wjert, 2024, Vol. 10 Issue 2, 66-83. *Original Article* ISSN 2454-695X

World Journal of Engineering Research and Technology

WJERT

www.wjert.org SJIF Impact Factor: 5.924

STRATEGIES FOR IMPROVING ENERGY EFFICIENCY OF RESIDENTIAL UNITS IN COASTAL TOURISTIC RESORTS OF HOT HUMID CLIMATES

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Article Received on 27/11/2023 Article Revised on 17/12/2023 Article Accepted on 07/01/2024

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ABSTRACT

Tourism has become one of the most important sources for variation of income. Saudi Arabia is seeking to establish a sustainable touristic sector through new projects in the Northwest of the Kingdom across the Red Sea shores. This study focuses on the development of current touristic facilities to keep abreast with touristic sustainability plans. Buildings' energy consumption increased from 33.7% to 41.1% between the years 1980 and 2010 in the United States (Cao, Dai, & Liu, 2016), and in 2021, buildings accounted for 37% of energy consumption (Hamilton, Kennard, & Others, 2022). Hence, retrofitting of building's envelope contributes to the reduction of energy consumption and mitigation of carbon emissions. The objective of this study is to improve the thermal efficiency of buildings by treating the façades of residential units. This study has been applied on Jeddah city which represents hot humid climate. The residential units were chosen in (Boho) complex and the (DesignBuilder) program was used to apply a number of architectural solutions for redesigning the building envelope. These solutions included treatments of windows, walls

and roofs to improve the heat transfer coefficient, and orientation was examined. The study concludes that applying these strategies leads to reduction of energy consumption by (57.1%), hence improving environmental performance.

KEYWORDS: Coastal touristic resorts, Jeddah, hot climate, buildings' energy efficiency, building envelope design.

RESEARCH INTRODUCTION

Kingdom of Saudi Arabia has taken serious steps to enhance the touristic sector in the past decade, since the increase of foreign visitors leads to variation of income sources and benefit from the touristic sector in supporting local economy (Wahba & Atef, 2021). With this rapid pace of development, the Kingdom seeks to develop a number of mega touristic projects, especially on the Red Sea Coasts, such as Neom, Red Sea Project, Amaala and some other projects. Hence, it is necessary to develop the current resorts for the optimization of environmental performance efficiency and rationalization of energy consumption. Many touristic resorts have spread across the Kingdom, particularly in Jeddah which is considered the largest and most important coastal city in the Kingdom at present. However, most residential units and coastal touristic resorts have design defects (عاشور، 2017) due to non-application of environmental design criteria and sustainability concepts. Because of the increasing energy consumption, it is imperative to achieve such criteria in touristic facilities to reduce the impact of environmental mark and preserve coasts, beaches and tourist attractions. Therefore, this research paper aims to set a methodology for optimizing environmental performance efficiency of residential units. It is noted that the construction sector consumes a huge amount of energy worldwide and is expected to grow by third to half by 2050. This will be due to the spread of new technologies that affect lifestyle, population growth and climate change (Kumar, Alam & Sanjayan, 2021).

1. Research methodology

A domestic resort (Boho) has been chosen as a case of study because it contains service buildings and residential units, all of which are separate buildings in construction representing standalone buildings that are not adjacent. The main building has various functions. It includes services on the ground floor, and residential units and services on the first floor. The research focuses on studies of standalone residential units consisting of 8 residential villas overlooking the sea. This research is divided into three main sections: Examining the current situation of residential villas built with the current construction materials and orientation, then identifying the optimal orientation and conducting treatments of architectural elements (walls, roofs and windows) according to the Saudi building code, and finally these treatments are combined into a final proposal to reach a strategy for optimizing thermal performance efficiency inside touristic residential units in hot humid regions.

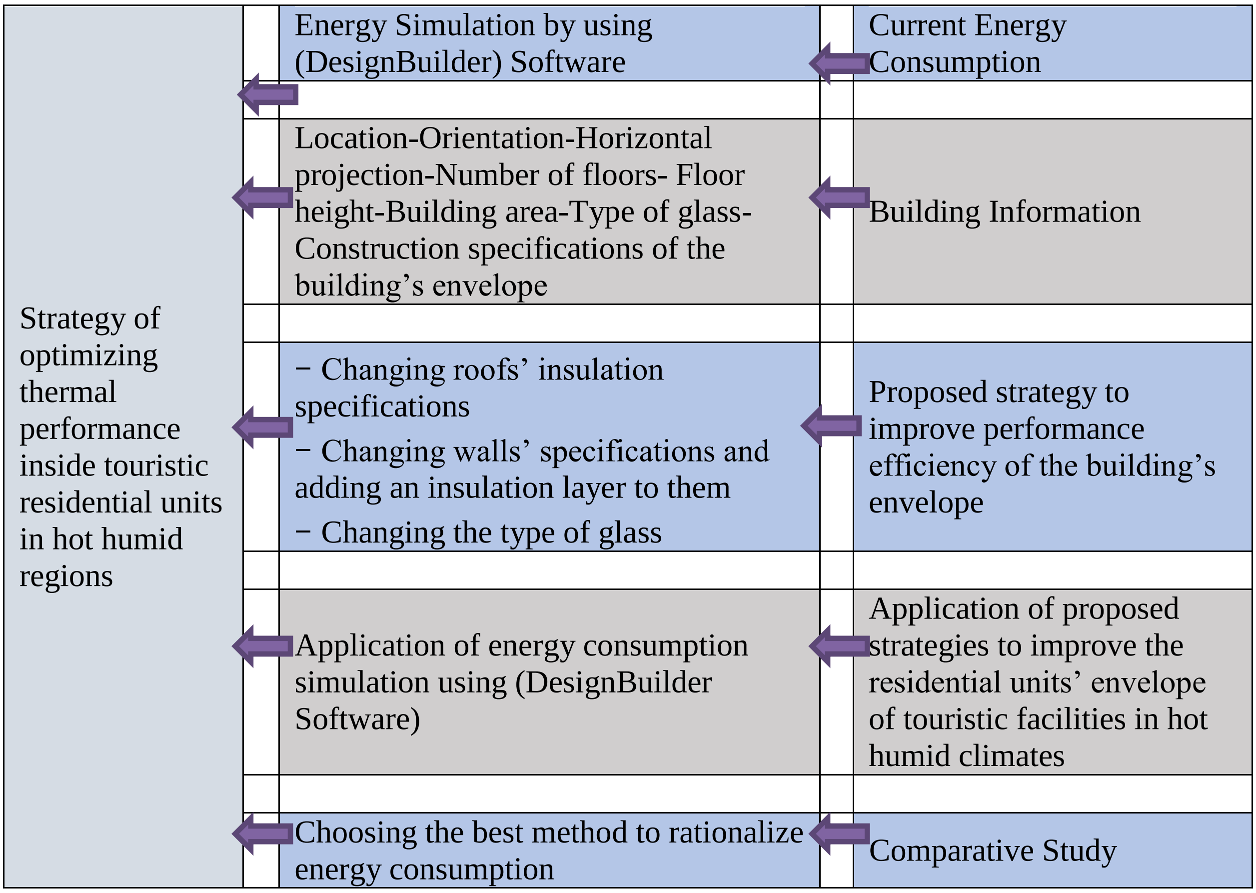

Figure 1: Adopted Methodology (Devised by the Researchers).

2. Research Problem

Increased energy consumption by mechanical means negatively affects CO_2 emissions percentage. Additionally, some designers do not take into consideration environmental design fundamentals for improving efficiency inside residential units.

3. Research questions

This research aims to answer the following questions: (1) What is the effect of orientation on residential units in coastal touristic resorts in Jeddah City and the impact of this on improving energy consumption? (2) What are the architectural treatments that can be added to the residential units' envelope in coastal resorts of hot climate for optimizing building's thermal performance? (3) To what extent can these optimizations contribute to the efficiency of thermal performance of the existing unit?.

4. Review of Literature

Numerous research and experiments tackle the means of improving buildings' energy efficiency generally through the treatment of buildings' envelope. It is noted that 16.5% of energy consumption can be saved when using a gray unilateral glass of 6 mm thickness in hot climates (Edeisy & Cecere, 2017). There is also a wide consensus in the scientific community that buildings' envelope modifications lead to huge optimizations of buildings' thermal performance and energy consumption efficiency (Kobeyev, Tokbolat, & Durdyev, 2021). After conducting a study on a building in Jeddah, the following energy consumption saving was noted: Window glass from transparent to double 21%, wall insulation 11%, reflective material on roofs, thereby saving 10% and 17% when the roof is insulated (Wahl, 2017).

5. Analytical Study of thermal performance efficiency of residential units in Boho Resort-Jeddah City

Boho resort lies in Jeddah city on the banks of the Red Sea. The resort lies at the north of the city in Obhur region. Islands called "Bayada" are directly opposite to the resort in the wide sea, and they are considered an environmental tourist attraction frequented by swimming and diving lovers. The area of the resort is 6830 m^2.

Figure 2: Resort location in Jeddah City (Devised by the Researchers).

The resort's analytical study is divided as follows (Examining the present situation, examining the current orientation, examining the optimal orientation, changing roofs', walls' and windows' specifications separately, offering a final proposal that combines the previous specifications).

6.1 Present situation of residential villas in Boho resort

Residential villas in Boho resort were designed on two parallel lines with a garden in between, where all villas overlook the sea. This was the basic idea in designing the resort. Villas on the northern side have a south orientation (The main façade is oriented to the south), while the other villas have a northwest orientation, as shown in figure 1. The area of each villa is 48 m^2 and the built area is 96 m^2.

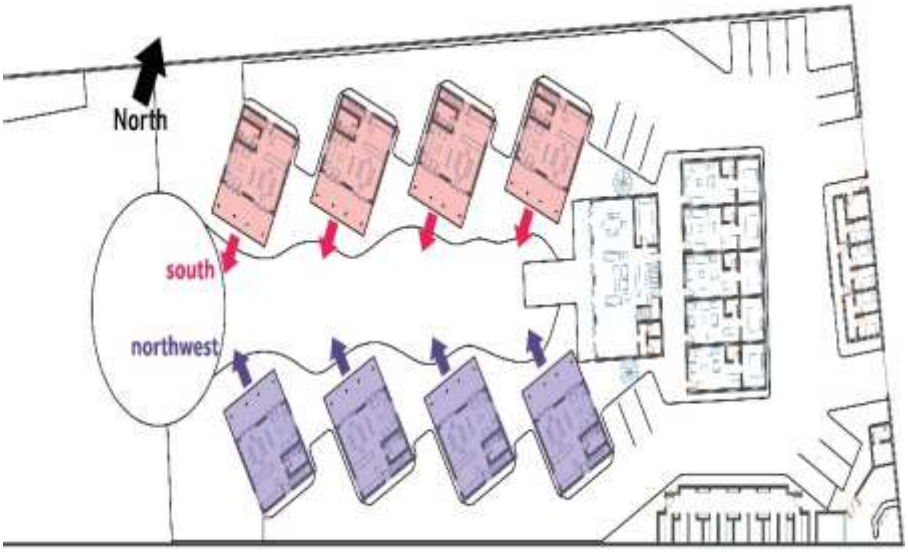

Figure 3: General Location and Residential Villas' Orientation in Boho Resort (Devised by the Researchers).

The ground floor includes a living room, toilet and kitchen, while the first floor comprises three bedrooms as shown in figures 3 and 4. The façade of villas has a simple Bohemian-style design, as shown in figure 5.

Figure 6: shows the villa's façade (Devised by the Researchers).

Figure 5: shows the first-floor projection of residential villas (Devised by the Researchers).

Figure 4: shows the ground floor projection of residential villas (Devised by the Researchers).

Table 1: Characteristics of materials used in residential villas (Devised by the Researchers).

	Material	Thickness (MM)	Thermal Connectivity (Watt/M. Kelvin)	Specific Heat(Joule/Kg. Kelvin)	Density (Kg/M^3
Upper Roof	Plastering	2	0.5	830	1300
	Reinforced Concrete	2000	2.7	832	2400
	Foam Concrete	70	0.24	879	700
	Waterproof	20	0.17	1470	0.17
	Sandstone	50	2	1045	1950

Thermal characteristics of roof construction materials with thermal resistance (R-Value) =0.579.

Exterior Walls	Plastering	2	0.5	830	1300
	Plastering Layer	20	0.35	840	950
	Red Block	200	0.73	800	1700
	Plastering Layer	20	0.35	840	950
	Exterior Paint	2	0.5	830	1300

Thermal Characteristics Of Roof Construction Materials With Thermal Resistance (R-VALUE) =0.579.

Windows	One layered Glass windows	6	Heat Transfer Coefficient =6.12	Light Transfer Coefficient =0.57

Table 1 shows the characteristics of materials used in the envelope, as well as the section in figure 6. These are the data and materials entered into the simulation program (Design Builder) to measure the building's thermal performance. The building internal temperature has been set between 20 ^{to} -24 ^{o}. This data has been used to measure thermal performance for both orientations (South and Northwest) as shown in figure 7.

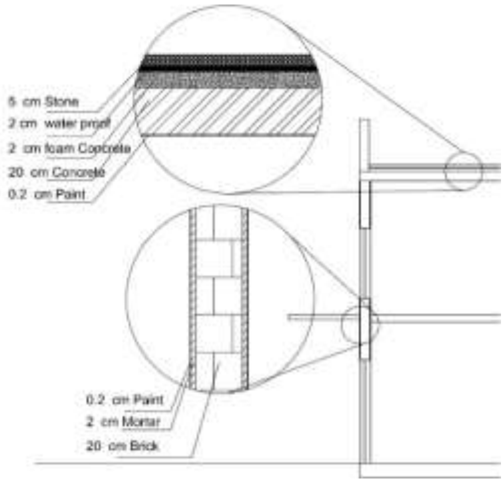

Figure 7: Wall section of residential villas' current situation (Devised by researchers).

Figure 8: Shows the difference in thermal loads between the current orientations of residential villas (Devised by the Researchers).

Generally, the performance of the two orientations is very close and the differences between them are slight. However, thermal loads increase in seasons (November to January) in the south orientation, while thermal loads in northwest orientation increase in seasons (May to August).

6.2 Buildings' optimal orientation

Data given in table 1 have been inserted. Then, the thermal performance of villas has been measured in the four main orientations (North, South, East, West) and the sub orientations (Northeast, Southeast, Northwest, Southwest). Figure 8 shows the thermal loads of every orientation according to the months of the year.

Figure 9: Shows the thermal loads of residential villas during the months of the year in the four main orientations (Devised by the Researchers).

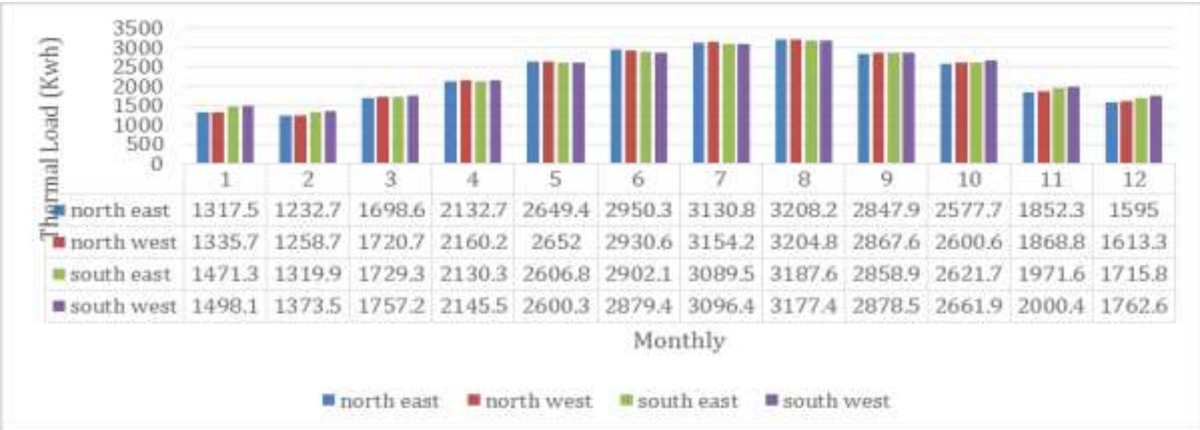

Figure 10: Shows the thermal loads of residential villas during the months of the year in the four sub orientations (Devised by the Researchers).

Buildings' optimal orientations are as follows, respectively: North, Northeast, Northwest, South, West, East, Southwest and finally Southeast, according to the annual consumption shown in table.

Table 2: Energy Consumption in the Eight Orientations (Devised by the Researchers).

Consumption Element		Cooling (Kilowatt/Hour)	Devices (Kilowatt/Hour)	Lighting (Kilowatt/Hour)	Total (Kilowatt/Hour)	Saving Percentage
Current Situation	Northwest	44071.56	4420.33	1031.41	49523.3	1%
	South	44594.24	4420.33	1031.41	50045.98	0%
North		43367.93	4420.33	1031.41	48819.67	2.5%
East		44812.98	4420.33	1031.41	50264.72	-0.4%
West		44729.69	4420.33	1031.41	50181.43	-0.3%
Northeast		44047.9	4420.33	1031.41	49499.64	1.1%
Southeast		45151.35	4420.33	1031.41	50603.09	-1.1%
Southwest		45147.65	4420.33	1031.41	50599.39	-1.1%

South orientation was taken as reference to measure the other percentages because it has the most consumption percentage in the current situation between the two orientations.

6.3 Treatments of Building Envelope (Roofs, Walls, Windows)

All the following architectural elements have been treated: Roofs, walls, and windows. One proposal was given for roofs and windows, while two proposals were given for walls. One of these proposals takes into consideration local materials and architectural character (Manqabi stone). The other proposal takes into account other functional materials that include materials fabricated in the local market. All proposals' thermal coefficient values comply with the Saudi building code. Table 2 shows the thermal coefficient values corresponding to the Saudi building code for each of the three elements and for every climatic region in the Kingdom. Jeddah lies in region no. 1 according to the guide to thermal insulation systems and materials in compliance with the Saudi building code requirements (المركز السعودي لكفاءة الطاقة، 2021).

Table 3: Heat Coefficient Values of every region in the Saudi building code (Guide to thermal insulation materials and systems in compliance with the requirements of the Saudi building code).

	Region 1		Region 2		Region 3	
	Walls	Roofs	Walls	Roofs	Walls	Roofs
Heat Transfer Coefficient Values	0.511	0.272	0.511	0.272	0.698	0.397
	0.454		0.454		0.591	

First: Treatments by change of specifications of roof materials

Roof characteristics have been modified by adding a thermal insulation layer (Polyethylene) of 13 cm thickness to achieve the thermal insulation value stated in table 3. The remaining layers are left as they are. Table 4 shows details of roof layers inserted into the simulation program after modification. Roofs have been modified so that their heat coefficient value corresponds to the Saudi building code, as shown in table 3.

Table 4: Characteristics of materials used in residential villas after modifying roof specifications (Devised by Researchers).

	Material	Thickness (MM)	Thermal Connectivity (Watt/M. Kelvin)	Specific Heat (Joule/Kg. Kelvin)	Density (Kg/M^3)
Upper Roof	Plastering	2	0.5	830	1300
	Reinforced Concrete	200	2.7	832	2400
	Foam Concrete	70	0.24	879	700

	Thermal insulation material (Polyethylene)*	130	0.04	840	40
	Waterproof	20	0.17	1470	0.17
	Sandstone	50	2	1045	1950
	Reinforced Concrete	2000	2.7	832	2400

Thermal characteristics of roof construction materials with thermal resistance (R-Value) = 3.793 *Added material

d Northwest) to

determine difference in thermal loads between the current situation and the situation after change of roof specifications as shown in Figure 10.

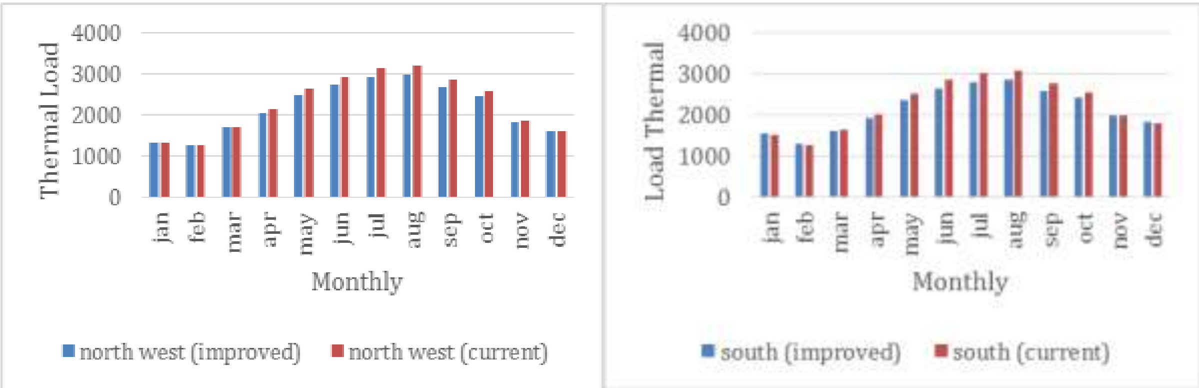

Figure 11: Shows differences in thermal loads of residential villas during the months of the year before and after change of roof specifications (Devised by the Researchers).

Difference in thermal loads between the current situation and the proposed situation increase in seasons (June to August), while differences are close as a result of treatments in seasons (December to March), since no great impact due to the increase of insulation layer can be noticed.

Table 5: Energy Consumption in North and West Orientations during the Current Situation and after Change of Roof Specifications (Devised by the Researchers)

Consumption Element		**Cooling (Kilowatt/Hour)**	**Devices (Kilowatt/Hour)**	**Lighting (Kilowatt/Hour)**	**Total (Kilowatt/Hour)**	**Saving Percentage**
Current Situation	Northwest	44071.56	4420.33	1031.41	49523.3	-
	South	44594.24	4420.33	1031.41	50045.98	-
After modifying specifications	Northwest	39871.38	4420.33	1031.41	45323.12	9.3%
	South	40494.07	4420.33	1031.41	45945.81	8.9%

Table 5 shows that the amount of energy consumption saving is 9.3% in northwest orientation, and 8.9% in south orientation. This saving represents a deficit in energy consumption used in the cooling process due to the increase of the insulation layer in roofs. This percentage is less in the south orientation than in the northwest orientation because the building receives more thermal loads.

Second: Treatments by change of specifications of materials used in walls

Two proposals were given for walls. The first proposed adding a basic layer of Manqabi stone (Stone used in Historical Jeddah) to respect the local character of the city. An insulation layer of 80 mm thickness and a gypsum board of 12 mm thickness were added. The second proposed changing the basis layer from red block to concrete block with the addition of an insulation layer of 80 mm thickness and gypsum board of 12 mm thickness. Both proposals correspond to the thermal loads of the Saudi building code shown in table 3 (المركز السعودي لكفاءة الطاقة، 2021). Details of both proposals are shown in table 6.

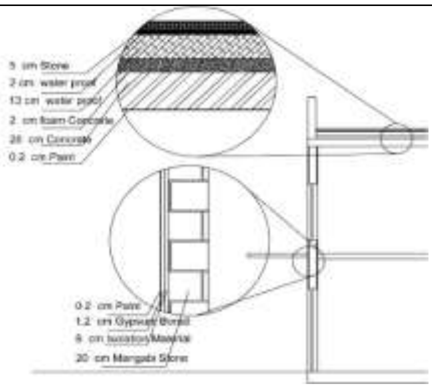

Figure 12: Shows section from the wall composed of Manqabi stone (Devised by the Researchers)

Figure 13: Shows Manqabi Stone in its original form (Bagader & Mohamed, 2020)

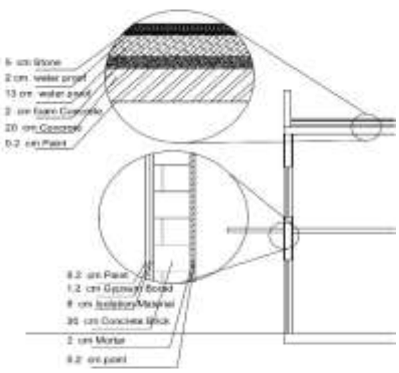

Figure 14: Shows a section of the wall composed of Concrete Brick.

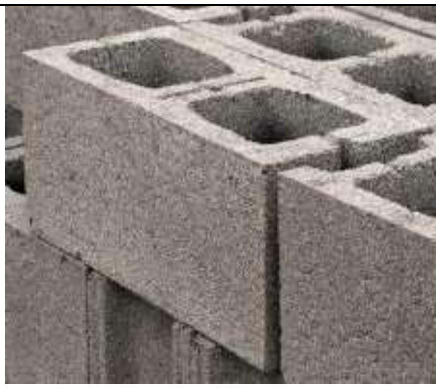

Figure 15: Shows Concrete Block (Devised by Researchers)

Table 6: Characteristics of Materials used in Residential Villas after changing Walls' Specifications in the two proposals (Devised by the Researchers).

	Material	Thickness (MM)	Thermal Connectivity (Watt/M. Kelvin)	Specific Heat(Joule/ Kg. Kelvin)	Density (Kg/M^3
Wall Proposal 1	Manqabi Stone (Exterior)*	200	0.64**	840	3000
	Thermal Insulation Material (Polyethylene) *	80	0.04	840	40
	Gypsum Board*	12	0.35	840	950
	Interior Paint	2	0.5	830	1300

Thermal characteristics of roof construction materials with thermal resistance (R-VALUE) =2,584

Wall of 294 mm thickness Material added*

(BAGADER & MOHAMED, 2020)**

Wall Proposal 2	Plastering	2	0.5	830	1300
	Plastering Layer	20	0.35	840	950
	Concrete Block	200	1.31	840	2240
	Insulation material (Polyethylene)	80	0.04	840	40
	Gypsum Board	12	0.35	840	950
	Interior Paint	2	0.5	830	1300

- **Thermal characteristics of roof construction materials with thermal resistance (R-VALUE) = 2.463**
- **Wall of 336 mm thickness Added material***

Data shown in Table 6 has been inserted in the simulation program and the results are shown in Figure 11.

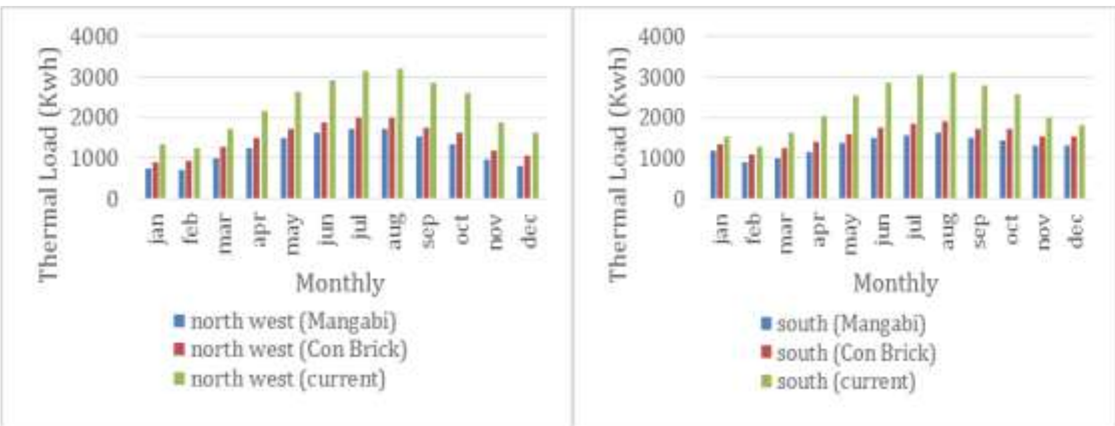

Figure 16: Shows the difference between thermal loads of residential villas during the months of the year before and after change of wall specifications (Researchers).

As seen in Figure 11, differences are huge between the thermal loads of the current situation and the two development proposals in summer seasons, while differences are much closer in winter seasons. However, there are still clear differences between them, and the saving amount obtained is measured as shown in Table 7.

Table 7: Energy Consumption in North and West Orientations during the current situation and after change of Wall specifications (Devised by Researchers).

Consumption Element		Cooling (Kilowatt/Hour)	Devices (Kilowatt/Hour)	Lighting (Kilowatt/Hour)	Total (Kilowatt/Hour)	Saving Percentage
Current Situation	Northwest	44071.56	4420.33	1031.41	49523.3	-
	South	44594.24	4420.33	1031.41	50045.98	-
After Modification (Proposal 1)	Northwest	30832.9	4420.33	1031.41	36284.64	36.5%
	South	31646.31	4420.33	1031.41	37098.05	34.9%
After modification (Proposal 2)	Northwest	33104.09	4420.33	1031.41	38555.83	28.4%
	South	34442.59	4420.33	1031.41	39894.33	25.4%

Table 7 shows that the amount of energy consumption is 36.5% in Northwest orientation and 34.9% in South orientation regarding the first proposal (Manqabi stone) and that saving is 28.4% in Northwest orientation and 25.4% in South orientation regarding the second proposal (Concrete block). It is noted that Northwest orientation is the best and that the best proposal is Manqabi stone proposal of 294 mm wall thickness.

Third: Treatments by changing window glass specifications

Saudi building code (المركز السعودي لكفاءة الطاقة، 2021) sets the percentages available for openings against heat transfer coefficient and solar heat gain coefficient in detail as shown in Table 8.

Table 8: Heat Transfer Coefficient and Solar Heat Gain Coefficient according to the percentage of openings in building envelopes in the Saudi building code (Guide to Heat Insulation Materials and Systems in compliance with the Saudi building code requirements).

Code	ALL REGIONS		
Residential Units	Percentage of Openings	Heat Transfer Coefficient Value	Solar Heat Gain Coefficient
	Less than 40%	2.89	0.25
	Between 40%-50%	2.38	0.25
	More than 50%	1.87	0.25

Glass specifications used in current windows have been changed to improve heat transfer coefficient values as shown in Table 8. Table 9 shows proposed window specifications used in the simulation program and compares it to the current situation. Figure 17 shows the percentage of reduction in the amount of energy used.

Table 9: Shows window specifications after modification (Devised by the Researchers).

Glass Type	Thickness	Heat Transfer Coefficient Value	Solar Heat Gain Coefficient %	OPTICAL TRANSMITTANCE
Current Situation	6 mm one layered blue glass (generic ref tint hi)	6.12	0.587	0.57
Building Code	Exterior Layer: 6 mm Air: 6 mm Interior layer: 6 mm (generic clear)	2.89	0.216	0.118

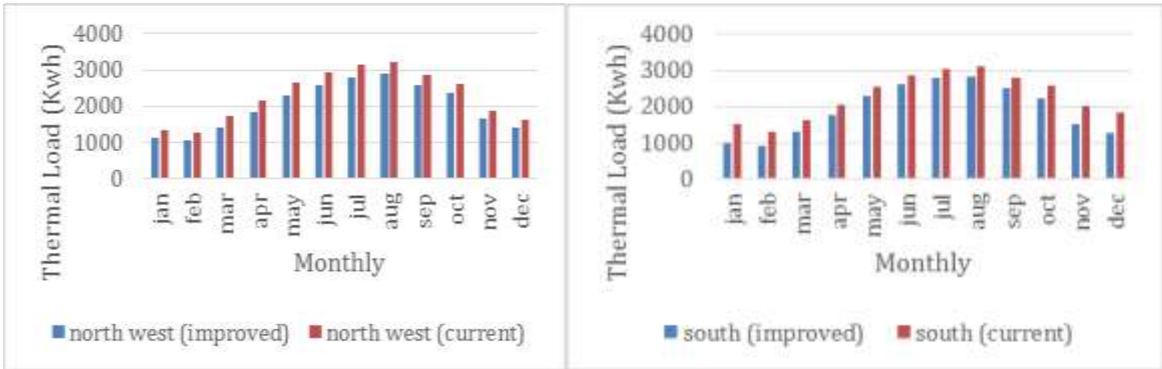

Figure 17: Shows differences in thermal loads during months of the year after changing window glass specifications (Devised by Researchers).

Figure 17 shows differences in thermal loads between the current situation and the situation after changing window specifications. Differences increase obviously in seasons (June to August) and decrease in seasons (December to March). However, differences remain clear between the two proposals. Differences in percentages between the current situation and the situation after changing window specifications have been calculated as shown in table 10, where consumption decreases by 12.8% in Northwest orientation and by14.3% in South orientation.

Table 10: Energy consumption in north and west orientations during the current situation and after change of wall specifications (devised by the researchers).

Consumption Element		Cooling (Kilowatt/Hour)	Devices (Kilowatt/Hour)	Lighting (Kilowatt/Hour)	Total (Kilowatt/Hour)	Saving Percentage
Current Situation	Northwest	44071.56	4420.33	1031.41	49523.3	-
	South	44594.24	4420.33	1031.41	50045.98	-
After Modification (Proposal 1)	Northwest	38471.12	4420.33	1031.41	43922.86	12.8%
	South	38350.66	4420.33	1031.41	43802.4	14.3%

6.4 Proposal that combines previous treatments

A final proposal that combines all these treatments has been prepared. Manqabi stone has been chosen in walls as the optimal alternative. Then, the final proposal has been compared with the current situation of residential units in the resort. Figure 18 shows differences in thermal loads between them. Differences clearly increase in months (July to August) and decrease in months (December, january, and February). Annual combined thermal loads and the amount of saving have been calculated as percentages given in table 11.

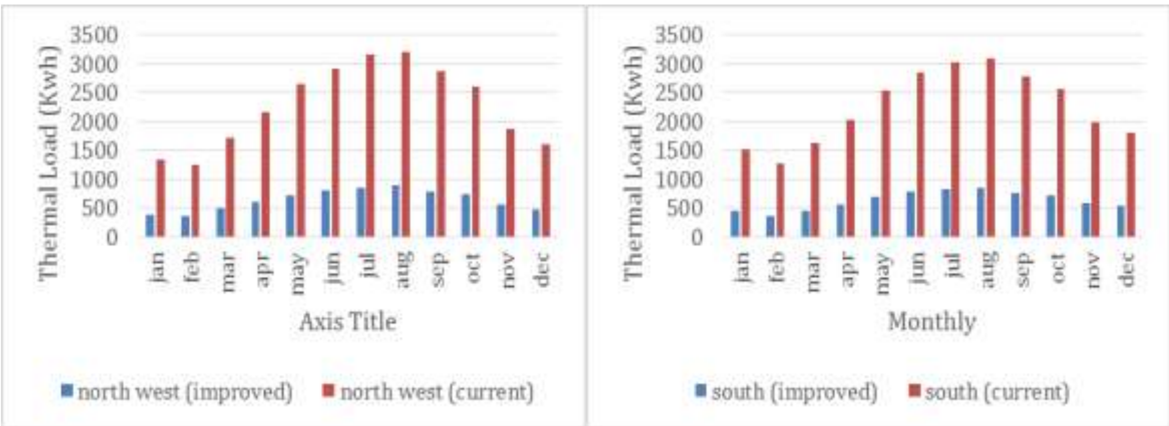

Figure 18: Shows differences between thermal loads of residential villas during months of the year in the four orientations selected for study before and after change of window glass specifications (Devised by Researchers)

Table 11 shows the saving percentage reaching 57.10% in the Northwest orientation and 56.75% in the South orientation.

Table 11: Energy Consumption in North and West Orientations during the Current Situation and after change of Wall specifications (Devised by Researchers).

Consumption Element		Cooling (Kilowatt/Hour)	Devices (Kilowatt/Hour)	Lighting (Kilowatt/Hour)	Total (Kilowatt/Hour)	Saving Percentage
Current Situation	Northwest	44071.56	4420.33	1031.41	49523.3	-
	South	44594.24	4420.33	1031.41	50045.98	-
Final Proposal	Northwest	22827.81	4420.33	1031.41	28279.55	57.1%
	South	22946.88	4420.33	1031.41	28398.62	56.75%

6. Energy Efficiency Proposed Modification Strategies

Applying the strategies of improving and modifying buildings' envelope generally means reducing heating and cooling loads in buildings. These strategies include replacement of building envelope components with more efficient elements. These strategies also efficient materials, such as high performing windows (Asadi, da Silva, Antunes, & Dias, 2012). The choice of using improvement strategies of negative solar energy depends on reducing heat transfer across the building envelope to avoid using high-cost techniques. Energy consumption management in buildings for purposes of heating and cooling requires modifying the building's texture, improving the building's envelope (Ahn, Kim, Jang, Leigh, & Jeong, 2016), modifying the type of glass used in openings, insulating roofs and increasing the thermal resistance coefficient of the building's exterior walls. Energy management in buildings also requires choosing the appropriate modification strategies. These strategies are summarized in this research paper and in studies pertaining to residential units in hot humid climates through presenting the advantages of energy efficiency chosen for the case study in table 12.

Table 12: Energy Consumption In North And West Orientations During The Current Situation And After Change Of Wall Specifications (Devised By The Researchers).

	Consumption Element	Name	Current Situation	Description of Re-Design Strategy
1	Roofs	Roof Design (X)	X Current Situation: Roofs base material is reinforced concrete of 200 mm thickness, 2 mm plastering, 70 mm foam concrete, 20 mm waterproof and 50 mm sandstone with thermal resistance: 0.579 Watt/M. Kelvin	X 1: reinforced concrete of 200 mm thickness, 2 mm plastering, 70 mm foam concrete, 20 mm waterproof and 50 mm sandstone (Polyethylene) of 130 mm thickness and thermal resistance: 3.793 Watt/M. Kelvin
2	Exterior Walls	Wall Design	Current Situation P: Plastering of 2 mm	P1: Manqabi Stone of 200 mm thickness,

		(P)	thickness, 20 mm plastering layer, 20 mm red block, 20 mm plastering layer, 2mm interior paint with thermal resistance=0.579 Watt/M. Kelvin	(Polyethylene) of 80 mm thickness, 12 mm gypsum board and interior paint of 2mm thickness and thermal resistance= 2.463 Watt/ M. Kelvin P2: 2 mm plastering, 20 mm plastering layer, 200 mm concrete block, polyethylene material of 80 mm thickness, gypsum board of 12 mm thickness, interior paint of 2 mm thickness and thermal resistance= 2.463 Watt/ Kelvin
3	Windows	Window Design (N)	N current situation: Transparent window of 6 mm thickness, light transmission coefficient= 0.57 and heat transfer coefficient = 6.12	N1: 6 mm double class, 6 mm air, light transmission coefficient= 0.118, heat transfer coefficient= 2.89

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