

Retrofitting Rural Dwellings in Delta Region to Enhance Climate Change Mitigation in Egypt

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Abstract – The current rural dwelling pattern in the Delta in Egypt consumes much energy to achieve dwellers' thermal comfort, increasing greenhouse gas emissions contributing to climate change threatening the region's coastal parts. Therefore, this study highlights the potential of retrofitting the existing rural house utilizing pervasive construction technologies in diminishing energy consumption and carbon dioxide emissions as a climate change mitigation strategy. The current modern rural house and the construction typologies were characterized. This study selected a typical modern rural dwelling located in Al-Gharbia Governorate in the Delta region. The suggested retrofitting strategies were applied to the external building envelope. The impact on the annual energy consumption of cooling and heating loads was evaluated using an Energy Performance Assessment Tool (*Design Builder*). An optimal envelope configuration was suggested, then an economic assessment and an investigation to the local acceptance were provided. The results showed that using the commonly used construction techniques as a retrofitting strategy can plummet the energy consumption and CO₂ emissions by one-third worthy of mentioning that the locals have shown a lack of interest in the investment in retrofitting their buildings as well as the economic model showed that the investment is not profitable. Further studies can be made by the author considering investigating different building typologies and engaging other stakeholders.

Keywords – Economic analysis; energy efficiency; energy simulation tools; modern rural house; passive envelope; social acceptance

1. INTRODUCTION

The rural Egyptian village is being reformed due to socio-economic and political aspects, which produced modern rural dwelling pattern with new walls and roofing configuration layers instead of the traditional ones [1]–[5]. These new-fangled building envelopes play a vital role in transferring the thermal load to/from inner spaces, which led to high annual energy consumption due to using cooling and heating systems such as fans and air conditioners to fulfil thermal comfort inside indoor spaces. Consequently, it increases greenhouse gas emissions contributing to climate change.

Globally, climate change has many indirect negative impacts at many levels, such as migration waves, crop productivity reduction, water sensitivity, increases in malnutrition and unemployment rates, and such ecological systems [6]–[10]. In Egypt, it is threatening the Delta region because its coastal areas are the most vulnerable in the world due to sea-level rise [11], and its area of land is declining rapidly [12]. However, Egypt contributes less than

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0.7 % of the total global carbon dioxide (CO₂) emissions [13]. It is the uppermost density region and the only agricultural region in Egypt.

Regarding the existing physical planning regions, Egypt has seven regional units, and each one consists of three levels, Governorates, District, and Villages and Satellites.

The Delta one of these regions that consist of five governorates, 106 districts and cities, and 1404 villages [14], with a total area of 12357.4 km² (2.94) million ‘feddans†’ representing about 1.22 % of the total area of Egypt. It has about 16.5 million inhabitants consists of (66 % rural and 34 % urban), representing 21 % of Egypt's total population. The total number of residential buildings is about 3.17 million buildings, represent 94 % of entire buildings. The average annual electricity consumption per inhabitant in Egypt is 2020 kWh [15]. Table 1 shows residential buildings by type and by (urban/rural) of the Delta region.

TABLE 1. BUILDINGS DISTRIBUTION BY (TYPE) & (RURAL/URBAN) IN DELTA REGION [16]

	Total Buildings	Residential buildings by type				
		House/ Apartment	Skyrise	Villa	Chalet	Country House
Rural	2 488 366	1 808 810	0	3924	860	212 085
Urban	678 756	1 017 226	250	4241	4374	15 279

Generally, energy consumption goes hand in hand with CO₂ emissions in a positive correlation [17] and [18], as well as energy consumption contains a nearly similar part of CO₂ emissions [19]. Reference [20] defined mitigation as ‘a human intervention to reduce the sources or enhance the sinks of greenhouse gases.’ In this realm, the buildings sector has an essential role in mitigating climate change impact [21]. In this context, passive improvements of the building envelope are considered essential strategies to enhance energy efficiency and thermal comfort [22] and [23].

Locally, Egypt pays considerable attention to the energy efficiency issue; for instance, it is one of the prime strategic goals of the 2030 National Sustainable Development Vision [24]. The Egyptian Residential Buildings' Energy Codes (ERBEC) has been established in 2006, which provides the minimum requirements to improve energy efficiency in existing and new residential buildings for different climatic zones in Egypt [25]. The local rating system Green Pyramid Rating System (GPRS) was launched to assess buildings' sustainability, as well as improving the building envelope is one of its seven parts [26].

Based on these facts and potentials, this study proposes an optimal external envelope design using the pervasive construction materials and technologies as guidelines to reduce energy consumption and to mitigate climate change in the existing rural houses in Delta region.

References [1] and [2] determined the prevailing housing typology in the Delta region. It has been built during the last four decades, surrounded by agricultural areas or urban mass. The range of footprint area is between 80 and 160 m²; the average floor height is 2.90 meters. It consists of two or three floors; it consists of a hall, three rooms, a bathroom, a kitchen, a staircase, a terrace, and, sometimes, a farmyard. Furthermore, the average room area is 14.00 m². In terms of construction, the roof is constructed of reinforced concrete slab, while the walls are constructed of red brick 12 and 25 cm, elevation finished by cement plaster. The average window to wall ratio (WWR) is 11 %. Windows are made of single clear glass 3 mm with a wooden frame and shading screen.

† Feddan is unit of area used in Egypt, it equals 4200 m².

2. METHODOLOGY

The methodology is divided into four phases. Firstly, a set of simulation runs was conducted for different passive configurations of the wall, roof, and windows using the available construction materials to investigate their impact on the annual cooling and heating energy consumption and CO₂ emissions. Secondly, an economic assessment for the different design variables was carried out. Then a comparison between the cost of refurbishment and the reduction in the consumption for all scenarios. Three retrofitting strategies (minor, optimum, and significant) were suggested based on the previous steps. A profitability analysis follows this. Moreover, a structured questionnaire was distributed among the dwellers to examine their awareness and acceptance of the refurbishing process. Finally, Multi-objective criteria were identified.

3. ORIGINAL CASE PARAMETERS

A west-oriented room in a typical rural dwelling pattern located in Nawag Village, Gharbiya Governorates, was selected. Room dimensions are 3.40×4.30 m. The interior room height is 2.90 m.

The external wall area is 11.20 m that consists of (2 cm plaster, 12 cm red brick and 2 cm plaster). The external roof area is 14.60 m that consists of a reinforced concrete slab of 15 cm thickness and 2 cm plaster from outside to inside. While the window makes up a single clear 3 mm glass with a wooden frame and a traditional wooden shading screen 'Sheesh' and the WWR is 11 %. The building relies on the air conditioning (split unit) for summer cooling. Fig. 1 depicts the traditional 'Sheesh' during manufacturing.

4. SIMULATION MODEL ALGORITHMS

The above-mentioned parameters were examined using the validated simulation tool, Design Builder version 4.5, as seen in Fig. 2, these tools also significantly optimize energy consumption in the design stage [27] and [28]. A climatic weather file data of Delta was selected. The artificial lighting and the electrical appliances were neglected. The occupancy density is 0.17 people/m². The setpoint and the setback degrees of cooling and heating are 25° and 28° C, and 21° and 12° C. The study assumed that air conditioning was used for winter heating. The inner partitions and floor are considered adiabatic surfaces. The simulation model is available on reference [29].



Fig. 1. The Traditional 'Sheesh'.

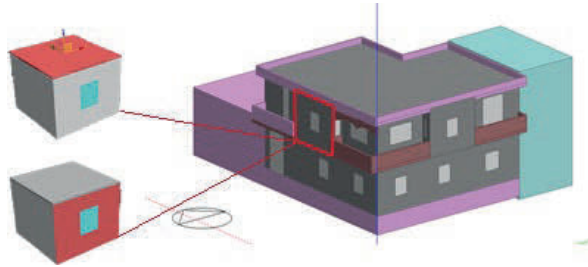


Fig. 2. The Simulation Model Extracted Room Design Builder.

A set of passive retrofitting variables were proposed and applied on:

- opaque parts: based on different thermal properties R -value of construction materials and used insulation;
- transparent parts: based on different thermal properties and solar heat gain coefficient SHGC of glazing types. Table 2 summarizes the suggested design variables.

TABLE 2. THE PROPOSED DESIGN VARIABLES

Design Variables	Description
Wall types	Redbrick (12×25×38 cm) thickness, and a mud-brick wall 40 cm thickness
Wall insulation	Insulated cored red brick 25 cm and (EPS), thickness from 1–10 cm
Window Glazing type	Single Clear Glass (3 mm, and 6mm), and double Clear Glass 6 mm with 13 mm Air
WWR	10 %, 20 % and 30 %
Shading Screen	Shading screen (SC) used, and without (SC)
Roof type	Reinforced concrete (RC) slab 15 cm thickness, and RC slab with cement tiles 5 cm thick
Roof insulation	RC slab and cement tiles 5 cm with various foam insulation thicknesses from 1–10 cm

4.1. External Wall Types' Influence

Firstly, four simulation runs were carried out, one for the base case (red brick 12 cm). The other three retrofitting alternatives are 25 cm red brick, 38 cm red brick, and 40 cm mud brick, considering that the roof is an adiabatic surface. Simultaneously, the window consists of a single clear glass 3 mm, wooden frame and shading screen with WWR 10 % with a U -Value of 5.894 W/m²K. Table 3 shows the U -Value of different wall section types extracted from Design Builder.

TABLE 3. THE U -VALUE OF THE DIFFERENT WALL CONSTRUCTION TYPES IN W/M²K

Wall Construction layers from outer to inner	U -Value
0.02 m cement plaster + 0.12 m red brick + 0.02 m cement plaster (Base Case)	2.545
0.02 m cement plaster + 0.25 m red brick + 0.02 m cement plaster	1.826
0.02 m cement plaster + 0.38 m red brick + 0.02 m cement plaster	1.424
Mud-brick wall 40 cm	0.665

The base case results have recorded 319 kWh of energy consumption and 193 CO₂ emissions. While altering the wall type to red brick (25 cm and 38 cm) decreased the energy consumption and the emissions by 16 % and 27 %, respectively, compared to the base case, utilizing a mud-brick wall reduced the consumption and emissions significantly by 44 %.

Fig. 3 illustrates the simulation results of the annual electricity consumption and CO₂ emissions of different wall types due to cooling and heating loads.

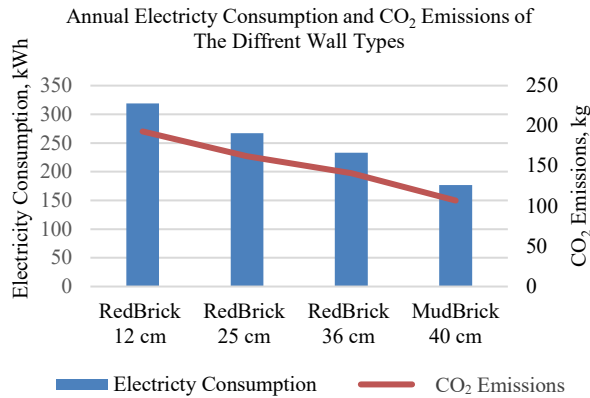


Fig. 3. Annual Electricity Consumption and CO₂ Emissions for Wall Section Pre and Post Retrofitting.

4.2. Walls' Insulation Thicknesses Influence

Secondly, to evaluate the impact of the different insulation thicknesses as retrofitting solutions, different wall section types on the annual electricity and CO₂ emissions of cooling and heating loads. A set of ten simulation runs took place. The cases consist of a cored red brick wall of 25 cm with a variable EPS insulation 1 to 10 cm. The roof is an adiabatic surface, while the window consists of a single clear glass 3 mm, wooden frame, and shading screen with WWR 10 % with a *U*-Value of 5.894 W/m²K for wall section before and after retrofitting. Table 4 shows the *U*-Value of the interventions.

TABLE 4. THE *U*-VALUE OF THE DIFFERENT WALL INSULATION THICKNESSES IN W/M²K)

Base case	EPS insulation thickness (added to cored red brick wall 25 cm)									
	1 cm	2 cm	3 cm	4 cm	5 cm	6 cm	7 cm	8 cm	9 cm	10 cm
2.545	1.273	0.966	0.778	0.651	0.560	0.491	0.437	0.394	0.359	0.329

The results showed that adding a layer of 1 cm EPS to the cored 25-cm red brick reduced one-third of consumption and emissions compared to the base case, by adding layers of 2, 3, and 4 cm EPS decreased more 12 %, 9 %, and 7 % respectively. While adding (5 and 6) cm of the EPS decreased another 5 % and 4 %. It is evident that with every additional 1 cm insulation, the consumption rate decreases gradually to reach almost the same results. Thus, a layer of 5 cm insulation can be considered as the optimal thickness. Fig. 4 shows the total annual energy consumption and CO₂ emissions of the wall sections pre- and post-retrofitting using different insulation thicknesses.

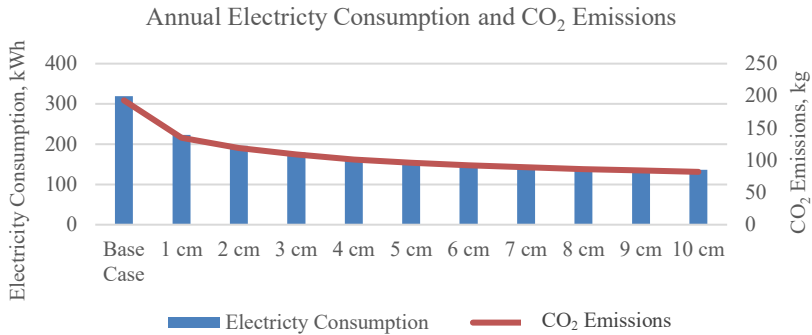


Fig. 4. Total Electricity Consumption and CO₂ Emissions Results for Wall Construction Layers Simulation Runs.

4.3. Roof Insulation Influence

Thirdly, in order to evaluate the impact of the roof on the energy consumption and CO₂ emissions. The simulation examined a set of twelve roof scenarios; the first is the base case before retrofitting, consisting of (2 cm cement plaster and 15 cm reinforcement concrete slab). In the second, two layers of 5 cm cement tiles and 5 cm mortar were added, while in the other ten solutions, layers of foam insulation with varies thicknesses from 1 cm to 10 cm. Table 5 shows the *U*-Value of all scenarios pre and post retrofitting.

TABLE 5. ROOF INSULATION THERMAL PROPERTIES (U-VALUE IN W/M²K)

EPS insulation line thickness			
Base case	0.909	5 cm	0.407
N/A	0.828	6 cm	0.369
1 cm	0.628	7 cm	0.338
2 cm	0.586	8 cm	0.312
3 cm	0.511	9 cm	0.289
4 cm	0.453	10 cm	0.270

The results showed that adding cement flooring tiles on a cement mortar to the reinforcement concrete slab reduced only 3 % compared to the base case. Moreover, adding 1, 2, and 3 cm of foam reduced more 12 %, 10 %, 9 %, respectively, while by adding 4 cm, the consumption dropped by 13 % compared to the previous values. It is evident that with every additional 1 cm insulation, the consumption rate reduces progressively to reach nearly results. Therefore, a layer of 4 cm insulation can be considered as the optimal thickness. Fig. 5 illustrates the total annual energy consumption and CO₂ emissions of the roof sections before and after retrofitting using cement flooring tiles with insulation and without.

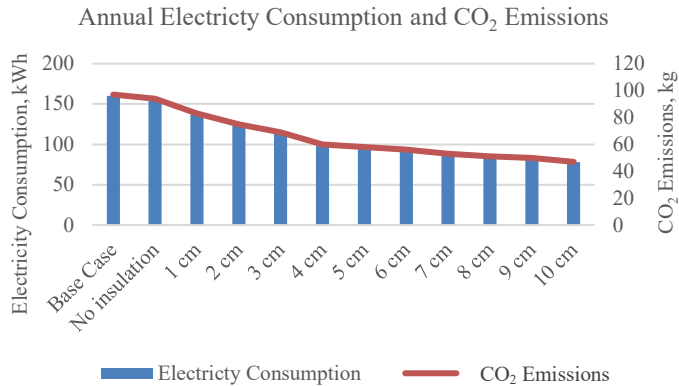


Fig. 5. Total Electricity Consumption and CO₂ emissions for Roof Construction Layers Simulation Runs.

4.4. Fenestration Influence

Three simulation runs were carried out to assess the impact of different glazing types on the annual electricity and CO₂ emissions of cooling and heating loads. The first is for the window, using a single clear glass 3 mm thickness with a wooden frame and without a shading screen; the others are single clear glass 6 mm thickness, and double clear glass 6 mm with 13 mm air in-between. Considering the roof is an adiabatic surface, WWR 10 %, and the wall section is 12 cm red brick. Table 6 shows the *U*-Value and the Solar Heat Gain coefficient (SHGC) of the different glazing types.

TABLE 6. ROOF INSULATION THERMAL PROPERTIES (U-VALUE IN W/M²K)

	3 mm Single clear glass	6 mm Single clear glass	6 mm Double clear glass / 13 mm Air
SHGC	0.861	0.819	0.703
<i>U</i> -Value	5.894	5.778	2.665

The single clear glass 3 mm achieved the highest consumption and CO₂ emissions by 393 kWh and 238 kg. By using the single clear 6 mm glass has no impact on both energy consumption and emissions. While using 6 mm double clear glass with 13 mm air, reduced energy and emissions by 14 %.

In contemplation of assessing the impact of different WWR 10 %, 20 %, and 30 %, one using a local shading screen ‘sheesh’ and the other without shading screen on the annual electricity consumption CO₂ emissions. A set of six simulation runs were implemented. Considering the roof is an adiabatic surface, the wall section is 12 cm red brick, and the glazing type is 3 mm single clear glass.

To assess WWR 10 %'s impact on the electricity consumption and CO₂ emissions, the base case with shading screen recorded 393 kWh and 238 kg. While adding the shading screen decreased 19 % of the energy consumption and the CO₂ emissions.

By altering WWR to 20 %, the energy consumption and CO₂ emissions recorded 522 kWh and 316 kg, respectively, with an increase of 25 % in energy consumption and CO₂ emissions than the same circumstances of WWR 10 %. Meanwhile, by adding a shading screen to WWR 20 %, the energy consumption and CO₂ emissions dropped by 34 %.

Eventually, by changing WWR to 30 %, the energy consumption and CO₂ emissions recorded the highest results by 661 kWh and 401 kg, respectively, with an increase of 41 %

in energy consumption and CO₂ emissions in the same circumstances of the WWR 10 %. While adding shading screen to WWR 30 % reduced the energy consumption and CO₂ emissions by 44 %. Fig. 6 summarizes the results of the six simulation runs of different WWR and shading screen strategies.

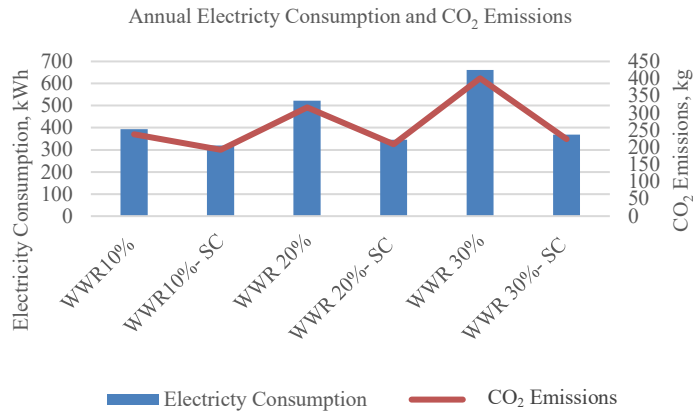


Fig. 6. Total Electricity Consumption and CO₂ emissions for the Different WWR and Shading Screens Scenarios.

4.5. Discussion of Simulation Results

A group of design variables for building envelope was investigated separately. In order to optimize the building envelope, a suggested retrofitting solution is recommended that can decrease the annual energy consumption and CO₂ emissions efficiently.

Firstly, for the wall section, altering the original wall to 25 cm red brick reduced annual CO₂ emissions and energy consumption by 16 %; it is considered a minor renovation. While adding an insulation layer of the EPS 5 cm to the cored wall decreased the consumption by one-half. The higher insulation values decreased energy almost likely; thus, it is considered the optimum thickness. Finally, the maximum reduction was achieved (136 kWh) using a layer of EPS 10, which beheld the major renovation.

Likewise, adding cement flooring tiles and mortar to the original roof configurations reduced the energy by 4 % for the roof. Withal adding a layer of 5 cm foam thickness lessened the consumption by 38 %, the higher insulation values almost likely decreased, so it beheld the optimal strategy[‡]. In contrast, the uppermost reduction attained by utilizing 10 cm foam by 78 kWh, which is considered the major one.

Finally, the original window configuration (3 mm single clear glass, WWR 10 %, and Shading Screen) recorded the lowest energy consumption results, so it is considered the optimal configuration in all scenarios.

In the final analysis, four simulation runs were conducted, one for the base case's entire envelope and the others for the recommended (minor, optimal, and significant) refurbishment scenarios. The base case results recorded 442 kWh energy consumption and 268 kg CO₂. Table 7. summarizes the energy and CO₂ consumptions of the proposed bare and optimum wall and roof layers configurations.

[‡] Another factor supports applying 5 cm thickness of the insulation materials to the wall and the roof. The majority of the local suppliers provide it as a typical insulation solution, regardless of the essential needs and technical studies.

TABLE 7. ENERGY CONSUMPTION AND CO₂ EMISSIONS PRE AND POST ENVELOPE RETROFITTING

Different Design Variables of the Envelope			Different Retrofitting Scenarios Consumption		Saving compared to the Base Case	
Wall	Window	Roof	Energy	CO ₂	Energy	CO ₂
Base Case						
Red brick 12 cm	3 mm Sgl Clr + SC+WWR10 %	RC + Cement Tiles	442 kWh	268 kg	N/A	N/A
Scenario 1						
Red brick 25 cm	3 mm Sgl Clr + SC+WWR10 %	RC + Cement Tiles	318 kWh	192 kg	28 %	28 %
Scenario 2						
Cored red brick 25 cm + EPS 5 cm	3 mm Sgl Clr + SC+WWR10 %	RC+ Cement Tiles + 5 cm Foam	206 kWh	125 kg	34 %	34 %
Scenario 3						
Cored red brick 25 cm + EPS 10 cm	3 mm Sgl Clr + SC+WWR10 %	RC+ Cement Tiles + 10 cm Foam	170 kWh	103 kg	40 %	40 %

5. ECONOMIC ASSESSMENT

Regarding the local market and reference [30], the conventional envelope's supply-and-apply price for the wall and roof was identified. Firstly, for the wall, the cost of red bricks ($0.25 \times 0.12 \times 0.06$ m), the 1000 red brick costs about 2000 Egyptian Pounds (EGP), the 1000 brick gives 17 m². Thus, the meter square costs about 120 EGP and 90 EGP for two layers of 2cm cement plaster thicknesses, so the meter square costs around 210 EGP.

While estimating the cost of retrofitting solution of 5 cm EPS insulation layer; the meter cubic costs around 1550 EGP, which gives twenty slices of 5cm-thick sheets, so the meter square costs 75 EGP. To conclude, the entire retrofitted wall consists of a cored wall with 5 cm EPS in-between costs about 495 EGP. The differentiation between the cost of the wall before and after retrofitting is 285 EGP.

Secondly, the cost of 1 m² wooden window thickness 2.54 cm (1 inch) is 1750 EGP as seen in Fig. 1, the price includes glass, accessories, and the painting.

Thirdly, the cubic meter of reinforcement concrete (RC) slab costs about 3500 EGP. The slab thickness equals 0.15 m, and the entire roof's room area is 14.6 m², which equals 2.2 m³ of a reinforced concrete slab. To estimate the price of the retrofitted roof, adding 5 cm concrete tiles on a 5 cm mortar costs 100 EGP, in addition to 85 EGP for 5 cm foam; thus, the differentiation between the original roof and the retrofitted solution is 185 EGP.

Fourthly, the cost of electricity consumption reduction based on the electricity price was determined. The tariff of 1 kWh in Egypt varies from 0.38 to 1.40 EGP based on the seven consumption segments, for instance, the cost of the kWh costs 0.48 EGP in the third segment, which ranges between 0 and 200 kWh monthly. The base case's real monthly consumption is collected from the owner's electricity bills, and it is between 201 and 350 kWh – the fourth segment. Table 8 summarises the cost of the suggested retrofitting variables.

Table 8 shows the price of annual savings due to different retrofitting scenarios. The cost variation between retrofitting scenarios (1, 2, and 3) and the base case are 1320, 2157, and 3094 EGP, respectively, which is considered the cash of investment. In parallel, the cost of the annual saving in energy for these scenarios compared to the base case's consumption are 124, 236, and 272 kWh, as seen in Table 9, which costs 122, 231, and 267 EGP, considering the consumption segment Tarif 0.98 EGP.

TABLE 8. THE SUPPLY-AND-APPLY PRICE OF THE ENVELOPE BEFORE AND AFTER RETROFITTING

Item	Unit	Quantity	Unit Price, EGP	Total, EGP
Base Case				
12 cm red brick wall	m ²	10	210	2100
RC Slab + 2 cm cement plaster	m ³	2.2	3500	7700
Windows Sgl Clr 3 mm + SC (WWR 10 %)	m ²	1.20	1700	2040
TOTAL				11 840
Scenario 1				
25 cm red brick Wall + EPS 5 cm	m ²	10	320	3200
Roof + Tiles	m ³	2.2	3600	7920
Windows Sgl Clr 3 mm + SC (WWR 10 %)	m ²	1.20	1700	2040
TOTAL				13 160
Scenario 2				
Wall+ EPS 5 cm	m ²	10	385	3850
Roof + Cement Tiles+ Foam 5 cm	m ³	2.2	3685	8107
Windows Sgl Clr 3 mm + SC (WWR 10 %)	m ²	1.20	1700	2040
TOTAL				13 997
Scenario 3				
25 cm red brick Wall + EPS 10 cm	m ²	10	460	4600
Roof + Tiles+ Foam 10 cm	m ³	2.2	3770	8294
Windows Sgl Clr 3 mm + SC (WWR 10 %)	m ²	1.20	1700	2040
TOTAL				14 934

Many studies discussed the financial and economic analysis to provide a multicriteria optimization of the retrofitting process using different techniques and approaches, such as [31]–[35]. Net Present Value (NPV) model is one of 25 commonly used models in building energy evaluation [36].

NPV is the present value of anticipated cash inflows associated with the project less the present value of the project's expected cash outflows, discounted at the appropriate cost of capital, it is used to assess such a project's profitability[§], represented by Eq. (1) [37].

$$\sum_{t=0}^N \frac{CF_t}{(1+r)^t}, \quad (1)$$

where:

- CF_t the expected net cash flow at time t represents the investment amount in retrofitting the envelope (annual saving due retrofitting);
- N the estimated life of the investment;
- r the discount rate (opportunity cost of capital). In this study r equals the annual interest rate of 0.825 % regarding the Central Bank of Egypt [38].

If the results give a negative value, it means the project is not profitable and vice versa; positive values mean it is profitable in a particular year. Table 9 summarises the equation parameters.

[§] For example, the value of 1000 EGP now does not equal its value after one year due to several aspects such as inflation, risk, and interest rate.

TABLE 9. VARIATION'S COST OF RETROFITTING AND THE ANNUAL SAVING OF ELECTRICITY

Scenario	Retrofit cost's variation compared to the base case	Annual saving due to Retrofitting	Consumption Segment Tarif of the kWh	Annual saving due to Retrofitting (CF_i)	positive results' achieving year of NPV
Scenario 1	1320 EGP	124 kWh	0.98 EGP	122 EGP	The 29 th Year
Scenario 2	2157 EGP	236 kWh	0.98 EGP	231 EGP	The 19 th Year
Scenario 3	3094 EGP	272 kWh	0.98 EGP	267 EGP	The 40 th Year

By applying the equation [39] for the first scenario, the initial investment is 1320 EGP, and the cash flow is 122 EGP; the results showed the profitability would be achieved in the twenty-ninth year. In the second scenario, the initial investment is 2157 EGP, and the annual cash flow is 231 EGP; the profitability would be achieved in the nineteenth year. Then, at the initial cost of 3094 EGP and cash flow, 267 EGP achieved profitability in the fortieth year.

6. DWELLERS INVOLVEMENT

In a similar context, the architect Hassan Fathy in his role model of Al Gournia Village development in the 1960s, emphasized the importance of engaging locals in retrofitting and development processes because the inhabitants did not accept these strategies [40]. Many studies discussed the social acceptance for different related-energy retrofitting technical solutions in many contexts to measure inhabitants satisfaction [41]–[44] or clients expectations [45].

To investigate the acceptance of the proposed retrofitting strategies, Lasaifar Al-Balad village in Kafr El-Shiekh Governorate was selected for many reasons. It represented a typical village pattern out of 1404 villages in the Delta region. It has the same dwellings typology, and, finally, the author examines other factors within his Ph.D. thesis.

A sample of 31 inhabitants** represented 31 families was selected. Personal meetings with four of them were implemented as a pilot test stage to adapt and ensure the clearness of the questions. A structured questionnaire (Google Form) [46] was distributed to two private groups of the village on Facebook. The investigation was implemented in the third week of January 2021.

The questionnaire was divided into two groups. Firstly, the close-ended, to identify the sample dwellers characteristics and dwellings typology. Secondly, a mix of closed-ended and the open-ended part to assess their awareness about the climate change issue, examine the liaison between houses and thermal comfort in summer and winter, inspect their acceptance of retrofitting process in terms of the technical and economic perspectives, eventually, an optional question to examine their point of view.

The results of detecting the sample can be seen in Fig. 7, where the pie charts tell us that most dwellings are located on the urban mass. The three-story buildings have prevailed by 43%, followed by the two-floor and more than three-floor by 29 % and 18 %, and 10 % has one floor. 57 % of the buildings are for one extended family. Their units are distributed on the ground, in-between, and the last floor equally. Most of them with an average area between 70 and 150 m², while 22 % have a range between 200 and 250 m². The bulk is relying on cooling devices in summer; namely, fans and air conditioning by 90 % and 10 % correspondingly, on the contrary, 76 % do not utilize such device for winter heating while 24 % are using heaters and only 6 % use air conditioning for heating.

** Regarding the official census 2006 the number of inhabitants is 8589.

The graphs in Fig. 8 tell us that respondents preponderance lacked awareness of climate change issues by 71 % bar a few linked it is to the agriculture waste and the garbage. In comparison, 29 % identified climate change. In terms of thermal comfort, one-third feel comfort in their dwellings, 15 % responded moderately, and one-half expressed a lack of comfort in summer and winter. It is worth mention that 6 % recognized the relationship between the unit's position and thermal comfort, namely moderate on the ground floor and scorching and cold on the last floor in terms of the exposed roof to climatic conditions.

In connection with technical retrofitting acceptance, the minority responded by the probability, while 87 % agreed. The acceptance dropped to 48 % in the economic realm, while one-third declined to invest in retrofitting, and 22 % responded 'Maybe.' In the optional question, two of those who answered 'Maybe' highlighted the private sector's importance in funding this kind of project. Then, they can pay long-term monthly installments instead of the initial cost. Only one respondent proposed 'what needed is unifying is elevation's colours integrated with the photovoltaic cells and to cover the open sewage canals to reduce their negative impacts'.

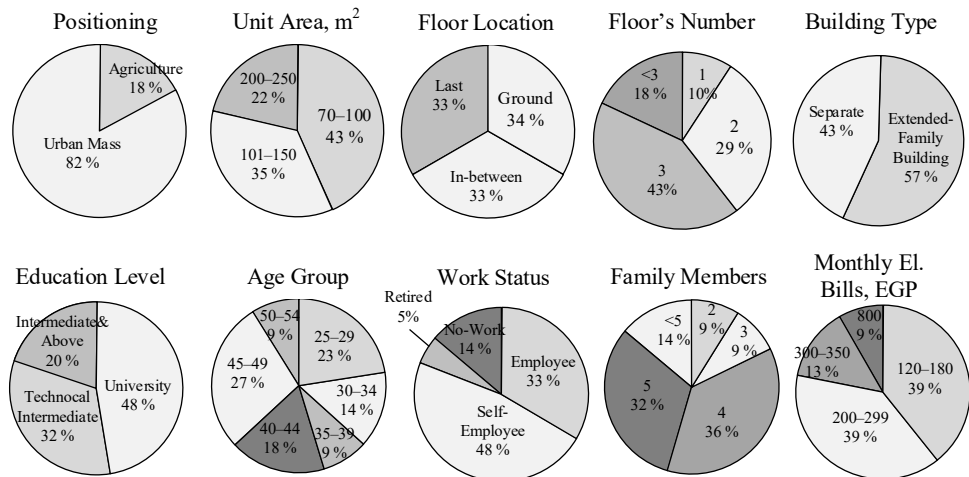


Fig. 7. The results of respondents' characteristics and their dwellings' patterns.

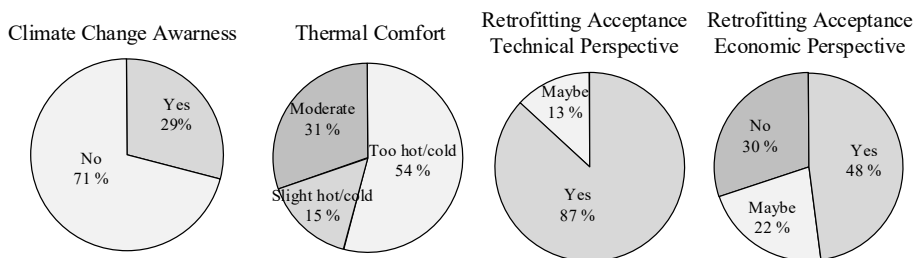


Fig. 8. The results of the open-ended questions.

7. CONCLUSIONS

This study investigated the impact of using available construction materials in the building envelope on the annual operating energy consumption and CO₂ emissions of an existing typical dwelling typology in the Delta region. A set of passive retrofitting strategies were conducted on a west-oriented room in a typical modern dwelling in the Delta Region using an energy performance assessment tool, Design Builder.

Three suggested retrofitting strategies were provided and evaluated from technical and price perspectives. The results have been proven that altering the envelope to another configuration without insulation, namely (25 cm red brick and adding cement flooring tiles) lessened energy consumption and CO₂ emissions by 28 %. While adding 5 cm of insulation in the roof and wall reduced 34 %, eventually doubling the insulation layer decreased the highest amount by 40 %.

The existing window configuration recorded the lowest energy consumption; moreover, the 'Sheesh' is considered an energy-efficient solution because consumption's variation between the WWR 10–20 % and 20–30 % is neglectable. That sheds light on conventional materials' role in increasing energy efficiency notably.

Regarding the economic analysis, the NPV model proved the investment in the three refurbishment strategies is unprofitable; however, the second scenario achieved profitability in the shortest period by 19 years, followed by the first and third scenarios: 29 and 40 years, respectively. Thus, the second scenario can be considered the most efficient one. What highlighted the importance of considering is the beyond-technical solutions.

Regarding the on-site investigation, a group of population samples with a different characteristics responded to an online questionnaire. One-third showed a significant awareness level towards climate change. The results supported the study's argument that existing dwellings patterns in the Delta region do not meet thermal comfort requirements. The majority agreed to refurbish their buildings from a technical standpoint, vice-versa from the economic perspective, which reflected a potential of locals' acceptance to such development in the Delta region.

Another prospective benefit would be considered based on the low amount of consumed energy 200–350 kWh monthly, compared to the urban context, namely, harvesting renewable energy that would drastically reduce energy consumption and CO₂ emissions.

To conclude, the study provided multi-objective optimization criteria, from technical, financial, and social perspectives based on utilizing pervasive construction materials in the local market that can provide retrofitting guidelines to existing buildings to mitigate climate change. The author believes that further optimizing studies to widen the subject would be beneficial to examine different rural building typologies, including early design stages and new construction, and involve decision-makers.

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