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Evaluating and improving the thermal performance of the modern rural house in Farafra Oasis

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Abstract

Complementarity between the architectural product of housing, conditions, and components of the surrounding environment is an important and influential factor in the success of new residential complexes, especially in developing countries, in order to contribute to achieving environmental balance, which is one of the most important trends worldwide nowadays. This study discusses the assessment of the thermal performance of the modern rural dwelling of the modern village project in Farafra Oasis and its suitability for the surrounding climatic conditions through studying the materials and techniques used and achieving the requirements of the Egyptian Energy Code for residential buildings. In addition to suggestions and treatments to improve the thermal performance of the house. This study was based on a field visit to the modern rural dwelling project at Farafra Oasis for the purpose of raising, documenting, and identifying the housing model, its characteristics, the building materials and techniques used, and the climatic conditions of the site. And the compatibility of the housing's outer envelope with the climatic conditions of the desert region. Thus, the thermal performance of the existing housing spaces is assessed by using simulation software to explore the thermal comfort of occupants. Suggestions and treatments were then put forward to improve the thermal performance of the house and evaluated to determine its impact on the housing's thermal efficiency.

By comparing the obtained results with the boundaries of thermal comfort and the specifications of the Egyptian code for residential buildings, the results demonstrated the home model's inadequate thermal performance. An improvement in internal space thermal comfort hours all year long has been attributed to proposed treatments aimed at enhancing the home's thermal performance. In addition, it uses less energy and is more efficient than the current model.

Keywords: Thermal comfort, rural house, Farafra Oasis, thermal performance

1. Introduction.

In view of the repercussions of climate change, which has become a reality, we must adapt to it and make every effort to mitigate the effects of heat warming, which has affected warming significantly. [1] This has reduced the thermal comfort of the residential buildings' indoor environment and increased energy consumption, especially in the hot areas. [2] Which illustrates the importance of designing residential buildings that are compatible with the surrounding environment and choosing appropriate materials and techniques. The residential and commercial sectors account for approximately 50% of total energy consumption per year in Egypt. [3] It is especially important to consider how to guarantee inhabitants' thermal comfort while conserving energy and protecting the environment. [4]

According to the state's strategy for developing desert areas, the construction of new residential complexes helps to relieve population density in the narrow valley and promotes horizontal urbanization in desert regions where groundwater is accessible.[5] The state went towards the Oases area because of its special features and an integrated environmental system and placed it on the map of urban development in Egypt, especially Farafra Oasis, which is one of the most important Egyptian oases with a promising future in the field of comprehensive urban development because of groundwater availability and soil fertility, making it attractive to the population. [6] Nowadays, some contemporary housing projects have emerged to develop Farafra Oasis, among them the land reclamation project, the development of one and a half million acres and the construction of modern integrated housing villages. [7] This requires a study and analysis of the modern rural housing model to determine its suitability and compatibility with the environmental conditions.

2. Novelty statement.

This study aims to assess the thermal performance of the modern rural dwelling model at the Farafra Oasis, verifying the thermal comfort conditions of the occupants in the internal spaces of the dwelling and comparing it with the requirements of the Egyptian Energy Code for residential buildings.

Using a model simulated by Design Builder V.6 software. In addition, the research discusses the impact of natural ventilation, building materials, and techniques used in the building's facades on the thermal performance of the residence to provide an indoor environment compatible with local environmental conditions. Some of the proposed treatments were therefore put forward to contribute to improving the house's thermal performance, increasing occupants' thermal comfort, and reducing energy consumption.

3. Methodology.

To achieve the aim of this study, an analytical approach was followed to analyze the data and climatic conditions of Farafra Oasis. In addition to the documentation and analytical description of the housing model studied at Farafra Oasis through analysis of the building envelope materials and methods based on the field visit to the project site.

Design Builder V6 simulation software was used to evaluate the housing model and then evaluate the suggested treatments of the building's outer shell that are applied to improve the thermal performance of the building by trying different alternatives for walls and roof layers, using heat insulation material in different thicknesses, and the extraction, analysis, and graphic representation of the results.

4. Literature review.

In this section, we review some of the basic concepts to which this paper is exposed, including the concepts of thermal comfort and thermal comfort zone. Thermal comfort was defined by the (ASHRAE) standard as the state of mind that expresses satisfaction with the thermal environment and is assessed subjectively. [8] A person's sensation of the thermal atmosphere can be described as a neutral feeling concerning a specific thermal environment without sweating. [8] Moreover, it is a challenge to please everyone in a room due to the significant physiological and psychological differences between individuals. Not everyone requires the same set of surroundings to be comfortable. [9]

Six primary elements need to be considered when determining thermal comfort settings. In certain situations, a variety of different secondary elements influence comfort; these are air temperature, radiant temperature, humidity, air speed, clothing insulation, and metabolic rate. [8] There is no doubt that the actual thermal perception is influenced by a variety of factors, including the residents' age and gender, living habits, local customs, and thermal history. [10]

The thermal comfort zone refers to a range of operating temperatures that offers thermally acceptable ambient circumstances or to combinations of air temperatures that people find tolerable. (ASHRAE) also defined the thermal comfort zone as the area where the majority of humans will feel comfortable due to certain environmental conditions. [8,9] It is one of the most effective energy-saving strategies. [9] In addition, achieving indoor thermal comfort will increase people's work efficiency by 15% in a comfortable environment. [11]

Fanger's model of thermal comfort; in this model, Fanger has created the predicted mean vote (PMV) model of thermal comfort, which is one of the most famous and widely used thermal evaluation criteria. [12] The predicted mean vote for thermal comfort (PMV) is determined by the heat balance of the human being with his environment. The PMV model is calculated from the air temperature and mean radiant temperature in question, along with the applicable metabolic rate, clothing insulation, air speed, and humidity. If the resulting PMV value generated by the model is within the recommended range, then the conditions are within the comfort zone. [8-12]

The predicted mean vote (PMV) was developed to be used in measuring people's thermal experience. The ASHRAE thermal sensation scale is defined as follows: +3 hot, +2 warm, +1 slightly warm, 0 neutral, –1 slightly cool, –2 cool, and –3 cold. The PMV model uses heat balance principles to relate the six essential elements of thermal comfort to the mean response of individuals on the scale. as shown in Fig. 1. The PPD (predicted percentage of dissatisfaction) is based on the assumption that people's voting of +2, +3, –2, or –3 on the thermal sensation scale means that they are dissatisfied, and the fact that the PPD is symmetric about a neutral PMV, which simplifies things. Generally, the range of the accepted thermal environment PMV range is (-0.5 < PMV < + 0.5), while that of PPD is < 10. [8]

The adaptive model is a model for assessing thermal comfort; it is a model that relates indoor design temperatures, or acceptable temperature ranges, to outdoor meteorological or climatological parameters. [8]. Therefore, outdoor temperature represents an important predictor of indoor comfort and a well-established thermal adaptive model. [10] Numerous experts have stated that the human body is not a passive recipient of its surroundings. Thermal comfort will be greatly impacted by a range of adaptabilities, which will work together to advance the adaptive theory. Additionally, other international and local regulations, such as (ASHRAE) 55, have adopted this technique. [10,8]

The adaptive model for determining the thermally acceptable temperature for voids is dependent on the monthly average of the external temperature, as represented in Fig 2. The allowable indoor operative temperatures for spaces that meet these criteria may be determined from the relationship described in the graph shown in Fig. 2. This comprises two sets of acceptable operating temperature limits, one for 80% and the other for 90%. When further information is unavailable, the 80% acceptable limit that is intended for standard applications must be applied. If a higher level of thermal comfort is required, the 90% acceptable limit can be applied. The arithmetic average of the mean daily minimum and mean daily maximum outdoor (dry-bulb) temperatures for a given month is used to calculate the mean monthly air temperature. [8]

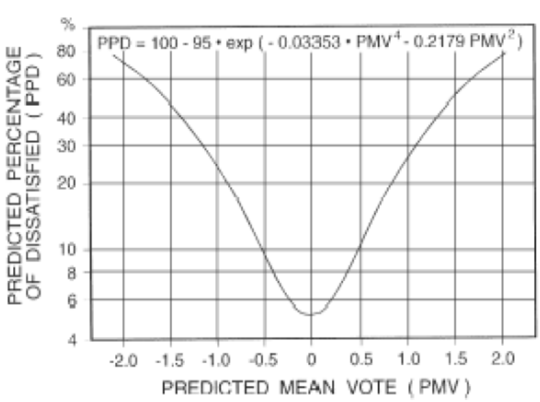

Fig 1. Predicted percentage dissatisfied (PPD) as a Function of predicted mean vote (PMV). [8]

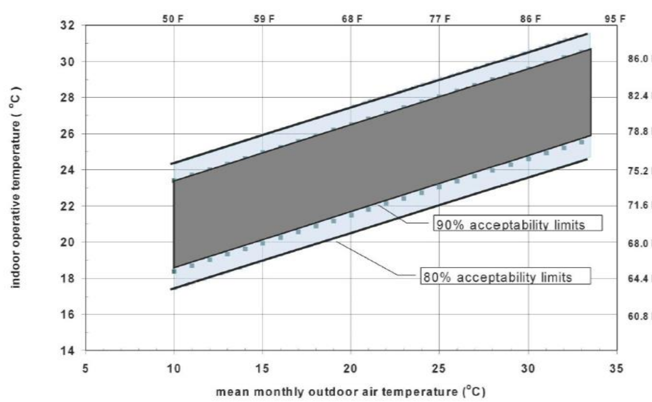

Fig 2. Acceptable operative temperature ranges for naturally conditioned spaces. [8]

5. Climate Regions in Egypt.

Egypt is located between 22◦ N to 32◦ N latitudes and 24◦E to 37◦ E longitude. Egypt’s area is about 1.002 million km^2. The Nile valley and delta are less than 4% of the total Egyptian area. [3] The Western Desert is about 68% of Egypt's area.

Egypt is divided into 8 different climate regions, the North Coast Region: Delta Region, Cairo, North Upper Egypt Region, South Upper Egypt Region, East Coast Region, Highland Region, and Desert Region. As shown in Fig. 3 [2] the largest proportion of Egypt's area is located in the desert region, while Farafra Oasis is located in the 7th region, which is the hot desert region and has a dry, hot climate.

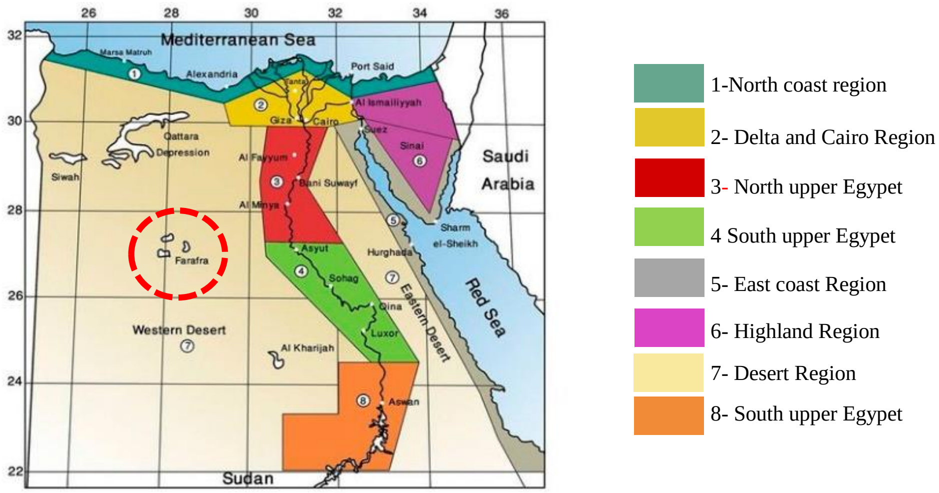

Fig. 3. Climate regions in Egypt. [3,13]

5. 1. Geographic location of Al-Farafra Oasis

Farafra Oasis is a small Oasis located in the heart of the Western Desert. It is 170 km south of Al-Bahariya Oasis and 627 km from Cairo. Its capital is an Al-Farafra Palace. It is a famous Oasis because of its location, history, rock quality, and sunny weather. The Farafra oasis is the most isolated oasis in the New Valley, and it has its own traditions and customs. It is surrounded by several natural water eyes, many palm trees, and olives. [6] Also, it dates back to the Pharaonic era. It was mentioned in some ancient Egyptian documents, especially since the tenth dynasty in the 21st century BC, and was called "Ta Aht" (i.e., the land of the cow). It was given this term by the ancient Egyptians because of so many meadows and cows. [14]

5. 2. Weather data analysis of Farafra Oasis.

According to climate reports issued by the Climate Monitoring Station and documented by Al Farafra Weather data files, (EGY_WJ_Farafra.624230_TMYx.2007-2021). [15] This data was analyzed using Climate consultant V 6.0. Software. Climate Consultant's software objective is to provide you with several graphical representations of climate data for your selected region and to investigate how to adapt outdoor circumstances to indoor comfort.

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VOLUME 6, ISSUE 2, 2023, 356 – 375.

Table. 1 shows the summary of weather data for Farafra Oasis, where July and August represent the hottest months in the year, in which the monthly average temperature reaches 32 °C, and January represents the coldest month throughout the year, where the temperature reaches. 13 °C.

From Fig. 3. It is obvious that relative humidity varies from 23% to 53%. It is also noted that RH reached its lowest limit during the summer, especially in August, while the higher limit was reached during the winter, especially in January. The wind direction in the north and north-west is a little bit northeastern year-round. Furthermore, the wind speed varies from 1 m/s to 3 m/s, where the highest speed was observed during July and August, in addition to the sunny climate of the Oasis throughout the year, as shown in Fig. 4.

Table. 1. Weather data summary for Farafra Oasis. [15]

Monthly Mean	Jan	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Dry Bulb Temperature (Avg Month) C°	13	15	19	24	28	31	32	32	29	25	19	15
Relative Humidity (Avg Monthly) %	51	37	33	27	23	24	23	26	30	43	45	53
Wind Direction (Monthly mode) degree	350	320	340	0	0	0	340	350	0	350	330	340
Wind Speed (Av Monthly) m/s	2	2	1	1	1	2	3	3	3	2	2	1
Direct normal radiation (Avg) W/m^2	637	666	651	645	622	613	603	609	613	633	658	619

The limits of adaptive thermal comfort that correspond to external weather conditions according to (ASHRAE 55) were extracted by analyzing climate data; it varies between 24 °C and 30.5 °C In the summer months, while ranging between 19 °C and 27 °C during the winter, as shown in Figs. 4 and 5.

Figure 6 reveals the range of values for adaptive comfort throughout the year, which is between 19.5 °C and 30.5 °C. Also, the thermal comfort period represents only 23.6% of the hour's in a year.

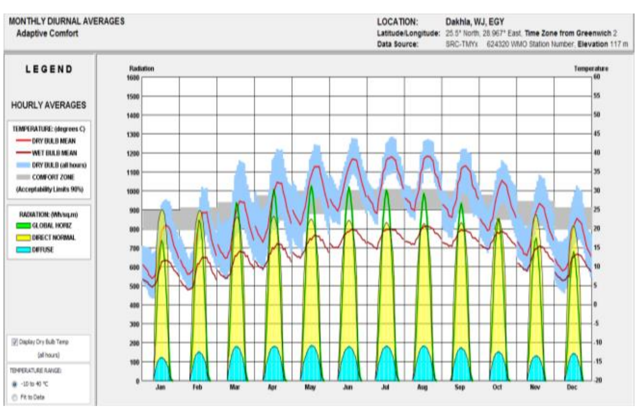


Fig. 4. Monthly diurnal averages adaptive Comfort.

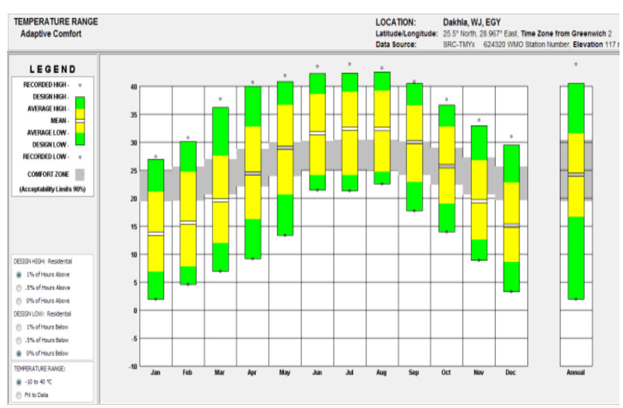


Fig. 5. The highest temperatures and limits of the thermal comfort zone.

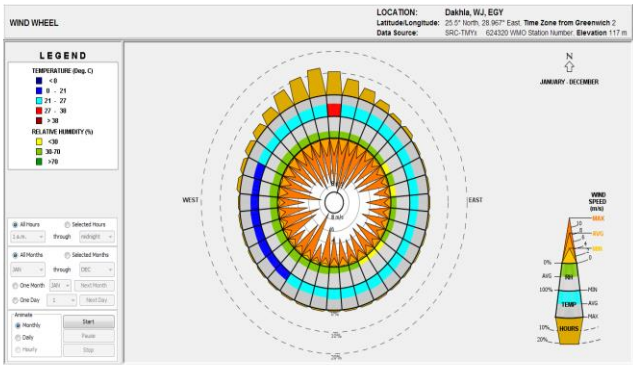


Fig. 6. Wind wheel for Farafra Oasis.

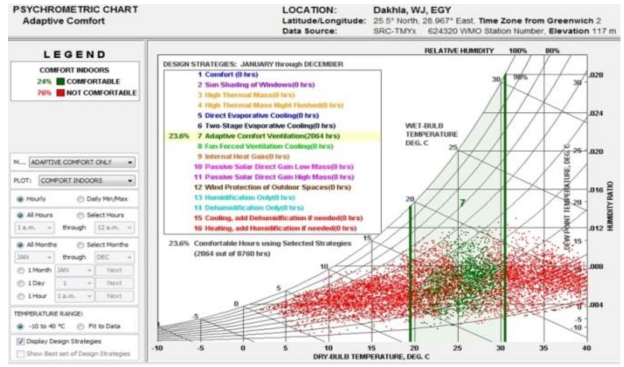


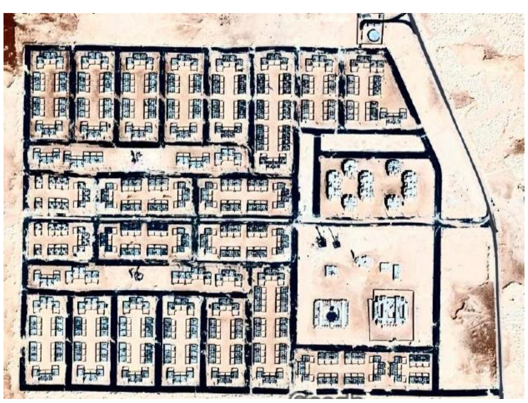
Fig. 7. Chart adaptive comfort During the monthly.

6. Case Study Definition and Modeling.

The case study of this investigation is the modern rural dwelling model in Farafra Oasis as a part of the development and rehabilitation project implemented by the Egyptian government on one and a half million acres. [16]

The project consists of residential groups that are regularly monolithic in rows, where the housing units are assembled as attached units consisting of quad models and triple models. The research focuses on the study of the quad models. As shown in Fig. 7, the residential model consists of an entrance, a living room, three bedrooms, a kitchen, a bathroom,

a backyard, a building area of 110 m,^{2} and a backyard area of about 90 m^2 as shown in Fig. 8. The building block is square with a ratio of 1:1 and has a backyard for privacy.



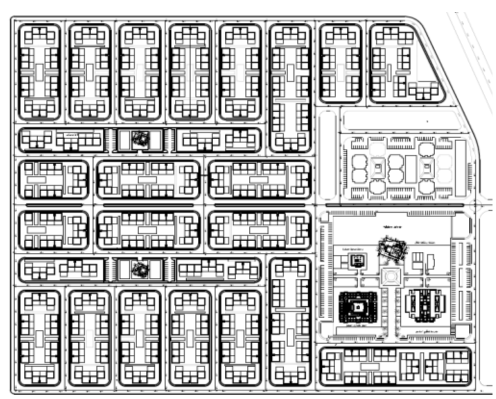


Fig. 7. a) The location of residential village, Farafar. [17]. b) layout for the residential village, Farafar. Author

INTERNATIONAL JOURNAL OF
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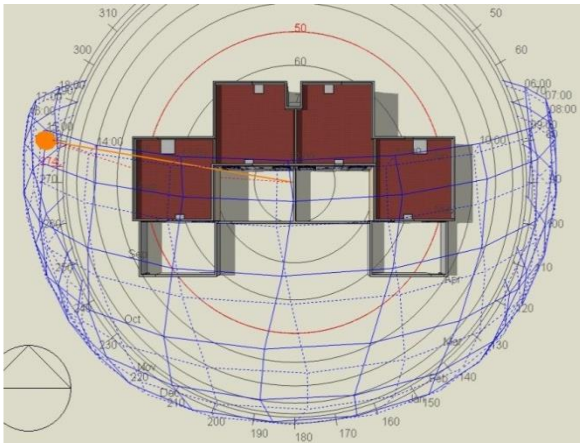

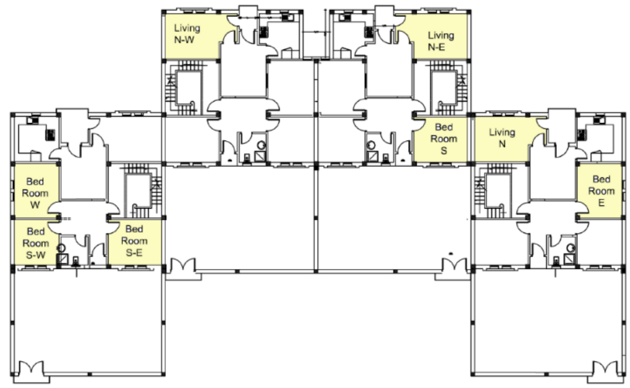

Fig. 8. a) layout for housing model, in Farafra. b) Ground floor plan for housing model in Farafra Oasis, Author.

Fig. 9. (a & b) main Facades for rural house in Farafra Oasis, Author.

6.1. Building envelops components for case study.

The construction of the building depends on the skeleton system. Firstly, the exterior walls are composed of hollow clay bricks with a thickness of 25cm, and the roof is composed of a solid slab of reinforced concrete with a thickness of 12 cm. The ratio of openings in the main facade is 7.5%, while in the back facade it is about 5%, and that of the side façade is 3%, all windows have external louver shutters, as shown in Fig. 9. To protect the openings from sunlight, they were shaded 100%. The ratio of openings in facades complies with the Egyptian code requirements. Fig. 10. shows the building model for simulation.

A three-dimensional model of the residence was built using the Design Builder simulation software by entering the characteristics, data of the building, and thermal properties of the used building materials, in addition to the recorded climate data of the site. The specifications for construction materials used in the simulation are listed in Table 2, as cross sections for the walls and roof layers.

INTERNATIONAL JOURNAL OF
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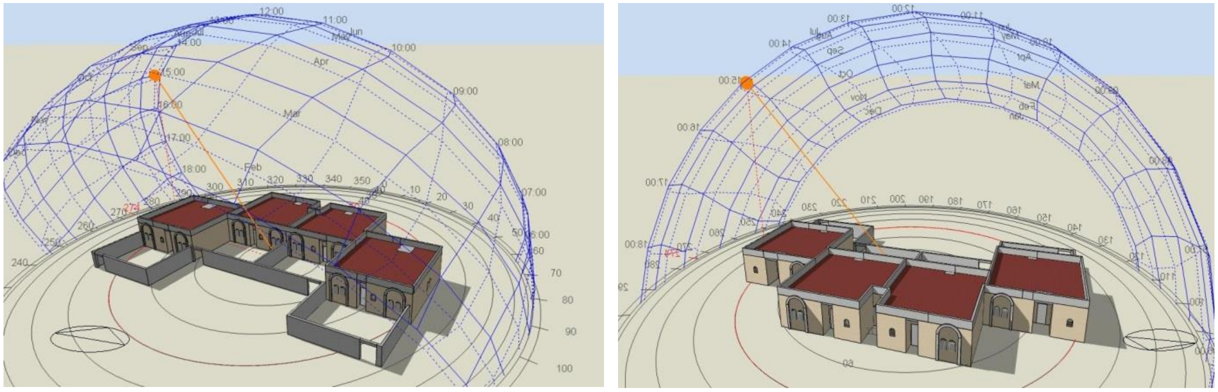


Fig. 10. (a, b) Sun path diagram of the building model for rural house. Author.

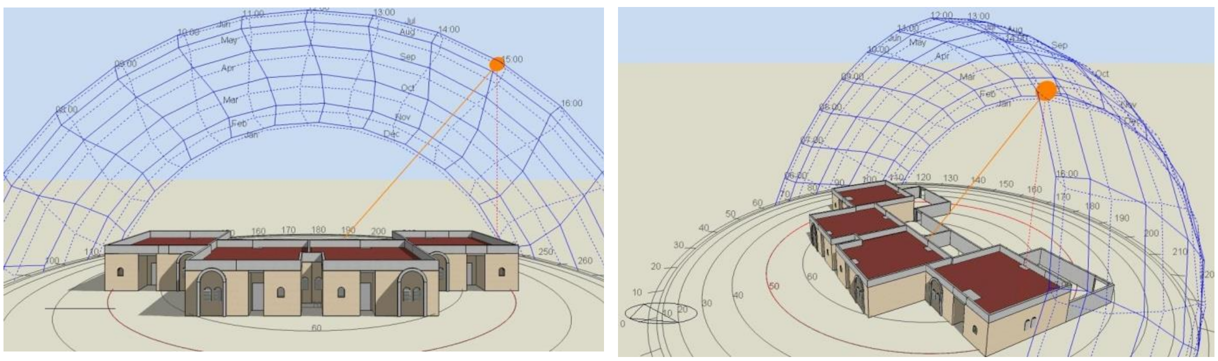
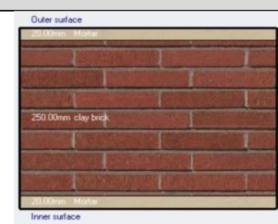
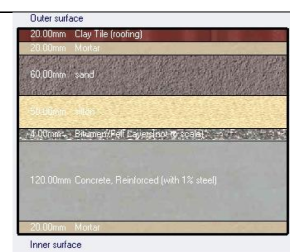


Fig. 11. (a, b) North facade of the building model for rural house. Author.

Table. 2 Thermal properties of the opaque parts of the building envelope. Author

Building envelop component	Density kg/m3	Conductivity W/m.K	Specific heat J/kg.K	Cross Section
External wall Construction layers.				
2 cm Cement/plaster/mortar	2800	0.88	896	
25 cm Brickwork outer	1500	0.85	840	
2 cm Cement/plaster/mortar	2800	0.88	896	
	R. value total = 0.633 m^2.ºC /w	-	U .value = 1.58 w/m^2.c	
Building envelop component	Density kg/m3	Conductivity W/m.K	Specific heat J/kg.K	Cross Section
Roof layers				
2 cm Cement tiles	2000	1.00	800	
2 cm Cement/plaster/mortar	2800	0.88	896	
6 cm Sand	1520	0.33	800	
5 cm silton	480	0.17	1200	
0.4 Cm bitumen felt/ sheet	1100	0.23	1000	
12cm Reinforced concert	2300	2.3	1000	
2 cm Cement/plaster/mortar	2800	0.88	896	
	R. value total = 0.742 m^2.ºC /w	-	U .value = 1.35 w/m^2.c	

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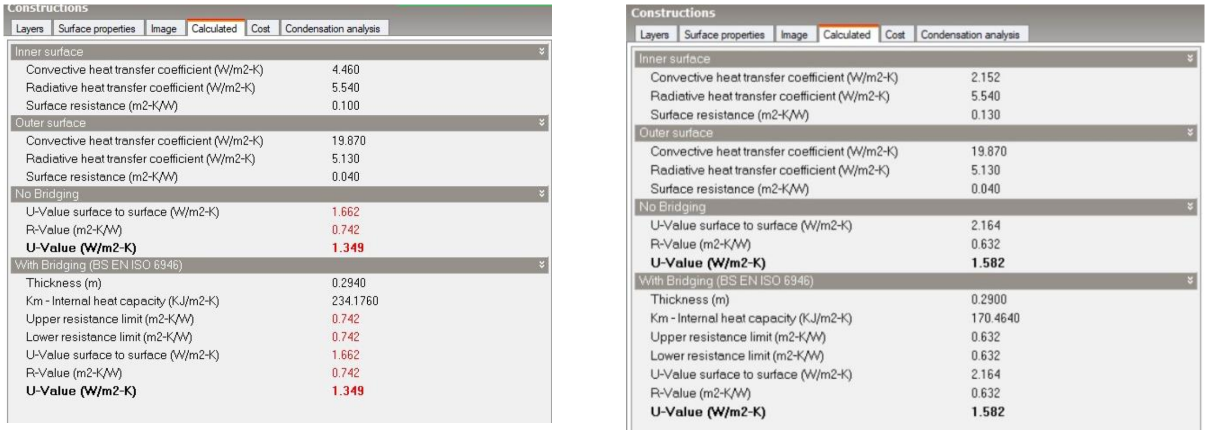
VOLUME 6, ISSUE 2, 2023, 356 – 375.

The glazing type used for windows was a single clear 6mm thick, with a solar heat gain coefficient (SHGC) of 0.81 and a Windows Shading Ratio SGR of 100%.



Constructions — Layers | Surface properties | Image | Calculated | Cost | Condensation analysis

(a)	
Inner surface	
Convective heat transfer coefficient (W/m2-K)	4.460
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.100
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	1.662
R-Value (m2-K/W)	0.742
U-Value (W/m2-K)	**1.349**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.2940
Km - Internal heat capacity (KJ/m2-K)	234.1760
Upper resistance limit (m2-K/W)	0.742
Lower resistance limit (m2-K/W)	0.742
U-Value surface to surface (W/m2-K)	1.662
R-Value (m2-K/W)	0.742
U-Value (W/m2-K)	**1.349**

(b)	
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	2.164
R-Value (m2-K/W)	0.632
U-Value (W/m2-K)	**1.582**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.2900
Km - Internal heat capacity (KJ/m2-K)	170.4640
Upper resistance limit (m2-K/W)	0.632
Lower resistance limit (m2-K/W)	0.632
U-Value surface to surface (W/m2-K)	2.164
R-Value (m2-K/W)	0.632
U-Value (W/m2-K)	**1.582**

Fig. 12. (a, b) Thermal resistance and thermal transition for roof and external wall. Author.

The simulation of the residential building took place during the summer critical week (July 29 to August 4), according to which the cooling systems were designed, because it represents the highest temperature outdoors, without the use of natural ventilation to assess the thermal status of the indoor spaces for the base case.

6.2. Assessment of the thermal performance of the internal spaces of the housing model.

The graphically represented results of the simulation illustrated in Fig.12 indicate the relationship between the internal temperature degrees of the residential spaces with different directions and the external temperatures during the hours of the summer design week. The results indicate that the highest external temperature during this week was 42.5 ˚C at 4 p.m., while the lowest temperature during this week was 22.5 ˚C at 6 a.m. The temperatures of the internal spaces range from 33.5 ˚C to 39 ˚C, showing that all spaces are outside the limits of thermal comfort.
Furthermore, the highest internal temperature is the Eastern bedroom (B.R/East) is represented on the yellow curve, followed by the western bedroom, and the lowest internal temperature is in the northern space (Liv/N) represented by the green line, and the south bedroom almost matches it. The internal temperatures of the other spaces differ by only about 1 °C.

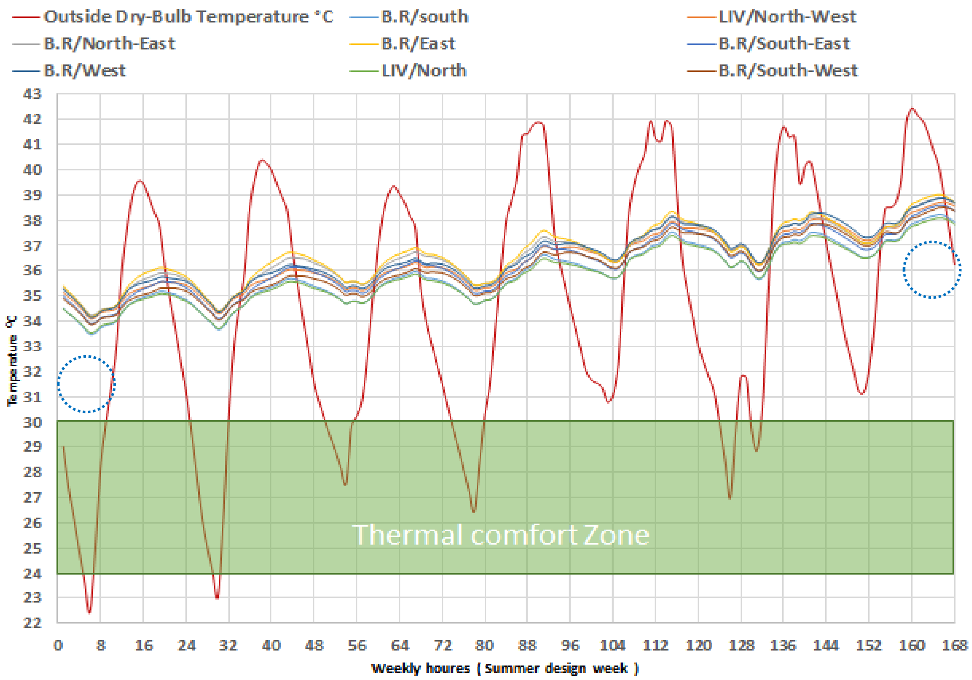


Fig. 13. Relationship between indoor and outdoor temperatures of various spaces during Critical week hours without natural ventilation. Author.

6.3. Effect of natural ventilation on internal thermal comfort.

The effect of ventilation on lowering the internal temperatures of the dwelling spaces is tested by opening windows when the external temperature drops after sunset in the summer from 8 pm to 7 am. The simulation results shown in Fig. 14 indicate that the internal temperatures of all spaces are reduced by up to 2 °C during daylight hours and up to 6 °C during night hours. From Fig. 14, it is clear that several hours of the week are located within the thermal rest range of about 18 hours, proofing the positive impact of natural ventilation on the building's thermal performance.

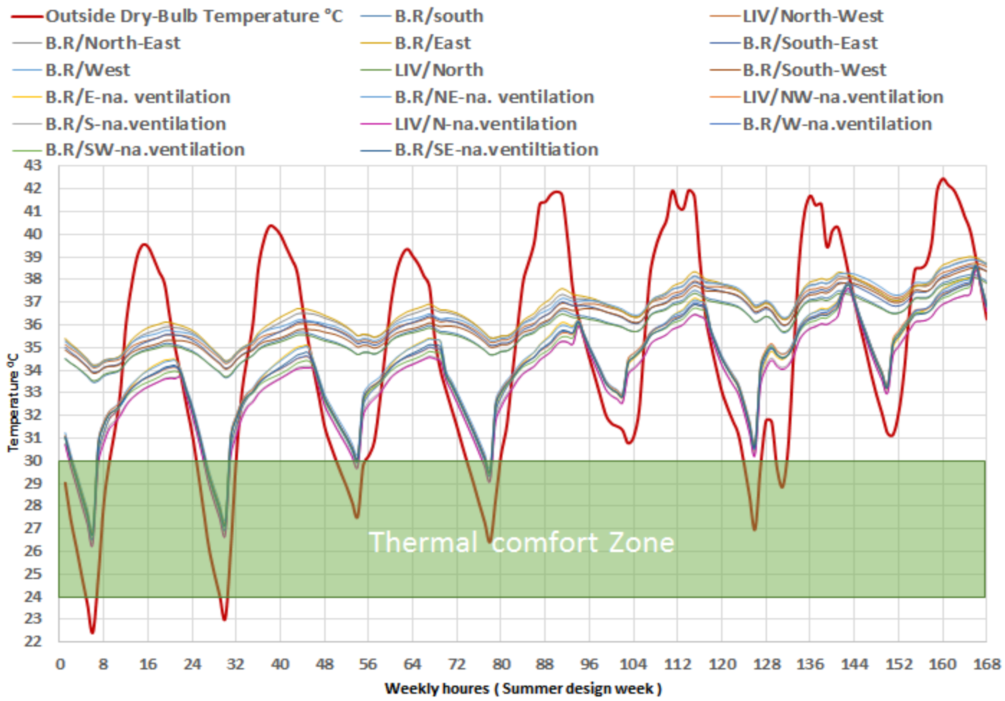


Fig. 14. The effect of natural ventilation periods on internal temperatures of spaces with different directions. Author.

6.4. Proposed treatments to improve the building's thermal performance.

The Egyptian code sets the requirements for the outer envelope of non-adapted residential buildings in the desert region in which Farafra Oasis is located through the total thermal resistance value of the roof and external walls according to the wall orientation. As shown in Table. 3, which states the alternative treatments to achieve the Egyptian code requirements to improve thermal performance.

- Treatments for roof layers involve the usage of thermal insulation materials with different thicknesses as alternatives.
- Alternative treatments for exterior wall design.

INTERNATIONAL JOURNAL OF
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VOLUME 6, ISSUE 2, 2023, 356 – 375.

Table 3. Egyptian code requirements for the design of non-adapted residential buildings in the desert region. [8]

	Building envelop component	Thermal Resistance (R-value) m^2-ºC /w	Thermal Transition (U-value) w/m^2-c
	Roof	3.0	0.33
Walls	North facade	0.90	1.1
	Eastern facade	1.3	0.77
	Western facade	1.3	0.77
	South Facade	0.9	1.1
	North/ west North/ East	1.0	1.0
	South/ West South/ West	1.2	1.0

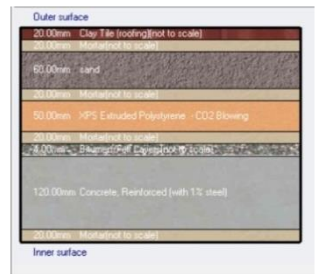
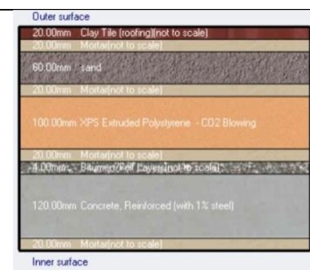
The previous table shows that the highest values of both eastern and western facades are equal in thermal resistance due to their exposure to direct sunlight. Also, the values of thermal resistance for the northern and southern facades are equal. This confirms the validity of the simulation results. Since the east bedroom is thermally the worst with the highest internal temperature, it has been selected for applying various treatments to study their contributions to improving the thermal performance of this bedroom and the possibility of applying these treatments to other spaces.

6.5. Proposed treatments and alternatives for roof layers.

Different cases of the roof's thermal insulation layer are experimented with in comparison with the basic condition, and their effect is inferred to conclude the optimal thermal insulation thickness that meets the requirements of the Egyptian code. Table 4. shows the different alternatives applied to roof layers, their thermal properties, and the total values of thermal resistance (R_{vt}). The cases are as follows:

- Roof 1: Base case: used 5 cm silton. R_{vt}= 0.74 m2-k/W
- Roof 2: used 5 cm extruded polystyrene board. R_{vt}= 2.0 m2-k/W
- Roof 3: used 8 cm extruded polystyrene board. R_{vt}= 2.9 m2-k/W
- Roof 4: used 5 cm extruded polystyrene board. R_{vt}= 3.5 m2-k/W

Table. 4. The alternative layers for roof material input. Author.

Roof layers materials	Conductivity W/m.K	R- Value (m2 - k/W)	U- Value (W/m2-K)	Cross section
Roof 1: base case		0.742	1.34	
2 cm Cement Tiles	1			
2 cm Cement mortar	0.88			
6 cm sand	0.33			
5 cm silton	0.17			
0.4 cm bitumen felt layers.	0.50			
12 cm Reinforced concrete	2.30			
2 cm Cement mortar	0.88			
Roof 2:		2.00	0.50	
2 cm Cement Tiles	1			
2 cm Cement mortar	0.88			
6 cm sand	0.33			
7 cm concrete tendencies	0.88			
5 cm extruded polystyrene.	0.034			
2 cm Cement mortar	0.88			
0.4 cm bitumen felt layers.	0.50			
2 cm Cement mortar	0.88			
12 cm Reinforced concrete	2.30			
2 cm Cement mortar	0.88			
Roof 3:		2.90	0.34	
2 cm Cement Tiles	1			
2 cm Cement mortar	0.88			
6 cm sand	0.33			
7cm concrete tendencies	0.88			
8 cm extruded polystyrene.	0.034			
2 cm Cement mortar	0.88			
0.4 cm bitumen felt layers.	0.50			
2 cm Cement mortar	0.88			
12 cm Reinforced concrete	2.30			
2 cm Cement mortar	0.88			
Roof 4:		3.5	0.28	
2 cm Cement Tiles	1			
2 cm Cement mortar	0.88			
6 cm sand	0.33			
7 cm concrete tendencies	0.88			
10 cm extruded polystyrene.	0.034			
2 cm Cement mortar	0.88			
0.4 cm bitumen felt layers.	0.50			
2 cm Cement mortar	0.88			
12 cm Reinforced concrete	2.30			
2 cm Cement mortar	0.88			

6.6. Simulation results.

The results reveal that during the week hours as the thickness of the thermal insulation material increased, the internal temperatures decreased by about 2°C, as shown in Fig.15. The results also show that the optimal thickness of the heat insulation material used is 8 cm, which corresponds to the thermal resistance value of 2.9 m^2-k/W for the roof layers represented by the blue curve. While

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ARCHITECTURAL ENGINEERING AND URBAN RESEARCH
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VOLUME 6, ISSUE 2, 2023, 356 – 375.

increasing the insulation material thickness to 10 cm did not significantly affect temperatures. This is consistent with the value of thermal resistance of roofs in the Egyptian code.

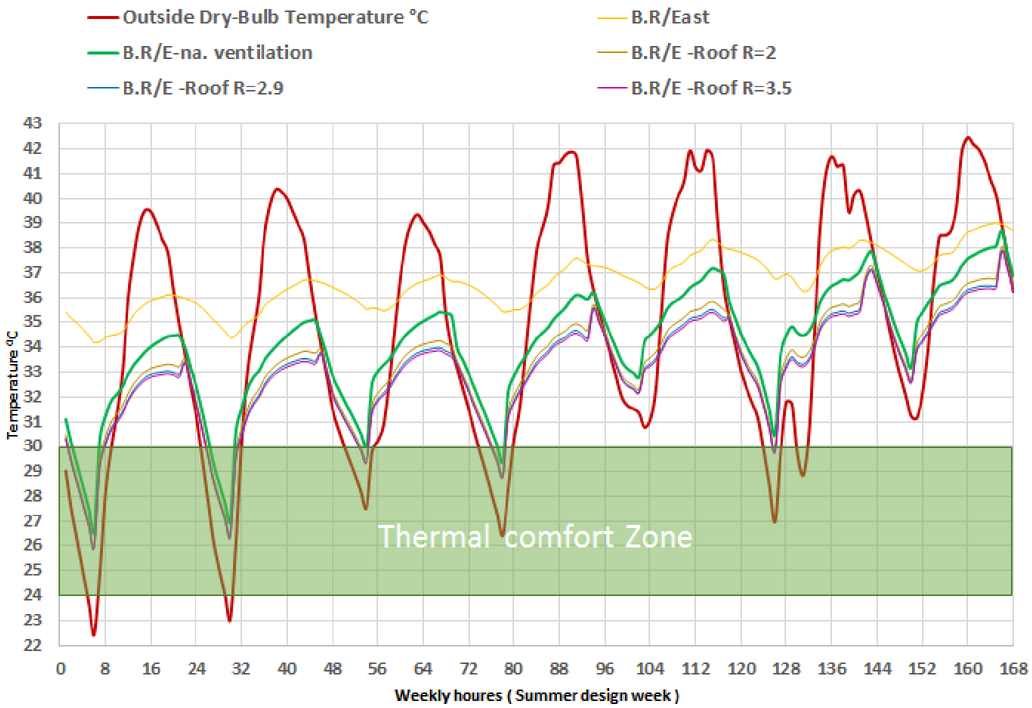


Fig. 15. Simulation results of different alternatives to roof layers and their impact on internal temperatures. Author

6.7. Alternative treatments for exterior wall design.

Wall 1: Base case, single clay brick wall 25 cm thickness. $R_{vt} = 0.83$ m^2-k/W

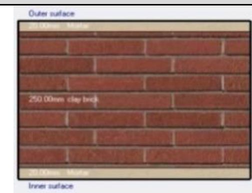
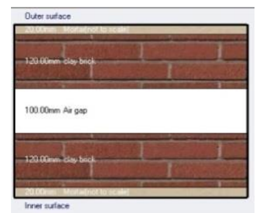
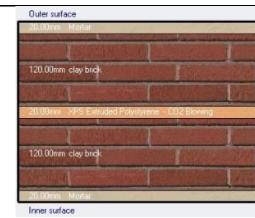
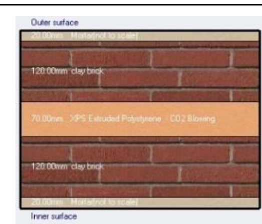
Wall 2: Double wall with Air gap 10 cm (12cm Clay Brick wall+ 10 cm air gap+12 cm Clay Brick wall) $R_{vt} = 0.83$ m^2-k/W

Wall 3: Double wall with insulation 2 cm extruded polystyrene board (12cm Clay Brick wall+ 2cm insulation +12 cm Clay Brick wall) $R_{vt} = 1.20$ m^2-k/W

Wall 4: Double wall with insulation 5 cm extruded polystyrene board (12cm Clay Brick wall+ 5cm insulation +12 cm Clay Brick wall) $R_{vt} = 2.0$ m^2-k/W

Wall 5: Double wall with insulation 7 cm extruded polystyrene board (12cm Clay Brick wall+ 7 cm insulation +12cm Clay Brick wall) $R_{vt} = 2.7$ m^2-k/W

Table. 5. Wall Construction material input for alternatives.

Wall Type Alternative	Conductivity W/m.K	R- Value (m2 - k/W)	U- Value (W/m2-K)	Cross section/wall
Wall 1: Base case. 2 cm Cement/plaster/mortar 25 cm Clay Brick work outer 2 cm Cement/plaster/mortar	 0.88 0.60 0.88	0.63	1.59	
Wall 2: Double wall with Air gap 10 cm. 2 cm Cement/plaster/mortar 12 cm Clay Brick work outer 10 cm air gap 12 cm Clay Brick work inner 2 cm Cement/plaster/mortar	 0.88 0.60 0.6 0.88	0.83	1.2	
Wall 3: Double wall with insulation 2 cm extruded polystyrene. 2 cm Cement/plaster/mortar 12 cm Clay Brick work outer 2 cm extruded polystyrene. 12 cm Clay Brick work inner 2 cm Cement/plaster/mortar	 0.88 0.60 0.034 0.60 0.88	1.20	0.83	
Wall 4: Double wall with insulation 5 cm extruded polystyrene. 2 cm Cement/plaster/mortar 12 cm Clay Brick work outer 5cm extruded polystyrene. 12 cm Clay Brick work inner 2 cm Cement/plaster/mortar	 0.88 0.60 0.034 0.60 0.88	2.00	0.50	
Wall 5: Double wall with insulation 7 cm extruded polystyrene. 2 cm Cement/plaster/mortar 12 cm Clay Brick work outer 7cm extruded polystyrene. 12 cm Clay Brick work inner 2 cm Cement/plaster/mortar	 0.88 0.60 0.034 0.60 0.88	2.70	0.37	

6.8. Simulation results for wall.

The results reveal that the wall used in the basic case has the worst thermal performance and that when various alternatives to the wall are utilized, the internal temperature drops by up to 2°C, as shown in Fig. 16. Results also show that the thermal performance of the double wall with thermal insulation is better than the double wall with an air gap. Additionally, the optimal thickness of thermal insulation is 5cm, and when the thickness of the insulation material increased to 7cm, there was no significant effect on the internal temperatures.

INTERNATIONAL JOURNAL OF
ARCHITECTURAL ENGINEERING AND URBAN RESEARCH
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VOLUME 6, ISSUE 2, 2023, 356 – 375.

The simulation results indicate that, by the application of the optimal thickness of the proposed insulation material for the roof and exterior walls, the indoor temperature decreases up to 3.5 °C, especially during daylight hours, at the peak of the external temperature, as shown in Fig. 16. The results also show that the optimal value of the total thermal resistance of the eastern wall represents was R_{VT} = 2.0 (m^2.k/W), which is greater than the value mentioned in the Egyptian code R_{VT} = 1.1 (m^2.k/W), with improved thermal performance that contributed to increasing thermal comfort hours about 20%, as shown in Fig. 17. In addition, it uses less energy and is more efficient than the current model, as shown in Fig. 18.

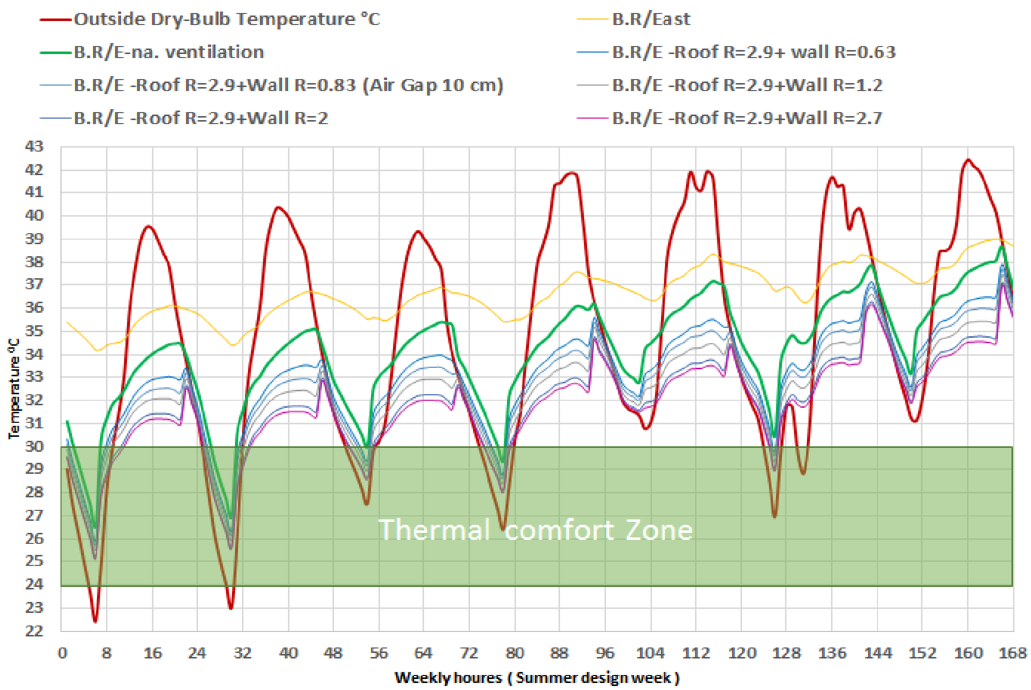

Fig. 16. Simulation results of different alternatives for wall. Author

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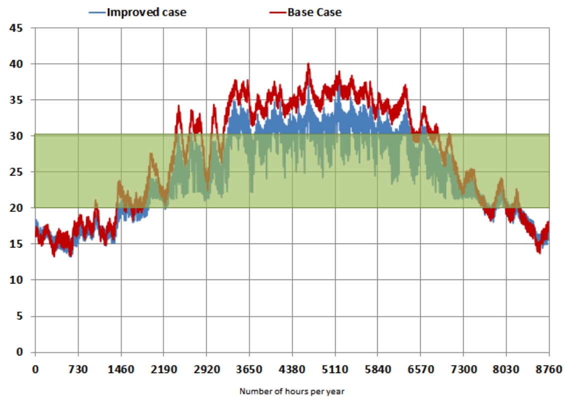

Fig. 17. The proposed treatments contributed to increased internal thermal comfort hours.

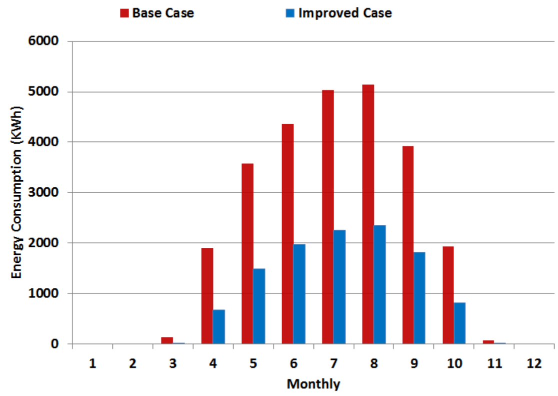

Fig. 18. Reduce the building's energy consumption after improvement.

7. Conclusion.

This study investigated the thermal performance of the modern rural dwelling in Farafra Oasis and proposed alternative designs to improve the thermal efficiency of the building's outer envelope and to increase the internal thermal comfort hours of occupants throughout the year. This, in turn, was reflected in the reduction of cooling energy consumption. The study is based on an adaptive model of thermal comfort to assess the thermal comfort limit according to (ASHRAE) 55, the following are the study's primary accomplishments.

- According to the simulation results, the proposed treatments contributed to improved thermal performance and increased internal thermal comfort hours throughout the year about 20%. Also, the comfort hours increased from 3,226 H for the basic case to 4,918 H for the treated cases per year. Also, the value of the thermal resistance of the roof that achieves the best thermal performance of the building is compatible with that reported in the Egyptian code.
- The study revealed that the effective thickness of thermal insulation of the extruded polystyrene material is 8cm for roof insulation.
- Furthermore, it is better to increase the total thermal resistance value of the eastern and western walls in the desert climate to R_{vt} = 2.0 (m^2. k/W)
- Additionally, the double wall with 5cm of thick thermal insulation represents the optimal condition of the eastern and western walls of the residential building in the desert climate.
- The study proved the importance of natural ventilation within the period from sunset to sunrise during the summer, especially at night hours, and its positive effect on reducing the internal temperatures of the building spaces.
- Finally, improving the thermal performance of the building's envelope could contribute to saving up to 55% of energy consumption for cooling throughout the year.

8. Recommendations.

Some cities with special climatic characteristics such as Farafra Oasis largely require architects and designers more serious attention to climatic conditions and the surrounding environment, to reach the ideal positive design of the building envelope through the best selection of building materials and implementation techniques for achieving the thermal comfort of the residents and thus attaining the indoor environmental quality.

Natural ventilation can effectively relieve heat discomfort by reducing indoor temperatures through opening windows during the period from sunset to the beginning of sunrise, which is a simple and low-cost treatment to improve indoor thermal conditions.

Thermal insulation should be widely used for the outer envelope elements of residential buildings to improve the internal thermal environment. Therefore, more attention must be paid to developing the characteristics of thermal insulation materials in order to increase the efficiency of thermal insulation and achieve better internal thermal quality and comfort.

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