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Environmental Retrofit and Energy Performance Scenarios of Building's Skin in Temperate Climates: Case of Office Buildings in Palestine

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Abstract

Despite the rapid increase in energy demand in Palestinian office buildings and the widespread, imitation-driven adoption of fully glazed façades, locally adapted façade design and retrofit guidelines remain absent. Consequently, a significant research gap exists in understanding the performance potential of glazing retrofit strategies to enhance thermal performance, reduce heating and cooling loads, and improve energy and cost-effectiveness under the specific climatic and political conditions of Palestinian cities. This research thoroughly assesses the energy and cost impacts of retrofitting glazed façades in office buildings across Palestine, aiming to develop environmental retrofit solutions adaptable to the specific microclimatic conditions of the city of Hebron. Simulations tested shading devices, advanced glazing types, and multi-glazed skin façades, both separately and in combination, to identify the best solutions for improving the overall energy and cost performance of glazed façades. Three office buildings were selected as case studies, each with a single-glazed facade facing a different orientation. Cases were simulated using Design Builder software. The results show the best retrofit option for each case to save the most energy and obtain long-term financial benefits. These two factors were the focus of the evaluation. The results suggest a combination that works well in terms of function and cost, achieving energy savings between 38% and 81% in the retrofit scenarios, depending on the specific conditions. In terms of cost, the study shows that implementing the optimal retrofit scenario can yield annual savings of approximately $149 to $442. This insight encourages engineers and investors to adopt a cost-effective, environmentally friendly approach for improving energy and cost efficiency in existing office buildings.

Keywords: *Energy-cost optimization; Energy efficiency; Environmental Retrofitting; Highly Glazed Facades; Office buildings; Temperate Climate*

Introduction

The building envelope, or skin, serves as a barrier that separates the indoor environment from the outdoors. Timmeren (2009) describes it as "a mediator of interaction between indoor and outdoor conditions." From a sustainability standpoint, the envelope acts as a "thermal shield," limiting reliance on mechanical systems to maintain comfort and extending the building's lifespan (Kadlubowsk and Yates, 2009). In an integrated design, the envelope functions as a "contextual generator" that adapts to the surrounding climate (Timmeren, 2009). Facades, as a critical part of the envelope, serve multiple roles and significantly affect building performance, particularly when constructed from lightweight materials.

The emergence of fully transparent skeletal buildings during the First Industrial Revolution (Vries, 2008) was driven by the introduction of new materials such as glass and steel (Britannica, 2019). These building envelopes significantly affect indoor thermal conditions, leading to an increased reliance on mechanical heating and cooling and, consequently, higher energy consumption

From an architectural perspective, the façade serves as the building's interface, expressing the place's identity while conveying the architect's design concept and aesthetic vision. Facade materials have always been closely linked to technological advancement and aesthetic values, enriched with symbolism that expresses change, time, development levels, and human inspiration. The rise of transparent facades has been progressively shaped by architectural imagination, evolving from larger glass windows to full-glass façades and ultimately fully glazed buildings, facilitated by technological advancements that enabled the realization of these aesthetic and conceptual aspirations (Gunasekaran et al., 2010). Transparent façades significantly influence building performance and sustainability, posing a complex challenge for architects to strike an optimal balance among aesthetic quality, energy efficiency, reliability, and safety. This has drawn global attention to facades as multifunctional, adaptive tools that should be properly designed to meet energy goals in line with architectural principles.

However, the trend toward increased transparency in building façades has become more evident in contemporary Palestinian architecture, particularly in high-rise administrative buildings. While highly glazed façades enhance interior aesthetics and spatial quality, they also lead to substantial energy demands, elevated summer cooling loads, and significant heat loss through thermally inefficient glazing in winter.

As global energy consumption continues to rise rapidly (BP, 2019), the building sector remains one of the most significant energy consumers (Allouhi et al., 2015). Buildings account for 30% of global energy consumption and 26% of global energy-related emissions (IEA, 2023). However, it is widely accepted that the building envelope can reliably improve energy performance; for example, energy-efficient building envelopes have reduced space heating by 7% since 2015 (IEA, 2023). Even so, this remains insufficient in warm climates and becomes increasingly critical in highly glazed buildings, where transparent façades permit substantial heat gains and losses. Consequently, maintaining thermal comfort in such spaces requires significantly higher heating and cooling loads.

Despite efforts by various local researchers to improve energy efficiency in buildings and implement sustainable measures in Palestine, the building sector still needs to shift towards more sustainable practices. (Asfour, O., 2014) is one of the researchers who highlighted the significant absence of basic sustainability concepts in the Palestinian construction sector. Lack of research is one of the reasons cited by Asfour O. (2014): public awareness, financial constraints, political instability, and the absence of an effective regulatory agenda. Thus, sustainability in Palestine has gradually become a crucial issue, and it is the responsibility of Palestinian architects and engineers to implement sustainable concepts and measures in buildings, with support from further studies and research.

Literature Review

Regarding buildings with highly glazed facades, the following literature presents many international studies on the energy performance of glazed-envelope buildings, which have sought to define the most efficient glazed facades, as high energy consumption in high-rise buildings with highly glazed envelopes has been evident since the mid-twentieth century. Studies have shown that an optimal Window-to-Wall Ratio (WWR) for cooling demand is approximately 30%, and that the preferable position of the window is the top half of the façade. For heating demand, the optimal minimum is approximately 50% WWR. Daylighting is highly affected by WWR for glazing areas up to 50%; however, beyond 50%, the advantage of a larger area is negligible (Bokel, 2007).

Poirazis et al. (2008) studied the effect of the glazing ratio on the energy consumption of office buildings in Sweden with WWRs of 30%, 60%, and 100%. The results showed that total energy consumption increased by 23% and 47% for the 60% and 100% glazed buildings, respectively, compared to the 30% glazed building. Moreover, implementing glazing with lower thermal and solar transmittance resulted in a total energy consumption only 15% higher for 100% glazed buildings than for the 30% glazed building with clear glazing.

Tzempelikos and Athienitis (2005) studied the impact of glazing orientation on heating and cooling Loads in an office with one exterior wall. The results showed that the difference in the cooling load between the east, west, and south façades was approximately 17%. For north orientation, the cooling load of the south-facing façade was 2-3 times higher. Thus, the orientation effect on the cooling load was significant. The difference in heating load between the south and north façades is less than 13%, as the solar effect on heating is minimal. This was also confirmed by Aksoy and Inalli (2006), who rotated test models with different shapes between 0° and 90° in 10° increments and found that the difference between the minimum and maximum annual heating energy consumption was approximately 5% in cold regions.

Moreover, ongoing research aims to enhance the thermal performance of glazed envelopes. In this regard, Saroglou, T., et al (2019) demonstrated through simulations and comparisons that external shading performed better than a double-skin envelope with low-energy glazing as the interior layer. However, with an improved Double Skin Façade (DSF) as a more advanced envelope with controlled ventilation and acoustic insulation, further simulations showed that implementing low-emissive glazing as the outer layer of the DSF is the most energy-efficient choice in the Mediterranean climate. The comparison between the building envelope with the proposed DSF and that with external shading favored the advanced DSF (Saroglou et al., 2019). Another study from Qahtan, A., (2019) found that the DSF is effective at controlling heat gain due to differences between indoor and outdoor temperatures and variations in surface temperatures. The study concluded that DSF is inadequate in very hot climates for protecting indoor spaces from direct solar radiation (Qahtan, 2019).

Although global interest in energy-efficient buildings has spurred investment in glazed facades, transparent PV panels, double skins, etc., as an effective means of improving energy efficiency, the initiative-driven implementation of glazed facades has recently emerged in Palestinian architecture. It is excessively used in public buildings, although transparency has adopted an international style far removed from Palestinian architectural identity. The problem is greater than just disconnecting from identity and culture, randomness, and environmental inconsideration in the design. The orientation of the glazed facades regarding the solar characteristics led to a situation that made it difficult to control the heat losses and the overheating caused by solar heat gains without consuming much energy, especially for being in a Mediterranean region characterized by dry hot summers with high solar radiation and wet cold winters, which requires special treatment to maintain diverse seasons. Moreover, the energy consumption of the commercial and services sectors in Palestine accounted for 26% of total energy consumption in 2018 (Njore, M.M., 2019), with heating and cooling among the main energy consumers.

In addressing these issues, retrofitting can offer solutions for building owners in areas where reliable access to the electric grid is challenging, especially in Palestine, where political restrictions prohibit electricity generation or use. In Palestine, the total demand for petroleum products is met by the Israeli market, and approximately 98% of electrical energy is supplied by the Israeli Electric Corporation (IEC) (Njore, M.M., 2019). In addition, the amount of electricity purchased cannot keep pace with population growth if energy consumption continues to grow at the same rate. Retrofitting existing buildings to be energy-efficient, especially when the façade is integrated into a complete building solution, can address many of these challenges in the Palestinian building sector and help prevent future energy crises.

Methodology

The theoretical part of this research involved a comprehensive literature review. The review was developed from scientific journals, research papers, and books to address the problems associated with highly glazed facades and to provide a strong foundation of knowledge and experience on glazing technologies and retrofit strategies for office buildings. This review is also intended to identify and assess the most common methodologies used in similar research and data analysis, compare them, select, and justify the most appropriate method based on availability and suitability for the local context. The practical part consists of a field study and simulation work, followed by an optimization process using simulation software and financial analysis. Subsequently, the optimal solutions are selected and justified. Finally, the research plan, required resources, method of data analysis, and study process are discussed.

This study was conducted using a deductive method, starting from existing assumptions about glazing performance and testing multiple solutions to determine which option best improves the building's energy efficiency. This research also employed both quantitative and qualitative approaches to data collection and analysis. A quantitative method was used to identify energy consumption and associated variables, such as the thermal performance of the glazed facades, to quantify the likely effects of different retrofits on energy and cost, and to assess the differences between them. In contrast, the qualitative method is based on exploring the phenomenon of highly glazed facades and on a deep understanding of energy consumption, the external forces that shape and are shaped by energy variables.

The data were collected through in-depth literature research and fieldwork, including participant observation, case study selection, a questionnaire, and measurements of ambient air temperature and relative humidity with a thermometer, and of illumination with a lux meter for natural and artificial lighting. The simulation was conducted using Design-Builder v6 software.

Although full model validation through long-term monitoring was not performed, several verification procedures were applied to enhance the reliability of the simulation outputs. On-site temperature measurements taken during different months were used to compare the general thermal behavior with the model results, ensuring that the simulated patterns reasonably represented the actual building conditions. This study also relied on internationally recognized climatic datasets and standard weather files to verify the accuracy of the outdoor environmental inputs. Additionally, a user questionnaire captured occupants' perceptions of thermal comfort and indoor conditions, providing an indirect validation layer by assessing the consistency between simulated thermal performance and users' actual experiences. Together, these steps strengthened the plausibility and coherence of the simulation findings, despite the absence of full empirical validation.

1. Goals and Scope

The main objective is to assess the opportunities and associated consequences of retrofitting glazed facades in Palestine by developing a retrofitting strategy and a retrofit process to support the successful and cost-effective implementation of solar and energy retrofitting measures for glazed office buildings. The retrofit strategy aims to provide a process for retrofitting and rating methodologies and to integrate the results into an assessment methodology for retrofitting office buildings with highly glazed facades. The sub-objectives are as follows:

a. To assess different retrofit options in terms of energy efficiency and reduced cooling and heating energy demand without affecting the benefit of natural daylight.

b. To define a cost-effective retrofit scenario with lower operating costs associated with energy use and a minimum payback period.

The boundaries of this study focus on the city of Hebron, as it is a trade town linking the northern West Bank with the south-central regions, and glazed skins are widely used and have continued to be implemented in this city over the last two decades. This study was limited to office buildings with highly glazed façades in a Mediterranean climate. The solutions for the selected cases must respect the constraints of location, abundant solar radiation, case orientation, and consider acoustics and ventilation.

2. Case studies

A fully glazed building and two highly glazed buildings were selected based on the findings of the satellite study (Figure 1). The sample was chosen based on the higher glazing ratio and the different orientations of the West, South, and East for careful study (Table 1). The main aim was to investigate the general situation in the glazed offices in the study area and then select offices from among them as cases for further in-depth study. The questionnaire was distributed and completed by employees in the three buildings on 15-16 March.

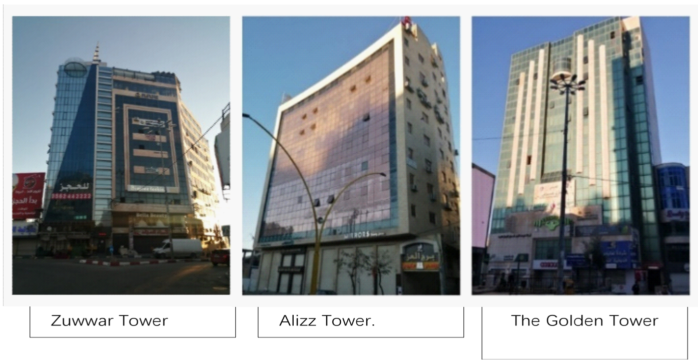


Figure 1. The Three Selected Buildings
Source: Authors

Table 1. The Investigative Survey Sample of Glazed Office Buildings In The Study Area

Elevation	Building	Location	Glazing Ratio	Glazing Type
East	Alizz Tower	Ain Sarah	60-80%	Tinted
South Southeast	The Golden Tower	Ibn Rushd	Fully	Reflective
West	Zuwwar Tower	Ras Jorah	60-80%	Reflective

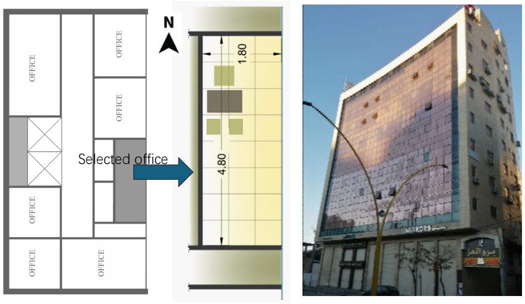
Source: Authors

The buildings examined in this study (Zuwwar Tower, Alizz Tower, and Golden Tower) were identified through local municipal records and on-site verification by the authors. While these names are not widely cited in international publications, they are commonly used by local people in Hebron. Field verification confirmed that all three buildings were still standing, fully accessible, actively used, and in good condition from the time of the study to the present. Each building consists of a ground floor used for commercial purposes, and the remaining floors are .dedicated to administrative offices.

In each building, six offices were selected, and a total of 18 respondents were interviewed. The responses were analyzed in Excel for thermal individual differences, thermo-visual comfort, employee satisfaction, energy consumption patterns for heating and cooling end-uses, means for maintaining the indoor environment, solar protection tools, occupancy schedules, and the working environment. Within each building, one of the six offices was selected to serve as a case for simulation and retrofit applications. These cases are:

a. Case 1: Alizz Tower.

Al Izz Tower is a seven-story administrative office building located on Ain Sara Street, opposite the Alhussien stadium. The glazed curtain façade includes 28 offices distributed across the floors with double brown-tinted glass (6 mm panes with a 12 mm air layer). No external shading devices were installed, and internal curtains were used to reduce glare. Fans primarily provide cooling, as installing split units on a glazed façade is challenging. Measurements were taken in six offices on the first, third, and seventh floors, and no significant temperature differences were observed between the floors. The office selected for this study is located on the third floor and follows a cellular plan, as shown in Figure 2. The interior finishes include white-painted ceilings, porcelain tile floors, uninsulated concrete walls with stone cladding, and 20 cm cement block partitions. The building is near a crowded main square, approximately 16 m from a three-story stadium. Indoor temperature varies seasonally, with 22°C in March, 27°C in June, and 32°C in August, while relative humidity ranges from 61% to 46%. Daylight levels were high, reaching 2300 lux in March, 2100 lux in June, and 15.5 klux in August, providing excellent visual comfort with minimal reliance on artificial lighting. Occupants reported feeling very hot in summer and moderately uncomfortable in winter, with the most uncomfortable periods occurring in the morning during summer and in the afternoon during winter. A 75 W fan operating meets cooling loads for 8 hours per day, while heating is provided by 2000 W electric heaters operating for 6 hours per day. The building operates from 8:00 am to 4:00 pm.



a b

Figure 2. a – Plan of the selected office in Alizz Tower; b – Alizz Tower, 1st October.
Source: Authors

b. Case 2: The Golden Tower

The Golden Tower is a nine-story administrative office building located in Ibn Rushd Square, with 36 offices distributed across its floors. The last two floors were unoccupied. The building features a glazed curtain façade made of double green reflective glass (6 mm panes with a 12 mm air layer), with curtains installed on the eastern and southern façades to reduce glare; no external shading devices were used. The office selected for this study is on the seventh floor and has a deep plan, as shown in Figure 3. Interior finishes include white-painted ceilings, porcelain tile floors, uninsulated concrete walls with stone cladding, and 20 cm cement block partitions. The building is situated near a crowded main street, approximately 32 m from the opposing 3–7-story buildings. Indoor temperatures vary seasonally, ranging from 20°C in March to 33°C in August, while relative humidity ranges from 55% to 47%. Daylight levels at desk height range from 350 to 800 lux, providing reasonable visual comfort but often necessitating artificial lighting. Occupants reported feeling hot during summer and moderately uncomfortable in winter, with the most uncomfortable periods occurring at noon in summer and in the afternoon in winter. The energy consumption data indicate that both cooling and heating loads are served by 3500 W split units, operating for 4 hours per day over 3 months annually. Occupants reported a limited preference for outdoor connectivity. The building operates on a schedule from 8:00 am to 4:00 pm.

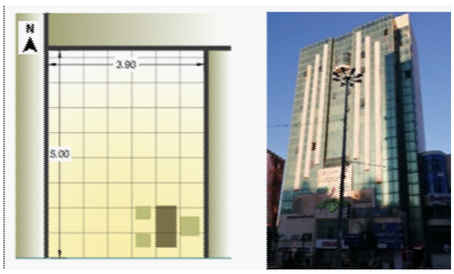


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Figure 3. a – Plan of the selected office in the Golden Tower; b – The Golden Tower, 1st October
Source: Authors

c. Case 3: Zuwwar Tower

Zuwwar Tower is a ten-story administrative office building located on Ras Aljorah Street, with a west-facing glazed curtain façade. Most offices rely on mechanical ventilation, and several floors are unoccupied. The curtain façade consists of double-glazing in blue reflective glass (6 mm panes with a 12 mm air gap), with internal shutters to reduce glare; no external shading devices were installed. The office selected for this study is located on the seventh floor and has an open-plan layout, as shown in Figure 4. Interior finishes include white-painted ceilings, porcelain tile floors, uninsulated concrete walls with stone cladding, and 20 cm cement block partitions. The building is situated near a crowded main street, approximately 18 m from the opposing 3–4 story buildings. Indoor temperatures vary seasonally from 21°C in March to 31°C in August, while relative humidity ranges from 57% to 40%. Daylight levels at desk height range from 200 to 600 lux, providing moderate visual comfort but often necessitating artificial lighting.

Occupants reported feeling very hot in summer and moderate to cool in winter, with the most uncomfortable periods occurring at noon in summer and in the afternoon during winter. Cooling and heating loads are met by 3500 W split units, which operate for 4–8 hours per day over several months each year. Occupants reported limited preference for connectivity with the outdoors. The building operates from 8:00 am to 4:00 pm.

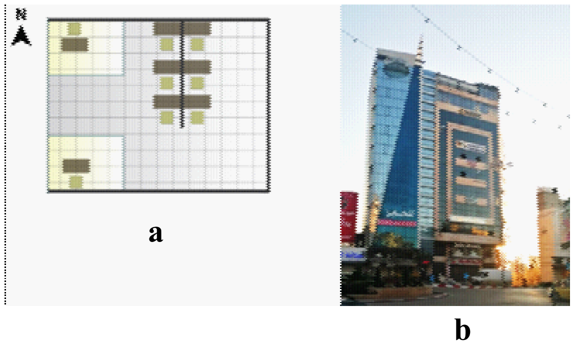


Figure 4. a –Plan of the selected office in Zuwwar Tower; b – Zuwwar Tower, 1st October
Source: Authors

Overall, the three studied buildings (Al Izz Tower, Golden Tower, and Zuwwar Tower) are functioning administrative office buildings with standard interior finishes, moderate occupancy levels, and seasonal variations in thermal and visual conditions. These characteristics collectively highlight several opportunities to enhance the façade performance and improve the overall energy efficiency of the studied cases.

3. Retrofitting Scenarios

The retrofit process consists of three main phases, as illustrated in Figure 5.

Phase 1: Creating Base models (Figure 6). This phase relied heavily on data collected from the field survey through observations, measurements, and questionnaires, including the interior layouts of cases, dimensions, glazing types and ratios, number of occupants in the space, cooling and heating devices, shading devices, occupancy schedules, and the urban context. In addition, climatic data were obtained for the study area.

Figure 5. Retrofitting process
Source: Authors

Data on daylight illuminance, air temperature, envelope properties, urban context, climate data, and all data obtained through measurements and observations are required to confirm the base model by comparing field parameters with simulation results. In addition, because there are no measurements or data for the exact heating and cooling loads by the electrical company in the study area, the calculated energy consumption for heating and cooling was obtained from the questionnaire based on the number of months and daily hours for operating cooling and heating devices and their operating power and device properties.

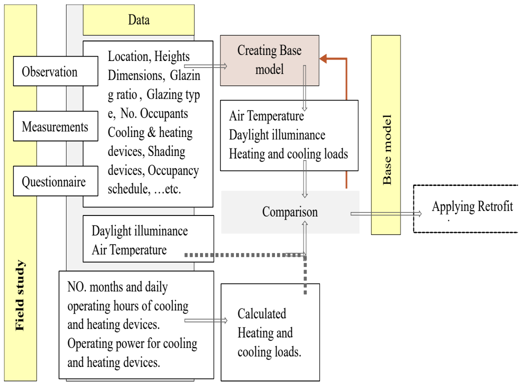


Figure 6. Retrofitting phase 1: creating the base model
Source: Authors

Phase 2: Proposing and selecting retrofit alternatives to develop different scenarios that include solutions to improve energy efficiency in glazed offices by handling high heat gains and losses through applying optimized shading devices, glazing types, or adding extra skins to the original façade, and a combination of two or all of them. In this phase, new models were created by retrofitting the base models for each case, then multiple simulations were performed to obtain the results of applied retrofits.

Shading devices were selected from overhangs, blinds, louvers, and their combinations, in addition to some advanced shades, as shown in Figure 7. For each case with a specific orientation, the appropriate shading device for cooling and heating was determined. This scenario is based on two main procedures: the first is the estimation of the cooling loads of each shading device of different types for each case, and choosing those with the lowest cooling load, and then the lowest heating and cooling loads of the chosen shading types, which demonstrates Scenario 1 for each case.

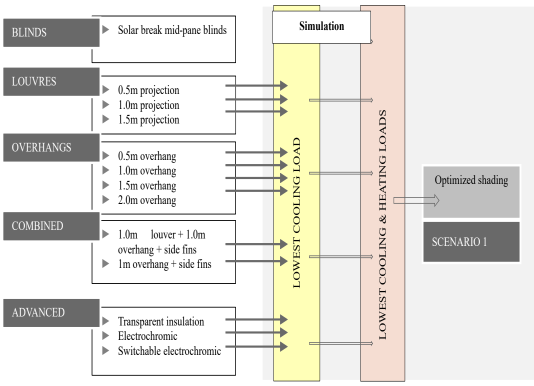


Figure 7. Retrofitting phase 2 proposed a retrofit scenario based on shading devices
Source: Authors

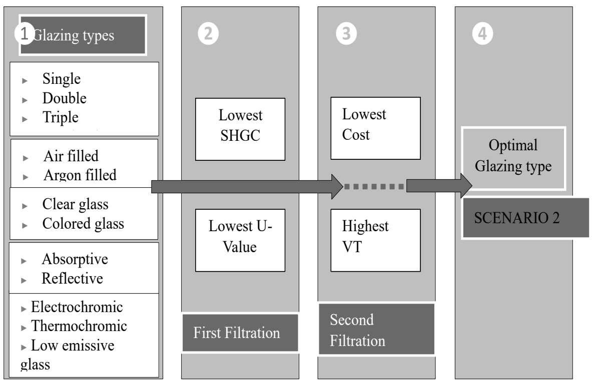


Figure 8. Retrofitting phase 2 proposed a retrofit scenario based on the glazing type
Source: Authors

There were 44 types of glazing, including 14 different glazing technologies (Figure 8). The optimal glazing type for each case was determined by filtering the 44 types for the lowest solar heat gain coefficient (SHGC) and U-value, and then again for the lowest cost and the highest visible transmittance (VT). The multi-skins scenario includes the application of double and triple skins (Figure 9). In which the added skins were simulated and classified in terms of heating and cooling loads as follows:

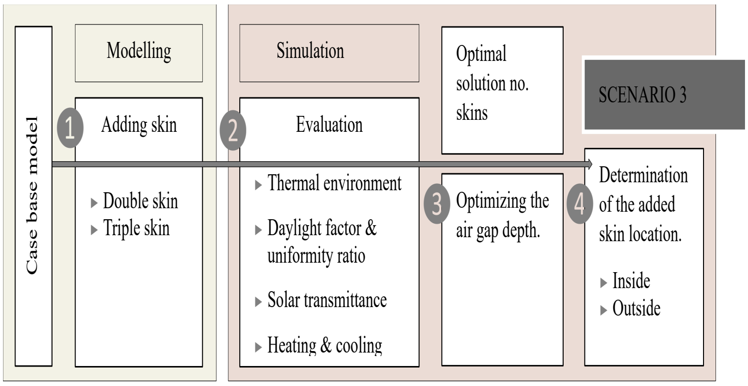


Figure 9. Retrofitting phase 2 proposed a retrofit scenario based on applying multiple skins
Source: Authors

1- Adding skin: Double and triple-tinted glazed skins were added to the outside of the office's original façade with an air gap depth of 30 cm.

2- Evaluation: the evaluation of adding double and triple skin for each case was conducted in terms of the indoor thermal environment, including ambient and operative air temperatures, humidity, and occupants' satisfaction, daylight factor & uniformity ratio, solar heat gains & losses, and heating & cooling loads. The evaluation is based on comparisons and rating points (Table 2), with the multi-skin model achieving the highest total score corresponding to scenario 3 for each case.

Table 2. The rating system for a multi-skin scenario.

Points of comparison	The result	Rating points
1. Thermal environment 2. Daylight factor & uniformity ratio 3. Solar transmittance 4. Heating & cooling loads	No change compared to single skin (the base model).	0 point
	Better than single skin.	1 point
	The best among double, triple skin.	2 points

Source: Authors

3- Optimizing the air gap depth: after deciding the optimal number of skins for each case, different depth options of the air gap were examined in terms of the cooling load (Table 3), where the case with the lowest cooling load demonstrated the optimized air gap depth.

Table 3. The proposed options for air gap depths.

Double skin	0.30m	0.60m	0.90m	1.2m
Triple skin*	0.3m/0.3m	0.6m/0.3m	0.6m/0.6m	0.9m/0.3m

Note: *Triple skin has two air gaps.
Source: Authors

4- Determination of the added skin location: to check whether it is better in terms of cost efficiency to add the skin from the inside, where some of the office space gets lost, or outside, where the installation gets costlier. Thus, a cost analysis was conducted by comparing the cost savings from adding a second or third inside skin with the annual rent per square meter of office area, based on rent prices in the study area.

Phase 3: Choosing the optimal retrofit scenario. In this phase, an optimization process was conducted by comparing different retrofit scenarios in terms of energy and cost efficiency (Figure 10). The optimized solution that offers the greatest energy savings and better cost efficiency has been chosen for each case to enable further improvements and extract additional benefits.

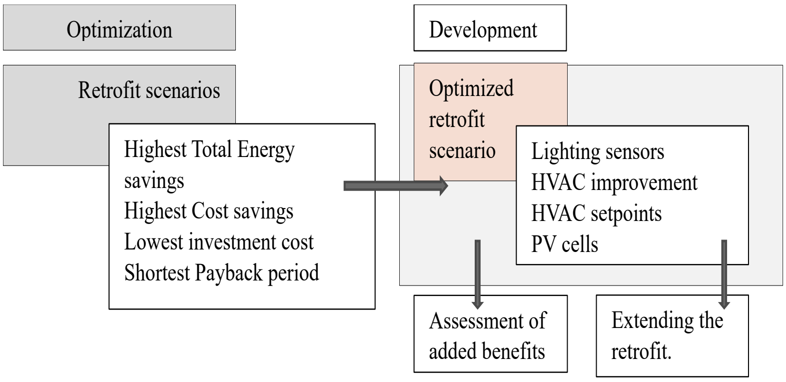


Figure 10. Retrofitting phase 3, Choose the optimal retrofit scenario.
Source: Authors

For this, different retrofit scenarios were developed, modeled, and compared with the base case, which was based on data collected during the field survey. Table 4 shows the proposed retrofit scenarios.

Table 4. Proposed retrofit scenarios.

Scenario 1	Shading devices
Scenario 2	Glazing type
Scenario 3	Multi skins
Scenario 4	Optimal Shading device & optimal glazing type
Scenario 5	Optimal shading device & optimal number of skins
Scenario 6	Optimal glazing type & optimal number of skins
Scenario 7	Optimal shading device & optimal glazing type & optimal number of skins

Source: Authors

In the optimization process for energy and cost efficiency, comparisons were made across heating, cooling, and lighting loads, as well as costs. Subsequently, a financial analysis was made using the simple payback method to justify the best scenario for each case. In which the cost savings resulting from applying the optimal scenario to a certain case are compared to the estimated investment cost. For this, pricing for all retrofit scenarios was required. The pricing had been obtained through interviews with local contractors and engineers. Accordingly, the shortest payback period and the highest energy savings indicated the optimal scenario among the seven proposed retrofits.

Result and Discussion

Seven scenarios were applied to each case. The results of the simulation of the applied retrofits are presented in terms of total energy savings for lighting, heating, and cooling, as well as cost savings, in addition to the initial costs.

For case 1, the greatest energy savings result from scenario 1, which is installing four 1.5m louvers as a shading device, and scenario 2, which is replacing the existing glazed façade with double low-emissive electrochromic reflective colored glass. The highest savings reached only 46% by scenario 2 (Table 5).

Table 5. Retrofit scenario results of each case in terms of total energy savings of lighting, heating, and cooling end uses.

CASE 1: Al Izz Tower		EAST orientation		
Scenario NO.	Base case	Proposed case	Annual Energy Savings (kWh)	% savings
Base case annual energy consumption			1929	0%
1 Shading system	Curtains & tinted glass	4 blades 1.5m louvers.	820	43%

2 Glazing type	Tinted brown	Dbl. LoE Elec. Ref. Colored	886.45	46%
3 Façade system	One skin	Double skin with a 90cm air gap.	586.5	30%
4 The optimal shading & glass type			541	28%
5 Façade system & glass type			650	34%
6 Façade system & Shading			716	37%
7 Façade system & Shading & glass type			610	32%

Note: Point of comparison: Heating, Cooling, and lighting loads.
Source: Authors

For case 2, the greatest energy savings result from scenario 1, which is to install a 1m louver with a 1m overhang and side fins as shading devices, and scenario 2, which is to replace the existing glazed façade with double low-emissive electrochromic reflective colored glass. The highest savings were reached by only 38% by both scenarios 1 and 2, as shown in Table 6.

Table 6. Retrofit scenarios results of each case in terms of total energy savings of lighting, heating, and cooling end uses.

CASE 2: Golden Tower		SOUTH orientation		
Scenario NO.	Base case	Proposed case	Annual Energy Savings (kWh)	% savings
Base case annual energy consumption			2631	0%
1 Shading system	Curtains & Ref. glass	1m louver+1m overhang+ side fins	999.5	38%
2 Glazing type	Ref. blue	Dbl. LoE Elec. Ref. Colored	1012	38%
3 Façade system	One skin	Triple skin with air gaps of 0.6cm and 0.3cm.	221.77	8%
4 The optimal shading & glass type			631.5	24%
5 Façade system & glass type			400.23	15%
6 Façade system & Shading			418.64	16%
7 Façade system & Shading & glass type			466.3	18%

Note: Point of comparison: Heating, Cooling, and lighting loads.
Source: Authors

For case 3, the greatest energy savings are in scenarios 3, which is to add a second glazed façade with a 30 cm air gap, and scenarios 5, 6, and 7. The highest savings reached 81% in scenarios 5 and 6, as shown in Table 7.

Table 7. Retrofit scenarios: results for each case in terms of total energy savings for lighting, heating, and cooling end uses.

CASE 3: Zuwwar Tower		WEST orientation		
Scenario NO.	Base case	Proposed case	Annual Energy Savings (kWh)	% savings
Base case annual energy consumption			2993	0%
1 Shading system	Shutters & Ref. glass	1m louver+1m overhang+ side fins	387	13%
2 Glazing type	Ref. blue	Dbl. LoE Elec. Ref. Colored	1165	39%
3 Façade system	One skin	Double skin with a 30cm air gap.	2340	78%
4 The optimal shading & optimal glass type			613.7	21%
5 Façade system & glass type			2424	81%

6 Façade system & Shading	2422	81%
7 Façade system & Shading & glass type	2221.8	74%

Note: Point of comparison: Heating, Cooling, and lighting loads.
Source: Authors

However, it is not necessarily the case that the scenario with the highest savings is the best, as cost plays a significant role: the scenario may provide significant savings in energy and associated operating costs, whilst the initial investment cost of the installation may exceed its benefits. Thus, an optimization process was conducted to improve cost and energy efficiency. This required detailed pricing for all proposed scenarios to conduct a cost analysis that determined the optimized scenario for each case.

The pricing sheet for the proposed retrofit scenarios is presented in Table 8 below, based on local contractor interviews. The resulting cost savings for the proposed scenarios, using the 1 kWh electricity price in Hebron for the commercial sector (0.63 ILS), are 0.19 ILS (0.05 USD) (PIPA, 2022).

Table 8. Retrofit scenarios pricing sheet

		Scenario	Price in dollars
Sc. 1	Case 1	4 blades 1.5m louvers.	435 $
	Case 2	1m louver+1m overhang+ side fins	580 $
	Case 3	1m louver+1m overhang+ side fins	435 $
Sc. 2	Case 1	Dbl. LoE Elec. Ref. Colored	1252 $
	Case 2		939 $
	Case 3		522 $
Sc. 3	Case 1	Double skin with a 90cm air gap.	1957 $
	Case 2	Triple skin with air gaps of 0.6cm and 0.3cm.	1493 $
	Case 3	Double skin with a 30cm air gap.	971 $
Sc. 4	Case 1	4 blades 1.5m louvers, Dbl. LoE Elec. Ref. Colored	1595 $
	Case 2	1m louver+1m overhang + side fins, Dbl. LoE Elec. Ref. Colored	1450 $
	Case 3	1m louver+1m overhang + side fins, Dbl. LoE Elec. Ref. Colored	870 $
Sc. 5	Case 1	Double skin with a 90cm air gap, Dbl. LoE Elec. Ref. Colored	1687 $
	Case 2	Triple skin with air gaps 0.6cm,0.3cm, Dbl. LoE Elec. Ref. Colored	1519 $
	Case 3	Double skin with a 30cm air gap, Dbl. LoE Elec. Ref. Colored	957 $
Sc. 6	Case 1	4 blades, 1.5m louvers, Double-skin with a 90cm air gap.	2320 $
	Case 2	1m louver+1m overhang + side fins, Triple skin with air gaps 0.6cm,0.3cm.	2030 $
	Case 3	1m louver+1m overhang + side fins, Double skin with a 30cm air gap.	1363 $
Sc. 7	Case 1	4 blades 1.5m louvers. Dbl. LoE Elec. Ref. Colored, Double skin with a 90cm air gap.	3335 $
	Case 2	1m louver+1m overhang+ side fins. Dbl. LoE Elec. Ref. Colored, Triple skin with air gaps of 0.6cm and 0.3cm.	2900 $
	Case 3	1m louver+1m overhang+ side fins. Dbl. LoE Elec. Ref. Colored, Double skin with a 30cm air gap.	1740 $

Source: Authors

1. The Results of Optimizing the Retrofit Scenarios

The results of scenarios optimization in terms of energy-cost efficiency based on choosing the highest energy savings with the lowest cost and shortest payback period are shown in (Table 9, Table 10, and Table 11).

Table 9. Case 1 optimization

CASE 1: Al Izz Tower		EAST orientation				
	Component	Annual Energy Savings (kWh)	% savings	I. Cost	cost savings $	payback period (year)
Sc. 1	Shading system	820	43%	435 $	149.8	3
Sc. 2	Glazing type	886.45	46%	1252 $	161.9	8
Sc. 3	Façade system	586.5	30%	1957 $	107.2	18
Sc. 4	Shading & glass type	541	28%	1595 $	98.8	16
Sc. 5	Façade system & glass type	650	34%	1687 $	118.7	14
Sc. 6	Façade system & Shading	716	37%	2320 $	130.8	18
Sc. 7	Façade system & Shading & glass type	610	32%	3335 $	111.4	30

Source: Authors

Table 9 shows the optimization of retrofit scenarios for Al Izz Tower (east orientation), demonstrating that single measures, such as implementing a shading system or upgrading the glazing type, can achieve the highest energy savings. 43% and 46% respectively, while maintaining relatively short payback periods of 3-8 years. Combined interventions, such as integrating the façade system with shading or glazing upgrades, provide moderate energy savings (28-37%) but require higher initial investments and longer payback periods, up to 30 years for the most comprehensive scenario.

Table 10. Case 2 optimization.

CASE 2: Golden Tower		SOUTH orientation				
	Component	Annual Energy Savings (kWh)	% savings	I. Cost	cost savings $	payback period (year)
Sc. 1	Shading system	999.5	38%	580 $	182 $	3
Sc. 2	Glazing type	1012	38%	939 $	185 $	5
Sc. 3	Façade system	221.77	8%	1493 $	41 $	37
Sc. 4	Shading & glass type	631.5	24%	1450 $	115 $	13
Sc. 5	Façade system & glass type	400.23	15%	1519 $	73 $	21
Sc. 6	Façade system & Shading	418.64	16%	2030 $	76 $	27
Sc. 7	Façade system & Shading & glass type	466.3	18%	2900 $	85 $	34

Source: Authors

Table 10 shows the optimization of retrofit scenarios for Golden Tower, which shows that single interventions, such as installing a shading system or upgrading the glazing type, achieve the highest energy savings of 38% (999.5–1012 kWh) with short payback periods of 3–5 years, making them the most cost-effective measures. In contrast, the façade system alone provides minimal energy savings (8%) and requires a very long payback period of 37 years. Combined measures, such as shading with glass upgrades or integrating the façade system with other interventions, yield moderate energy savings (15–24%) but entail higher initial costs and longer payback periods of 13-34 years.

These results highlight that while simple interventions may offer the most cost-effective energy improvements, more complex combinations should be carefully evaluated to balance performance gains with economic feasibility.

Table 11 presents the optimization of retrofit scenarios for Zuwwar Tower, indicating that individual measures have varying impacts on energy savings. Implementing a shading system alone yields limited savings (13%) and a moderate payback period of 6 years, whereas upgrading the glazing type achieves 39% energy savings (1165 kWh) with a short payback period of 2.5 years. The façade system alone delivers the highest savings (78%) at a low initial cost, resulting in a payback period of only 2 years. Combinations of interventions, such as façade systems with glazing or shading, further increase energy savings to 81% while maintaining short payback periods of 2–3 years. The most comprehensive scenario, integrating façade system, shading, and glazing, achieves slightly lower savings (74%) with a payback of 4 years.

Table 11. Case 3 optimization.

CASE 3: Zuwwar Tower		**WEST orientation**				
	Component	Annual Energy Savings (kWh)	% savings	I. Cost	cost savings $	payback period (year)
Sc. 1	Shading system	387	13%	435 $	70 $	6
Sc. 2	Glazing type	1165	39%	522 $	212 $	2.5
Sc. 3	Façade system	2340	78%	971 $	427 $	2
Sc. 4	Shading & glass type	613.7	21%	870 $	112 $	8
Sc. 5	Façade system & glass type	2424	81%	957 $	442 $	2
Sc. 6	Façade system & Shading	2422	81%	1363 $	442 $	3
Sc. 7	Façade system & Shading & glass type	2221.8	74%	1740 $	406 $	4

Source: Authors

These results highlight that for Zuwwar Tower, the façade system and glazing upgrades are highly effective and cost-efficient measures, and combining interventions can maximize energy performance while maintaining economic feasibility. The final findings were summarized in Table 12.

Table 12. Summary of the final optimized retrofit scenarios.

Case	**Orientation**	**Office depth (m)**	**Optimal scenario**	**% Annual energy saving**	**Payback period (year)**
1	East	1.8	Shading devices 4 blades 1.5m louvers.	43%	3
2	South	3.9	Shading devices 1m louver+1m overhang+ side fins	38%	3
3	West	5.4	Façade system double skin with 30 cm air gap & glass type Dbl. LoE Elec. Ref. Colored	81%	2

Source: Authors

The findings of this study highlight that improving the performance of glazed façades is not solely a matter of selecting advanced glazing materials but rather requires a comprehensive understanding of how thermal properties respond to the surrounding climatic conditions. The results indicate that glazing ratios, shading configurations, and overall façade composition have a substantial impact on both cooling and heating energy demands. Moreover, the optimization outcomes show that integrating improved glazing systems with effective shading strategies generates combined benefits that surpass the impact of individual measures. These improvements also help reduce overall energy consumption and shorten the payback period, underscoring the importance of adopting a holistic, performance-oriented approach to façade design.

These insights provide clear architectural implications for both retrofit practice and early-stage design. In retrofit scenarios, the results help identify which interventions yield the most substantial improvements with minimal structural impact. For new buildings, the study demonstrates how context-appropriate combinations of glazing and shading can inform façade articulation in Mediterranean climatic regions, enabling designers to balance daylight access, thermal comfort, and energy efficiency from the conceptual phase.

Moreover, the findings underscore the importance of tailoring façade strategies to local climatic conditions rather than adopting generic or imported solutions. The variability in performance and payback outcomes across the optimized scenarios confirms that orientation-specific design decisions are critical and that façade interventions should be approached as a climate-responsive and performance-oriented system. The scalability of the proposed energy- and cost-efficient strategies further suggests that similar retrofit measures can be adapted across different office and administrative building types, provided that decisions remain rooted in site-specific environmental characteristics and architectural expression.

Conclusion

This study aims to evaluate the potential energy-saving and the feasibility of retrofitting office buildings with highly glazed façades in a Mediterranean climate, and hence to generate a process that can be used in any retrofitting practices for such buildings through the introduction of new glazing technologies and the use of solar protection means with a multi-skin system. Seven retrofit scenarios were applied to three carefully selected cases for in-depth analysis, providing a useful and convenient process for addressing different offices to achieve this goal. Passive retrofitting strategies were accurately tested, showing different degrees of effectiveness and feasibility for each case in terms of energy and cost savings. These scenarios include adding appropriate shading devices, replacing conventional glass in the glazed façade with an advanced one, adding multi-skins that make up the building with a double- or triple-glazing system, and finally a combination of two or all of these scenarios.

The effectiveness of applying retrofit scenarios depends on reducing the electricity required to operate the mechanical HVAC system cost-effectively. To determine whether the proposed retrofits and improvements address the aims and objectives of this research, the economic outcomes and energy savings have been considered for each case compared with their base models. To assess energy efficiency using an optimization approach, a series of simulations was carried out using the Design Builder software and the Energy Plus calculation program, incorporating all available information on weather data, solar radiation, location, occupancy schedules, space use, etc.

The analysis of the baseline conditions has pointed out three cases with different orientations. The research revealed similarities in energy consumption patterns, thermal sensation in summer and winter, and HVAC set points, but also key differences in the potential impact of diverse retrofitting scenarios across the three cases. The following conclusion explains this, considering energy consumption patterns, and the research objectives, which include retrofit energy efficiency and retrofit cost-effectiveness of the adopted retrofit scenarios.

1- The Energy Consumption Patterns of Highly Glazed Office Buildings

As observed in the research, building orientation greatly affects energy consumption. The case studies were intentionally selected as exemplars of the glazed offices with the highest glazing ratio and different orientations. The energy consumption for the Alizz tower office, a shallow-plan, east-oriented office, was found to be high in terms of thermal and electrical energy. The high solar exposure, together with a shallow depth, was identified as the key reason for its poor thermal performance. Despite having a good average daylight factor, the shallow office space causes glare, leading the curtains to remain closed most of the time and preventing employees from connecting with the outdoors. However, reduced use of artificial lighting results in lower electricity consumption. The energy performance of the Golden Tower showed a similar pattern. Due to a southern orientation, the glazed façade was exposed for long periods during the day, resulting in greater solar gains and higher indoor temperatures. However, the space benefits from acceptable daylight levels and better illuminance uniformity. The energy performance of the Zuwwar tower showed a distinct pattern. Due to a west orientation, the glazed façade was less exposed to the sun during working hours, resulting in lower solar gains and indoor temperatures. However, the west-oriented glazed façade prevented adequate daylight penetration. Consequently, an increased reliance on artificial lighting and electricity consumption. Besides, heat losses in winter exceed heat gains, thereby increasing heating loads.

The analysis found that the contradiction between cooling and heating demand made the cases similar in total consumption but different in the potential impact of diverse retrofitting scenarios. This is due to the case with higher cooling energy caused by high solar gains, which, in turn, has lower heating energy, and vice versa. However, the analysis found that, in the Mediterranean climate of Hebron, cooling energy is always the dominant and determining factor in total energy consumption across all cases. Additionally, for the three cases, given the considerable heating and cooling loads required and the simulations performed, it is possible to conclude that energy consumption has been reduced with increased indoor comfort, but at the expense of indoor daylight.

2- Retrofit Energy Efficiency

The retrofitting has been assessed and has proven highly effective in providing the buildings with energy-saving measures. It is necessary to adapt to the increased heat gains and losses through a glazed façade, as well as the increased running costs of mechanical ventilation. However, it has been found that better energy savings are not necessarily a better scenario when cost-effectiveness is the major determinant.

External shading devices can be designed to shield the glazed facades from undesirable summer solar gains, without compromising the outdoor connectivity. Louvers, for instance, are particularly useful for shading the building when the sun angle is very low, as in the early morning and late afternoon, and they can help to prevent glare. Changing glazing types also showed high effectiveness, in addition to their ability to shade the building and prevent heat gains or losses due to their high insulating properties. The advantage of this scenario is that it maintains all views through the glazing façade and doesn't affect the desired appearance of the glazed façade, unlike shading devices.

However, installing and maintaining the changed glazing type is more expensive than using shading devices. The multi-skinned scenario was not at all effective as a retrofit for the east and south facades, since multi-skins are more effective at preventing heat losses in winter than at providing shading in hot summer. Besides, without appropriate ventilation, it can create a greenhouse effect that warms adjacent spaces, thereby yielding better results for the west case, where heating loads were the highest.

3- Retrofit Cost-Effectiveness

For the east- and south-oriented glazed facades, the proposed shading scenario was found to be a reasonable retrofit in terms of cost-effectiveness. Followed by changing the glazing type scenario, where neither of the other proposed scenarios was efficient in terms of profitability, since the initial investment cost was much higher than the benefits obtained from each. A double-skin system was found to have a lower impact on thermal efficiency than other alternatives. The shading scenario has proved very effective in reducing heat gains and is also considered a cost-effective passive retrofit strategy; thus, it is the most practicable option among all retrofit scenarios for both the Alizz tower and the Golden tower. For the west-oriented glazed facade, adding a second skin with an advanced glazing type showed impressive energy savings of about 81% compared to the base model and was very cost-effective, with a payback of only 2 years. The retrofit with passive strategies was found to be effective, achieving 46% and 38% energy savings for the east- and south-oriented cases, and superlative savings of 81% for the west-oriented case. For solar-exposed cases, such as east and south orientations in general and the Golden Tower office in particular, a façade-system strategy of adding skins to the original façade showed no superior results in terms of cost and energy savings.

The study concludes that effective façade retrofitting in Mediterranean climates requires integrated strategies that evaluate both thermal performance and economic feasibility. The results show that glazing ratios, shading configurations, and façade depth significantly influence heating and cooling demands, and should therefore be treated as performance-driven variables rather than purely aesthetic elements. These findings offer practical guidance for both retrofit decisions and early-stage architectural design, highlighting the importance of climate-responsive, context-specific solutions that improve energy performance while ensuring cost-effective payback outcomes.

Recommendations

The recommendation obtained can be addressed to two important phases of the life cycle of offices with a glazed façade. The first is the preliminary design phase, which can be recommended to avoid the eastern and southern orientations when planning to design glazed facades, since it has been proven that these two orientations have the highest energy consumption.

Figure 11. a– The proposed shading devices for the East-oriented Alizz tower, in which the shading system covered most of the glazed façade and affected the transparent appearance. b– A plan illustration of the added shading consists of 1.5 m louvres with 4 vertical blades. c– Section a-a shows the added shading
Source: Authors

Then it will require high shading, which will, in the end, affect the appearance of the façade (Figures 11, 12), or use an advanced glazing type, which is costly, and it usually requires importation, which adds extra costs. Hence, in this case, it's better to design multi-glazed skins where the shadings can be implemented inside the gap and provide the required thermal performance, besides the desired transparent appearance.

For the west-oriented, the shadings are not so useful compared to the solutions that prevent air leakages and heat losses, as well as exploit the solar radiation availability to gain more heat and gently warm the spaces in winter and cold periods. Besides, it's important to design such facades with careful study of the right proportions of space depth with the glazed area and ceiling height for lighting considerations

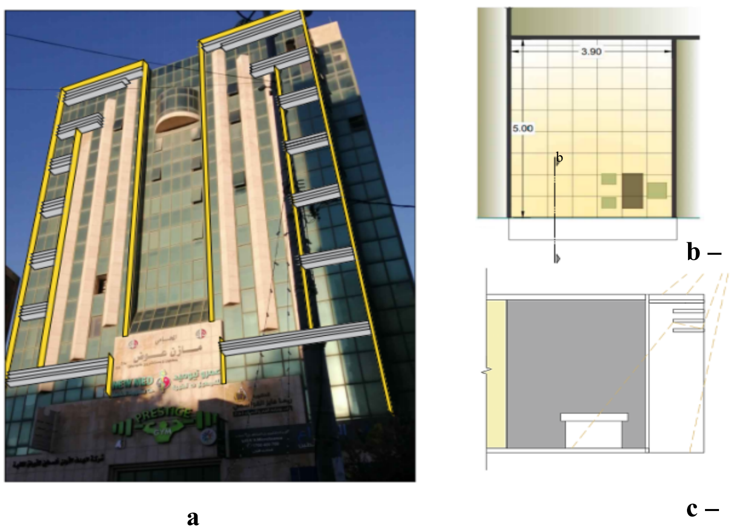
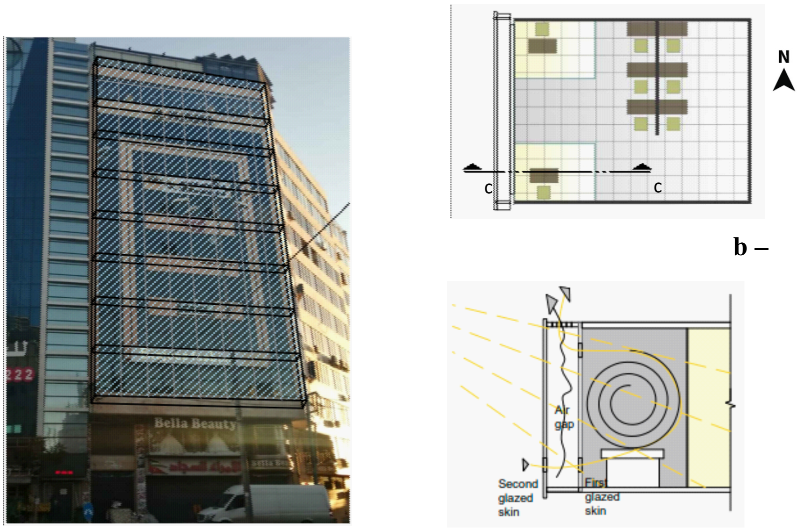


Figure 12. a– The proposed shading devices for the South-oriented Golden tower, in which the shading system covered most of the glazed façade and affected the transparent appearance. b– A plan illustration of the added shading consists of side fins, 1m overhang, and 1 m louvre. c– section b-b of the added shading
Source: Authors

The second, and it's the core concept of this research, is the retrofit phase of the existing buildings. It's useful for following such a process in any location, climate, typology, and conditions of highly glazed buildings, but with different scenarios that fit the climatic conditions. From the literature review, the way of sourcing all and the recent information about glazed technologies, and which is most appropriate for the studied area climate, choosing the cases, investigating them, developing different scenarios, and finally choosing the optimized solution. Furthermore, the horizontal projection of the proposed shading devices, as well as the air gap of the added skins, can be used as a transitional space between inside and outside, such as terraces for the offices. In glazed facades, it is well known that a double-glazed façade system is better at keeping the curtain façade appearance and daylight availability than shading devices (Figure 13). However, the study showed that the shading system is more effective in summer for eastern and southern facades, so the owner can take advantage of multi-skin with less energy and cost-effectiveness.



b –

a –

c –

Figure 13. a – The proposed 2nd glazed façade for the west-oriented Zuwwar tower, in which the new façade kept the desired transparent appearance. b – A plan illustration of the proposed second glazed façade for the west-oriented Zuwwar tower. c – Section c-c shows the double-glazed façade with a ventilated air gap
Source: Authors

Future Extension

Further studies are required to develop holistic guidelines for both retrofitting and preliminary design of highly glazed office buildings. In this regard, further studies with continuous follow-up with glass market changes and manufacturing updates are necessary. Several recommendations are made for future research and the practical development of the highly glazed façade in the following:

– Further research can be conducted to study the consequences of the energy-cost retrofits on the glazed facades' structure and the feasibility of applying the proposed shadings and multi-skins in particular, and the architecturally pleasing appearance in general. Besides, the impact of the proposed solutions on daylight availability and the indoor environment conditions (such as thermal and visual comfort).

– Further research can be conducted to achieve more energy-cost effectiveness by adding some active solutions, such as daylight sensors, using advanced mechanical devices, and installing transparent PV cells.

– The social benefit of the proposed retrofitting strategies and scenarios is a vital consideration when evaluating the retrofit of an existing office building, from the owner to the occupants. While the retrofitting strategies were presented briefly in terms of energy and cost, the social effects of each were not examined in depth.

– The analysis showed that orientation and climatic constraints affected the proposed retrofits, limiting their effectiveness. The case studies have examined buildings in a Mediterranean climate, where the challenge is to prevent solar gain without affecting daylight. It would be interesting to perform simulations at locations farther from Hebron city to assess whether varying climatic conditions would yield a considerable improvement in performance. Since the three cases are in similar climatic regions, it would have been better, with more time and resources, to extend the case study approach to a range of glazed buildings across different parts of Palestine.

– Further studies and research on the effect of indoor materials, different arrangements of office layout, different occupant density, and ceiling heights are required to investigate the different potentials of the discussed retrofits.

– Finally, it's recommended to consider the discount rate by using a discount payback method instead of the simple payback method for calculating financial profitability.

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Notations

Abbreviations

Sc. – scenario

Dbl – double

LoE – low emissive

Elec. – electrochromic

Ref. – reflective