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Evaluation of a retrofitted heritage building in downtown Cairo as a best-practice example

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Abstract. Energy retrofitting standards and guidelines, together with benefitting from best existing experiences, are effective in retrofitting heritage buildings towards low-carbon emissions. In Downtown Cairo, many heritage buildings are exposed to adaptive reuse practices, after moving to the 'New Administrative Capital'. Integrating energy saving in said practices has become a crucial aspect. Therefore, the aim of this study is to evaluate a recent retrofitted heritage building called 'La Viennoise' as an example of best practice for retrofitting processes in Downtown Cairo. The study carried out a field survey for data gathering. A monitoring-based simulation model was created and calibrated, and the building envelope and energy use were evaluated. The simulation results are presented into two cases. The first includes the original state as a base case, showing a very low building envelope thermal performance. The second includes the current state as an improved case. A comparison of both cases shows that the implemented retrofitting scenarios in the case study effectively improved its building envelope and reduced annual energy consumption, and CO_2 emissions. This paper allows further benefit from such example by setting a retrofitting guideline to expand this concept in other buildings with similar conditions to achieve a low carbon-built heritage.
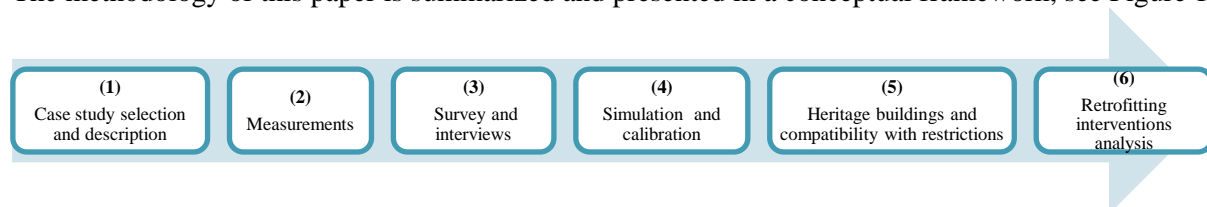
1. Introduction

The urgent need to implement retrofitting strategies on existing buildings by 2030 is one of the aspects that the Paris Agreement asserts in order to bring down global CO_2 global emissions, as it has great potential towards low carbon-emissions [1]. Moreover, built heritage constitutes a large portion of existing buildings in different countries [2]. Thus, in last decade, the number of retrofitted heritage buildings and scientific publications of addressing them have increased, more specifically in Italy [3]. Additionally, several initiatives have recently been introduced. Research projects such as Energy Efficiency for EU Historic Districts' Sustainability (EFFESUS), and standards such as the European Standard, EN 16883:2017 have also flourished [4, 5]. Moreover, environmental certification protocols such as the Green Building Council of Italy has developed a new tool called "GBC Historic Building®" [6]. Furthermore, ASHRAE Guideline 34 has been published in 2019, providing advice on processes and practices of energy retrofitting in historic buildings [7]. However, in 2019 Herrera-Avellanosa et al. highlighted the fact that "despite the number of resources and efforts spent on standardisation in recent

years within the cultural heritage field, little attention has been paid to how those standards are actually used in practice". For that reason, in 2017, a recent collaborative research project called IEA-SHC Task 59 was initiated by the International Energy Agency (IEA) and the Solar Heating and Cooling programme (SHC). The task of this project is to share knowledge, current research, and updated results across involved partners (about 25 organisations from different countries) in order to aid decision makers of retrofitting-built heritage to reach their goal of "Renovating Historic Buildings towards Zero Energy". Task 59 has used two tools: "dissemination of best-practice and process-oriented guidelines", which are not new within the field of low-carbon construction, but can be used as a new approach of retrofitting built heritage [7]. Femenías (2004) defined 'best-practice' to be "the best that can be achieved with present technology and methods" while the 'basic' practice was defined as "business as usual" [8]. The concept of 'best practice' recognizes potentiality of development within contemporary building practices in terms of quality, as opposed to basic practices which are seen to waste such quality. Therefore, the review of the literature, guidelines, together with learning from best practises can all be effective in retrofitting heritage buildings, more specifically in hot climates. Despite the intensive initiatives in this field, little attention has been paid to retrofitting heritage buildings and related scientific publications in the Middle east and North Africa (as hot climates) [3]. Moreover, climate is an important factor in these territories. For instance, according to Köppen climate classification system, Cairo's climate is classified as Group (B), which is known as an extremely hot and dry zone [9]. The change of climate conditions in Cairo in the past 30 years has led to depending mainly on electricity as a source of ventilation and cooling systems [10]. Besides, the considerable share of existing heritage buildings in Cairo, for example, is 13.5% (2000 buildings) built before 1940, and 32% (640 buildings) listed as heritage properties by the National Organization of Urban Harmony (NOUH) [11]. Moreover, in Downtown Cairo - well known as Khedivial Cairo - more than 200 listed heritage buildings are exposed to adaptive reuse strategies for conservation purposes after moving most government buildings to the 'New Administrative Capital' [12]. Therefore, there is a need to integrate energy improvement during those reuse projects, through developing retrofitting methodologies together with learning from best practices. For instance, A building called 'La Viennoise', owned by Al Ismaelia For Real Estate Investment S.A.E, is the first building to be recently retrofitted and reopened in 2018 [13]. Therefore, this study aims at evaluating 'La Viennoise' building in terms of building envelope performance, energy use and CO_2 emissions, and includes the analysis of the implemented retrofitting procedures and scenarios. The added value of this work is not only to investigate retrofitting scenarios in a listed heritage building Downtown Cairo, but also to contribute to setting a database of retrofitting scenarios of built heritage in hot climates. This database can support building professionals and policy makers to retrofit heritage buildings in similar climates.

2. Methods
The methodology of this paper is summarized and presented in a conceptual framework, see Figure 1.

| (1) Case study selection and description | (2) Measurements | (3) Survey and interviews | (4) Simulation and calibration | (5) Heritage buildings and compatibility with restrictions | (6) Retrofitting interventions analysis |

Figure 1. Conceptual framework of this study

2.1. Case study selection and description
Four criteria were used to select the building as a best-practice example: 1) a real retrofitted building, 2) the entire building was retrofitted, 3) the implemented retrofitting scenarios have met heritage value requirements, and 4) significant energy saving was achieved. These criteria were inspired by the work of Herrera-Avellanosa et al. [7]. Accordingly, 'La Viennoise' building on 7 Champollion Street in Downtown Cairo was selected as a case study, see Figure 2. The building was established in 1890s with

Italian-Renaissance-style. It is identified as a free-standing, forty-five-degree angle-shaped, and three-story building with load bearing walls construction system. It was originally built as an apartment house, then in 1928 was turned into a hotel [14]. Afterwards, it was subjected to much negligence for a few decades, until owned by Al Ismaelia Company to upgrade and re-use it with a new function.

(a)   (b)   (c)   (d)

Figure 2. (a) Main façade before interventions, (b) main façade after interventions, (c) staircase before interventions, (d) staircase after interventions (first author's Ph.D. research)

2.2. Survey and interviews
A field survey was conducted in the summer season of (2020), using a semi-structured interview with occupants and involved stakeholders to gather required data for the building simulation and modelling, such as drawings, details of building materials, and schedules (occupancy, lighting, and Domestic Hot Water (DHW)) before and after interventions. Besides, information about clothing and metabolism values was observed during field survey. In deciding on the functionality of the base case, we assumed the base case to be an office building to make results comparable. Table 1 shows the input data used for the building simulation and modelling.

2.3. Measurements
The indoor air temperature was monitored in the building security agents/officers room on the ground floor with a different occupancy schedule. The selection of location and duration of the measurements was left up to the involved employees due to security/timing restraints. Therefore, the measurements were done in the room used for calibration purposes. The indoor air temperature was monitored using a HOBO U12-012 data logger. The hourly measurement was done in summer season for two weeks, from 27th July to 7th August 2020. This method was used in some studies such as (Mahar) [15].

2.4. Building simulation and calibration
Based on the collected data, a virtual 3D model was created by using DesignBuilder software, see Fig.3. Table 1 shows the input data used for the building simulation and modelling, and Table 2 shows the thermal properties of the building elements of both the base case and the improved case.

(a)   (b)   (c)
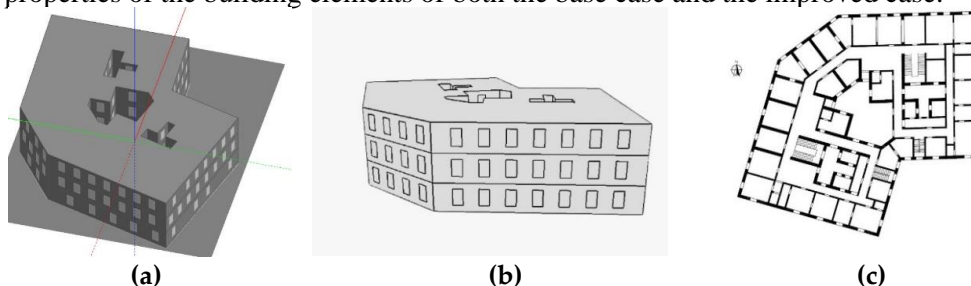
Figure 3. (a), (b) 3D perspectives of the model and (c) typical plan (first author's Ph.D. research)

We applied a manual calibration method together with statistical methods to validate the improved case (the current state) simulation model by a software program. The simulated data was calibrated by comparing with the deviation of temperature differences between the measured and the simulated ones. This comparison was done by using statistical methods such as ASHRAE Guideline 14; 1) the normalized means bias error (NMBE); 2) the coefficient of variation of root square means error (CV(RMSE)), as presented in Equations 1 and 2. Based on ASHRAE Guideline 14, the simulation model

is considered calibrated if monthly NMBE values are within±5% and monthly CV (RMSE) values are below 15%, or if hourly NMBE values are within±10% and hourly CV (RMSE) values are below 30%. In this present work, we used hourly data for calibration the simulated model. Additionally, we used a linear regression (R^2) analysis method to graphically assess the accuracy and correlation between real measurements and simulated ones. It is important to keep in mind that we applied some appropriate modifications to the model to make it closer to reality. This method is used in some studies such as (Mahar and Semahi) [15, 16]

$$NMBE = \frac{\sum_{i=1}^{Np}.(Mi-Si)}{\sum_{i=1}^{Np}.Mi} \ (\%) \qquad (1) \qquad RMSE = \frac{1}{M}\sqrt[2]{\frac{\sum_{i=1}^{Np}\ (Mi-Si)^2}{Np}} \ (\%) \qquad (2)$$

Where Np is the total number of data values, Mi represents the measured data, and Si represents the simulated data.

Table 1. Input data used for the building simulation and modelling.

	Model input measures	Base case	Improved case
Envelope	External wall (w/m². k)	U = 1.901	U = 0.296
	Roof (w/m². k)	U =5.492	U = 0.302
	Air tightness (ac/h)	5	2
	WWR (%)	15 N, 15 W, 17 E,17S	15 N, 15 W, 17 E,17 S
	Glass U-value (w/m². K)	5.894	2.629
	SHGC	0.861	0.342
	LT	0.898	0.509
	Glass type and thickness	Single clear 3 mm	Double-glazed 6mm+6 mm argon
Occupancy	No. of occupants	assumed to be 350	350
	Area of the building	1260 m2	1260 m2
	Density (people/m²)	0.27	0.27
Lighting	Installation power density (w/m²)	assumed to be 5	5
	Type	Incandescent light bulb	LED
Ventilation and air conditioning	Outside air (l/s per person)	20	20
	Temperature set point (°C)	Heating 21,Cooling 23	Heating 21, Cooling 23
	COP	0.85	2.4
	Type	Split units	Fan coil units FCU
DHW	Period 1 (October–April) (l/m²/day)	0.67	0.67
	Period 2 (May–September) (l/m²/day)	0.05	0.05
Plug loads	Average installation power density (w/m²)	20	20
Activity/ Clothing	Average metabolism level	assumed to be 1.5	1.5 office work
	Summer and Winter (clo)	Male 0.4, Female 0.6, and Male 0.8, Female 1.0	Male 0.4, Female 0.6, and Male 0.8, Female 1.0

Table 2. Thermal properties of the building elements of the base case and improved case.

No.	Building element	Outside to inside	Composition	Thickness (m)	Conductivity (W/m.k)	Specific Heat Capacity (J/kg.k)	Density (Kg/m³)
1	Exterior wall	Layer 1	Limestone hard	0.8	1.7	1000	2200
		Layer 2	Cement mortar	0.02	0.72	840	1760
		Layer 3	EPS	0.1	0.035	1400	25
		Layer 4	Cement plaster	0.02	0.72	840	1760
2	Internal wall	Layer 1	Cement plaster	0.02	0.72	840	1760
		Layer 2	limestone hard	0.25	1.7	1000	2200
		Layer 3	Cement plaster	0.02	0.72	840	1760
3	Internal floor	Layer 1	Marble white	0.04	2.77	802	2600
		Layer 2	Mortar	0.02	0.88	896	2800
		Layer 3	Sand	0.04	2	1045	1950
		Layer 4	Reinforced Concrete slab	0.15	1.9	840	2300
		Layer 5	Cement plaster	0.02	0.72	840	1760
4	Roof	Layer 1	Roofing Tiles	0.02	0.38	840	1120
		Layer 2	Mortar	0.02	0.88	896	2800
		Layer 3	Sand	0.06	2	1045	1950
		Layer 4	EXP	0.1	0.034	1400	35
		Layer 5	Bitumen	0.005	0.23	1000	1100
		Layer 6	Concrete, Cast, no fines	0.07	0.96	840	1800
		Layer 7	Reinforced Concrete slab	0.15	1.9	840	2300
		Layer 8	Cement plaster	0.02	0.72	840	1760

added layers into the improved case.

2.5. Heritage buildings and compatibility with restrictions

According to the Egyptian Conservation Law 144/2006, a heritage building listed in *'Heritage Grade B'* when it is preserved on high standards, but some flexibility is allowed for internal modifications [17, 18, 19]. Thus, the implemented retrofitting scenarios were analysed to ensure that the interventions respected the heritage values of the case study.
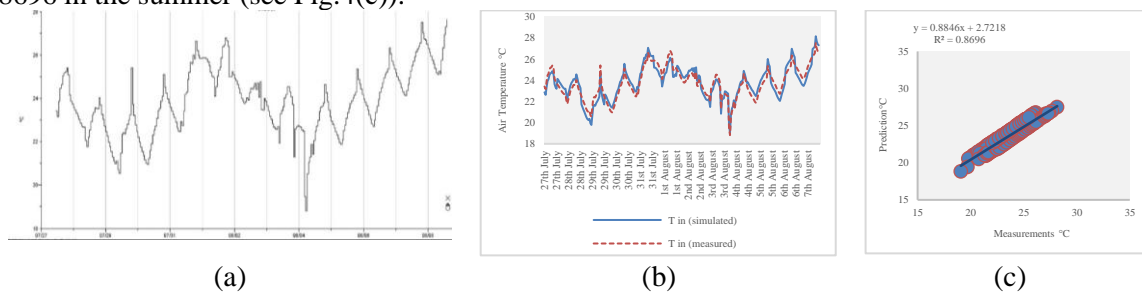
2.6. Retrofitting interventions analysis

Four types of analysis took place at this stage: 1) analyzing of the preparation phases before retrofitting interventions, 2) analyzing of the implemented retrofitting scenarios from a heritage-value perspective, 3) analyzing of the improvements achieved, and 4) analyzing of maintenance costs and obstacles.

3. Results

### 3.1. Validation of Calibration of the Simulation Model

The measured indoor air temperatures (see Fig.4(a)) were used to calibrate the simulation model for a week in the summer season (see Fig.4 (b)). Thus, the NMBE and CV(RMSE) equations were applied, considering the accepted limits as mentioned in subsection 2.4. The values of NMBE and RMSE are (0%) and (2%) respectively. The correlation coefficient ($R2$) of the prediction and measurements is 0.8696 in the summer (see Fig.4(c)).

| (a) | (b) | (c) |

Figure 4. (a) Measured hourly indoor air temperatures, (b) Comparison between the hourly simulated indoor air temperatures and the measured ones, (c) linear regression analysis of the calibration of simulation model.

3.2. Retrofitting intervention analysis

A summary of the investigation and retrofitting procedures is presented into three stages in a flow chart as shown in Fig 5. These stages are analyzed and articulated into subsections as listed below:
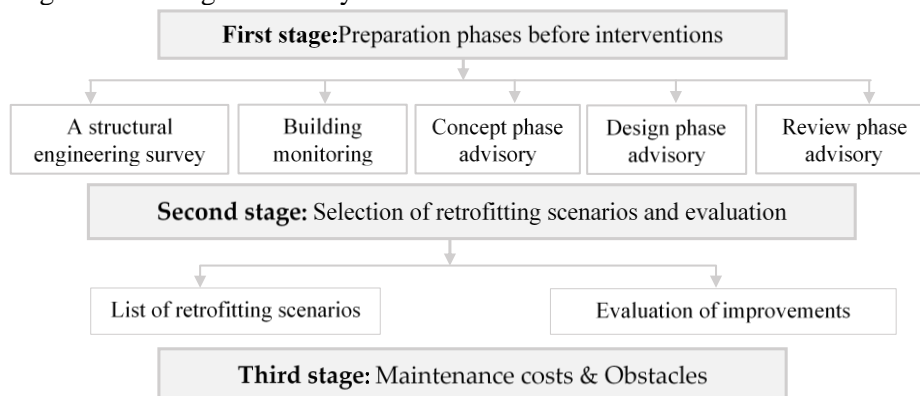
Figure 5. Flow chart of the implemented retrofitting procedures

3.2.1. Preparation phases before retrofitting interventions

A five-phase process was established before implementation of retrofitting scenarios:

1) **A structural engineering survey**: the outcome was that the building is associated with

local construction material.

2) **Building monitoring:** the outcome of this phase was a detailed report of current state with field measurements.
3) **Concept phase**: the outcome of this phase was an agreement with involved stakeholders on energy efficiency criteria and targets.
4) **Design phase:** the outcome of this phase was a set of selected technical variants, planning, and cost estimations.
5) **Review phase:** the outcome of this phase was a final decision by involved experts on concrete technical solutions and detailed planning, Moreover, this work was approved by the NOUH and the municipality as explained later.

3.2.2. List of retrofitting scenarios appropriate for heritage grade

According to the conducted interviews, the feedback was analysed and summarised in Table 3. The retrofitting interventions regarding colours and materials used were approved by the NOUH and the municipality.

Table 3. List of implemented retrofitting scenarios

	Element/location	Retrofitting scenarios
Exterior	Finishes	Preserved (maintaining original materials)
External walls	Insulation	Allowed (internal insulation and appropriate external insulation materials that respect cultural values [20])
	Decoration	Preserved (maintaining original materials)
Roof	Finishes	Changed (replacing with new materials)
	Insulation	Added (adding new materials)
	Decoration	Preserved (maintaining original materials)
	Parapet	Preserved (maintaining original materials)
Windows	Glazing, Frame and Shading	Changed (replacing with new materials)
Doors	Frame and Finishes	Changed (replacing with new materials)
Balconies	Finishes and Handrail	Preserved (maintaining original materials)
	Decoration	Preserved (maintaining original materials)
Shops	Glazing, Frame, and Signs	Changed (replacing with new materials)
Interior	Finishes	Changed (replacing with new materials)
Internal Walls	Decoration	Preserved (maintaining original materials)
	Finishes	Changed (replacing with new materials)
Ceiling	Finishes	Changed (replacing with new materials)
	Decoration	Preserved (maintaining original materials)
Windows	Glazing, Frame, and Joints	Changed (replacing with new materials)
Doors	Frame and Finishes	Changed (replacing with new materials)

3.2.3. Evaluation of achieved improvements

The summary of all achieved improvements in the improved case, compared with the base case, can be found in Table 4. Bearing in mind that the total electricity in both cases includes heating, cooling, lighting and plug loads.

3.2.4. Maintenance costs and obstacles

The results of interviews with stakeholders revealed that this building is one 22 heritage buildings owned by Al Ismaelia company. This project is funded by the European Bank for Reconstruction and Development (EBRD) with total amount 433.6 million EGP (27.4 million USD). This building costs 25 million EGP (1.6 million USD). Besides, the interviewees stated that the main obstacles that face retrofitting procedures were that the existing standards in Egypt (heritage conservation laws, and energy codes) do not include any improvements of energy performance for heritage buildings.

3.3. Interviews with occupants after operation

The field survey investigation and interviews with the building occupants revealed that the occupants are satisfied with the workspace indoor environment in terms of thermal comfort, acoustics, and integration of daylighting with artificial lighting.

Table 4. Evaluation of improvements achieved.

		Base case	Improved case	Improvements %
Building Envelope (m².k/W)	Total R value of Walls	0.5	3.4	84.4 %
	Total R value of Roof	0.2	3.2	94.4 %
	SHGC	0.9	0.3	60.3 %
Internal Gains (kwh/m²) Year	Solar Gains Exterior Windows	28.7	15.1	47.3 %
Energy (kwh/m²) Year	Interior lighting	6.5	1.0	84.9 %
	Cooling (Electricity)	37.2	12.8	65.7 %
	Exterior lighting	0.23	0.15	34.0 %
	Total Electricity	99.7	68.6	31.2 %
	Total Natural Gas	1.4	0.6	56.0 %
System load (kwh/m²) Year	Sensible Cooling	105.0	35.7	66.0 %
	Total Cooling	121.5	43.0	64.6 %
	Zone Heating	0.5	0.2	65.8 %
	Chiller Load	122.4	43.4	64.6 %
CO_2 Production (t/m²) Year	CO_2 Emissions	110.4	60.8	45.0 %

4. Discussion

In this present study, a retrofitted heritage building was selected as a best-practice example in Downtown Cairo. A field survey (observations, interviews, and site measurements) was conducted for data collection and calibration of a virtual model. The virtual model of the selected building was created using DesignBuilder. This model was simulated and calibrated by comparing the measured indoor air temperatures and simulated ones. The simulation results indicated that building envelope performance of the base case was very low, especially the exterior windows, which led to higher electricity consumption for cooling. On the other hand, the building envelope of the improved case was significantly enhanced by adding internal thermal insulation (EPS with thickness 0.1 m) for walls, thermal insulation (EXP with thickness 0.1 m), and waterproofing insulation (Bitumen with thickness 0.005 m) for the roof, as well as adding the same waterproofing insulation for the ground floor. Furthermore, the original windows were replaced by double glazed ones (6 mm + 6 m argon gas) with the following specifications: Glass U-value (w/m². k) =2.629, SHGC = 0.342, and LT =0.509. Accordingly, the above-mentioned scenarios and the rest of the building system changes have led to the following findings: **1)** The improved percentages of building envelope of roof and walls were (94.4%) and (84.4%) respectively, and the improved percentage of SHGC of the external glass windows was (60.3%). Accordingly, the internal gains through exterior windows for (kwh/m²) per year were reduced with (47.3 %). **2)** Replacing the Incandescent light bulbs with LED light together with daylighting integration have led to up to (84.9 %) of electricity annual reduction of (kwh/m²) for interior lighting. **3)** The improved percentages for (kwh/m²) per year of the sensible cooling, total cooling, zone heating, and chiller load were (66%), (64.6%), (65.8%) and (64.6%) respectively. **4)** The improved percentages for (kwh/m²) per year of total natural gas and electricity were (56%) and (31.2%) respectively. **5)** The reduction percentage of the CO_2 emissions for (t/m²) per year was (45%), taking into consideration that electricity is the main source of cooling, ventilation, heating system, lighting, and other systems, while natural gas was only used for cooking and domestic hot water [10]. It should be noted that the building envelope performance of the improved case would have further positive impact on electricity use if the occupants used night-time ventilation strategy, but in this case it is not an option because of the building function and occupancy schedule.

The results of interviews with stakeholders revealed that the implemented scenarios respected the building heritage grade, and all its decorations were preserved. Stakeholders added that the main obstacle faced was the existence of gaps in the applicability of the current energy standards in Egypt to heritage buildings, because they do not include the aspect of heritage and cultural identity, and that is why this building was renovated directly under NOUH supervision. Eventually, the study recommends that the summary of the investigation and retrofitting procedures can be used as a guideline for further retrofitting projects in the same context. It also can be used as an initial step towards setting a database of best practices in the Middle East, North Africa or hot climates in general.

5. Conclusion

This paper evaluated building envelope performance and energy use of a retrofitted building in Downtown Cairo, and investigated the applied retrofitting procedures and techniques used to learn/benefit from this experience. The 'La Viennoise' office building was selected as a case study, listed as *"Heritage Grade B"* by NOUH. A field survey and dynamic simulations were carried out. The results of this study summarised the retrofitting procedures carried out in the case study building into three stages; 1) A five-phase process before retrofitting interventions, 2) actual retrofitting scenarios and achieved improvements after applying these scenarios, and 3) overall maintenance costs and obstacles. The results of investigating the actual retrofitting scenarios and achieved improvements indicated that by adding internal insulation materials (EPS with thickness 0.1 m) for external walls of the base case this raised the thermal resistance from 0.5 to 3.4 (m^2.k/w). Adding insulated roof composed of Extruded Polystyrene (EXP with thickness 0.1 m) and Bitumen felt sheet (with thickness 0.005 m) raised the thermal resistance from 0.2 to 3.2 (m^2.k/w). Replacing the original windows reduced the SHGC from 0.9 to 0.3. The overall implemented retrofitting scenarios have led to decreased total energy use (total electricity with 31.2 % and total natural gas with 56.0 %) for (kw/m^2) year, and reduced CO_2 emissions (45%) for (t/m^2) year of the improved case compared with the base case. For future retrofitting projects, the achieved results of this present work can be used for further studies in similar climates as a guideline.

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