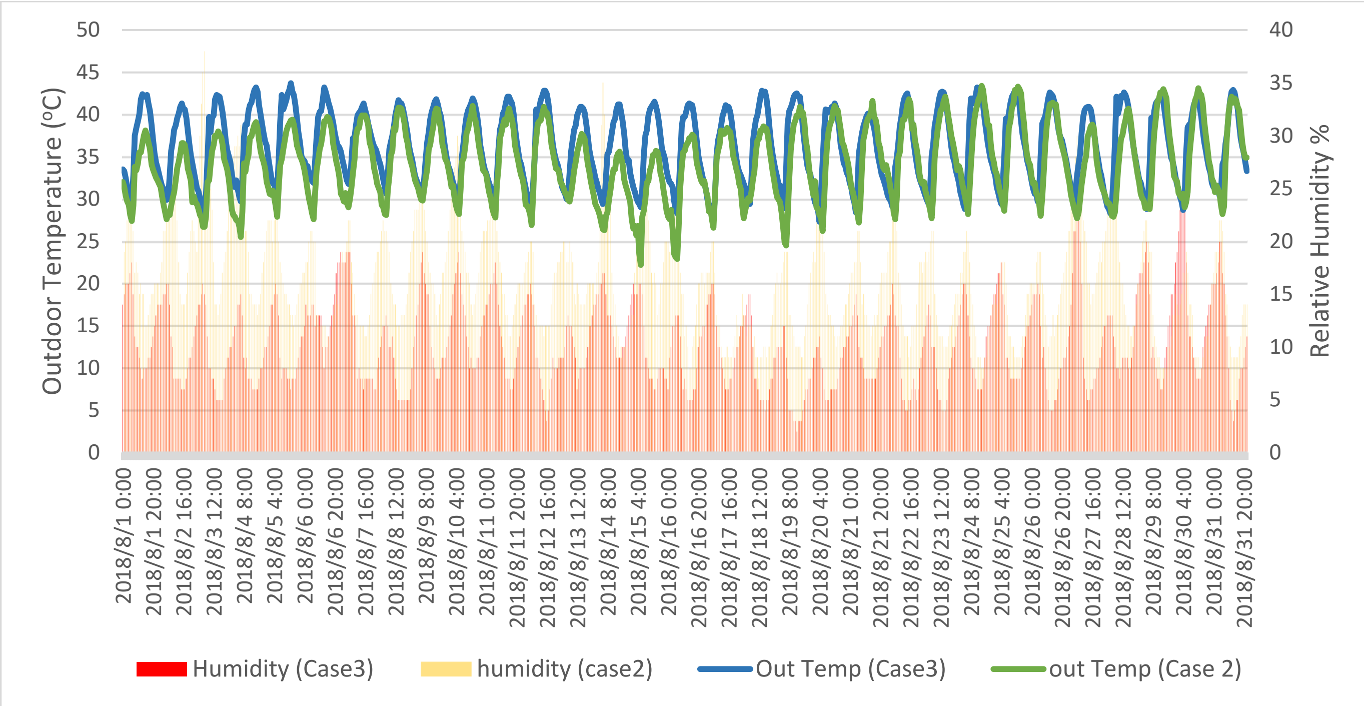


Figure 12. Cases 2 and 3 hourly measured outdoor weather data for August 2020.

A comparison of Case 2 and Case 3, Figure 12 indicated that the long trees in Case 2 led to a significant deviation in relative humidity of 53.2%, which significantly reduced the outdoor temperature by 5.5%. Trees also reduced long-wave radiation from the ground, sky, and surrounding buildings. The warming effect of leaves on the urban air is also very significant [27]. Figure 13a,b depicts the top view of Cases 2 and 3, respectively, demonstrating how the green area modifies the sites' planes in the specified cases.

(**a**) (**b**)

Figure 13. (**a**) top view for Case 2; and (**b**) top view for Case 3.

An hourly comparison of the temperatures at the two locations between 1 August and 5 September during the measurement period (Table 5) indicates that the maximum temperature for Case 3, was registered as 44.4 degrees Celsius at 15:00 on 4 August compared to 40.6 degrees Celsius for Case 3 during the same time period. In the same measurement period (06:00 on 15 August), the lowest temperature measured was 22.2 °C for Case 3 and 29 °C for Case 2.

Table 5. Weather data analysis for two locations in Hail city.

	Case 2 Temp	Case 2 Hum	Case 3 Temp	Case 3 Hum	Different % of Temp	Different % of Hum
Average	34.5	15.9	36.4	10.2	−5.5	45.3
Max	43.9	38.0	44.4	25.0	9.3	133.3
Min	22.2	7.0	27.3	2.0	−33.3	−48.6

In Hail city, the weather data for the summer period was modified based on average differences in temperature and relative humidity. As a result of the modification, the hourly temperature data decreased by 5.5% and the relative humidity level increased by 45.3%. To calculate the energy savings during the summer period, the researchers uploaded an updated weather file into the simulation model for Case 2.

The simulation results demonstrate that long tree strategies positively contribute to the total cooling energy output during the summer period since they maximize the cooling effect, resulting in significantly reduced outdoor temperatures and relative humidity levels. According to the simulations, cooling energy consumption for a traditional house in Hail city rose by up to 3.9% when the weather file was modified. Taking into consideration the weather conditions for Case 3, which did not use long trees, the researcher modified the weather file for Case 2. To account for the entire summer of 2020 (Figure 14), the simulation was conducted over three months.

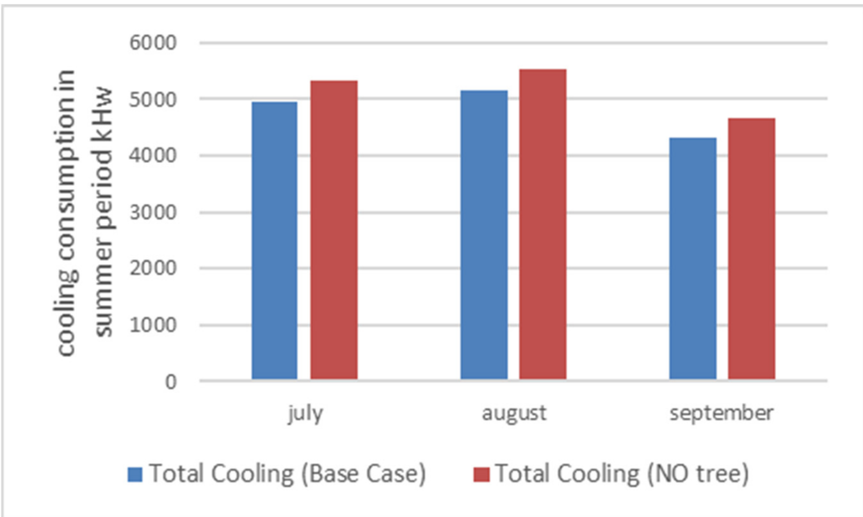


Figure 14. Cooling consumption in the summer period for Case 2 with modifying the weather file.

4.2. Investigation into the Impact of WWR on Vernacular Architecture

The WWR is an important factor that affects the energy proficiency of traditional buildings. The WWR is the ratio of glazing to the overall exterior area of a building, taken as a percentage of the exterior area [14]. In a traditional house, the areas of the windows and the exterior walls are calculated according to the total glazed area of the rooms divided by the total exterior wall area.

The present study tested the impact of the new WWR value on total energy demand and daylight levels in traditional houses using the base case models of the traditional houses. In traditional buildings in Riyadh city (Case 1), energy consumption increased by approximately 9% (Figure 15). The rise in WWR increased by about 950 kWh over the course of four months in the summer (June to September) due to the hard weather. Although there was a slight variation in energy performance during the winter due to the rise in WWR, energy usage during the winter fell by around 3.5 percent or roughly 75 kWh. However, lowering the WWR significantly improves the annual energy performance of typical homes in the Najd region, saving about 1350 kWh.

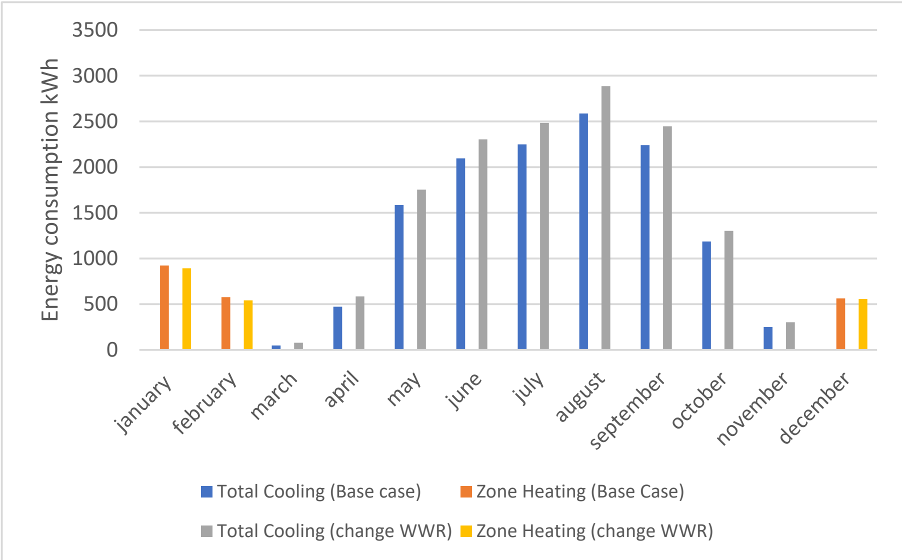


Figure 15. The annual energy consumption for Case 1 with modifying the WWR to adapt the contemporary house characteristics.

In Hail city (Case 2), the total annual energy consumption increased by approximately 3.8% (Figure 16). During the summer, more than 1200 kWh are redacted. The increase in WWR will result in an additional 870 kWh of total cooling and heating usage over the summer's four-month adverse weather period (June to September). However, because it will allow the sun's rays to enter interior spaces directly, the rise in WWR has a favourable effect on the amount of heat consumed during the winter.

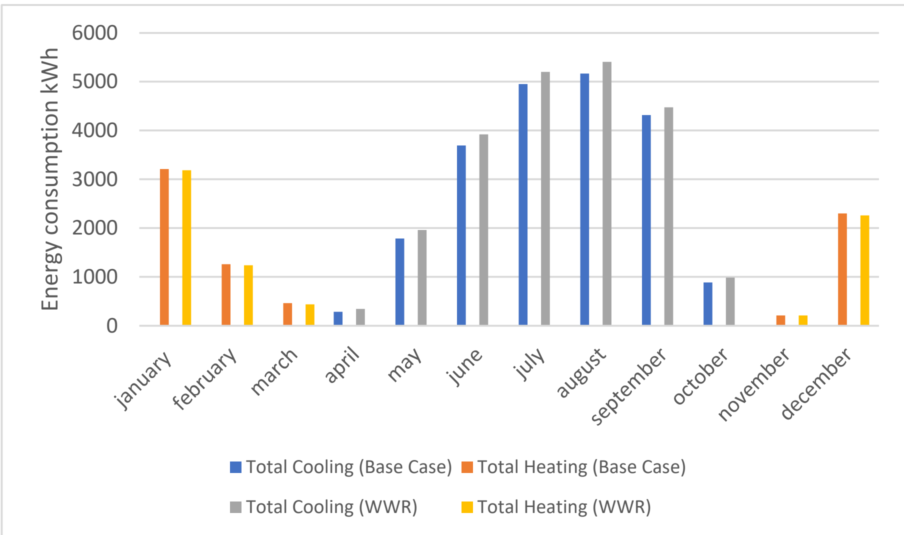


Figure 16. The annual energy consumption for Case 2 with modifying the WWR to adapt the contemporary house characteristics.

4.3. Investigation into the Impact of Shading Devices on Vernacular Architecture

The study also investigated the impact of solid projection shading on the energy efficiency of vernacular houses. Several traditional houses were modelled, while the shading device (courtyard corridor) was not taken into account (Figures 17 and 18).

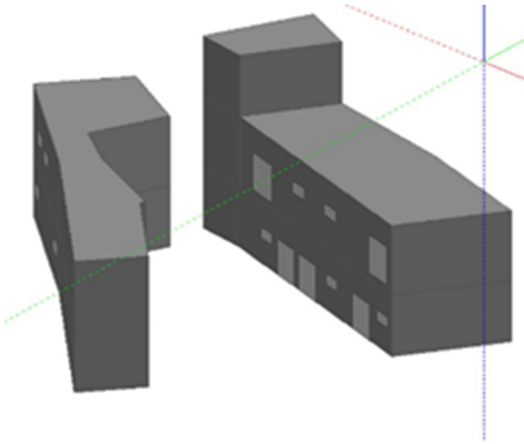


Figure 17. Riyadh traditional house without courtyard corridor (Case 1).

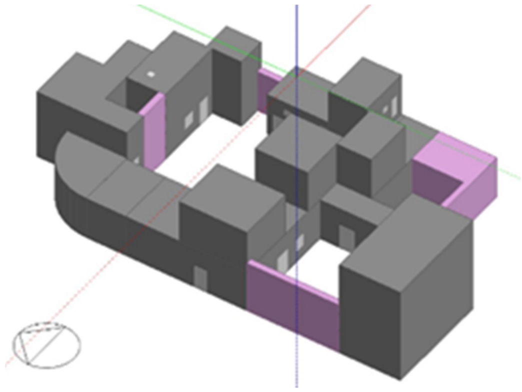


Figure 18. Hail Tradition house without courtyard corridor (Case 2).

Shading devices can reduce the total energy consumption for traditional houses in Riyadh by 3%, according to simulation results. For Case 1 in Riyadh, Figure 19 illustrates the influence of the shading device to the energy performance, which, due to the summer's tough weather, surged by about 290 kWh in August and September. Annual savings of 450 kWh were attainable. The winter season, however, could be detrimental to the employment of shading devices because they prevent direct sunlight from entering interior spaces, which is crucial for heating those spaces. Thus, during winter, shading tactics will reduce energy use by roughly 400 kWh.

Figure 20 illustrates the negligible influence of the shading device on the design for Case 2 in Hail city. When the shading device was removed from the simulation model, energy consumption increased by 0.3%. This indicates that the shade device has a negligible impact on the energy used for cooling in a standard home in Hail City, saving up to 220 kWh during the summer. On the other hand, the use of shading devices will increase the need for heating during the winter season. Termination of the shading device will result in savings of about 2.5% in overall heating use.

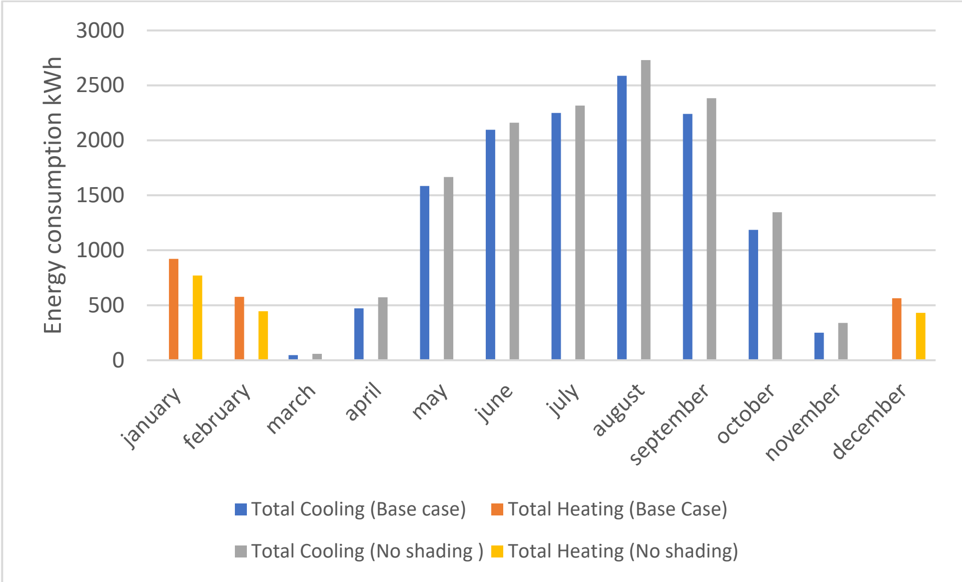


Figure 19. Annual energy consumption for Case 1 with and without shading device.

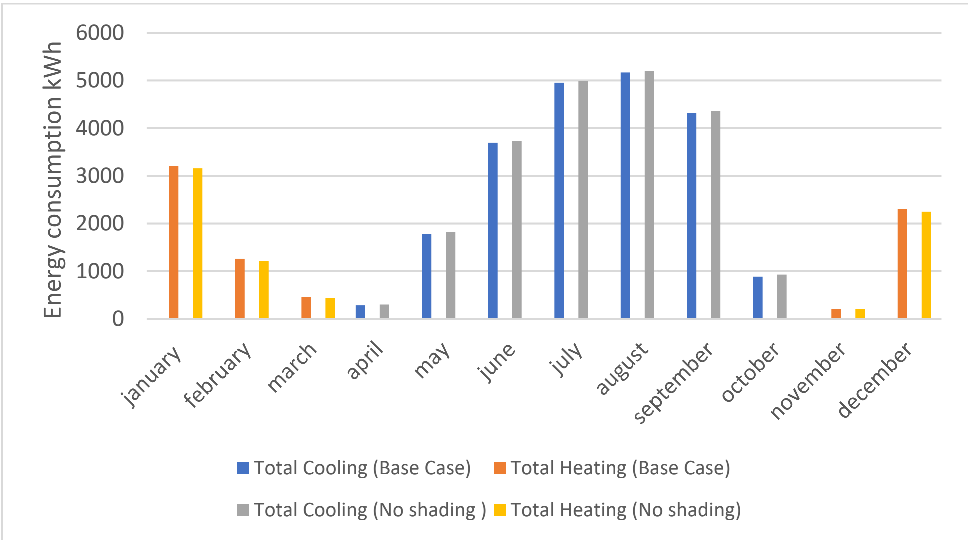


Figure 20. Annual energy consumption for Case 2 with and without shading device.

4.4. Investigation into the Impact of Thermal Mass on Vernacular Architecture

This phase examined the energy demand for traditional houses in Saudi Arabia that use thermal mass walls. According to the simulation results, thermal mass walls play an imperative role in decreasing the total amount of energy consumed by traditional houses in Najd. The researchers simulated thermal mass walls and modified them to resemble the exterior wall structure of a contemporary house. For traditional houses in Riyadh (Case 1) the energy consumption increased by 33% (Figure 21). Energy performance throughout the entire year is significantly impacted by thermal mass strategy. Thermal mass can reduce the amount of energy used for cooling and heating in the summer by about 4500 kWh, i.e., approximately 35%. The amount of energy used for cooling and heating thermal mass increased by about 1000 kWh in August. Thermal mass can also conserve about 20% of the energy used for heating and cooling during winter.

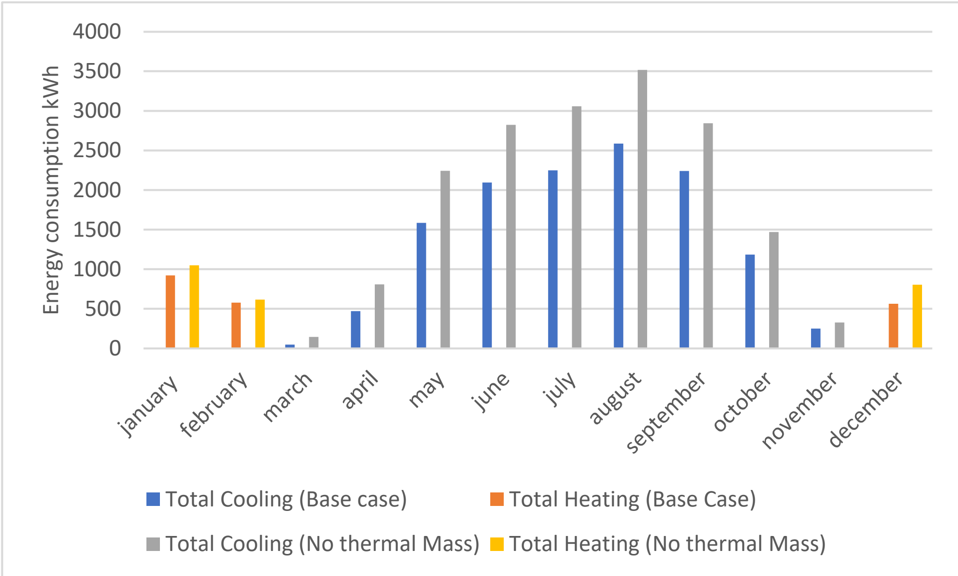


Figure 21. The annual energy consumption for Case 1 with modified thermal mass wall to imitate the contemporary house's exterior wall structure.

The energy consumption in Case 2 will increase by approximately 9.5 percent as a result of removing thermal mass from the standard house envelope (Figure 22). This method grew by about 1500 kwh during the summer's severe weather (July to September). By utilizing thermal mass strategies, which produce about 2400 kWh, the traditional home in Hail City can reduce its cooling energy consumption by about 11.5 percent during summer.

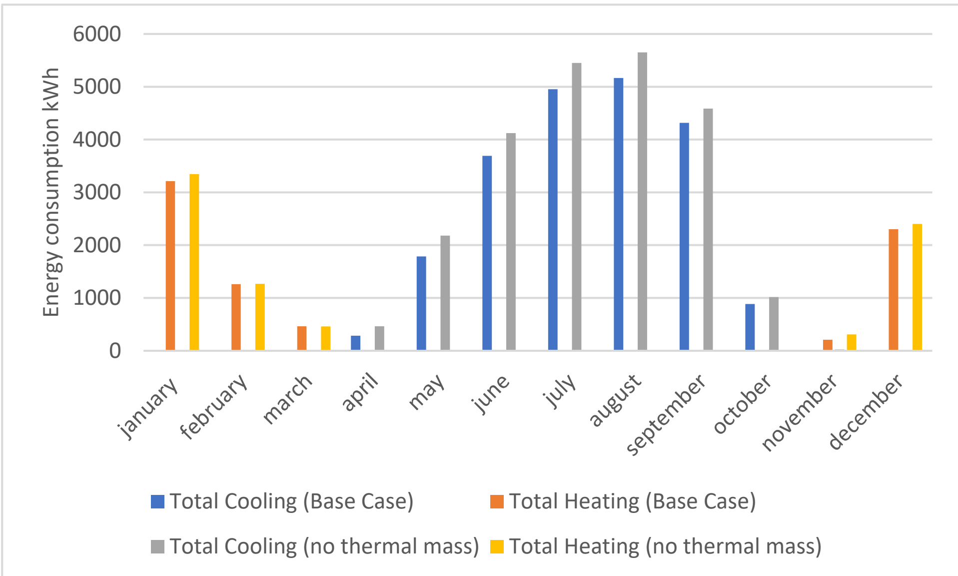


Figure 22. The annual energy consumption for Case 2 with modified thermal mass wall to imitate the contemporary house's exterior wall structure.

5. Conclusions

This research focused on an initial survey and research experience in KSA, which included the vernacular passive methods in current design methodologies, that identified the techniques in the use of structural and operational resources to grasp the issue in a practical setting. This exploratory research assisted researchers in developing many contemporary designs for building components, such as walls, towers, floors, and windows using regional and useful building compositions. It comprised the specified passive tactics.

In order to determine how the four passive techniques affected the energy performance of the traditional homes in the Najd region of Saudi Arabia, this study used three stages of the investigation. To identify the passive design techniques applied to the building, the research first examined the architectural principles for traditional house design. The implementation of a monitoring approach to assess the effectiveness of the current building envelope required a field trip to the two traditional houses during this stage. Second, during the field trip, researchers gathered internal meteorological data that were used to build computational models in selected scenarios. Lastly, models of the two homes were built in DesignBuilder to adapt to the chosen passive techniques. Computational simulations revealed that passive strategies have an important role to play in the overall energy performance of traditional houses in Saudi Arabia. In light of this, the present research examined whether these strategies can be incorporated into contemporary housing designs. As part of the designs for traditional houses, this paper designed five simulation models for each house. To determine whether these strategies could be adapted to a contemporary house, the simulation results were compared with the base case model.

The use of shade devices, thermal mass, and green outside spaces are a few of these approaches. The computational simulations demonstrated that passive techniques are crucial for the successful energy performance of traditional homes in the Najd region of Saudi Arabia.

As a result, suggestions from many parties, including architects and engineers, were consulted on new contemporary house design and construction. The need to safeguard the present and future climatic conditions must be grasped by architects and engineers, who believe in the vitality of passive strategies. In order to benefit from the newest scientific advances, they should also be in close communication with the research centre.

Author Contributions: Conceptualization, A.A. (Ali Aldersoni), M.A., A.A. (Abdullah Albaker) and M.A.S.; Methodology, A.A. (Ali Aldersoni), A.A. (Abdullah Albaker), M.A. and M.A.S.; Software, A.A. (Ali Aldersoni) and M.A.; Validation, A.A. (Abdullah Albaker), M.A. and M.A.S.; Formal Analysis, A.A. (Ali Aldersoni), M.A., A.A. (Abdullah Albaker) and M.A.S.; Investigation, A.A. (Ali Aldersoni), A.A. (Abdullah Albaker) and M.A.S.; Writing—Original Draft Preparation, A.A. (Ali Aldersoni), M.A., A.A. (Abdullah Albaker) and M.A.S.; Writing—Review and Editing, A.A. (Ali Aldersoni), A.A. (Abdullah Albaker) and M.A.S.; Supervision, A.A. (Ali Aldersoni) and A.A. (Abdullah Albaker); Project Administration, A.A. (Ali Aldersoni); Funding, University of Ha'il. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Scientific Research Deanship at the University of Ha'il, Ha'il Saudi Arabia (grant number: BA-2214).

Data Availability Statement: Not applicable.

Acknowledgments: This research has been funded by the Scientific Research Deanship at the University of Ha'il, Saudi Arabia, through project number (BA-2214).

Conflicts of Interest: The authors declare no conflict of interest.

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