Palestine Polytechnic University
Deanship of Graduate Studies and Scientific Research
Master of Architecture – Sustainable Design

ENHANCING ENERGY PERFORMANCE OF HIGHLY GLAZED FACADES

Case of Office Buildings in Hebron, Palestine

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Supervisor

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Thesis submitted in partial fulfillment of requirements of the degree
Master of Architecture- Sustainable Design

September, 2020

The undersigned hereby certify that they have read, examined and recommended to the Deanship of Graduate Studies and Scientific Research at Palestine Polytechnic University:

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ENHANCING ENERGY PERFORMANCE OF HIGHLY GLAZED FACADES
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ABSTRACT

The building envelope is the major component that protects the indoor environment against the outdoor atmosphere, and in particular, building facades technologies play a significant role in controlling the indoor thermo-visual conditions and energy saving in buildings. In Palestine, regardless of the orientation or climatic zone, the increased transparency of the building's facades became more prominent in the current architectural tendency, especially in high rise office buildings. Although highly glazed facades create more attractive indoor spaces, high energy loads are required to cool down the adjacent spaces in summer and also the heating energy is wasted through the thermally weak glazed parts in winter. This study aims to evaluate the technical opportunities and environmental consequences of retrofitting glazed facades in Palestinian office buildings, in terms of energy-cost optimization with the associated cooling, heating and lighting loads, based on a review of the recent international retrofitting studies to develop solutions that can be applied in the local microclimate of Hebron city in Palestine. In order to analyze the performance of highly glazed facades and the necessity for retrofitting, Design Builder software is used to visualize indoor environmental quality for three offices with one glazed wall in different orientations. Simulations, among shading devices, advanced glazing types and multi-glazed skin facades, demonstrate the optimal retrofit scenario that accommodates the conditions of each case. Results were analyzed and presented in terms of the energy loads and relevant operating costs with the payback period to assess the ability to recover the investment cost. The study achieved viable results with 50% to 80% energy savings in the adopted retrofit scenarios depending on different circumstances in addition to extra outcomes that can be gained with further enhancements reached to 105% energy savings when employing transparent photovoltaic PV cells in one of the studied cases. Regarding the cost and environmental consequences, the study outcome around 30 tons of carbon dioxide CO^2 emissions and 12452$ can be annually reduced when the optimal retrofit scenario applied to the whole building with extra profitability gained by improved employees' productivity and social costs. This is a very important insight for engineers and investors to take advantage of this study to go beyond the improvement of the energy and cost efficiency by such a cost-environmentally productive approach in existing office buildings.

تحسين اداء الطاقة في المباني ذات الواجهات الزجاجية

حالة دراسية: مباني المكاتب في مدينة الخليل - فلسطين

سميحة "محمد سميح" الهشلمون

المستخلص

يشكل غلاف المبنى العنصر الأساسي في حماية البيئة الداخلية للمبنى من الظروف الخارجية المحيطة، حيث للغلاف الخارجي دور مهم في التحكم براحة المستخدمين الحرارية والبصرية وتقليل فقد الطاقة المستخدمة في تبريد وتدفئة المبنى. في الأونة الاخيرة، ازداد التوجه المعماري في فلسطين نحو استخدام الواجهات الزجاجية في المباني. وعلى الرغم من أن الواجهات الزجاجية تعتبر من أهم الوسائل في توفير الإضاءة الطبيعية والإتصال البصري مع الخارج، إلا أن عدم الإهتمام الكافي بالأسس والمعايير في تصميم الواجهات الزجاجية وعدم تحقيق المتطلبات البيئية جعلت لها تأثيرا كبيراً على الأداء الحراري وما يتبعه من استهلاك للطاقة. ففي أيام الصيف الحارة حيث الإشعاع الشمسي العالي يزداد استهلاك الطاقة في تبريد الفراغات ذات الواجهات الزجاجية بسبب ارتفاع الإكتساب الحراري فيها، وكذلك يتم إهدار الطاقة المستخدمة في التدفئة من خلال الأجزاء الزجاجية ذات الأداء الحراري الضعيف في فصل الشتاء. تهدف هذه الدراسة إلى تقييم الفرص التقنية والتبعات البيئية لإعادة تحسين المكاتب ذات الواجهات الزجاجية في فلسطين، في ضوء الإستخدام الأمثل للطاقة وتكلفتها وما يتعلق بها من أحمال التكييف والتدفئة والإضاءة بالاستناد الى الدراسات السابقة لإستنباط وتطوير الحلول الممكنة في المناخ المحلي لمدينة الخليل في فلسطين. ولغاية تحليل أداء الواجهات الزجاجية وحاجتها الى التحسين، تم استخدام برنامج (Design Builder) بهدف تمثيل ومحاكاة البيئة الداخلية لثلاث مباني مكتبية ذات واجهة زجاجية مختلفة التوجيه. ولإيجاد السيناريو الأمثل والملائم لكل حالة، تمت المحاكاة لحلول مختلفة شملت وسائل التظليل المختلفة، أنواع مختلفة من الزجاج المعالج وأنظمة الواجهات ذات الغلاف المتعدد. حيث تم اختبار الحلول في ضوء الطاقة المستهلكة والتكلفة التشغيلية وزمن الاسترداد لتقدير إمكانية استرداد تكلفتها الاستثمارية. وقد حققت الدراسة نتائجاً مجدية ما يقارب 50% الى 80% توفيراً للطاقة من خلال الحلول المقترحة بناءاً على الظروف الخاصة بكل حالة دراسية. بالإضافة إلى أن مع بعض التحسينات وصلت الطاقة التي تم توفيرها الى 105% ما يعني إنتاج للطاقة في إحدى الحالات عند توظيف الخلايا الشمسية الشفافة. أما بالنسبة الى التكاليف والتأثيرات البيئية، فقد توصلت الدراسة إلى خفض انبعاث الكربون حوالي 30 طن و توفير 12452$ سنوياً عند تطبيق السيناريو الأمثل على كامل المبنى بكافة مكاتبه عدا عن تحسين أداء الموظفين والتكلفة الاجتماعية. وتقدم هذه الدراسة رؤية مهمة للمهندسين والمستثمرين للاستفادة منها في تحسين أداء الطاقة في المكاتب وخفض استهلاكها وبالتالي تكلفة تشغيلها من خلال منهج اقتصادي، بيئي و منتج مماثل.

DECLARATION

I declare that the master thesis entitled ″Enhancing Energy Performance Of Highly Glazed Facades: Case Of Office Buildings In Hebron, Palestine″ is my own original work, and herby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

Student Name………………………………….

Signature:——————————— Date:——————————

DEDICATION

I dedicate this work to my family, my great husband Eng. Saleh Sabateen, for being my ever supporter who always has been by my side, and encouraged me up. To my darling boy Mohammad, having you is enough to provide me the motivation to be strong and to go on. To my sisters and brother, to my tutors and colleagues at Palestine Polytechnic University. I dedicate this work to my parents. This is for you Da, I know you are very proud. For you Mama, I did it thanks to your prayers for me.

Sameeha M. Hushlamoun

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Finally, great gratitude to everybody who have contributed to this work.

Table of Contents

List of Abbreviations

A H	High Reflectivity Metallic Coating
A L	Low Reflectivity Metallic Coating
Arg.	Filled with Argon
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
avg.	Average
BREEAM	Building Research Establishment Environmental Assessment Method.
clo	Cloth value
Clr.	Clear
CO^2	Carbon Dioxide
Dbl.	Double
DF	Daylight Factor
DGNB	German Sustainable Building Council
Elec	Electrochromic
Eq.	Equation
I. Cost	Initial Cost
kg	Kilo Gram
kWh	Kilo Watt Per Hour
LEED	Leadership in Energy and Environmental Design.
Lo E.	Low Emissive
met	Metabolic rate
PV Cell	Photovoltaic Cell
R. Cost	Running Cost
Ref	Reflective
Sc.	Scenario
Sel.	Selective
Sgl.	Single
SHGC	Solar Heat Gain Coefficient
Spec.	Spectral
Trp.	Triple
USGBC	U.S. Green Building Council
U -Value	Transmittance Value
VT	Visible Transmittance

List of Figures

List of Tables

Chapter 1

Introduction

1.1. Preface

Two centuries ago, the first industrial revolution had a significant role in increasing the energy consumption of buildings, new building materials emerged namely glass and steel (Britannica, 2019), resulting in the appearance of new buildings' envelopes, such as fully transparent and skeleton buildings which became common in that era (Vries, 2008). These envelopes considerably affected the indoor environment, especially the thermal environment. Therefore, to keep up with these new structures, spaces became mechanically heated and cooled which cause the consumption of more energy. The industrialized era was a result of the energy revolution, during this period there was no awareness regarding resource depletion, and energy was excessively used without any constraints.

Sometime after, in the late 18^{th} century, the rapid expansion of new industries gave a rise to the urbanization of great civilized cities with unprecedented population growth (Mohajan, 2019). This led to more and more energy consumption as a result of the increased demand for comfort standards and life quality. The ability to optimize energy use with the comfort conditions[1] in the buildings had been lost. The energy crisis in 1973, when the Arab Petroleum exporting countries banned the oil supply led to an energy crisis in Europe and the awareness of energy conservation had increased for the first time (Mohajan, 2019).

Other consequences were caused by the second industrial revolution of the 19th century; like the excessive consumption of fuel as the main energy source, which led to adverse environmental impacts., and the world started to find new alternatives to meet the global warming and climate change in parallel with buildings that have become increasingly uncomfortable and the most challenge was to decrease the energy consumption (Zhang and Yang, 2020). Thus, global recognition of paybacks related to the energy loads reduction in buildings is growing in an attempt to protect the environment from the rising carbon emissions and also the nonrenewable energy depletion. For this reason, new means of energy-efficient

[1] Comfort conditions in the buildings include: thermal comfort which is characterized by indoor air temperature, air movement, relative humidity and air freshness, and visual comfort include daylight availability, uniformity ratio and the connectivity with the outside.

buildings, nearly zero-energy buildings and passive design were developed for improving the buildings' energy performance. Besides, many rating systems such as Leadership in Energy and Environmental Design. (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), German Sustainable Building Council (DGNB), energy-related organizations as U.S. Green Building Council (USGBC), The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and some national building codes had appeared along with the sustainability concept, which allowed a great potential of energy savings in new buildings while maintaining the climate and human needs.

1.2. Theoretical Background

The term building envelope or skin can be defined as a key component that acts as a defensive separator between the external forces and the indoor, which keeps the indoor environment more comfortable than the outside. In other words: "a mediator of interaction between in-ness and outness conditions" (Timmeren, 2009). From a sustainability viewpoint, building envelope/skin is defined as a "thermal shield" that lessens the rely on the mechanical systems to guarantee indoor comfort and together extending the building lifecycle (Kadlubowsk and Yates, 2009), while integrated design recognizes the envelope as "a contextual generator" that performs a response reaction to the climate (Timmeren, 2009). However, facades are the most important component in a building envelope, that can perform multi-functions and significantly affects the overall performance, especially if the first "defensive barrier"[2] is made of thermally light material.

From the architectural perspective, the façade serves as the building interface that reflects the place identity, translates the concept and the aesthetic qualities of the architect's design. The facade materials have always been deeply linked to technological advancement, aesthetic values, enriched with symbolism, expressing the change, the time, the development level, and human inspirations. The spread of transparent facades has been gradually driven by architects' imaginations from larger glass windows, then glass facades to fully glazed buildings with the available technology that helped to fulfill these aesthetic inspirations (Gunasekaran et al., 2010). Indeed, a transparent facade is highly affecting building performance and sustainability,

[2] Defensive barrier: is a term used for describing the building envelope as a defensive layer that protect the building indoor spaces from the outside weather conditions.

thus it is a challenge for sustainable architects to optimally balance the aesthetical quality with energy efficiency, reliability and safety. This has turned the global attention to the facades as a multifunctional and adaptive tool to be properly designed in order to reach the energy goals in line with architectural principles in buildings.

The total energy consumption of either renewable or nonrenewable resources of the world is continuing to rapidly grow (BP, 2019). The building sector is still considered the main energy consumer (Allouhi et al., 2015), thus it has a serious role in the consumption of more than a quarter of the global final energy consumption for about 36% and 40% of the total CO2 emissions (IEA, 2019). However, it is widely accepted that the building envelope can reliably bring about a systemic change to enhance the energy performance but it becomes more critical in highly glazed buildings; where the glazed façades allow a significant amount of heat gain and loss, and subsequently, the amount of heating or cooling loads required to thermally satisfy the users of such space is higher.

In this regard, many recent studies in Palestine contributed to energy efficiency, except to those related to highly glazed facades. Palestine has developed a Consumption and Production National Action Plan (SCPNAP) supported by international organizations, where residential buildings and constructions are one of the sectors that are mainly targeted (Environment Quality Authority (EQA), 2016). Despite the various local researchers' efforts made to ensure energy efficiency in buildings and applying sustainable measures in Palestine, the building sector in Palestine still needs to shift towards more sustainable practice. (Asfour, O., 2013) is one of the researchers who pointed to the great absence of the basic concepts of sustainability within the Palestinian construction sector. Lack of researches is one of the reasons that (Asfour, O., 2013) referred to and that is due to the lack of public awareness, financial lack, political instability, and the absence of an effective regulative agenda. Thus, sustainability in Palestine has gradually become a crucial issue and it is the responsibility of Palestinian architects and engineers to implement the concepts and measures of sustainability in buildings supported by further studies and researches.

In respect of buildings with highly glazed facades, the following literature shows many international studies concerning energy performance of glazed enveloped buildings which have tried to define the most efficient glazed facades, as a high energy consumption resulted from the high-rise buildings with highly glazed envelopes from the mid-twentieth century. Studies showed that an optimal Window to Wall Ratio (WWR) is about 30% for cooling demand and the preferable position of the window is a top half of the façade. While for heating demand, there is an optimal minimum about 50% WWR. Regarding daylighting, it is highly affected by WWR for glazing areas up to 50% while for the larger WWR the advantage of larger area is negligible (Bokel, 2007).

A study of (Poirazis et al., 2008) studied the effect of glazing ratio on the energy consumption of office building with 30%, 60% and 100% WWR in Sweden. The results showed that the total energy consumption, by using clear glazing, increased by 23% and 47% for the 60% and 100% glazed building respectively in comparison with energy consumption of 30% glazed building. Moreover, by implementing glazing with lower thermal and solar transmittance, the results showed only 15% higher total energy consumption of 100% glazed buildings when compared to 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 cooling load between east, west and south façade is about 17%. For north orientation, the cooling load of south façade is 2-3 times higher. Thus, the orientation effect on cooling load is significant. While the difference in heating load between a south façade and north façade is less than 13% as the solar effect is small on heating. That's also been confirmed by (Aksoy and Inalli, 2006) who rotated test models with different shapes among 0°-90° with 10° step between each position, and found that the difference between the minimum and maximum annual heating energy consumption is about 5% in cold regions.

Moreover, continual researches intended to enhance the thermal performance of glazed envelopes. In this regard, (Saroglou, T., Theodosiou, T., Givoni, B. and Meir, I., 2019) proved by simulations and comparisons that external shading performed better than a double skin envelope with low energy glazing as an interior layer. But by improved DSF (Double Skin Façade) as a more advanced envelope with controlled ventilation, acoustic insulation., etc., 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. Comparison results between the building envelope with the proposed DSF and the one with external shading was in favor of the advanced DSF (Saroglou et al., 2019). Another study of (Qahtan, A., 2019) pointed out that the DSF is effective in controlling the heat gain amounts because of the different inside and outside temperatures and the variances in surface temperature. The study concluded that DSF is inadequate in very hot climates to protect indoor spaces from direct solar radiation (Qahtan, 2019).

1.3. Current Situation

Despite the fact that global increased interest toward energy-efficient buildings has pushed the efforts towards investing in the glazed facades, using transparent PV panels, double skins, etc., as an adequate means of energy effectiveness, the imitational-driven implementation of the glazed facades is recently existing in architecture in Palestine. It is excessively used in public buildings despite that transparency has gained an international style which is far apart from Palestinian architectural identity. The problem is greater than disconnecting from the identity and culture, the randomness and the environmental inconsideration in the design, as well as 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 sector in Palestine reached 26% of the total energy consumption in 2018 (PENRA, 2019) where heating and cooling became one of the main energy consumers.

In addressing these issues, retrofitting can offer solutions to building owners where reliable access to the electric grid is a challenge, especially in Palestine where electric energy generating or even import is forbidden by political restrictions. In Palestine, the total need for petroleum products is acquired from the Israeli market and about 98% of electrical energy is from the Israeli Electric Corporation (IEC) (PENRA, 2019). As well, the purchased electricity cannot keep pace with the population growth if the increasing energy consumption remained the same. Retrofitting existing buildings to be energy efficient, especially if the façade is employed as a part of a complete building solution, can provide solutions to many of these challenges in the Palestinian building sector and prevent future energy crises.

1.4. Research Significance

This study explores the potentials of environmental retrofit for highly glazed office buildings in Palestine. Such facades induce extensive heat gain and losses with high energy consumption and affect occupants' thermal and optical comfort. In this study, the proposed retrofit solutions shall provide maximum thermal comfort and minimum energy consumption, preserve employee's physiological needs of thermal and visual comfort and keep them pleased, enhance users' wellbeing, productivity and amenity by keeping the glazed facades as possible as transparent to have them in contact with the outside, reduce the reliance on the HVAC systems, which in turn saves energy in office buildings and integrates facade retrofit with the building environmental performance.

1.5. Research Question & Hypothesis

Glass is a remarkable material and despite the fact that glass is considered the weakest point in the building envelope, the buildings' overall performance can be enhanced when the glass is adapted to be part of a facade system. For instant, enhanced glazed facades positively contribute to energy-efficient buildings in Europe by reducing the energy required for artificial light, heating, cooling and ventilation (*The smart use of glass in sustainable buildings*, 2018). Accordingly, this study assumes that enhanced glazed facades can provide added intrinsic capabilities with a retrofit strategy that can enhance glazing functionality, not only reduce energy use and operating cost but also provide indirect profit by increasing employee's amenity. This directly leads to the research question: To what extent retrofitting can enhance the energy performance of the existing glass enveloped offices in the temperate climate of Palestine? Consequently, the following sub-questions were raised:

1. What is the most energy-efficient retrofit strategy that balances between energetic measures and the satisfactory level of office indoor environment?
2. Can the adopted retrofit strategy be cost-effective?
3. To what extent the façade retrofit can reduce the environmental impacts of energy use?

1.6. Research Objectives

This thesis aims to evaluate the technical opportunities and environmental consequences of retrofitting glazed facades as a growing tendency to constructing highly glazed office buildings in Palestine. In line with this aim, the study tends to incorporate passive and active solutions into more comprehensive façade system with enhanced solar protection in a manner that optimizes energy consumption for heating and cooling with the maximum benefit of natural lighting and outdoor views to provide reduced operating costs for owners by optimizing the daylighting thermal tradeoffs and contributes to improving the global health by reducing overall energy use and associated environmental impacts. From this perspective, the research objectives can be summarized as follows:

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

1. To assess different retrofit options in terms of energy efficiency, and reduced cooling and heating energy demand without affecting the benefit of natural daylight.
2. To define the cost-effective retrofit scenario with the lower operating costs associated with the energy use and minimum payback period.
3. To assess the environmental consequences of the adopted retrofit scenario to increase the potential to decrease energy use related to CO_2 emissions.

1.7. Research Limits

The study focuses on Hebron city as it is a trade town that links the north of West Bank with the south-central regions and the glazed skins are widely spread and continues to be implemented in this city during the last two decades. The study is 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, ventilation, etc.

1.8. Research Limitations

Some limitations were faced in this research and are as follows:

- Since office buildings in the study area have no common typology of offices, the research results are restricted to the chosen cases but the retrofit process highlights issues and aspects of broad validity.

- Lack of cooperation by Hebron Municipality in respect to providing plans and drawings of buildings and the inability to know and interview the designers of these buildings.

- Since the available devices for measuring temperature and daylight are mostly not updated in line with time limits, the base models of the cases were modeled as real as possible but cannot be validated.

- Some offices refused to take measurements or investigate the indoor environment.

- Finally, the lack of researches and statistics of energy consumption patterns and the bills of the monthly paid costs for heating and cooling loads in Palestinian office buildings poses a limitation to get tangible results in the intended sector.

1.9. Research Structure

This research was divided into four parts as follows:

First part: the conceptual study of the thesis, which is covered through Chapter 1. It gives a brief introduction to the research and indicates the conceptual model upon which the research is based. The conceptual study is mainly based on justification behind the need to balance between the energy-efficient use of highly transparent office facades in Palestine with the related environmental considerations and physical needs. It discusses the research background and then presents the research significance, hypothesis, objectives, limits, and limitations. The chapter ends by giving a complete overview of the research structure.

Second part: the theoretical study in both the second and third chapters are dedicated to the required literature review and definitions. Chapter 2 introduces a chronological study of glazed application in architecture, demonstrates glazing performance according to comfort and environmental performance, energy use and economic aspects, and socio-cultural aspects. In environmental aspects, it discusses the thermo-visual performance of glazed facades, maintaining an indoor environment means and solar protection tools, the aesthetical value of transparency and its relevance in providing an external view and natural daylighting. The environmental performance consequences and impacts on energy use and economic aspects and finally, the socio-cultural aspects discuss the owners and architects' preferences and intents to design glazing facades, and the psychological values of glazing and its impact on the employees' productivity and satisfaction. Chapter 3 provides the bases of the office environmental retrofitting to pave the way for detecting the potentials of different retrofitting scenarios, which are tested and presented in a comparative manner.

Third part: the practical study that is covered by chapters 4 and 5 and which are the core of the thesis; presenting the research methodology in chapter 4, and the results that are presented and discussed in chapter 5, in which, three cases of contemporary office buildings with a fully glazed facade located in Hebron, Palestine and which have high energy consumption patterns have been studied. Environmental analysis is performed, first to assess baseline conditions and the buildings retrofitting potentials, and secondly to compare the effectiveness of proposed retrofitting scenarios.

Fourth part: The final chapter includes final reflections and recommendations of the present study in order to provide a scientific process and retrofit strategy when retrofitting in similar scenarios.

Chapter 2

Glazed Envelope Technology

2.1 Preface

The facade is the most complex element of building envelopes as well as the most important determinant of a building's overall thermal performance. The performance of the glazed façade is mainly influenced by several parameters such as the orientation, Window to Floor Ratio (WFR) and glass type, etc. Each of them has a different influence on environmental, economic and social performances. Finding the best performance combination is challenging without identifying a distinct approach and strategy. This chapter represents most recent of the obtained theoretical knowledge from the literature review that covers the widest possible range of glazed envelope design solutions from an environmental, economic, and socio-cultural point of view.

2.2 Comfort and Environmental Performance

Glazing in facades by its nature is thermally poor, a potential source of undesired solar gains as well as heat loss and so the feeling of discomfort (Sayed, M., Fikry, M., 2019). The dramatic improvement had been made in the energy efficiency of glazing technologies and had been introduced to the market by manufacturers and glass companies. With shading and insulative enhancements, technologies added more thermal capabilities for glazed surfaces and hence provide the opportunity to the inclusion of larger glazed areas in a climate where highly glazed facades are not recommended due to high solar radiation such as sunny Mediterranean climate (Flores Larsen et al., 2015).

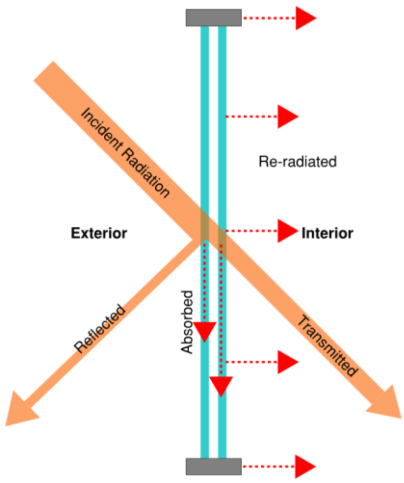


Figure 2.1: Solar heat flow through glazing parts (IMK Technical hub 2018).

During sunny times, once sun rays hit the glazed surface, some of the radiation transmitted through to the space behind glass, some reflected and the rest absorbed within the glass, (Figure 2.1). The absorbed radiation will heat up the glass until the thermal equilibrium state, which will then emit the excess heat to the surrounding through reradiation (Ferrari and Zanotto, 2016) and also by convection and conduction producing overheating in glazed spaces. These proportions depend on glass type, the orientation of the façade, and solar radiation intensity (Bajars and Persson, 2017). The glazed technology enhancement is mainly subjected to these characteristics of transmittance, reflectance, absorptance, and emittance which contribute to the properties of a specific glazing type that influence the choice of glass and expressed by various terminologies as solar heat gain coefficient (SHGC), thermal transmittance U-value, and visibility transmittance VT (Tang, 2013).

The following definitions of glazing terminologies are derived from Building Energy Efficiency Technical Guideline for Passive Design 2013, chapter 5- glazing properties (Tang, 2013) as follows:

- Solar Heat Gain Coefficient (SHGC) has a direct correlation with the amount of transmitted or absorbed incident solar radiation through a glassed surface (Figure 2.3), determined by the glazing type, the number of panes and glass coatings, which indicated by values between 0 and 1.

- While thermal transmittance U-value indicates the thermal performance or the heat gain or loss through the glass and is measured in units of W/m^2K, (Figure 2.2 & Figure 2.4). The lower U-value the less energy able to transfer through glass and better thermal performance. This can be achieved by insulating measures such as doubling and tripling glazing layers, argon gas filling which delay the convection and heat escape through the gas cavity, or coating the glass pane that reflects radiant heat energy from inside back in, all of these technologies ensure a good overall U-value of the glazed surface. The glass area, the glass to frame ratio, and fixing thermal breaks through frames also affects U-Value.

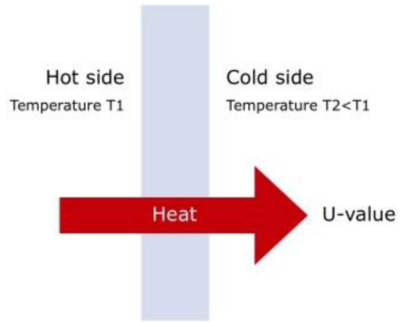


Figure 2.2: Thermal transmittance factor (Morn Building Materials Co., Ltd 2019).

- Visible transmittance VT is the amount of spectrum visible light that is permitted through a glazing material, where a higher VT means more daylight in a space. Clear glass, highly reflective and tinted glass provide VT ranges above 90% to less than 10% according to the glazing type consequently.

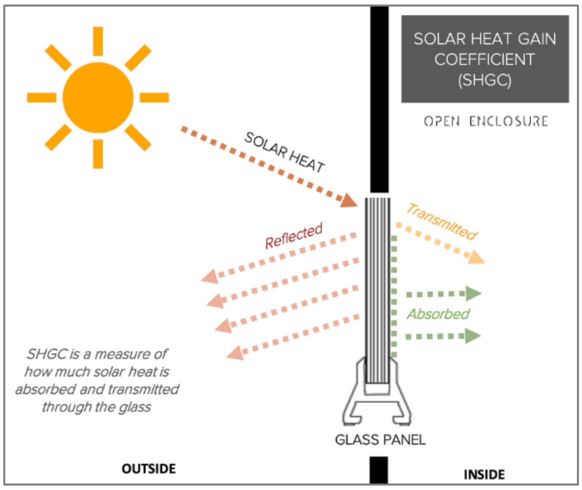


Figure 2.3: Solar heat gain coefficient (Open Enclosure n.d).

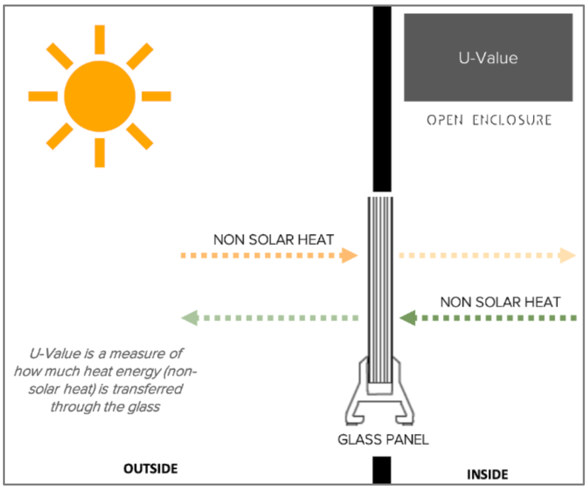


Figure 2.4: Thermal transmittance U-Value (Open Enclosure n.d).

In glazed spaces, direct solar heat gain occurs when the thermal mass absorbs the (transmitted, emitted, reflected and convicted) radiant solar heat within glazed space during the day, and then releases it as the indoor space temperature decreases mainly during the night (Bajars and Persson, 2017). Hence, wisely allowing and preventing the solar radiation passage through transparent surfaces can positively advance the energy performance of a building during heating and cooling periods. In this regard, Tables 2.1, 2.2 summarize the diverse glazing technologies with different properties and classify them according to their function into solar control glass, and thermally insulated glazing technologies with literature describes the advantages and disadvantages of each technology, and the predominant season in which different glazing technologies can most be appropriate. For example, glazing filled with Argon, Argon gas represents an insulation layer that prevents heat loss by reducing conduction through airspace between glass panes therefore it decreases heating energy making it suitable for cold weather.

However, in summer and hot climates, the overheating caused due to heat-trapping inside, for both generated heat by occupants or devices in an office, and the radiant heat that passes indoor and can't leave out. Hence, such technology is not suitable for neither hot climates nor summer season without appropriate ventilation or increasing cooling energy (Winther et al., 2010). The same for other technologies, with low SHGC, are suitable for hot weather due to the reduction in heat gain by blocking solar radiation or preventing heat transfer, but increasing the energy in winter for both heating and lighting (Aldawoud, 2017).

Table 2.1: Glazing Technologies, solar control glass.

	Technology		Function	Predominant season	CONCLUSIONS	
SOLAR CONTROL GLASS	Glass Coatings. Example: tinted glass, low e glass (Low emissivity)		Mainly metal coating applied directly to the glass to control solar heat gain by limiting light wavelengths that passed through the glass pane and reflects infrared radiation (Aldawoud, 2017), (Singh and Lazarus, 2015).	Summer	Tinted glass can reduce cooling energy by its good performance in blocks some of the solar radiation (Aldawoud, 2017), but increases both lighting and heating energy (Singh and Lazarus, 2015). LowE glass is coated by an invisible tin oxide or a silver-based coating that controls energy wavelengths and hence reduce the heat inside and can save up to 75% compared to single clear glazing (Achintha, 2016).	PASSIVE
	Reflective glass		Reflective glass has a mirror appearance that reflects and absorbs a major proportion of the sun's direct short-wave solar radiation (Aldawoud, 2017).	Summer	Reduce energy transmission by 37% compared to single glazing energy performance (Aldawoud, 2017).	
	Gas tropic		Change in optical properties by the chemical reaction between a special layer coated on the glass and gas fed into the cavity between the two glass panes (Beevor, 2011).	Summer and Winter	Advantage: It can retain high transmission properties in the clear unreacted state, also fast switching ability, taking 20 seconds to change from clear to colored, and less than a minute to switch back (Beevor, 2011). Disadvantages (Beevor, 2011): ▪ The complexity of the gas injection system. ▪ creation of water when H atoms added for the chemical process. ▪ Not commercially viable.	
	Electrotropic – switchable glazing systems	Liquid Crystal Technology (LC)	Two glass sheets around an LC film which has molecules that are randomly scattered giving a translucent opal white effect and diffusing the visual light. When the electric field is applied, it changes the orientation of its chains and so the glass allows light to pass (Beevor, 2011).	Summer and Winter	▪ It requires low power consumption of less than 5w/m2. ▪ It has an acceptable switching time, as the transition from opaque to clear is immediate. ▪ It is more used for indoor privacy partitions. ▪ It affects the way light is transferred but doesn't alter the quantity of radiation, hence it is not effective in reducing the amount of transmitted radiation.	
		Electrochromic glazing	A technology that controls the optical transmission properties. It consists of a thin solid electrochromic film sandwiched between two glassed layers which are activated when low voltage passing and changes from clear to dark color (Beevor, 2011).	Summer and Winter	Advantages: ▪ It can reduce the heating and cooling energy, and control visual comfort (Mayhoub and Labib, 2015). ▪ Able to control solar radiation by absorbing the heat in its darkened state (Beevor, 2011). ▪ Let the user vary the tint of the window, Controls the glass transmittance since they can be darkened or made lighter to adjust the light permitted to enter the space (Mayhoub and Labib, 2015). ▪ The low voltage needs until the desired coloration then it can Maintain radiation transmission for up to 48hrs (Beevor, 2011). ▪ Can be activated manually or by active sensors (Beevor, 2011). ▪ The glass can brighten reducing the need for artificial lighting (Beevor, 2011). Disadvantages (Beevor, 2011): ▪ It turns the glass cloudy. ▪ Absorbing the radiation leads to the heat of the glass. ▪ Not acceptable switching time; about 30 minutes for a 2.4m2 window size. ▪ Durability needs to be developed. ▪ Without shading devices, it cannot provide visual comfort in extreme glare situations.	ACTIVE
		Suspended Particle Devices SPD	A film contains particles suspended in billions of liquid droplets in random positions and block light transmissions as a dark blue tint. When a voltage is applied the particles align and light is allowed (Beevor, 2011).	Summer and Winter	▪ The change in tint is instant. acceptable switching time ▪ A changed level of tint and so the transmission properties can be provided by varying the passing voltage. ▪ Radiation-absorbing particles provide energy-saving potential. ▪ Visual advantage allows clear sight even in a state of minimum transmission. ▪ Disadvantage: High cost.	
	Spectrally selective glass		Involves films, tints, or coatings which reflect selected wavelengths of light and allowing others to pass (Aldawoud, 2017). Some types respond to an applied electrical current that offers variable opacity control of the direct solar gain & glare.	Summer	Spectrally selective glass transmits nearly all visible but reflects the infrared radiation (Selkowitz et al., 2020). Studies showed that double low e spectrally selective clear (3mm glass-13mm air-06mm glass) can save 60% energy compared to single glazing (Aldawoud, 2017).	

Table 2.2: Glazing Technologies, thermally insulated glazing.

		Technology	Function	Season	CONCLUSIONS	
THERMALLY INSULATED GLAZING	Glazing systems	IGUs Insulated Glazing Units: Example: double glazed, triple glazed, etc.	▪ Two or three panes of glass separated by an air space to control heat transfer. ▪ The concept is to reduce conduction through airspace (Aldawoud, 2017).	winter	▪ IGUs can improve thermal performance and decrease heating energy but overheat occurs in summer so, it increases the cooling energy in hot climates (Winther et al., 2010). ▪ Double and triple glazing has better energy performance than single glazing and heat loss reduced by an increased air gap (Aldawoud, 2017). IGUs have low U-values of $1 Wm^2K^{-1}$ for double glazed and $0.7 Wm^2K^{-1}$ for triple glazed units which is significantly lower than the U-value of 5.8 of single glazing (Achintha, 2016).	PASSIVE
		Glazing filled with a gas or vacuum space between panes of glass	A gas is other than air such as argon or krypton to suppress conduction and convection between two or three panes (Aldawoud, 2017).	Winter	The size of the gap between glazing panes and the type of gas fill impact the performance of glazing. Argon and krypton gas fills show better performance than air (Aldawoud, 2017). However, it increases cooling energy by trapping heat inside the spaces (Winther et al., 2010). The main drawback of these gases is the Glass failure: this happened due to that these gases cannot expand as glass expanded by heating and this can eventually destroy the seals and allow the gas to escape to be replaced by moisture building up condensation inside the window (*Alliance to Save Energy*, 2006).	
	Advanced insulation	Transparent Phase Change Materials PCM	▪ PCMs can increase the thermal mass by store an amount of latent energy which is required to change the phase of the material change from solid to liquid and vice versa depending on room temperature (Fokaides et al., 2015). ▪ It is recommended to use PCMs with the HVAC system because if the set point temperature is imposed by the HVAC system is lower than the melting temperature of the PCM. Thus, it cannot be activated (Nocera, 2017).	Summer and Winter	▪ A reduction in the energy demand for heating and cooling was indicated when applying PCM in solar shading or the glazing in buildings utilized with the HVAC system and showed the same loads as the base case of the building without HVAC, PCM is the optimal solution in the Mediterranean climate among VIPs and other solutions tested in many studies (Winther et al., 2010),(Nocera, 2017). A study in Denmark showed that PCM reduced heating by about 3kwh/m2/yr and 37kwh/m2/yr of entire energy demand(Winther et al., 2010) ▪ The PCM position is affecting its performance, it performs better when applied in the inner side of glazing panes while Using PCM on the outer side showed the worst performance for indoor comfort in summer (Nocera, 2017).	
		Vacuum Insulated Panels VIPs	▪ The concept is derived from refrigerators, freezers ▪ and cold shipping boxes with limited space for insulation. Also, the VIPs industry followed the replacing insulation materials which contained harmful CFCs (Johansson, 2012). ▪ VIPs consist of two glass panes evacuated to a pressure of below 10-3 m bar and coated with a highly reflecting metal to decrease the heat transferred by conduction, convection, or radiation through the glazed panes (Weinläder et al., 2005).	Summer and Winter	▪ In the Mediterranean climate, VIPs are very useful to reduce heating energy needs. However, in summer the cooling energy is increased (Nocera, 2017). ▪ VIPs drawbacks: That it is causing high fluctuations in the indoor operative temperature, many studies showed that PCM is better than VIPs in the Mediterranean climate (Nocera, 2017). Also, it's a service life of around 25-40 years while the building service life is 80-100 years (Johansson, 2012).	
		Aerogels	Aerogel is an insulation material made of a polymer combined with a solvent to form a gel with liquid replaced by air (Winther et al., 2010). It can control the heat transfer as it is a porous low-density material.	Summer and winter	Aerogels have a capability of decreasing heating and cooling energy in buildings, where studies showed that applying only 1,5 cm of aerogel to the glass changed the U-value from 1,5 W/m2K to 0.5 W/m2k (Winther et al., 2010).	
		Thermotropic or thermochromic glass	It consists of two panes of glass sandwiching a polymer gel that can be transitioned from a clear transmissive state to a cloudy reflective state at a certain temperature to control thermal conductivity and transmittance value of the glass (Inoue et al., 2008), (Beevor, 2011).	Summer and Winter	▪ It decreases cooling but increases heating, and control lighting (Winther et al., 2010). ▪ Its' drawback is that it can't be manually overrun to control the visual light levels and requires low electric power to perform and depends on the solar radiation energy to maintain the cloudy state as required (Inoue et al., 2008), (Beevor, 2011).	ACTIVE

Table 2.3: Glazed Envelopes Technologies.

'	Tools	Function	CONCLUSIONS	
SHADING / LIGHTING control Devices	Blinds Louvers	Operable shading device that is used for solar penetration control and redirecting daylight to the ceiling at the same time. composed of multiple slats arranged vertically or horizontally, and made of galvanized steel or painted aluminum.	▪ Louvers and blinds are easier to operate and better in performance than fixed shadings (Winther et al., 2010). ▪ Need low maintenance and perform well in all climates. Provide flexibility as they can be tuned to specific climatic conditions and user preferences (Košir et al., 2013). Also, if the control is automated, they retracted and tilted responding to the outdoor conditions (Lee et al., 2002). ▪ in hot climates, they provide more energy efficiency if using external louvers or blinds for decreasing cooling load since the solar heat trapped by the glazing system is a problem of internal blinds (Jones and Kopitsis, 2020) and also due to the elimination of overheating of the internal environment because of reradiation of solar waves (Košir et al., 2013). However external positioning has a disadvantage of degradation. ▪ While in cold climates, they used to provide more daylight and tuned to increase the solar gain (Lee et al., 2002).	PASSIVE/ACTIVE
	Overhangs	Fixed shading device.		PASSIVE
	Window attachments: shutter, curtains	Manually operable shading device.		
	Reflective light shelves	Increasing light levels in areas far from windows by reflecting sunlight inside (Mayhoub and Labib, 2015).	▪ Useful for shading especially with highly glazed surfaces with heights greater than 2.2 m (Košir et al., 2013) ▪ Studies proved that the configuration of glazed facades with light shelves better than perforated facade due to the positive effect of the light shelves in enhancing the illumination uniformity distribution (Mayhoub and Labib, 2015). ▪ A combination of ultra-clear glazing with a high reflective light shelf showed a slight improvement in daylighting availability of more than 5% but doubled the lighting distribution and decreased the MRT by more than 5 degrees 1. And leads to a significant reduction in cooling loads (Mayhoub and Labib, 2015).	
Multi-layer facades	Double, triple skin façade.	A double-skin façade consists of a pair of glass skins separated by an air corridor, which works as thermal and acoustic insulation (Tang, 2013).	▪ The air gap provides a space to mount shading and daylight enhancing devices. ▪ The simulation showed that better energy saving can be achieved using a double skin façade rather than a single skin (Hamza, 2008), and the positive impact in building retrofit in terms of improving the building daylighting, thermal and acoustics performance (Lee et al., 2002). ▪ However, these systems have some disadvantages: overheating in summer seasons, high cost, reduced building floor space, additional cleaning costs, and increased fire risk and sound transmission (Selkowitz et al., 2020). ▪ Studies of Double skin façades showed that the rise in air temperature with floor height imposing an increasing cooling load and internal glass surface temperature on floors at a higher level than the fifth floor (Jones and Kopitsis, 2020).	

A unique combination of physical, optical, and thermal properties facilitate the widespread use of glass material in modern buildings (Achintha, 2016), (Figure 2.5). In general, solar control glass controls solar radiation (heat and light) by regulating reflections, transmittance and absorption. Recent solar control glass using tinting, translucent, opaque, and patterned coatings or multilayers to manage the penetration of solar radiation, (Table 2.1). Highly reflective glass can control heat gain, but also reduces daylight penetration and the mirror facades are not often preferred as lighting reflections can cause street accidents. Thermally insulated glazing, includes insulating glass units IGU, glass filled with gases and transparent phase change materials (PCM), etc., (Table 2.2), that are generally required for space heating in cold zones to minimize heat escaping through glazed surfaces. Glass insulation can stabilize the temperature inside and consequently reducing the heating and cooling energy. Besides thermal insulation and solar control abilities, the recent advances in glazing technologies include self-cleaning, noise control, fire-resistant and vibration control glass.

Figure 2.5: Strategies for improving the energy performance of glazing (Fairconditioning, n.d).

Glazing properties are the control variables for energy optimization, hence when choosing glazing type for energy efficiency purposes in a Mediterranean climate, it's important to guarantee visibility transmittance to ensure daylight with minimum overall energy consumed for heating and cooling. If good insulation brings positive effects in winter, it does not guarantee the achievement of proper performance in summer conditions. Therefore, it's important to accurately weigh these variables with factors like day-night and seasonal variations of solar radiation during the day and the year consequently. In a properly designed passive space, the space temperature shall be preserved between 20-26C° and the relative humidity 30%-60%, to guarantee the space is comfortable in all periods (Achintha, 2016).

Regarding facades' design, passive and active design strategies should be integrated very well. Many devices and systems have been developed for solar protection means. Facades solar control systems and technologies can be classified into solar control, daylighting control, multilayer facades and active dynamic facades, see Table 2.3. Exterior solar and daylighting control devices include window attachments shutters, curtains, overhangs, fins, louvers and blinds. Shading control devices are designed to interrupt the direct solar irradiation reaching glazing surfaces and reduce the amount of heat passes inside. These devices can be fixed such as overhangs, and manually or automatically operable used for control heat gain, reduce glare and redirect daylight. Automated shading devices can more effectively control the solar radiation than fixed devices, about 11.6-13.0% extra energy consumption can be saved by using automated shading when compared to fixed shading (Ghosh and Neogi, 2018) yet higher price, higher maintenance complexity, additional operating energy, and sometimes user acceptance are potential drawbacks of automatically controlled shading. Daylighting control devices such as light shelves are used for increasing daylight inside by reflecting sunlight and if it is designed appropriately, it can offset artificial lighting and its' associated cooling loads.

The position of shading and lighting devices is a key point in achieving the desired effect; for example, internal blinds cannot protect against heat gain as the solar heat have already entered and will be retained inside producing the greenhouse effect, however, this can be useful in winter for reducing heating loads. Also, the direction of these devices is strongly subjected to the façade orientation; as the eastern and western facades facing the low sun which makes it difficult to be controlled by horizontal external shading, while south-facing facades can permit adequate portions of light and direct sun heat will be reduced. This is an important point to design facades specific to their orientation to produce buildings more climatically designed and hence, more energy and carbon-efficient.

The optimized façade should be designed so that it exploits available solar heat during winter and avoids adding excess heat whilst admit daylight and control glare during summer. The double or triple glazing assemblies together with special coatings can provide reasonable control of heat gain but if they combined with the physical shading devices it will provide sufficient and strongest control since shading devices work on preventing the summer sun rays before reaching the glazed surfaces of the façade. Also, in this combination, shading devices can be used for providing light shelf effects; by reflecting and diffusing the sunlight deeper into spaces while preventing glare. Different movable and static solar shadings are being invented, movable shading devices provide more flexibility to regulate users' preferences and outside ever-changing conditions. These can be manually operated (shutters, blinds) or motorized control by building management system BMS that can be programmed to get-up with the different patterns of the solar path through the day and throughout the year. However, the combination of multiple techniques can strengthen each other, but also can weaken the effect as a whole if not properly designed.

For buildings with highly glazed facades that require the strongest scrutiny to manage the exposure to the extra light and heat and their associated fluctuations, it may be more feasible to employ multi skin glazed facades instead of shading devices where the inner layer welcomes daylight and the second layer restricts sun heat. In some cases of single highly glazed facades, due to the excessive solar exposure, occupants tend to use curtains to cut down the glare, and hence make them miss the amenity of the daylight reminding effect and hence the transparency values of the highly glazed façade become useless. Besides, local technics to control the indoor environment comes against the desire of a significant number of buildings designers and owners who would like to obtain the architectural pleasing and modern appearance of glazed facades. As a result, new façade systems such as multi skin facades have been emerged to provide a multifunctional design to reconcile the conflicting needs of the thermo-optical property, energy performance and owners' desires.

2.3 Double Glazed Skin Facades

The double-glazed skin façade DGSF is a European phenomenon motivated by the desire of having full glazed facades with natural ventilation without acoustics problems as in a single skin (Lee et al., 2002). DGSF consists of two glazed skins separated by a ventilated air cavity with a depth of 15-150cm and provides weather protection for the inner skin (Zhang et al., 2016).

Many studies extracted many benefits for the system; the DGSF used in the renovation of historical buildings by placing a second layer of glass to a conventional façade in targets of having reduced sound levels in noisy locations (Lee et al., 2002) or retrofit buildings in case that is difficult to replace the old layer or to preserve the historical identity. Another benefit; DGSF provides a good natural ventilation system of heat recovery in winter and heat extraction in summer (Boake and Chatham, 2003). Besides, the cavity between the skins added many values to the system; it can be useful by placing shading devices and protect them from degradation by the outside weather conditions, control sound, affording a walkway for maintenance and cleaning purposes, and providing a thermal buffer zone between inside and outside and hence, better thermal performance with significant energy savings than the single-layer glazed facade. In addition to this, the cavity can perform as an auxiliary heat source during the heating season and habitable space for plants and other benefits.

Double skin facades system can be classified into many types: buffer system, extract air system and twin-face system. A buffer system allows fresh air in from the bottom and exhausts air at the top of the cavity. In the extract air system, the fresh air supplied by HVAC and exhausted through the cavity. The twin-face system includes openings in the inner skin to allow natural ventilation without the associated turbulence which occurred in high air cavities in high rise buildings (Boake and Chatham, 2003). Also, DGSF can operate different ventilation modes which can be provided by controlling operable windows in the two skins (Flores Larsen et al., 2015), they can be placed at the top or bottom of the inner and outer skin to provide different ventilation patterns: the extraction mode during summer, the supply mode during winter and the air circulation mode to only ventilate the cavity from moisture and excess heat which is being extracted from the top definitely by stack effect or supported by mechanical vents and grills (Zhang et al., 2016).

This air cavity can be undivided open-air space over the whole facade or divided vertically between floors, horizontally on the same floor or both. The undivided type without proper ventilation for the cavity can create overheating on the upper floors as the hot air is collected by convection at the top of the air space. Where divided air space can reduce the overheating on the upper floors and reduce the noise, fire and smoke incidence (Boake and Chatham, 2003). This demonstrates that the way you regulate the air cavity, the effect you have; the airflow in the cavity between layers can push hot or cold air depending on the height, depth of the cavity and glazing type. A study of (Poirazis. H, 2007) in energy optimization for double skin glazed offices in Goteborg, Sweden showed that the glazing type affecting directly the energy targets. The solar control in outer panes has a negative impact during winter and positive in summer since they result in lower inner pane temperatures and transmit less heat inside. Where the low emissive glazing with solar control in the outer panes of the two skins performs well during winter due to the less heat transmittance losses through the outer panes (Poirazis, 2020).

In hot climates, the environmental rationale behind DSGF systems appears reasonable only if conventional glazing is replaced by high-performance glazing since the cavity can cause overheating without an appropriate selection of glazing. A study investigates the DGSF cavity in the Mediterranean climate found that the temperature inside the cavity is always higher up to 2-10C° than the outside temperature during the whole day. Regarding temperature variation in different positions inside the cavity, it founds that temperature on different floor levels is very similar, and there is no temperature variation in the same horizontal level between the center and lateral side (Flores Larsen et al., 2015), depending on solar exposure, shading factor and the ventilation mode.

However, in all advanced glazing technologies and systems stated, a static glazed envelope will not be able to give optimal performance except for a few periods during the year especially in a Mediterranean climate where the challenge is to reduce thermal loads in both summer and winter without the daylight benefits exceed the losses. In this regard, recent advances increased focus on intelligent dynamic façade system that meet the comfort while satisfying owner economic needs and broader environmental social concerns.

Taking into consideration more than the environmental aspect, it can lead to different preferences and investigate the feasibility of alternate solutions when retrofitting the different buildings. For this, economic and social aspects had been reviewed and integrated into this study.

2.4 Energy Use and Economic Aspects

In recent years, despite a radical global improvement in the approach for energy-efficient buildings with an increased call for sustainability, there is still an imperative need for internationalizing energy efficiency measures in nations missing legal obligation to building distinct codes that intended reductions in the energy required for lighting, heating, cooling and ventilation consumed by buildings. Especially in retrofitting practices, energy retrofit measures can significantly reduce the energy consumption for the different building typologies (Lazzeroni et al., 2017). Energy efficiency is related to consuming less energy to produce the same output (Muhaisen and Asfour, 2017) while energy economically efficient is to produce the best outcome at the lowest cost results in maximizing the effectiveness of the building (Perera and Ashworth, 2015). In addition to energy savings, energy-efficient buildings added values include resources preservation as less energy demand less resource use, environment protection due to the lesser amount of energy use lessen embodied carbon emissions, and definitely, the reduction in the operating costs of buildings associated with electricity consumption for mechanical and lighting loads (Muhaisen and Asfour, 2017). On a smaller individual scale, buildings that are efficiently designed have longer building lifespan, better occupant comfort, and increased property value (Lee et al., 2002).

Achieving energy savings and high comfort levels can be a challenge in high rise buildings with highly glazed facades (Bayraktar et al., 2020). Transparent offices are generally associated with increased energy consumption and high operating costs and hence should be operated in a much more efficient scheme. It's essential to determine which improvements are most appropriate or even necessary for better energy management, this can make the difference between efforts made to improve building energy performance and those that waste more energy more than they save. For example, the employed advanced and costly technology that may be intended to reduce heat losses is appropriate for cold weather but increase the cooling loads in hot climates. So, the concept is to set energy objectives that are attainable for the building conditions and its' local climate.

Energy savings technologies can be classified into:

- Active technologies, such as the employment of renewable energy using solar photovoltaic panels, wind power, or utilizing smart control system as smart HVAC, lighting, using economizer control with the HVAC, etc. which is usually expensive but significantly decrease the loads' profile of the building.
- Passive technologies that included good thermal insulation, efficient use of daylight and solar gain, improvement in HVAC system settings such as using mechanical heat recovery mode from exhaust air, reduce temperatures setpoints, etc. In which the design invests passive technologies in attempts to reduce the energy use, the running costs, and the carbon footprint.

Regarding buildings with highly glazed facades, innovative advances in glass products encourage using glass in low energy passive buildings due to its ability to provide dynamic multifunctional design (Selkowitz et al., 2020). As described previously, the appropriate choice of glazing type can reduce heat loss but allows solar heat gain to heat spaces in winter, and proper use of solar control tools whilst maintaining an adequate level of daylight can eliminate the need for cooling systems.

Highly glazing facades are mainly linked to users' visual comfort in climates with low solar resources where there is a need to utilize most of the available daylight. Whereas in the sunny Mediterranean climate, transparent buildings will always have a worse overall economic performance than opaque buildings due to the increased investment cost required for transparent designs to reach only in the best cases the same energy performance levels as opaque designs. A study investigated how double skin facades perform in a Mediterranean climate, showed that daylighting optimization using shading devices and artificial lighting control in double glazed facades brings greater savings than thermal optimization using shading devices but the combination of both optimizations is the most efficient, however, the reference opaque façade remains economically more profitable than the most efficient DGSF, and the great savings obtained from optimizing DGSF don't compensate the much higher investment cost and the overall life cycle cost (Pascual et al., 2010).

In any efforts are being made to enhance the energy performance of high-profile buildings, economic aspects have to be integrated to ensure the practicability of the adopted solution. The energy enhancement of buildings sounds to be a cost-effective initiative (Lazzeroni et al., 2017). For this, energy-cost efficiency actions that are combined from different energy solutions must be well studied to not only implement the most energy-efficient measures but also include profitability measures (Muhaisen and Asfour, 2017). In this way, energy-saving measures that are profitable can then satisfy the required investment profitability in a reasonable period. In this regard, the increased first cost can be offset by other changes, e.g. smart glazing could allow smaller conditioners or elimination of conventional shades, lower heating and cooling loads will help offset the capital cost for energy-efficient investments and vice versa the avoided capital cost can be used to fund further efficiency measures.

Economic analysis is an important effective strategy that includes cost forecasting considerations, there are many methods to analyze different alternatives and their respective investment costs. Life Cycle Cost Analysis LCCA is a method to monitor and assess initial and operating costs caused by various investments (Perera and Ashworth, 2015). LCCA compares the future energy and maintenance costs for alternate energy-efficient investments over the whole economic life span. The payoff or payback period is another method that calculates the repayment period i.e. the time where the surplus of direct or indirect income exceeds the initial investment cost. The investment with the total lowest life cycle cost and reasonable payoff period is the most profitable (Perera and Ashworth, 2015).

Making the façade energy neutral or even an energy supplier is an advanced integrated approach. Photovoltaic panels (PV panels) are becoming part of an increasing number of façade systems and provide attractive financial possibility; the solar access to exposed facades led to an adoption of transparent PV panels or Building Integrated Photo Voltaic BIPV to generate renewable energy that can partially or totally cover the electric energy demand (Zhang et al., 2016). In addition to this, the cost of the PV system can be offset by the cost savings of electrical energy which would have been purchased for mechanical system loads.

The crucial role that building occupants play in the building operation makes indoor thermal comfort is quite important for building energy efficiency improvement. Co-benefits can be added to building energy efficiency enhancement, which starts from the increased productivity and less absence of the employees to broader benefit for climate and health. A slight increase in overall productivity can provide large economic benefits. Also, the value of avoided CO^2 emissions from energy use reduction improves public health and decreases the death rate. For instance, LEED-certified buildings in many countries have already avoided 33 million tons of CO^2 emissions, and only 3.5% of the total LEED commercial building in the United States prevented between 172-405 premature deaths in 2016 (Macnaughton et al., 2018).

In conclusion, energy efficiency outcomes can be concerning financial measures that owners or developers may expect and socially effective at the same time. However, the health co-benefits, or in other words, the social cost of energy-efficient buildings should be also considered.

2.5 Socio-Cultural Aspects

Glazed facades buildings usually quite the opposite of comfort preferences; they tend to be cold in winter and warm in summer. Besides, glare from high direct and reflected sunlight reflected on computer screens. However, proper design and control of glazed spaces can create environmentally responsible while providing the amenities and working environment that owners and occupants seek (Selkowitz, S., Aschehoug, Ø., Lee, E., 2003).

Users' perception of indoor thermal comfort is typically linked to their sense of the space temperature among hot, cold or neutral, etc. Their reactions to this sensation or discomfort almost have an adverse impact in terms of energy. For example, users used to overcome glare shaped by glazing façade by using curtains which in turn block the daylight hence needed auxiliary artificial lighting. Despite these curtains cut glare but the heat gain remained and sometimes curtains increase the inside temperature by reradiating the absorbed heat (Freewan, 2011). For this, providing adequate comfort to users should be the main aim of any decision making when enhancing building performance. For instance, when energy-saving strategies are proposed, it's necessary to make sure that users are provided with enough comfort (Bayraktar et al., 2020). Especially that energy savings in one aspect often be at the expense of another; e.g., enhanced thermal performance for glazing can affect the visual comfort and hence higher energy required for lighting and not necessarily increase the total energy demand.

With proper regulation, values of transparency can overweigh its possible shortcomings; workers in daylit spaced enjoying the outside view and have their control will have increased work productivity and Health (Bayraktar et al., 2020). In this regard, many studies provide shreds of evidence of the health benefits of exposure to daylight and views. Daylight exposure is associated with circadian rhythm regulation (Blume et al., 2019), which can have immediate and substantial impacts on sleep quality and the performance of office workers. A recent study in 2020 found that sleep duration significantly increased for employees who had the lowest baseline sleep duration and scored 42% higher on cognitive performance when exposed to daylight and outside views (Boubekri et al., 2020). Further benefits of ultraviolet radiation linked to the physiological aids which include the production of vitamin D in the body that increase the immunity, widening the capillaries of the skin and hence blood pressure reduction, increasing appetite, energetic activity stimulation, feeling of well-being and fatigue reduction (MELAKU, 2016). Views of nature and connectivity have also been shown to provide emotional and psychological benefits by healing depression, aid memory and mood compared to windowless spaces (Berman et al., 2012). All of these benefits reflect on the worker's physiological and psychological health and wellbeing hence increased productivity and output.

Regarding socio-cultural acceptance, Palestinian historical buildings are mainly didn't have excessive use of glass in residential, cultural, public buildings. Small openings were the most features and semblance in Palestinian vernacular architecture mainly for privacy, available building technlogy, solar considerations and due to the compactness in the urban context. However, in working environments, the comfortability and satisfying indoor environment are important aspect when the employees may find glazed spaces to be the most enjoyable part of space (MELAKU, 2016). This is due to the attractiveness of sunspaces, outside connectivity and natural daylighting definitely if the thermal control and ventilation are considered, and even high rise glazed commercial and office buildings are innovative in use, height, and style to their society.

In the Hebron context, highly glazed facades design is mainly coupled with aesthetics and the desire of visual characteristics and not environmental or cultural aspects, this makes the payback of these costly facades become a secondary question rather than a primary for owners and architects. However, with a broader social consideration, highly glazed facades provide more than elegant buildings appearance and a uniform facade surface pattern which improves the architectural quality of the building, Mies van der Rohe (Marcin, 2019). The reinterpretation of modernism hides more social benefits; pleasing workspaces and unexpected urban identity are one of the roles these buildings have always played; they served as a unique highly identification for a company or even a particular city. These buildings are more than fashion driving façade; transparency can make the workspace more open and communicative with the urban environment. This desire for interconnection with the environment, provide also involvement with culture and daily experience within the city. This demonstrates the architect's responsible role in advocating a renovation in the built environment to provide an entirely new contemporary image. Additionally, the glazed facades play a dual informational role; reflected glass can be a screen or image walls or information walls by mirroring images inform the urban environment, or tinted glass that visually opening the building to the public, activates the building within the urban context by allowing the occupants to be visible to the exterior. In both cases, the indoor is connected with the outside environment and the occupants can enjoy the view through these glazed facades.

Embedding social desires with environmental and economic thinking is a crucial issue; if the environmental and economic aspects are considered with the absence of social acceptance then such projects often fail and it is going to be a waste of time and money. Some costly, energy efficient solutions may lead to failure and social unacceptability. For example, in dynamic advanced solutions occupants prefer to have some level of personal control of the indoor environment, this will conflict with owners' or architects' potential to eliminate cooling load when users prefer to open shading to view the outside.

2.6 Conclusion

In conclusion, there is quite social acceptance and a continual tendency toward highly glazed facades in the office buildings in Hebron city. However, without environmental and economic considerations that produce mean internal discomfort that could only be overcome with excessive HVAC systems, it will always be resulting in significant energy, cost, and environmental penalties. Hereby, users' discomfort and owners' financial stresses will reverse negatively on the social tendency. Hence, the core concept is that social acceptance and needs fulfillment plays a significant role in improving the three Es, Eco-Economic-Energy efficiency.

Chapter 3

Environmental Retrofit

3.1. Preface

Buildings' renovation is a common practice in Palestinian culture, but for historical buildings only. However, periodical maintenance and retrofit of the existing buildings and even demolishing office building stock is absent in Hebron society (Figure 3.1). Renovation and refurbishments of buildings are expected to be the tendency for existing stock in the near future, especially for stock office buildings, due to land scarcity and high land costs to build new structures. Retrofitting is usually conduct for occupied buildings (Dodo et al., 2013). However, fairly building stock needs to be retrofitted too. Unfinished and uninhabited buildings have scarce focus from policymakers and are mainly abandoned due to un-considering any environmental deliberations during design and construction, and driven by only economic investments which result in large areas of useless urban space. Therefore, there is an urgent need to increase awareness in terms of retrofit practice to improve the indoor environment of these buildings instead of demolishing or leaving them as stock. Nevertheless, the retrofit decision is always better than demolishing since renovating the inhabited buildings and bring them back into use saves a fair amount of the embodied energy used in the construction (Qadi et al., 2020).

Figure 3.1: An example of a stock office buildings in Hebron, Palestine, in which upper office floors are unused.

On the other hand, inhabited buildings have been considered as one of the fastest-growing energy consumption sectors which were responsible for 28% of global energy-related CO_2 emissions in 2019 (IEA, 2020), (Alghamdi et al., 2015), and are responsible for about 40% of the world's energy consumption (Ali and Al-Hashlamun, 2019). So, any building with high energy use, uncomfortable indoor environment and highly impact the environment have great retrofitting potentials; especially if the energy performance is taken into consideration, it will have a significant saving of the total energy demand and will extend the building service life for further 20-40 years (Alghamdi et al., 2015).

3.2. Retrofitting Types, Levels And Strategies

Many studies demonstrated a wide range of retrofit types, an energy retrofit guide had grouped office retrofitting into three main types according to the alternation size, (Figure 3.2), which depends on the owner's goals and the building conditions (Liu et al., 2020). The first is existing building commissioning: investigating and optimizing the facility performance and its systems to meet the current needs by conducting a routine, periodic physical maintenance. The second is standard retrofits: including equipment, system, and assembly retrofits based on an in-depth investigation and it is often carried out in stages. The third is deep retrofits: this type reduces energy consumption significantly by over 50%, in an integrated whole-building design approach but it requires a larger upfront investment and may have longer payback periods than the preceding types.

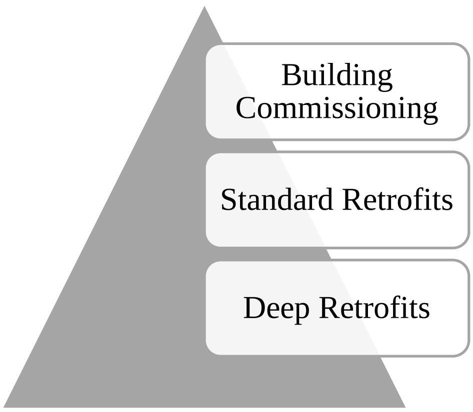


Figure 3.2: Retrofit types based on the alternation size according to (Liu et al., 2020).

However, in any building retrofit type, there are different levels of refurbishment which varies from a renovation of some components to a complete changing in the space layout or structure (Botti, 2012). In this regard, many studies had examined different levels of retrofit. A study of (BRE, 2000), that assessed the possibilities to achieve comfort in refurbished office buildings, had classified four levels of retrofit: the first level is minor renovation in the plan layout and envelope renovations, the second level is major renovation includes alternations in mechanical systems and services such as adding solar control or new energy-efficient lighting and control system, the third level is complete refurbishment involves the preceding two levels, and final level is to cause radical modification to the structure. Another study introduced that there are two primary retrofit levels in terms of energy efficiency: the first level is the renovations of the building envelope and the second is the replacement of existing systems and equipment (Alghamdi et al., 2015).

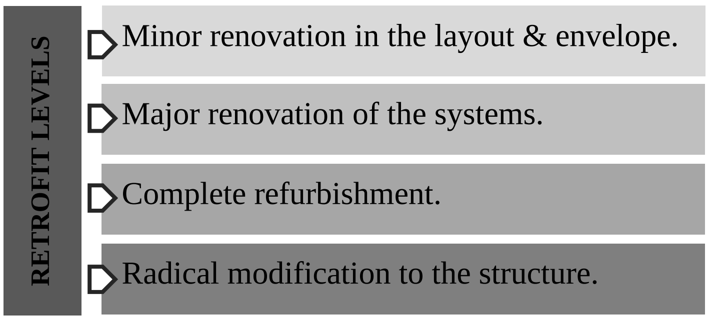


Figure 3.3: Retrofit levels according to (BRE, 2000).

Moreover, many studies classified retrofit activities under main strategies; a study of office building retrofitting strategies had discussed interventions on building façades considering environmental, socio-cultural and economic criteria, and grouped them into three strategies: the stabilization strategy that includes incremental interventions without changing the appearance, the substitution strategy that consists of a complete replacement and transforms the appearance and substances, and double skin façade strategy that stabilizes the façade and adds a new glass skin, in which preserving the original façade. (Rey, 2004). The same study had mentioned that retrofitting strategies affected by many parameters such as the age of the building and embraced the façade as a prominent area of refurbishment.

Another study demonstrated two primary retrofit approaches according to the way of the implementation of the different retrofit actions, the staged and integrated approaches. The staged approach is to complete building upgrades in a way that reveals the influence of one action on another, e.g., investigating the replacement of lighting system and its impact on HVAC demand as lights add heat to office spaces. The benefits of this approach are that costs can be distributed over an extended period and also provide the opportunity of starting with investments that have short paybacks to benefit from their savings in the costs of later investments. Whilst the integrated approach contributes to the synchronized retrofit of multiple building systems and optimized entire building energy performance rather than just optimizing individual measures, e.g., conducting retrofit of lighting system aligned with the HVAC system, building envelope, etc. The integrated retrofit is costly, but also it is substantially reducing energy consumption in a short period and bring about a package of the cost-effectiveness and energy savings of the conducted measures (Liu et al., 2020).

However, a total system approach that considers all systems together and their interactions as one bundle is a core strategy in achieving the desired objectives of energy-efficient retrofit (Banoczy and Szemes, 2015).

3.3. Office Building’s Retrofit

Retrofitting today is considered the most important practice to effectively save energy in the building sector alongside many global governments and organizations have made significant efforts for improving energy performance in existing buildings as well as building new low carbon buildings. In many European countries, retrofit is carried out for existing buildings in terms of the reduction of energy consumption and associated greenhouse gas emissions. Among different targets for retrofitting, there are the occupants' comfort, sustainable indoor environment, and better building performance in conjunction with reducing energy use (Dodo et al., 2013).

The office and commercial building sectors have the highest potential for energy savings regarding retrofit practice (Azar and Menassa, 2015). At the same time where this sector has high energy consumption and it's expected to increase more than 20% by 2035 (IEA, 2020). Besides, retrofitted commercial and office buildings presented higher energy consumption even with new energy-efficient systems (Ilter et al., 2016). For instance, the office and commercial sector consumes 9.8% of the total buildings' energy consumption in Palestine (PEBS, 2019) and needs about 23% of the annual electricity demand of Hebron city (Lazzeroni et al., 2017). Thus, it is important to involve environmental considerations in the conceptual and design phase and also during the maintenance process of the building as well as when taking retrofitting actions.

Recently, Hebron office buildings are directed towards the tallest and highly glazed buildings. The adoption of global trends of the highly glazed office building typology in Hebron city is carried out without climatic adaptation and scarcely applying any environmental considerations or conservation measures. Besides, very little attention is paid to the environmental impacts of these buildings on all levels from the cityscape to the building users. The challenges remain and opportunities exist, to find a way out of this impasse there is a need to adopt an environmentally responsible approach that fits the climatic and urban context of Hebron city in the early stages of the office buildings design or by taking retrofit practices for the existing ones. Especially that the Mediterranean climate provides the ability to integrate the indoor environment with the outdoor according to the climatic conditions; facades can be redesigned in a way that blocks the direct solar radiation in summer and at the same time traps solar heat that gently warm the indoor spaces in winter.

In this regard, studies showed how effective retrofitting buildings in the Mediterranean climate could be. For example, a study highlighted the poor performance of Occupied Palestine's offices especially those with large glazing areas could be significantly enhanced, even up to zero energy (Natanian, 2014). The study demonstrated "the open-air office approach" as an effective passive strategy for retrofitting glazed offices in the Palestinian climate. As overheating was the primary problem of glazed offices, the optimization process mostly focused on blocking solar heat gains while eliminating internal ones. It supposed a 3m transitional space as a dynamic semi-outdoor space with operable full-height glass partitions. This extension of the internal office space introduces the potential for working with the outdoor climate according to the user demand and the outdoor conditions. In which direct solar gains were effectively blocked, internal heat gains can be easily disposed and occupants' control, adaptability, and thermo-visual comfort balance had been solved.

3.4. Environmental Retrofitting of Buildings

In Europe, building retrofit is becoming widespread, where office buildings and educational institutions have the largest share of about 50% of all retrofit activities (Cantin et al., 2002). It is undoubtedly agreed that enhancing the energy performance of existed buildings is one of the most sustainable and efficient approaches for having sustainable buildings with fewer load profiles and less environmental impacts. Many retrofit studies identified the objectives behind retrofitting, these include the degradation of the building fabric, implementation of new technologies and systems, and application of energy codes and standards (Botti, 2012). Bedsides, buildings' retrofitting may aim to carbon footprint reduction by energy savings. The majority of studies focused on providing acceptable conditions, rather than better conditions within the context of buildings retrofits. However, if environmental measures are integrated into a retrofitting activity, in addition to energy benefits, it then can offer building owners and renters a low-risk investment that will reduce operating costs of the saved energy. As well as healthier environments and more competitive buildings regarding the renting and working environment, which benefit the entire economy and risen the property value (Liu et al., 2020).

In addition to this, studies focused on retrofitting more than redeveloping a new model of energy-efficient office buildings. On the contrary of the new model, it is more feasible to retrofit an existing office building that already has definite variables and conditions such as geographical constraints, site orientation and economic, social, environmental and architectural history which gives a framework for retrofitting (Cantin et al., 2002). Besides, retrofit is undoubtedly considered to be time-cost saving, environmentally friendly, and safer compared to the construction from the ground up, and also it is estimated to be 10-75% quicker and cheaper than the new-build (Wilkinson, 2012). In this regard, a growing body of evidence links retrofits solutions with lower environmental impacts and whole-life costs when compared to a new build. This is mainly due to the retained embodied energy in construction which accounts for 40-50% of the total environmental impact of a redevelopment (Botti, 2012). A study in Palestine compared the impact of environmental pressures related to the embodied energy and embodied CO_2 to take less impact decision between reconstructing and retrofitting of an existing building. The results showed that building retrofit can reduce the carbon emissions and the embodied energy by 33% and 18% respectively, compared with demolishing and reconstruct a new building (Qadi et al., 2020).

In an environmental retrofit, it is necessary to consider the interaction between achieving a high level of comfortable office conditions and reducing energy consumption with its' associated operating costs. However, there are some constraints include: the strong contradiction between the high level of comfort and the low energy consumption and the difficulty in achieving all of the thermal, visual and acoustic needs at once, besides that efficient retrofit, means higher cost and need a large financial budget (Cantin et al., 2002). Thus, the challenge is to compromise between these different performance targets.

3.5. Ecological Retrofit

The underestimation of ecological penalties, and taking into account an isolated energy-efficient objective, had driven away many researchers towards sustainability-related objectives. A study discussed the ecological impact of a building retrofit as well as environmental cost represented by the new environmental indicator "emergy" (spelled with "m"). In the process of energy-retrofit building, the less operational energy scenario is not necessarily in favor of environmental advantage or even occupants' comfort. Sometimes, it requires greater indirect energy in construction when these energy reduction strategies are carried out without a holistic view, it may lead to the depletion of non-renewable sources such as minerals, fossil fuels, etc. While energy and "emergy"-thinking yield different retrofit and design results in terms of different passive alternations such as windows ratio, building orientation, envelope materials regardless of mechanical systems (Yi, 2014).

Integrating energy with the environment in retrofitting does not mean installing the most advanced and expensive systems. It is a design philosophy and an optimization process of the choices that improve the indoor working environment and save resources simultaneously (Cantin et al., 2002). To sum up, the ecological retrofit is a part of environmental retrofit that tends to the activities that less harmful for the ecological system, and consider resource depletion which can be quantified by life cycle assessments of various retrofit activities.

3.6. Retrofit Motivations and Common Drivers

A typical office building's energy utility costs are estimated to be around 30% of the building's entire operational costs (Liu et al., 2020). Thus, the principal motivation for most energy efficiency retrofits is the direct benefit of reduced total operating costs as many studies showed that the long-term benefits from retrofits substantially offset the retrofit expenses. Besides, many environmental codes and rating systems such as Energy Star and LEED leveraged building owner's recognition by offering labels and certificates in building energy performance.

In addition to energy cost savings, energy efficiency improvements can have some non-energy benefits including extended building life, greater asset value, a better indoor environmental quality which leads to more satisfied occupants and higher productivity, improved sustainability, and associated marketing of energy-efficient buildings (Liu et al., 2020). Studies concerning energy efficiency have found that these office buildings have 6%-16% higher rents and improved occupancy rates than typical buildings which contribute to higher overall income for a building owner (Fuerst and McAllister, 2009). Another study showed that retrofitted offices in terms of energy efficiency had shown an increase of 10-25% in property value

(McArthur et al., 2015). All of these non-energy benefits are other drivers of building energy upgrades, that can support such motivation with attractive investment opportunities.

3.7. Retrofit Obstacles

However, some retrofit obstacles can prevent owners and developers from taking risks of retrofit interventions. These obstacles include the absence of tangible business real estate cases for up taking retrofit practices, sometimes the renter and occupiers benefit from energy conservation while the owner responsible for all the retrofit costs thus having no incentive for energy savings, and a lack of knowledge about possibilities and constraints associated with specific retrofit measures that make retrofit be risk-taking (Alam et al., 2016), (Botti, 2012). Besides, it is difficult to generalize the cost-effectiveness of different retrofit actions which differ according to climate and the conditions for a specific building (Alghamdi et al., 2015). The greatest barrier to retrofit is that retrofit tends to be costly, requires large capital investments, and followed by a long payback period via operational cost savings (Alam et al., 2016), (Banoczy and Szemes, 2015),(Güçyeter and Günaydın, 2012).

3.8. Economic Aspect of Building Retrofits

In any retrofit project, it is essential to conduct an economic analysis to justify the choice of certain retrofit actions for office buildings (Botti, 2012). It also allows owners to avoid costly investments, and provide a better balance of risk and return (Wilkinson, 2012). Especially in an energy-efficient retrofit that directly contributes to costs savings; in this regard, a study introduces significant savings as a result of controlling the natural and artificial lighting and managing the interior temperature in a retrofit process of an office building, which made a total annual energy savings of 4.4 million dollars (Alghamdi et al., 2015). Generally, studies showed that the reduction of electricity demand and changing old fabric brought about significant energy and cost savings in office buildings (IEA, 2020). For this, the economic study is needed to account for the profitability and if the retrofit is meaningful.

3.9. Retrofit and Occupant’s Satisfaction

The working environment is strongly influenced by thermal, visual and acoustical comfort (Dodo et al., 2013). Thermal comfort is a function of temperature, air movement and relative humidity in a space. Studies showed that hot, cold, and draughty spaces reduce occupants' attention and limit their productivity, and also need further energy which adding unnecessary cost (Cantin et al., 2002). Visual comfort can be achieved by the right integration of daylight and artificial lighting, which makes visual tasks easier for employees. While inadequate lighting or glare can cause eye strains and affect their ability to work. However, the mechanical systems and artificial lighting can meet the needs of working spaces which had been designed and constructed in a way that in-considering these requirements. but occupants do not accept living in an artificial environment for a long-time, they stay need a quiet natural environment. Thus, retrofits can substantially improve occupant comfort and productivity in a building (Liu et al., 2020).

Retrofit's effectiveness analysis is not confined to the economic perspective but also including a range of environmental, and occupant wellness considerations (McArthur et al., 2015). Retrofits driven by energy efficiency measures provide direct, quantifiable savings and have become a standard in renovation policies and codes. However, it should be associated with consideration of social aspects and occupants' comfort since energy consumption is strongly correlated with occupant behavior. Many green-certified office buildings failed in terms of occupant satisfaction and comfort and even though the majority of current retrofit practices are based on codes defined comfort standards (Aktas and Ozorhon, 2015). However, studies showed that the occupants remain dissatisfied with environmental conditions in offices after retrofits (Ilter et al., 2016). In this regard, many retrofit studies called for addressing occupants' needs in the pre-retrofit phase to avoid the performance gap between energy savings and occupant satisfaction. Studies also correlated between the way office retrofitted and workers' performance when social and environmental aspects were incorporated into building retrofits (McArthur et al., 2015).

There are many performance indicators of retrofit practice such as occupants’ comfort, indoor air quality, space use and control by occupants (Shrestha and Kulkarni, 2013). However, it's difficult to accurately quantify these indicators, whereas occupants' satisfaction can be measured by the change in their productivity and absence percentage. A study showed that occupants' amenity can achieve a higher economic value to the occupier than the energy conservation measures, where the results showed that a 1-2% improvement in productivity exceeded the total energy cost and a significant decrease of about 10% in vacancy rate (McArthur et al., 2015). Another study demonstrated that buildings retrofitting not only save energy and reduce operating costs but also contribute to the occupant’s health and comfort, resulting in decreased depression and increased productivity and hence increased investment returns (Ilter et al., 2016). Many wellbeing measures are also useful for improving energy efficiency, for example, improved daylight and increased natural ventilation are associated with the decreased load. Furthermore, when retrofitting an office with costly systems, the increased costs can be outweighed by other energy savings, and even the maximum possible energy savings can't cover them, it can be justified by the potential increase in occupants' productivity (McArthur et al., 2015).

Dependently, it is beyond any doubt that employee satisfaction can be one of the prominent determinates when retrofitting the existing buildings. A study of occupant satisfaction measures in office building retrofits concluded that occupants are a useful source of information in the identification of the retrofit actions required in office buildings (Azar and Menassa, 2015), hence their needs must be determined in the pre-retrofit phase and have the priority to work on. The same study provided a framework for identifying occupant satisfaction dimensions and indicators to be investigated during the pre-retrofit phase as follows:

- Thermal Comfort and its indicators: temperatures, radiant temperature, humidity, and temperature shift, etc.
- Indoor air quality and its indicators: the freshness of the air, natural ventilation, air movement and odors, etc.
- Acoustical comfort and its indicators: noise levels, echo, etc.
- Visual comfort and its indicators: daylight availability, artificial lighting levels, glare, and surface reflection, etc.
- Spatial comfort and its indicators: acoustical privacy, visual privacy, visual disturbance, and space layout, and area.
- User control and its indicators: controllability of the environment of heating, cooling humidity, lighting, shading, etc. usability of control devices such as manual descriptions and feasibility of using devices.
- Building design and its indicators: exterior façades, landscape design and interior design that provide an attractive personalized workspace, colors textures functionality, comfort furniture, ergonomics flexibility, accessibility and connectivity between different spaces, connection to the outdoor environment, and considering the vibration of the wind, vehicles and users.

- Building services and its indicators: service quality of HVAC, waste management, security, cleaning, periodical maintenance, renovation of equipment, using durable materials, preventing leakage, cracks insects, etc.

3.10. Façade's Retrofit

Many international retrofit studies focused on implementing retrofitting solutions of the envelope and the operational systems of the buildings (Alghamdi et al., 2015) since a great part of the used energy is associated with the right exploitation of the benefits and avoidance of the disadvantages of the external climate, and the aided mechanical systems are required to provide a comfortable indoor environment (Kaluarachchi et al., 2005). However, most of the studies had proven that the envelope upgrades have the most significant effect on energy consumption, especially with the emergence of new façade solutions that can respond to the needs of the occupants of both new and refurbished buildings. A study in Europe determined that the retrofit entails 50% energy saving and the most significant benefit was by the envelope improvements via thermal insulation and installing highly efficient windows (Ardente et al., 2011).

Energy-efficient envelope retrofits with insulation employment is a common approach, however, it is important to optimize a combination of all of the reduced infiltration, reduced transmission, reduced or increase solar gain through the envelope, implementing integrated renewable energy technologies and climate control strategies to determine the most appropriate envelope retrofit scenario (Güçyeter and Günaydın, 2012). A retrofit study of the large glazed facades in office buildings in Saudi Arabia focused on minimizing the glazing area and using proper shading and the study showed that a better result can be obtained by using insulation materials in addition to the glazing treatment, the results also showed that reducing the existing glazing area from 31% to 10% can results in energy use reduction by 20% in case of keeping the same glazing type, whilst implementing glazing treatments with better SHGC helped in further 6% energy savings (Alghamdi et al., 2015). Another study showed that heating loads, in an office's tower at Southampton university in the UK, could be annually reduced from 130-30 kWh/m^2/year by replacing the existing single glazing with advanced low emissive double glazing, however, it could result in an overheating, stale air and discomfort in the hot periods (Kaluarachchi et al., 2005).

For this, in the application of the refurbishment of facades, it is essential to assess their benefits and constraints. In many commercial buildings, solar radiation provides natural daylight but also introduces a significant heat gain. Though many studies had provided retrofit solutions; some studies demonstrated that building envelope retrofits should address infiltration first and then the thermal performance of the envelope materials (Liu et al., 2020). Other studies suggested modifying the building shading, glazing type. Others proposed adjusting the reflectivity of building materials since exterior finish colors and surfaces can cause building spaces to absorb heat in cold climates or reflect heat in hot climates. Whatever, most of the studies called to improve the performance of the existing and new build facades in a way that is climatically responsive, economically viable and socially acceptable (Kaluarachchi et al., 2005).

3.11. Retrofit Optimization Process

There is a wide range of retrofit actions that affect each other, and choosing the correct combination of actions, that align well with the retrofit objectives, can increase the overall effectiveness of the retrofit practice. Thus, an optimization process of an environmental retrofit is necessitated to evaluate the effect of individual measures and to discern the most feasible strategy in terms of annual energy consumption, reduction in CO_2 emissions, improvement in indoor thermal profiles and investment profitability, especially for retrofit strategies with costly investments and long payback periods (Güçyeter and Günaydın, 2012) such as in deep retrofits. In a study of (Banoczy and Szemes, 2015), the optimization was among nine retrofits included changing old construction, changing heating and cooling efficiency, changing electricity usage by renovating electric devices and computers, changing consumption habit, combining multiple previous actions such as heating and cooling with construction change and the final scenario was changing all the preceding parameters. The optimization for all parameters causes the most significant energy savings, but it was a very expensive solution. In such a process, the energy optimization is insufficient for an environmental retrofit; hence further optimization is needed, an optimization of energy-cost effectiveness to guarantee the goal's attainability as well as cost viability. Besides, some of the environmental benefits must be considered rather than take into account just energy savings. In this regard, another study examined different scenarios included adding insulations and low emissive glass for an office building envelope, the final results indicated a decrease in annual heating by 12.32% and the cooling load reduced by 19.42% due to applying the final optimized retrofit strategy. The study also showed that the optimized solution provided reduced CO_2 emissions by 19.27%, had a shorter payback period of 9 years, and better performing indoor environment (Güçyeter and Günaydın, 2012).

When it comes to energy efficiency retrofit, the optimization process must be conducted based on energy benchmarking. Implementation of benchmarking provides baseline information by a process of evaluating the energy performance of a building at a certain period that will help in performance comparison, set energy performance goals, and clarifies the scope of the retrofit including the metrics and data needed. A retrofit guide book provided four approaches to benchmarking; they include internal, external, quantitative and qualitative approaches. Internal benchmarking compares energy performance within a building portfolio, while external compare a building performance with similar buildings. A quantitative approach compares the changes in building performance or the divergence between the building and similar buildings through time. The qualitative approach analyzes the differences across the entire building's historical background to determine best practices and areas for improvement (Liu et al., 2020). However, there are common comparisons made when benchmarking that discussed in the same book:

- Best in class: the building performance compared to the best performing building within a range of buildings with similar features and characteristics.
- Average: the building performance compared to the average performance of buildings.
- Baseline: the building performance compared to its historical performance.
- Performance standard: the building performance compared to a defined building energy standards or codes.

3.12. Energy Efficiency Retrofit Planning

A carefully planned approach can record better achievements; thus, an energy efficiency retrofit plan includes a set of actions: retrofit goals, action plan, economic analysis and optimization process, implementation approach, and project completion (Alam et al., 2016), (Liu et al., 2020). Retrofit goal reflects the desires behind achieving improvement on a building’s baseline energy performance. An effective and achievable retrofit goal is supported by an action plan that explains how the goal will be achieved through the implementation of specific actions aligned with the available financing options. When completing an energy efficiency retrofit, it's necessary to check that the reduction goals are achieved to be considered successful (Liu et al., 2020).

Energy retrofit guides also provided an energy audit which analyzes building energy performance and identifies the required retrofits based on energy and cost savings. Energy audits involve:

- Pre-site visit analysis: before the retrofitting conception, a deep diagnosis of the existing building is essential (Cantin et al., 2002). This involves a review of available data relating to the office typology, shallow plan or open plan, naturally ventilated, or air-conditioned office (Botti, 2012). Besides, the building’s operations and energy performance. These data can be gathered through many actions such as monitoring the temperature profiles throughout the year (Soutullo et al., 2015).

- Site visit data gathering includes a walk through the building to investigate and observe the buildings' energy-consuming systems and operations. Supported by questionnaires, taking photos, and conducting interviews with building occupants.

- Post-site visit analysis and reporting: deep analysis of the buildings' energy consumption, the energy savings potential of different retrofit scenarios and improvements, and the determination of the most appropriate scenario based on cost-effectiveness and other priorities such as environmental impacts.

3.13. Conclusion

Retrofitting is an important practice for enhancing energy efficiency in the existing buildings with high energy consumption and poor indoor environment. It is more practicable to retrofit an existing office building with definite variables that provide a framework for retrofitting and hence save time, cost and land space when compared to build a new one.

Chapter 4

Research Methodology

4.1. Research Type and Data Collection Method

The theoretical part of this research involved a deep literature review that has been presented in detail in chapters 2 and 3. The review was developed based on scientific journals, research papers and books, to justify the problems associated with highly glazed facades and then to have a strong base, knowledge and experience about the glazing technologies and retrofit strategies associated with office buildings. The review also intended to obtain and determine the most common methodologies used in similar researches and data analysis methods, comparing them, selecting and justifying the most appropriate method depending on the availability and suitability to the local context. Whilst the practical part consists of field study and simulation work, followed by the optimization process using simulation software and financial analysis. Afterward, optimal solutions are selected and justified. Finally, the research plan, required resources, method of data analysis, and the process of the study are discussed.

This thesis is conducted in an inductive method, in which the glazed facades had been observed and simulated to confirm the most appropriate and optimum solution as the following procedure presented in Figure 4.1 below:

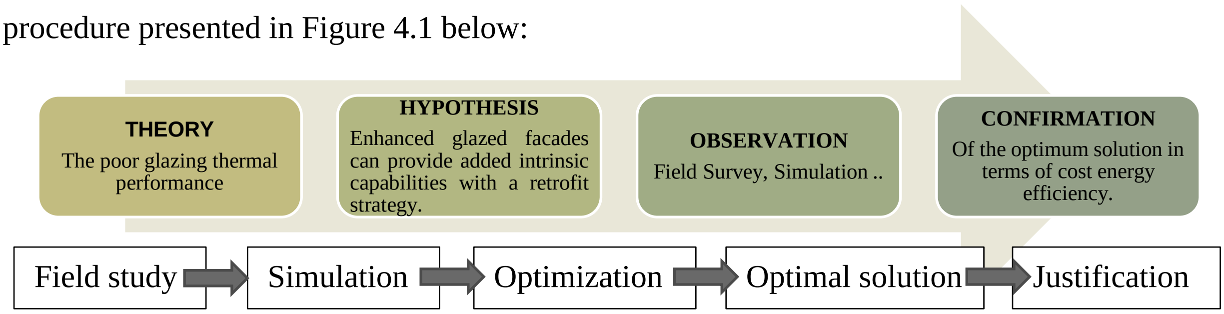


Figure 4.1: The upper chart shows the research inductive method according to (Kothari, 2004). The second chart shows the methods for observation and confirmation.

This research is also followed by both quantitative and qualitative approaches in data collection and data analysis processes. A quantitative method identified the energy consumption and the associated variables such as the thermal performance of the glazed facades and quantified the probable effects of different retrofits in terms of energy, cost and environmental impacts as well as assessing the differences between them. Whereas a qualitative method is based on exploring the phenomenon of highly glazed facades and a deep understanding of associated energy consumption with the external forces that shape and are shaped by energy variables. Figure 4.2 below demonstrate the difference between the two approaches.

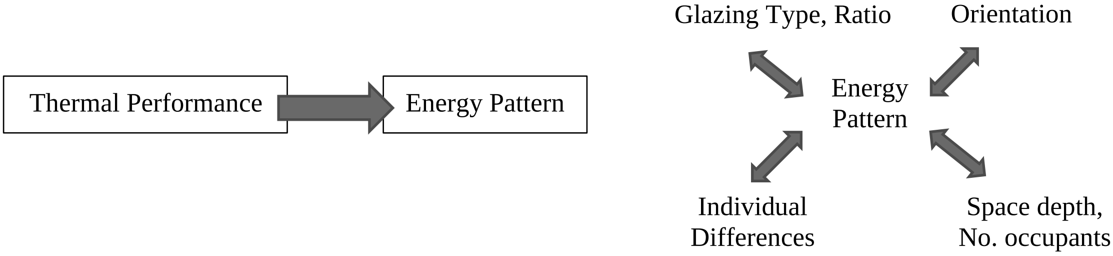


Figure 4.2: The research quantitative and qualitative approaches where the quantitative approach on the left and the qualitative approach on the right.

The data were collected through deep literature research and also the field research which included participant observation, case studies selection, questionnaire, measurements which were taken using a thermometer that measures the ambient air temperature and relative humidity and lux meter that measures the lighting illuminance of the natural and artificial lighting (Figure 4.3 demonstrates the devices used in field measurements). Simulation was conducted using DesignBuilder v6 software, an advanced tool that can model and compute building performance, enabling to develop comfortable and energy-efficient building designs from design concept to building operation to quantify the impact of any design strategies on building environmental performance or to validate compliance with different building regulatory codes and certification organizations such as LEED, Energy Star and BREEAM Building (*Energy Software Tools*, n.d.).

Figure 4.3: The used devices, a light meter on the left, humidity and temperature meter on the right.

4.2. Data Analysis Method

The data collected through literature was analyzed by comparing different glazing technologies in terms of shading and insulating capabilities and the availability and suitability to the local context, and different retrofit methods were analyzed according to suitability to the research purposes. Whilst the data gained by the field survey through measurements, observation and questionnaire which were presented as tabulated data sheets of each of three chosen cases. The measurements include indoor air temperatures in celsius, relative humidity, daylight intensity in lux, office dimensions, etc. The questionnaire was distributed and filled by the employees in three buildings on 15-16 March 2020. In each building, six chosen offices had been questioned with a total 18 responders. The responses were analyzed using excel sheets in terms of thermal individual differences, thermo-visual comfort and employee satisfaction, energy consumption patterns of heating and cooling end-uses, maintain indoor environment means and solar protection tools, occupancy schedules and working environment. The simulation results were analyzed using excel sheets, tables, charts, and comparisons in terms of energy performance and cost-efficiency.

4.3. Field Study

4.3.1. Case Study Area: Hebron

Hebron city is the largest city in the West Bank located in southern Palestine, 30 km south of Jerusalem, (Figure 4.4). It lies 943 meters above sea level with a latitude of 31.532569° and longitude 35.099826°. Hebron city has a Mediterranean climate of cold rainy winters and very warm arid summers. The warmest months are July and August with the highest average high temperature of 29°C, (Figure 4.5). The average annual humidity is about 61% with a mean annual rainfall of 130mm, (Figure 4.6).

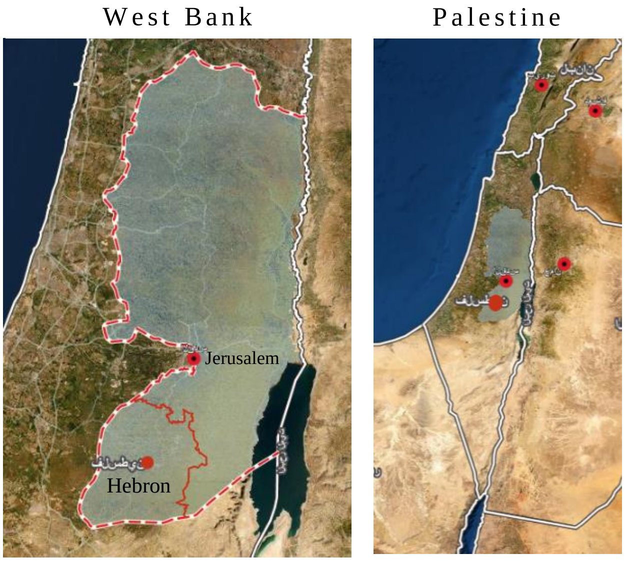


Figure 4.4: Hebron city location according to the West Bank in Palestine (mstkshf, 2019).

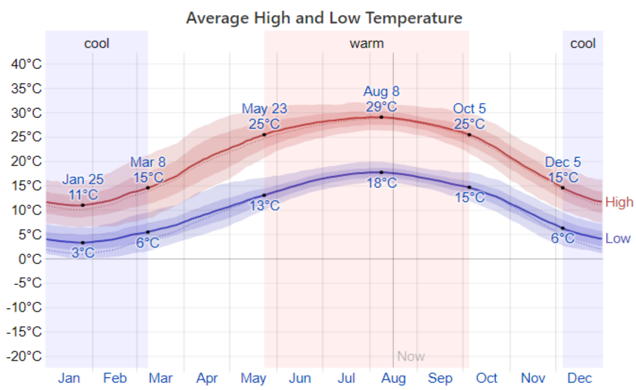


Figure 4.5: The daily average high (red line) and low (blue line) temperature in Hebron city (Weather spark, 2016).

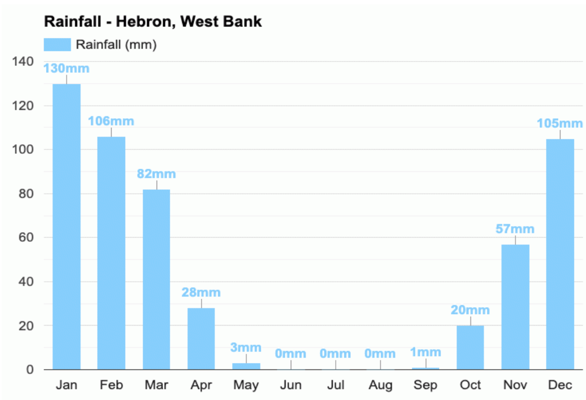


Figure 4.6: The average rainfall of Hebron city (Weather Atlas, 2020).

January has the lowest average high temperature of 12°C and the highest rainfall (Weather Atlas, 2020). Figures 4.5, 4.6, 4.7, 4.8, and 4.9 with table 4.1 show the yearly averages of temperatures, rainfall, solar radiation, and wind data of Hebron city.

In Hebron, the average daily solar radiation experiences seasonal variation over the year. Where June 21st is the sunniest day of the year with average radiation of 8.6 kWh/m^2 and 14 daylight hours. However, in winter the average solar energy is below 4.2 kWh/m^2, (Figure 4.7).

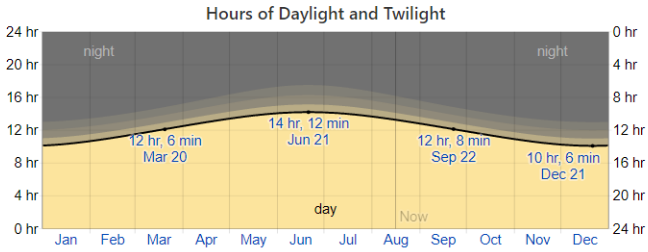


Figure 4.7: The average number of daylight hours (Weather spark, 2016).

Months from May to September are the windier period of the year with an average wind speed of more than 3.2 m/s. The windiest month is June with an average wind speed of 3.6 m/s. The calmer period is from September to May. The calmest month is December with an average wind speed of 2.8 m/s, (Figure 4.8).

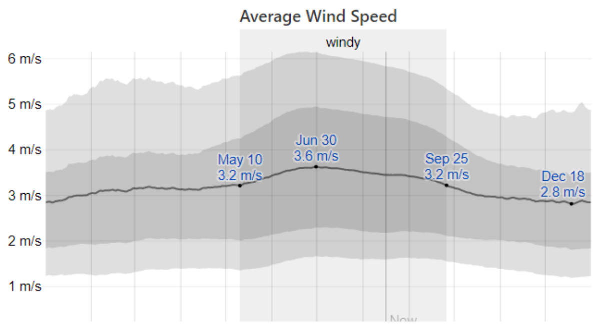


Figure 4.8: The average of mean hourly wind speeds (Weather spark, 2016).

The wind is most often from the North west for a period from August to November, and from the west for months from November to August, (Figure 4.9).

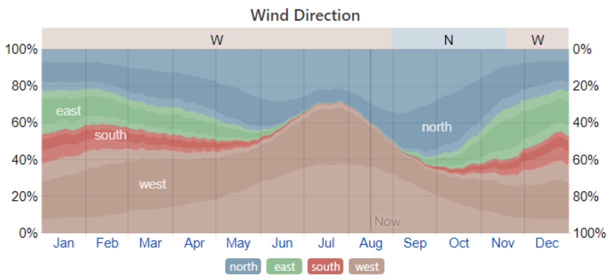
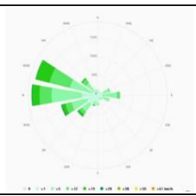


Figure 4.9: The mean wind direction (Weather spark, 2016).

Table 4.1: Hebron city monthly climate averages (Weather Atlas, 2020).

	Temperature (°C)		Wind speed (m/s)		Wind Direction		Humidity
	Average low	Average high	Average	Maximum			
Winter	4	12	2.8	5	West		65%
Summer	17	29	3.2	6	North West		45%

The field survey was carried out in two phases, a satellite survey and an investigatory survey as follows:

4.3.2. Satellite Survey

This survey was conducted in three days started on 1st February 2020 in the main arterial street in Hebron city (Ein Sara street) which represents around 23% of the city area, (Figure 4.10). The chosen study area is characterized as a commercial and business center of the city where glazed buildings are mostly assembled. Where highly glazed hotels and shopping centers in other areas are excluded. Taking into consideration the other adjacent major cities that have a fair number of glazed office buildings as Ramallah city and Bethlehem, the survey limited to cases of recent and different glazing types used in these cities.

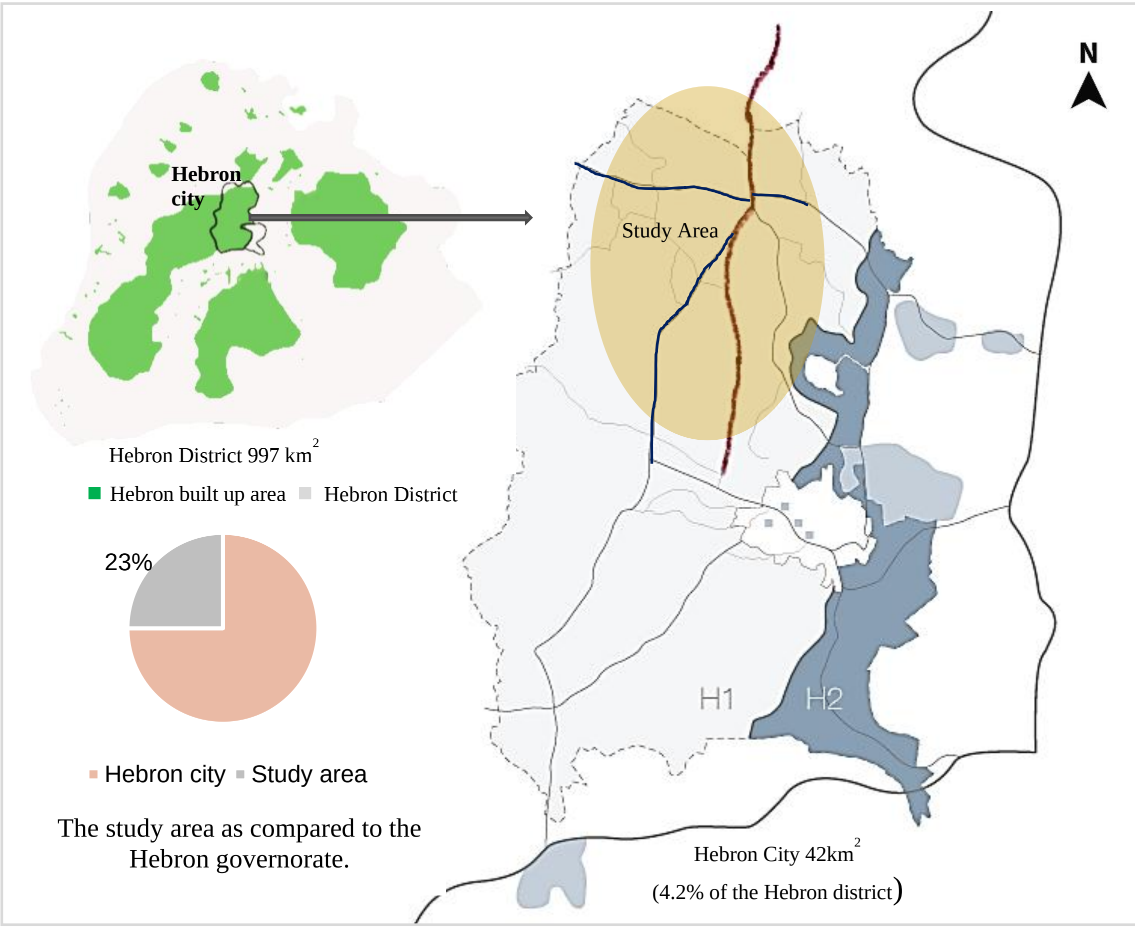


Figure 4.10: The study Area in Hebron city. (The shaded area represents the investigated study area. Where the red line is the main street in the city with the blue streets where the glazed office buildings are assembled).

The objective of this survey is to make a survey of the commercial and office buildings with a highly glazed façade in the study area in order to choose a representative sample for the investigatory survey.

4.3.2.1. Cases Classification & Description Criteria

The satellite survey sample was classified according to the glazed façade orientation. In this survey, the glazing to wall ratio, glazing type, insulation, and shading for each glazed building in the study area were determined.

4.3.2.2. Cases Selection Criteria

Among the comprehensive survey sample, a narrower sample of glazed buildings had been chosen based on the higher glazing ratio (more than 70%), the advanced common glazing type and different orientations between North, South, West and East to be studied in-depth as shown in Figure 4.11.

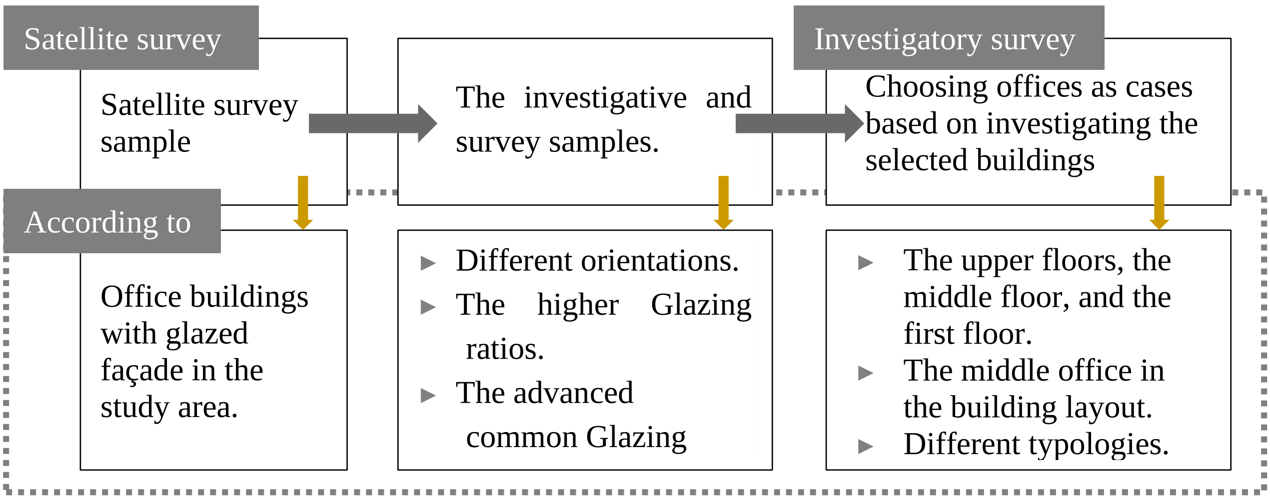


Figure 4.11: Cases selection criteria.

Besides, the offices in the chosen sample from the pilot survey had been selected to be investigated according to the floor height, and office typologies, location and dimensions. This investigation intended to choose which offices possible to be as cases for implementing the required retrofits.

The conceptual illustrations, (Figures 4.12, 4.13) show the selection of offices in each chosen building to be investigated based on floor height and the office location in the plan layout. The offices in the middle of the plan had been investigated to exclude the effect of the side windows and emphasis the only effect of the front glazed façade after investigating the upper, mid-floor and the first floor as the ground is used to be commercial and the upper is more exposed to the solar radiation, whilst the first floor more shaded from the surroundings. After that, a case from each building had been chosen among these investigated offices based on the investigation results and in the attempt to have different offices' typologies.

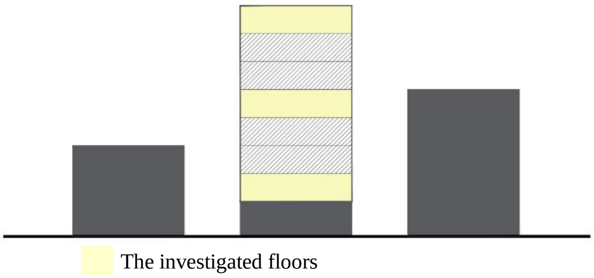


Figure 4.12: An illustration of sample selection according to floor height.

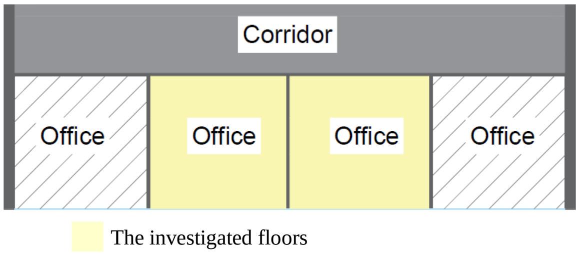


Figure 4.13: Cases selection based on location in the plan layout (illustration).

4.3.3. Investigatory Survey

The satellite survey study is followed by an investigatory survey for a selected building which is a deep investigation of selected glazed office buildings' in the study area to provide a benchmark for the retrofit practice. In which the baseline conditions are compared with the retrofitted models. Thus, this survey aims to represent the chosen cases as accurately as possible and to create more realistic base models; this survey based on:

a. An observation and a walk among the selected samples to investigate the general situation inside the offices include office depth, length and height, glazing to wall ratio, number of occupants, and their activities (Figure 4.14).

b. The measurements of daylight, air temperature, and air humidity to inspect the thermal visual performance (Figure 4.14).

c. A questionnaire to evaluate the thermo-visual comfort and the energy performance in the chosen glazed office buildings, the employee's preferences and attitudes, the used shading devices, the used cooling and heating devices.

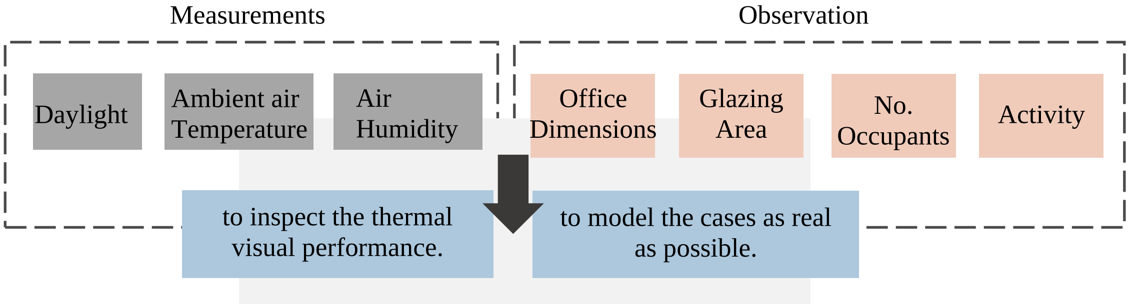


Figure 4.14: Observation and measuring parameters.

The office observation is mainly intending to obtain all the parameters that can be used as inputs in the DesignBuilder software to generate a real base model that can be compared to a developed model according to different retrofit scenarios. In which the parameters include: the dimensions, the glazing to wall ratio that affects the heat gains and losses, and the occupants' number with the activity that increase the internal heat gains and determine the metabolic ratio of the model.

The measurements were used for the assessment of the thermo visual performance of the investigated offices and also to model the cases as real as possible by comparing the measurements with the simulation results. For these purposes, the temperature measurements were taken on days that were chosen to be a cloudy or sunny day in March, June and August at 9:00 am, 12:00 pm and 1:00 pm. The temperature and humidity readings were taken at the center inside the office and outside the building, (Figure 4.15). The daylight illuminance (luminous flux per unit area measured in lux) was taken above the workstation and at the outermost part from the glazed facade in the office, (Figure 4.16).

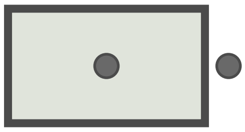


Figure 4.15: The temperature readings points.

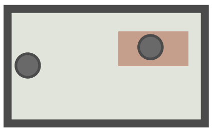


Figure 4.16: The daylight illuminance readings points.

The questionnaire required to justify the problems associated with highly glazed facades through questioning about thermo visual comfort, and also to estimate the energy demand for such offices. Besides, to obtain data of used solar protection tools, shading devices or glazing technologies, etc. To do so, a questionnaire had been developed to be filled by offices' employees for each of the selected cases. The questionnaire is based on the correlation of data concerning the indoor environment comfort and energy consumption by getting a set of questions that help in analyzing the glazed offices. The proposed questionnaire has been developed also following certain objectives, (Figure 4.17).

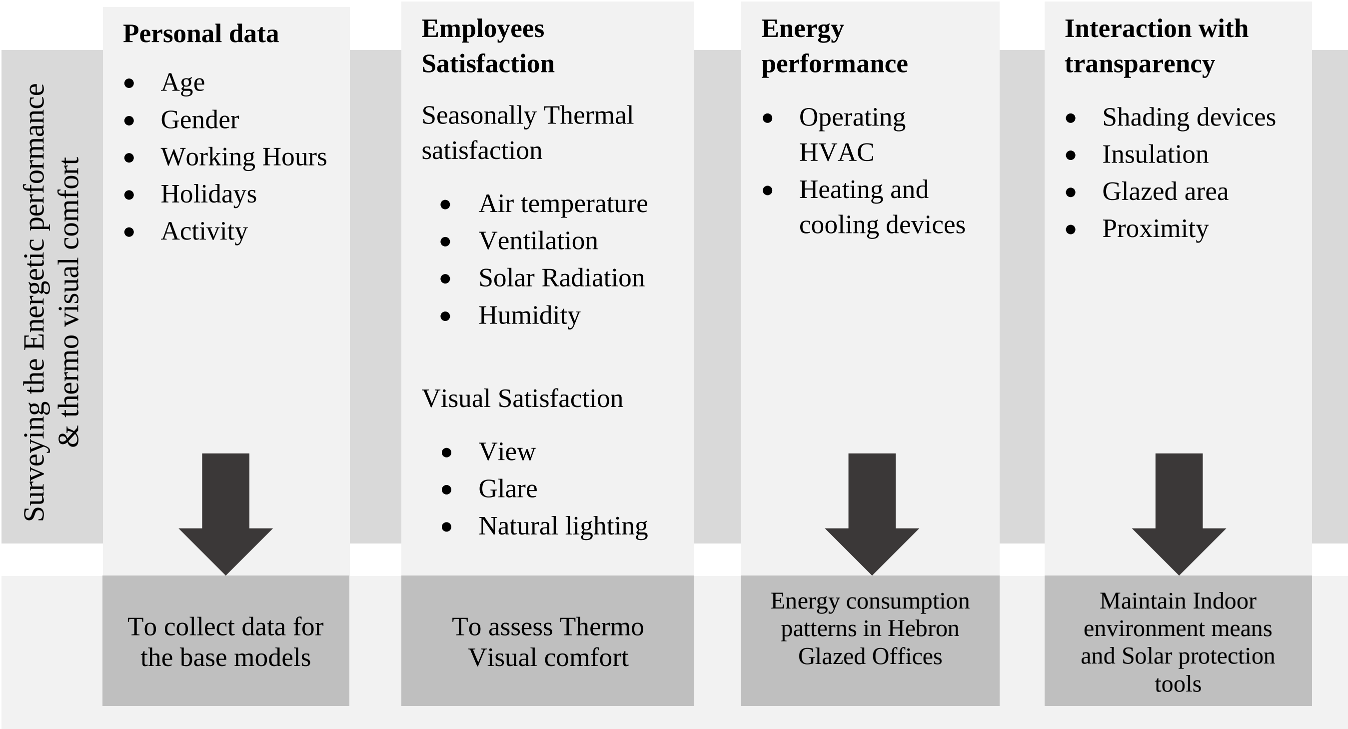


Figure 4.17: Questionnaire design concept.

The questionnaire addressed four main issues: 1. Personal data is related to employees' age, gender and working environment, schedules, etc. 2. Employees' satisfaction includes thermal and visual sensation and their assessment for air temperatures, ventilation, natural lighting and glare. 3. Energy performance by investigating the used heating and cooling devices and their setpoints and operating schedules. Dependently, these issues are distributed in four main sections following their specific objective: 1. General Personal data. 2. Thermal comfort in summer. 3. Thermal comfort in winter. 4. Visual comfort.

The general personal data (Table 4.2) is required to determine the thermal individual differences in case there is a large deviation in answers for the same case (office), this is mainly due to the thermal individual sensation related to age, gender, health state, etc. It is also used for determining heat gains produced by occupants during the occupancy period which is associated with their activity and devices they use in their work. All of these parameters help in generating the base model for each case as follows:

Table 4.2: Section 1 in the proposed questionnaire form.

Section 1. General Personal Data					
Question		Answer options			
Q1	Gender	Male	female		
Q2	Age	20-30	31-40	41-50	Above 51
Q3	Working schedule	Morning shift (8:00-12:00)	Evening shift (12:00-4:00)	Full (8:00-4:00)	
Q4	Career	Filled by employee			
*Q: Question.					

Question 1: Gender. In case the answers were different, the gender determines that the difference is referred to as thermal individual differences and also to determine the metabolic rate for the base model. Since studies showed that the comfortable temperature of females is 1 C° higher than males, they generally prefer slightly warmer temperature because females' skin temperature is consistently lower than males and they are physiologically more sensitive to the cool environment while males are more sensitive to the warm environment (Wang et al., 2018), (Chang and Kajackaite, 2019).

Question 2: Age. As in question 1, age can determine also the thermal individual differences. In this regard, it was found that elderly people are more sensitive and feel less comfortable in cold conditions than young (Wang et al., 2018), (Guergova and Dufour, 2011), (Schweiker et al., 2018).

Question 3: Working schedule. It is used as input for the base model which calculates the heat gains produced during the working day and other parameters such as the operation of lighting and HVAC systems.

Question 4: Career. The career is required to define the nature of the employee's activities and work environment to determine the metabolic rate and the used devices like computers, printers, etc.

Thermal comfort in summer and winter were analyzed in sections 2 (Table 4.3) and 3 (Table 4.4). The questions intended to assess the thermal comfort and occupant satisfaction, and the energy consumption patterns in glazed offices during heating and cooling periods to identify the general situation in these offices in terms of indoor thermal & visual environment and energy consumption as follows:

Table 4.3: Section 2 in the proposed questionnaire form.

Section 2. Thermal comfort in summer							
Question		Answer options					
Q1	How do you find the temperature inside the office in summer (without using any air conditioning)?	Very hot	Hot	Warm	Moderate		
Q2	The most time in summer the office is uncomfortable for you (More than one answer can be selected):	Morning	Noon	Afternoon			
Q3	Generally, windows in summer are:	Fully opened	Partially opened	Closed			
Q4	How do you feel the air in the office when opening windows in the summer?	Acceptable	Unacceptable				
Q5	If the previous answer is unacceptable, that is due to the air is:	Strong	Still				
Q6	What is the used cooling method?	Natural Ventilation	Fans	Mechanical Ventilation			
Q7	Select the months you use coolants (More than one answer can be selected):	May	June	July	August	September	October
Q8	Select periods when you use (fans or AC). More than one answer can be selected:	8:00-10:00	10:00-12:00	12:00-2:00	2:00-4:00		
Q9	If you use fans, you set the fan to:	Lowest speed	Moderate speed	Highest speed	Don't use		
Q10	If you are using the air conditioner, you set the temperature at:						
Q11	In the event of power outages and a feeling of hot weather inside what are the procedures you use:	Open all windows and doors	Have cold drinks	Move to outside	Other		
Q12	You think that alternatives are:	Sufficient	Insufficient				
*Q: Question.							

Question 1: How do you find the temperature inside the office in summer (without using any air conditioning)? It determines the occupant's satisfaction level during summer as the glazed office induced to high solar radiation.

Question 2: Most time in summer the office is uncomfortable. The answer helps to assess the exposure to the solar radiation and the ventilation in the office especially the night ventilation, e.g., if the answer is morning it may be related to the east orientation of the façade or due to the heat gains trapping during the day before. In addition to this, the answer indicates the validity of the questionnaire, e.g., the east oriented facades are most uncomfortable in the morning.

Question 3: Generally, windows in summer are fully or partially opened, or used to be closed? The answer can be correlated with the ventilation effect on the answers of the previous questions in a naturally ventilated space.

Question 4: How do you feel the air in the office when opening windows in the summer? The answer will determine the natural ventilation in the office to also assess the thermal performance.

Question 5: If the previous answer is unacceptable, so that is due to the air is? To describe the air movement in the space and dependently its effect on thermal performance.

Question 6: What is the used cooling method? The main objective is to calculate energy consumption depending on questions 7, 8, 9 and 10 and the power of the used devices.

Question 7: Select the months you use coolants. The answer is used in annual energy consumption calculation.

Question 8: Select periods when you use (fans or AC). The period depends mainly on the orientation and heat gains in the office, the answer is also used in annual energy consumption calculation.

Question 9: If you use fans, you set the fan speed to? It determines the power used for cooling the office since a higher fan speed consumes more electricity.

Question 10: If you are using the air conditioner, you set the temperature at? Besides the energy consumption calculation, the answer is used in determining the setpoints for the base model as warmer or colder setpoint temperatures correspond to higher energy demands.

Question 11: In the event of power outages and a feeling of hot weather inside what are the procedures you use? And Question 12: You think that alternatives are sufficient? It determines if the thermal environment can spare the cooling devices or not thus, the answer is required for the thermal performance assessment.

The same as the previous section, the thermal performance and occupant's satisfaction had been analyzed during the winter season as shown in Table 4.4 below.

Table 4.4: Section 3 in the proposed questionnaire form.

Section 3. Thermal comfort in Winter							
Question		Answer options					
Q1	How do you find the temperature inside the office in winter (without using any heating)?	Warm	Moderate	Cold	Very cold		
Q2	The most time in winter the office is comfortable for you (More than one answer can be selected):	Morning	Noon	Afternoon			
Q3	How is the office usually ventilated in winter?	Naturally	Mechanically				
Q4	What is the used heating method?	Electrical radiator	Split units	Central heating system	Sunrays		
Q5	Select the months you use heating (More than one answer can be selected):	October	November	December	January	February	March
Q6	Select periods when you use (fans or AC). More than one answer can be selected:	8:00-10:00	10:00-12:00	12:00-2:00	2:00-4:00		
Q7	If you are using mechanical heating, you set the temperature at:						
Q8	In the event of power outages and a feeling of cold weather inside what are the procedures you use:	Stay in sunny areas	Wearing more clothes	Close all openings	Have hot drinks		
Q9	You think that alternatives are:	Sufficient	Insufficient				
*Q: Question.							

The visual comfort section (Table 4.5) relied on the visual performance assessment and the determination of the means of maintaining the indoor environment and solar protection tools as follows:

Table 4.5: Section 4 in the proposed questionnaire form.

<table>
<tr><th colspan="14">Section 4. Visual comfort</th></tr>
<tr><th colspan="2">Question</th><th colspan="12">Answer options</th></tr>
<tr><td>Q1</td><td>How do you find the natural light in the office in general?</td><td colspan="4">Excellent (Sufficient)</td><td colspan="4">Good (still need artificial lighting)</td><td colspan="4">Disturbing (Glare)</td></tr>
<tr><td>Q2</td><td>How do you like the sun to be in summer?</td><td colspan="4">More shaded</td><td colspan="4">Sunnier</td><td colspan="4">No change</td></tr>
<tr><td>Q3</td><td>From your point of view, does visual contact with the outside through the glazed façade increase your activity and comfort at work?</td><td colspan="6">Yes</td><td colspan="6">No</td></tr>
<tr><td>Q4</td><td>Determine the methods used to avoid high glare, (More than one answer can be selected):</td><td colspan="3">Curtains</td><td colspan="3">Overhangs</td><td colspan="3">Tinted glass</td><td colspan="3">Louvers</td></tr>
<tr><td colspan="14">*Q: Question.</td></tr>
</table>

Question 1: How do you find the natural light in the office in general? And Question 2: How do you like the sun to be in summer? It directly provides the occupants' impression and assessment for natural daylight intensity and the need for artificial lights or solar protection tools.

Question3: From your point of view, does visual contact with the outside through the glazed façade increase your activity and comfort at work? It determines the occupant's preferences, proximity and interaction with transparency.

Question 4: Determine the methods used to avoid high glare? To determine the solar protection tools and shading devices to be defined in the base model.

4.4. Retrofitting Process

The retrofit process consists of three main phases as shown in Figure 4.18.

Figure 4.18: Retrofitting process.

Phase 1: Creating Base models, (Figure 4.19). This phase strongly relied on the data collected from the field survey by observation, measurements and questionnaires such as case interior layout, dimensions, glazing type and ratio, number of occupants in the space, the cooling & heating devices, shading devices, occupancy schedules, urban context, etc. Besides, the climatic data of the study area.

A data of daylight illuminance, air temperature, envelope properties, urban context, climate data and all the data obtained by measurements and observation is required for confirming the base model by comparing these parameters obtained from field work and the simulation results for the base model. Besides, since there are no measurements or data for exactly heating and cooling loads by the electrical company in the study area, the calculated energy consumption for heating and cooling were obtained from the questionnaire based on the number of months and daily hours for operating cooling and heating devices and their operating power and devices properties.

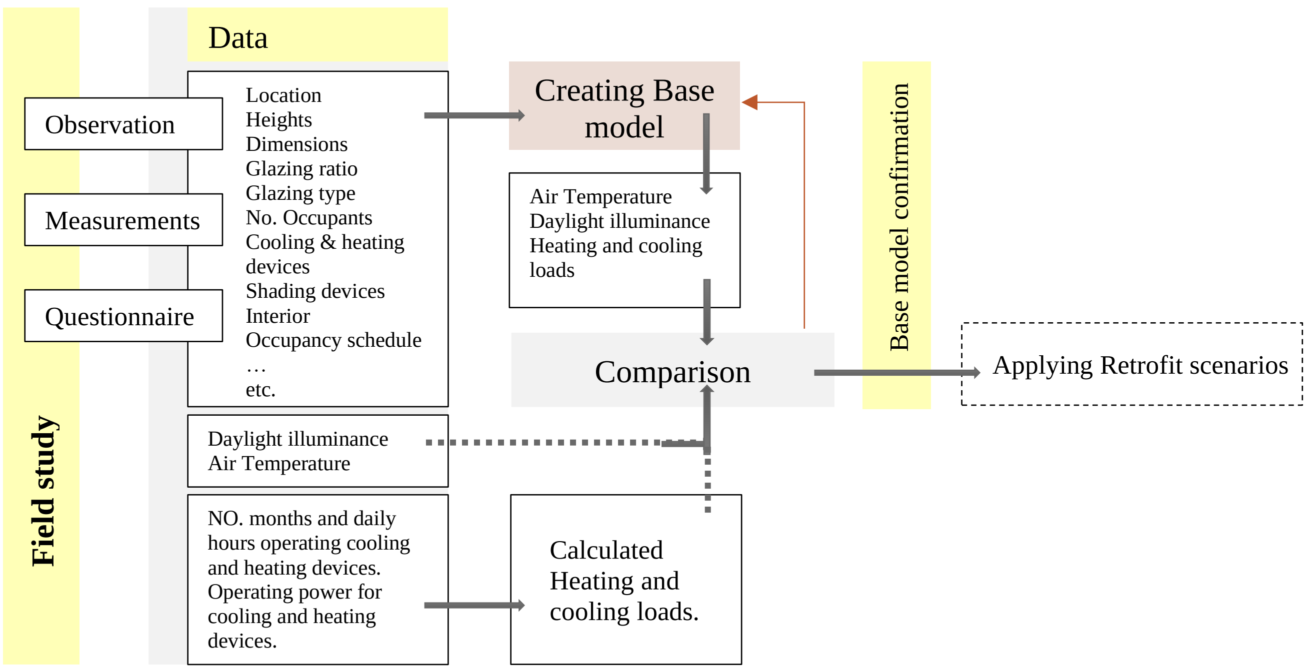


Figure 4.19: Retrofitting phase 1, creating of the base model.

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 also a combination of two or all of them. In this phase, new models had been created by retrofitting the base models for each case, and then multi simulations had taken place to obtain the results of applied retrofits.

The shading devices were selected among overhangs, blinds and louvers and combination between them besides some advanced shades as seen in Figure 4.20 below. For each case with a specific orientation, the appropriate shading device in terms of cooling and heating energy was determined. This scenario-based on two main procedures, the first is the estimation of the cooling loads of each shading device from 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 demonstrated scenario 1 for each case.

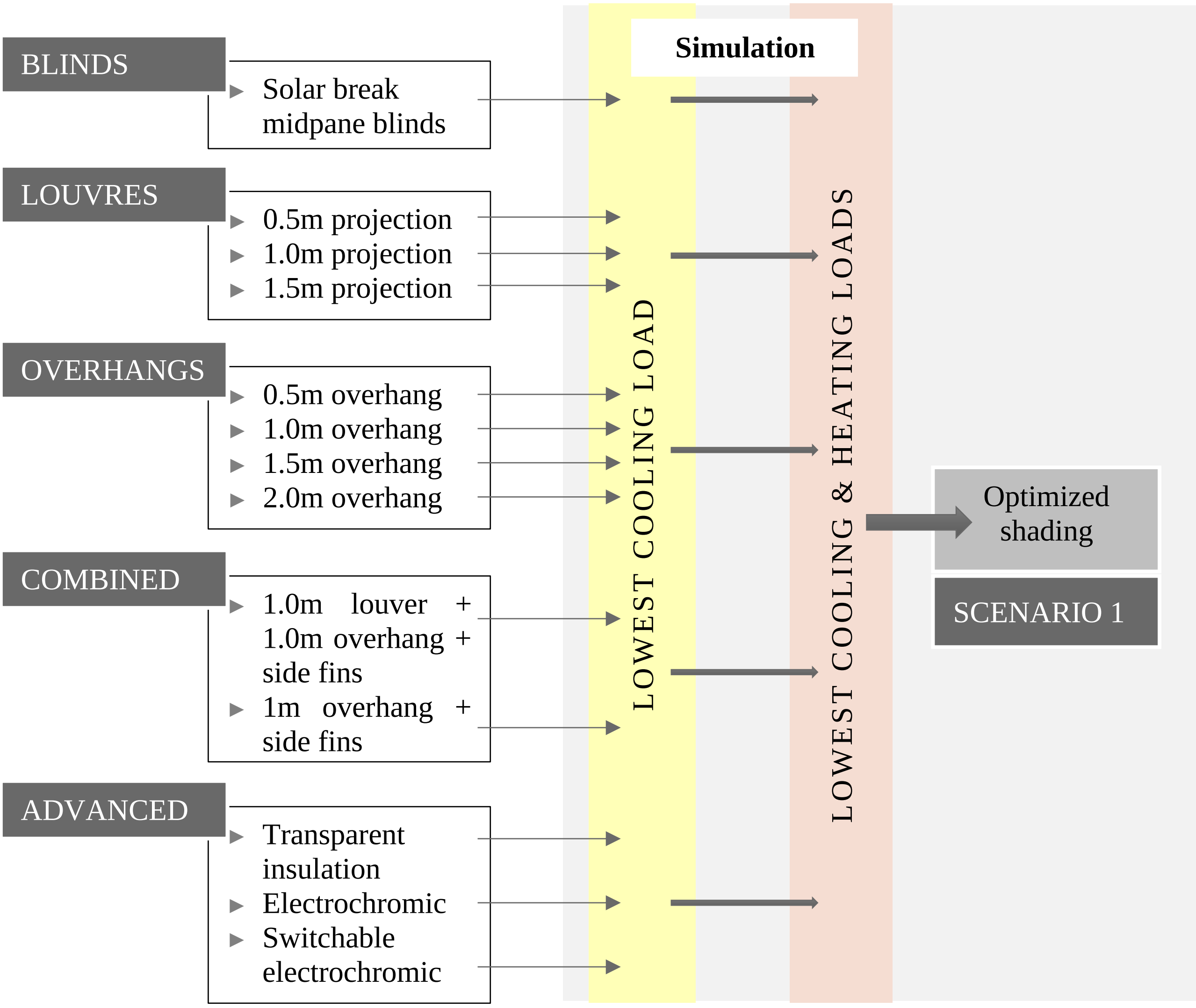


Figure 4.20: Retrofitting phase 2, proposing retrofit scenario based on shading devices.

Glazing types involved 44 types, which are presented later in chapter 5, among 14 different glazing technologies, (Figure 4.21). In which the optimal glazing type for each case was found after filtration of the 44 types according to the lowest solar heat gain coefficient SHFC and lowest transmittance U-value and then filtered again according to the lowest cost with the higher visibility transmittance value VT.

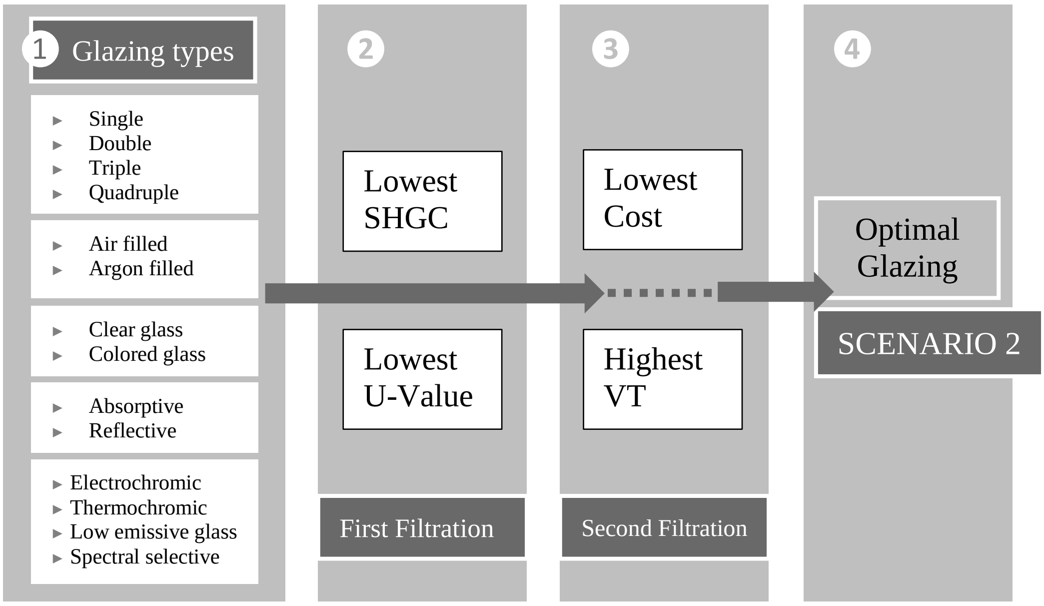


Figure 4.21: Retrofitting phase 2, proposing retrofit scenario based on glazing type.

Multi skins scenario includes applying double and triple skins (Figure 4.22). In which the added skins were simulated and classified in terms of heating and cooling loads as follows:

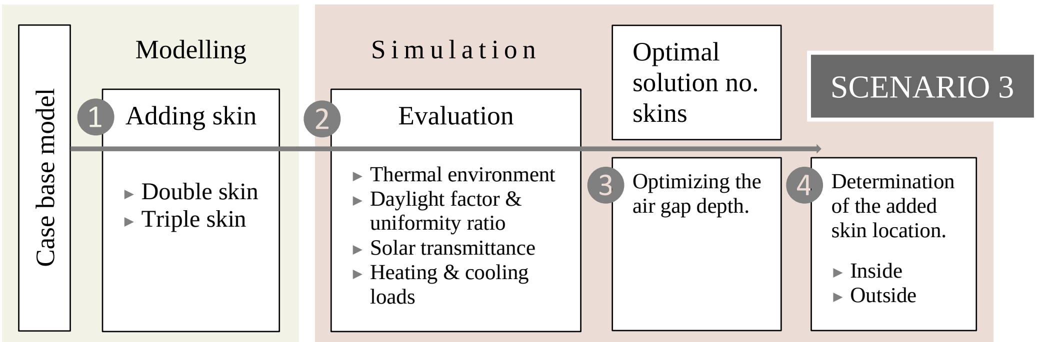


Figure 4.22: Retrofitting phase 2, proposing retrofit scenario based on applying multi skins.

1. Adding skin: Double and triple tinted glazed skins had been added from the outside of the office 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 include ambient and operative air temperatures, humidity and occupant's satisfaction, daylight factor & uniformity ratio, solar heat gains & losses, and heating & cooling loads. The evaluation based on comparisons and rating points, (Table 4.6), where the multi skin model with the highest total score demonstrated scenario 3 of each case.

Table 4.6: The rating system for multi skin scenario.

Points of comparison	The result	Rating points
►Thermal environment ►Daylight factor & uniformity ratio ►Solar transmittance ►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

3. Optimizing the air gap depth: after deciding the optimal number of skins for each case, different depth options of the air gap had been examined in terms of the cooling load (Table 4.7), where the case with the lowest cooling load demonstrated the optimized air gap depth.

Table 4.7: The proposed options for air gap depths.

Double skin	0.30m	0.60m	0.90m	1.2m
Triple skin*	0.30m/0.30m	0.6m/0.3m	0.6m/0.6m	0.9m/0.3m
* Triple skin has two air gaps.				

4. Determination of the added skin location: to check whether is better in terms of cost efficiency to add the skin from the inside, in which some of the office space gets lost, or outside, in which the installation gets more costly. Thus, a cost analysis had been made based on comparing the cost savings resulting from adding a second or third skin from inside with the annual rent costs per square meter of the office area according to the rent prices in the study area.

Phase 3: Choosing the optimal retrofit scenario. In this phase, an optimization process had been conducted based on a comparison between different retrofit scenarios in terms of energy and cost efficiency (Figure 4.23). The optimized solution that has the most energy savings with better cost efficiency had been chosen for each case to conduct further improvements and extract further benefits.

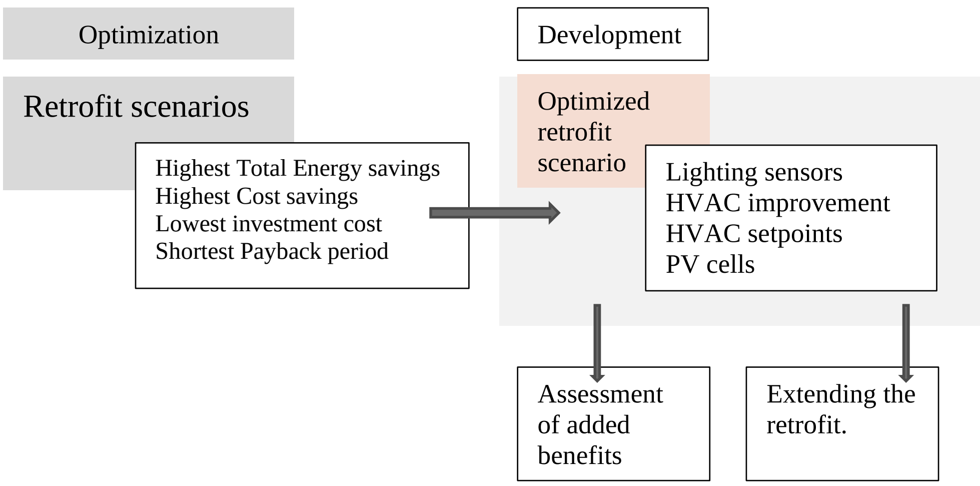


Figure 4.23: Retrofitting phase 3, choosing the optimal retrofit scenario.

For this, different retrofit scenarios were developed, modeled, and compared to the base case which was developed according to the data collected in the field survey. Table 4.8 shows the proposed retrofit scenarios.

Table 4.8: 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
Scenario7	Optimal shading device & optimal glazing type & optimal number of skins

In the optimization process of the energy efficiency with cost efficiency, the comparisons were made in terms of heating, cooling and lighting loads besides the cost. Subsequently, a financial analysis had been made using the simple payback period method to justify the best scenario for each case. In which the cost savings resulted 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. The pricing is discussed later in chapter 5 and the pricing sheets are attached in (appendix C, page 126). Dependently, the shortest payback period with the highest energy savings demonstrated the optimal scenario among the seven proposed retrofits.

Afterward, a development added to the adopted retrofit scenario which includes: adding daylight sensors, changing HVAC setpoints besides using an improved HVAC system with an economizer that control the HVAC operation according to the outside temperatures rather than fixed setpoints, and employing transparent PV cells to the glazed facade where the produced electricity was calculated. Later, the added benefits to the energy and cost savings such as environmental and economic advantages were assessed in terms of carbon emissions, and the possibility of covering the annual renting of the offices. Besides, the indoor temperatures and daylight factors were checked to ensure that the adopted solutions had made improvements regarding the indoor environment or even keep it in a standard range to be deemed successful. Finally, the final retrofits were extended to have a whole building rather than a single office to assess the maximized benefits and savings.

4.5. Results Discussion Method

The results discussion had been made in the following manner:

1. Discussion of the results of the field study results which include:

    a. The satellite survey findings of all highly glazed buildings in the study area and the chosen cases from them. Besides, a description of these buildings.

    b. The investigative survey findings presented as extracted sheets describing the cases besides their forms attached as appendices which include:

        - Observation results.
        - Measurements results.
        - Questionnaire results.

2. Simulation results discussion include:

    a. Description of the base models of the chosen cases, and their simulation results presented in terms of daylighting, temperature, and energy consumption.

    b. The result of the base models' confirmation. In which the results from the investigative survey and the simulation of the base models were compared.

    c. Retrofit scenarios results of each case in terms of total energy savings of lighting, heating and cooling end uses, and cost savings besides the initial costs.

    d. The pricing sheets of the proposed retrofit scenarios and the results of the interview.

    e. The result of optimizing the retrofit scenarios in terms of energy-cost efficiency, in another mean, the highest energy savings with the lowest cost and shortest payback period.

    f. The results of energy savings of the adopted retrofits when applying extra improvements such as installing lighting sensors, changing HVAC setpoints, using improved HVAC, and employing transparent PV cells. Besides, the results of sizing the PV cells and their associated calculations.

    g. The results of the assessment of the environmental benefits of the final retrofits for each case in terms of carbon emissions and the indoor environment.

    h. The impact of the final retrofits on the whole building.

4.6. Recommendations Extraction Method

The recommendations and conclusions were extracted based on the research objectives and key findings. Besides, some conclusions that were inferred from the simulation process were relevant to the impacts of various variables such as office depth, and orientation. In addition to this, recommendations had been made about the benefit of this research process in the preliminary design of highly glazed offices as well as in retrofitting practice.

Chapter 5

Results and Discussion

5.1. Field Work

Through field visits, it had been noticed that the contemporary buildings in Hebron as in the whole West Bank region are often based upon imitating the global architectural trends. Un-optimized glazed facades are being increasingly designed and constructed. Such architecture is entirely unsuited to a Mediterranean climate characterized by hot and dry summers and cool rainy winters; it disregards all means of protection against the intensive solar radiation and the poor thermally performance of the glass in both hot and cold weathering conditions.

5.1.1. The Satellite Survey Findings

Among Hebron office buildings within the study area which equals 3.72 km^2 and represents 5% of the Hebron city (Figure 5.1). The survey observed 16 office buildings with glazed facades that are assembled in the northern part of the city (Figures 5.2, 5.3-5.17).

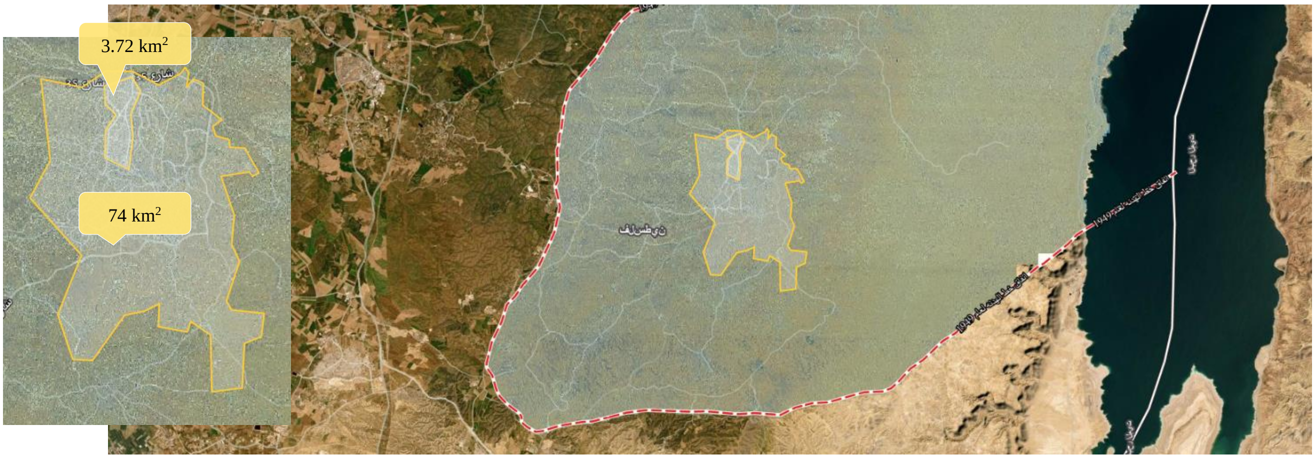


Figure 5.1: The study area within the city (mstkshf, 2019).

1

Figure 5.3: Ali Melhem office building in Halhul, Hebron. The Southern façade of the building is containing a curtain wall with reflective glass.

Figure 5.2: The buildings with glazed facades (red dots), the yellow line demonstrates the borders of the investigated area (mstkshf, 2019).

2

Figure 5.4: Om Al-Qura office building in Halhul, Hebron. A curtain walls of reflective and black tinted glass are facing the South orientation.

3

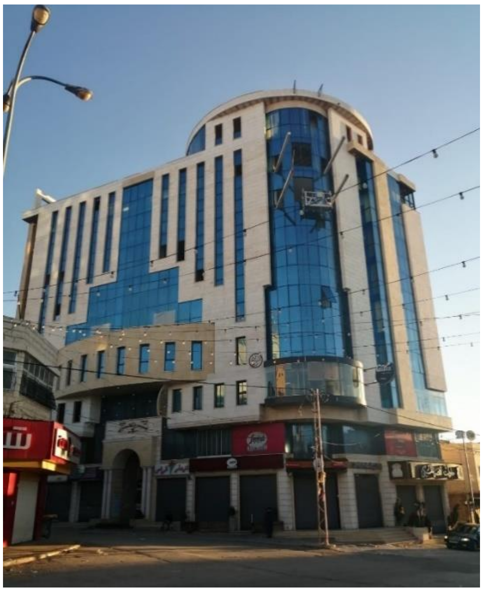


Figure 5.5: Office and commercial building in Daeret Seer, Hebron. The dark blue tinted curtain façade of the building is facing the south west orientation.

4

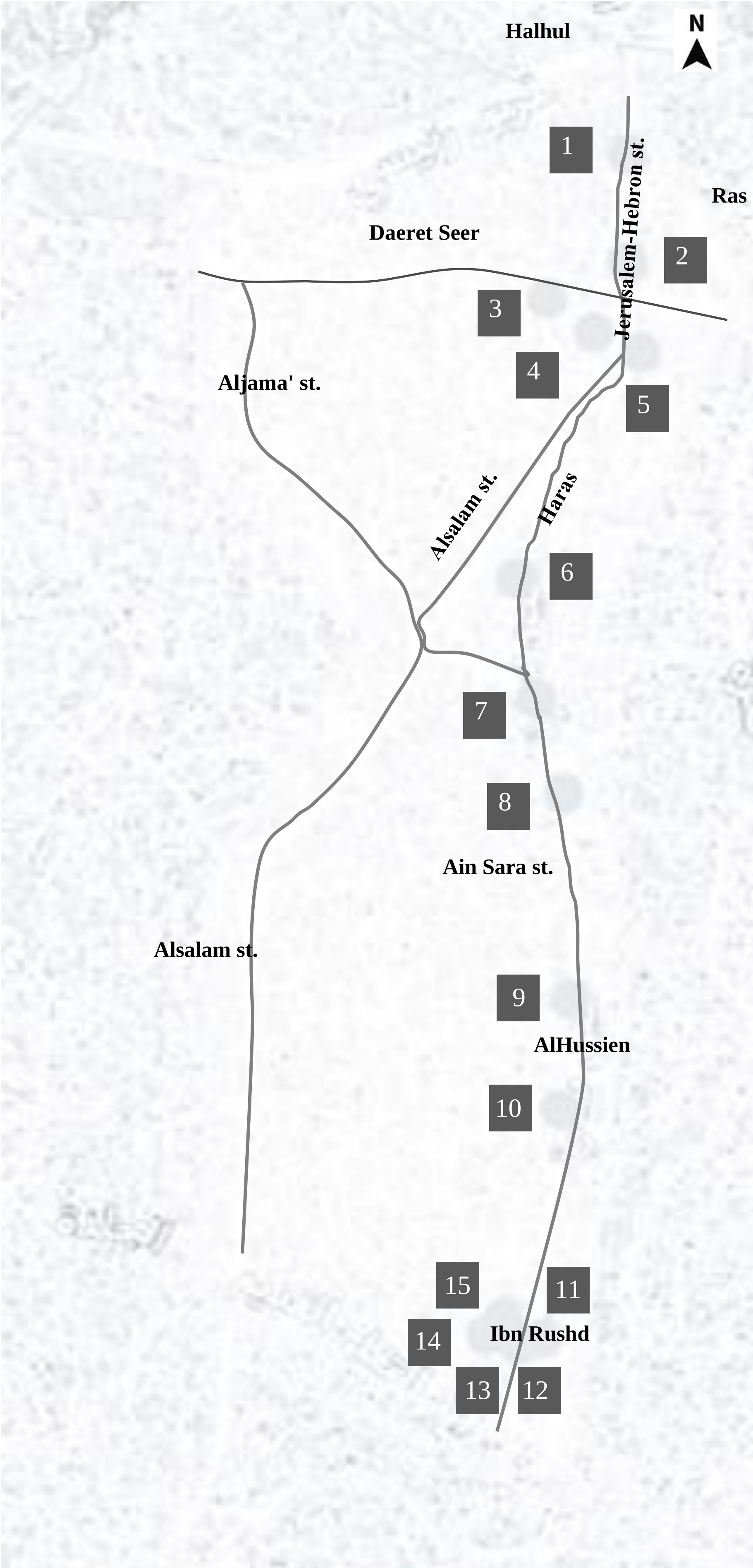
Figure 5.6: Borhan Al-Jabari building in Daeret Seer, Hebron. The Northern façade of the building is containing a curtain wall with reflective green glass.

5

Figure 5.7: Zuwwar Office and commercial building in Ras Aljorah, Hebron. The street façade of the building is fully glazed with tinted and reflective glazing and facing the West orientation but with no external shading devices.

6

Figure 5.8: Bank of Palestine in Alharas, Hebron. The street façade of the bank is fully glazed with tinted and reflective glazing and facing the North east orientation with no external shading devices. The picture was taken in February. However, the occupants also pulled down their internal shading for solar protection and ignoring the external view.



7

Figure 5.9: Alzogayer Office and commercial building in Ain Sarah street, Hebron. The street façade of the building is highly glazed with tinted and reflective glazing and facing the south west orientation but with no external shading devices.

8

Figure 5.10: Office building in Ain Sarah street, Hebron. The Southern façade of the building is containing a curtain walls of reflective glass.

10

Figure 5.12: Alrasheed Office and commercial building in Ain Sarah street, Hebron. The oldest one among the surveyed buildings. The street façade of the building is highly glazed with reflective glazing and facing the North East orientation.

9

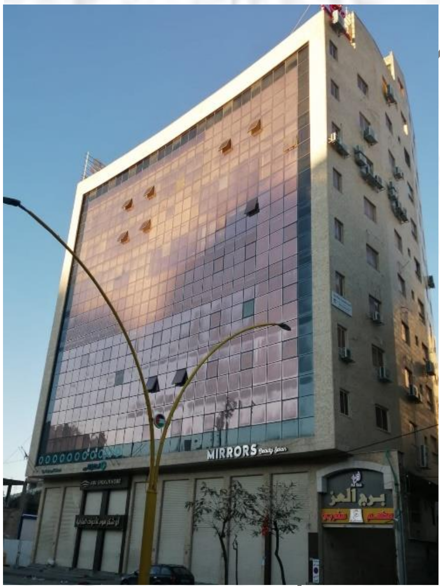


Figure 5.11: Alizz Office and commercial Tower in Ain Sarah, Hebron. The street façade of the building is highly glazed with reflective glazing and facing the East orientation.

11

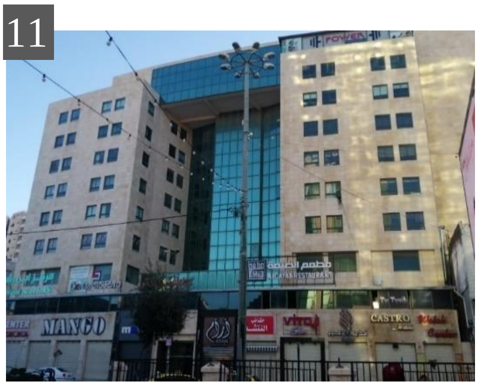


Figure 5.13: On the left, City Center Office and commercial building in Ibn Rushd square, Hebron. The reflective curtain façade of the building is facing the south west orientation.

12

Figure 5.14: The Golden Tower in Ibn Rushd, Hebron. The street façade of the building is fully glazed with reflective glazing and facing the South east orientation but with no external shading devices. The design displays the poor environmental and climatic considerations for hot and cold weathering conditions in Hebron.

13

Figure 5.15: Tabarrok Center Office and commercial building in Ibn Rushd square, Hebron. The blue tinted curtains of the building are facing the North orientation.

14

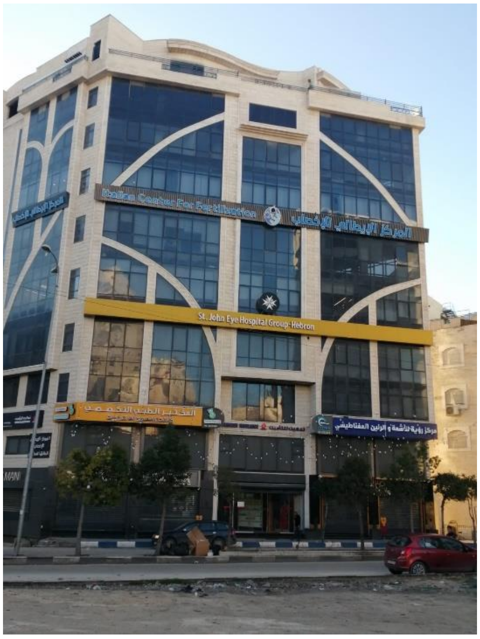


Figure 5.16: Office and commercial building in Ibn Rushd Square, Hebron. The street façade of the building is highly glazed with tinted and reflective glazing and facing the North and West orientation.

15

Figure 5.17: On the right, Alwaha building in Ibn Rushd Square, Hebron. The street façade is highly glazed with reflective glazing and facing the South orientation. The lower floors are shaded by the opposite building but the upper ones are opposed to the sun directly.

The survey sample was classified according to the glazed façade orientation as shown in Table 5.1 below; as it noticed that the construction of transparent buildings mainly reflects the owners desire to orient their towers to the main street according to the owned land for investment targets, neglecting the façade orientation or any solar consideration and environmental consequences.

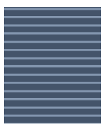
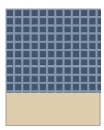
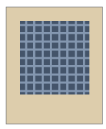
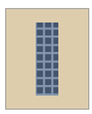
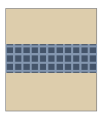
Table 5.1: The classification of the common glazed office buildings in the study area according to their elevation, glazing ratio and glazing type.

Elevation	Building	Location	Curtain Ratio	Glazing Type
North	Borhan Jabari	Daeret Seer	20-40%	Reflective
North East	Tabarok	Ibn Rushd	40-60%	Tinted Blue
	Center	Ibn Rushd	60-80%	Tinted Grey
South	Building	Daeret Seer	60-80%	Reflective
	Golden Tower	Ibn Rushd	Fully	Tinted
	Al Waha	Ibn Rushd	60-80%	Reflective
South East	Golden Tower	Ibn Rushd	Fully	Tinted
West	Ali Melhem	Halhul	20-40%	Reflective
	Om AlQura	Halhul	20-40%	Tinted
	Zuwwar Tower	Ras Jorah	Fully	A mix of Reflective, Tinted, Clear
	Zoghayer Tower	Ain Sara street	60-80%	Reflective Black
	Montada Falasteen	Ain Sara street	20-40%	Reflective
	City Center	Ibn Rushd	20-40%	Reflective
East	Bank of Palestine	Alharas	Fully	Tinted and Reflective Dark blue
	Al Izz Tower	Ain Sara street	60-80%	Reflective
	Alrasheed tower	Ain Sara street	60-80%	Reflective

The survey sample had been observed according to the window to wall ratio (WWR), glazing type, insulation and shading as follows:

1. Window to Wall Ratio (The curtain ratio):

Table 5.2: The common curtain ratio in the study area.

	Fully Glazed	60-80%	40-60%	20-40% Curtain entrance	20-40% Curtain Floor
Curtain ratio					
Example					

The curtain ratio is calculated according to the ratio of the curtain area to the whole main façade of the building, regardless of the other available single windows. The glazed office buildings vary between Fully glazed (80-95% curtain facade), 60-80%, 40-60%, and 20-40%, (Table 5.2).

The most common among the survey sample was the 60-80% ratio followed by 20-40% glazing which has two forms: the curtain are used for demonstrating the entrance and the curtain is used on one floor rather than the whole façade, (Figure 5.18).

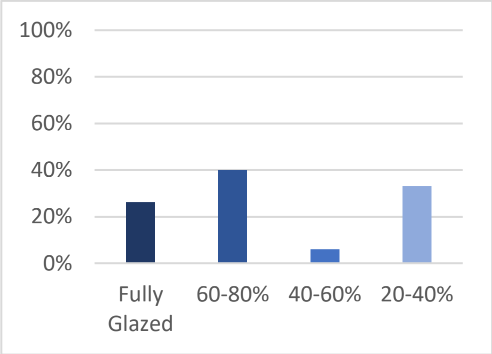


Figure 5.18: The percentage of different curtain ratios in the study area.

2. Glazing Type:

Among Glazing types, tempered glass, tinted, or reflective glass are the common types of glazed office buildings in Hebron city and there is no case of using clear glass. The reflective glass is mainly used to cut off the solar heat with a special metallic coating which also provides a mirror effect and prevent visibility from the outside and thus preserving privacy. The tinted glass has different colors varied between black, grey, dark blue, green, and blue which give the building a more attractive, aesthetically pleasing appearance while being insulated from the sun at the same time. There are no double-glazed skins among the survey sample.

3. Insulation:

The common curtain facades in the study area are made of tempered double pane glass (6mm pane -12mm air or gas- 6mm pane). In the study area, the glazing insulation is the 12 mm air gap between the two panes. Besides, the reflective glass which provides a one-way mirror effect with a metallic coating that reflects a greater amount of heat than normal tinted glass, making it less exposed to thermal leakage.

4. Shading:

The shading in glazed buildings in Hebron is mainly based on the use of tinted glass to reduce the solar glare and to limit ultraviolet light transmission through curtain facades and hence reducing heat gain inside by reflecting solar heat energy. Other solar control means are using manual shutters or fabric curtains. But there are no overhangs or louvers mainly to keep the aesthetic appearance of the buildings.

It had been found that these glazed buildings have used artificial lighting during the day since they are not optimized for quality daylighting. The negative effect of glare and solar heat gain is entirely exceeded and thus ignored the benefit of the natural daylight besides that the employees obscure the solar radiation, and so the daylight, with internal curtains or shutters. Even that, the internal curtains or shutters absorb the transmitted solar energy and gain more thermal heat where artificial lights and offices' equipment adding another source of heat.

For a research complement with more extensive study, a fully glazed and two highly glazed buildings had been chosen based on the satellite study findings, (Figure 5.21). The sample was chosen according to the higher glazing ratio and different orientations between West, South and East to be studied carefully, (Table 5.3).

Figure 5.19: The chosen buildings for the investigative survey.

Table 5.3: The investigative survey sample of glazed office buildings in the study area.

<table>
<tr><th>Elevation</th><th>Building</th><th>Location</th><th>Glazing Ratio</th><th>Glazing Type</th></tr>
<tr><td>East</td><td>Al Izz Tower</td><td>Ain Sarah</td><td>60-80%</td><td>Tinted</td></tr>
<tr><td>South</td><td rowspan="2">Golden Tower</td><td rowspan="2">Ibn Rushd</td><td rowspan="2">Fully</td><td rowspan="2">Reflective</td></tr>
<tr><td>South East</td></tr>
<tr><td>West</td><td>Zuwwar Twoer</td><td>Ras Jorah</td><td>60-80%</td><td>Reflective</td></tr>
</table>

5.1.2. The Investigative Survey Findings

5.1.2.1. Questionnaire Results

The main aim was to investigate the general situation in the glazed offices in the study area so then to choose offices among them as cases to conduct a further deep study. The questionnaire was distributed and filled by the employees in three buildings on 15-16 March 2020. In each building, six chosen offices had been questioned with a total 18 responders. The responses were analyzed using excel sheets in terms of thermal individual differences, thermo-visual comfort and employee satisfaction, energy consumption patterns of heating and cooling end-uses, maintain indoor environment means and solar protection tools, occupancy schedules and working environment.

The questionnaire results were as follows:

► Thermal comfort & employee satisfaction

The seasonally comfort had been assessed by rating the thermal environment inside the chosen cases when there are no cooling or heating aids, and most time the employees feel they comfortable or not during the day.

The chart on the right shows the highest percentages of the responses for six offices that had been questioned in each building as shown in Figure 5.22. The analysis showed that the most of responses in the three buildings in terms of the thermal environment inside the offices were "hot" and "very hot" in summer. However, the highest percentages of the answers are a hot environment in the offices that face the east and south orientations, which is due to the extensive solar exposure for long periods during the occupancy.

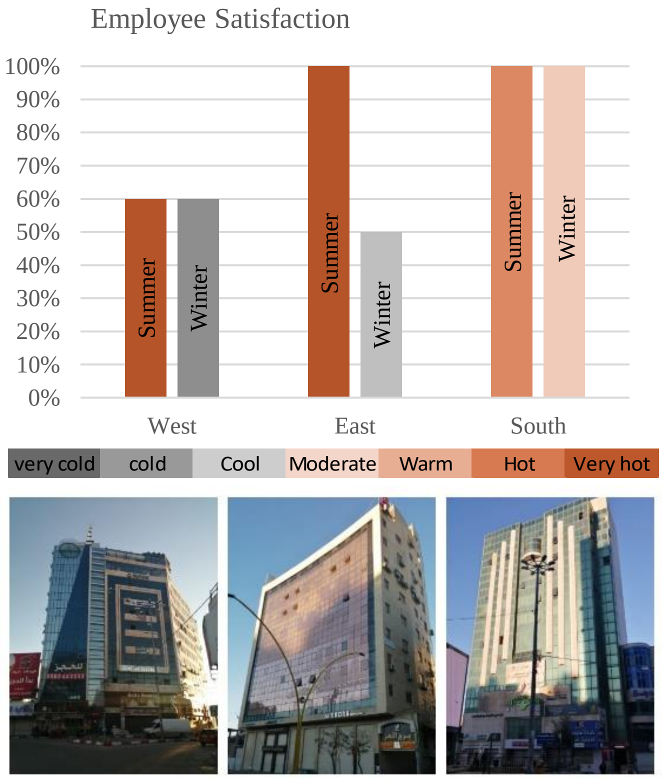


Figure 5.20: The questioned buildings and the results of thermal sensation analysis.

Whilst in winter, the buildings that face the east or south, the higher percentages of their answers were a mild and moderate feeling inside offices in winter. The "cold" sensation was in the buildings facing the west as those have a little exposure to solar radiation during office hours.

Regarding the most uncomforting time during the day in summer and winter, (Figure 5.23), most of the answers were as follows:

1. For the west-facing offices, the most time during summer days in which the employees feel thermally uncomfortable was in the afternoon, mainly due to that the outside temperature is increasing gradually at noon and afternoon. In winter, the most comfortable time was at noon as the outside temperature is higher compared to afternoon or morning times, hence higher heat gains which warm the inside temperature in winter.

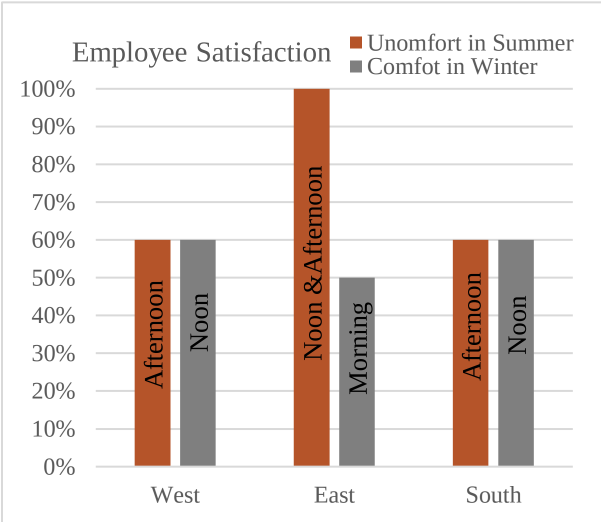


Figure 5.21: The analysis results of uncomforting periods in summer and comforting periods in winter in the questioned offices.

2. For the east-facing offices, the most time during summer days in which the employees feel uncomfortable was at the noon and afternoon because of the high temperature outside at these times and the few answers were for the morning, despite being highly exposed to the solar radiation in the morning for the eastern oriented office. This is due to that there is much solar heat gain through the east glazing before noon as an afternoon on any given day, though the employee might well feel hotter in the afternoon because ceiling, floor tiles, walls and other objects have been warming up all day and then releasing heat inside. Whereas in winter, the most comfortable time was in the morning and at noon since the low-angle sun is directly penetrating through the east glazed facade to warm the office on a cold winter day.

3. For the south-facing offices, the most time during summer days in which the employees feel uncomfortable is in the afternoon because of the high temperature outside at this time and because the envelope has been warming up all day and releasing heat inside. Whereas in winter, the most comfortable time was at noon since the southern-oriented façade is

directly exposed to the sun at noon hence the penetrated solar rays warming up the office in winter.

In general, according to thermal satisfaction analysis, during summer the overheating feel is mainly due to the high outside temperatures that warming up the envelope and then released inside, whilst in winter the glazed façade plays a key role in increasing comfortability due to the direct sun rays that pass through the glazed facades in and warm the cold office.

► Energy consumption patterns

The energy consumption analysis includes the used cooling and heating devices with their operating power and then the energy loads calculation based on the answers of operating months, working days, and operating hours. The calculations then based on the following equation (Eq. 5.1):

Q = avg. no. operating hours* ((no. working days*no. operating months)-no. holidays) *facility operating power. (Eq. 5.1)

Where:

Q: Energy,
no: number,
avg: average.

The results showed that the energy consumption is strongly related to the used cooling & heating devices and varies according to the average operating hours as shown in Figure 5.24, hence it is difficult to find a direct relationship between the glazed façade existence and the energy consumption unless comparing the office with and without glazed façade.

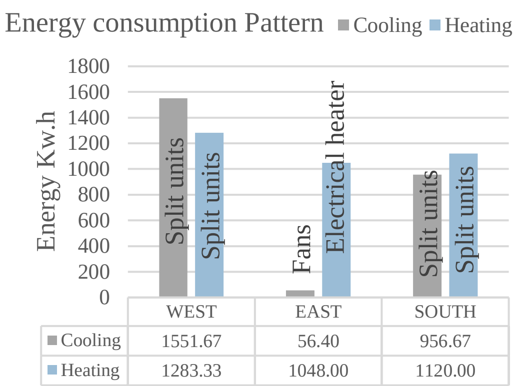


Figure 5.22: The analysis results of cooling and heating energy consumption pattern in the questioned offices.

In general, offices that are mechanically ventilated showed the highest consumption in summer and those use the electrical heater in winter. The offices that are using fans, the east façade has a higher consumption pattern than the south façade in summer as a lower sun angle passes directly through the east facade in the morning compared to the south.

In winter, the eastern is the higher among those using electrical heating. This is corresponding to the answers that showed that the southern façade is moderate in winter where the eastern is the coolest. This is due to that the eastern façade is sun vulnerable in the morning and then the glass allows massive heat losses as the cold wind sweeps across the surface, drawing heat from the interior. In addition to this, many mornings in winter are cloudy where noon is sunny almost every day and for a longer time than the morning sun. Although in case sunny mornings, the eastern solar path is shorter than the southern solar path, Figure 5.25. Besides, the southern façade starts to gain sun heat during sun rotation from the east toward the south as shown in Figure 5.26. Thus, in winter the southern façade is exposed to the sun longer time than the eastern facade.

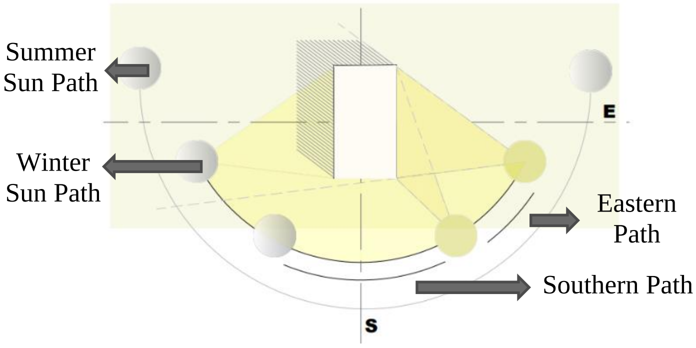


Figure 5.23: The exposed eastern façade.

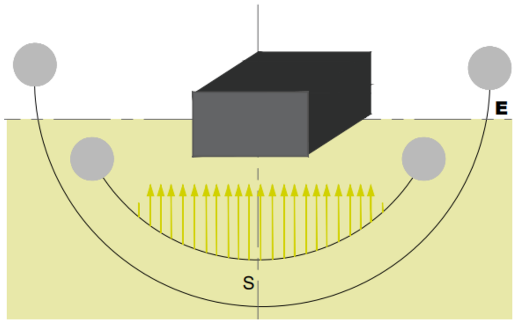


Figure 5.24: The exposed southern façade.

► Visual comfort Maintain Indoor environment means and Solar protection tools.

Visual comfort is analyzed in terms of solar protection tools, the employee preferences in the connectivity with the outside, and the daylight intensity, (Figure 5.27).

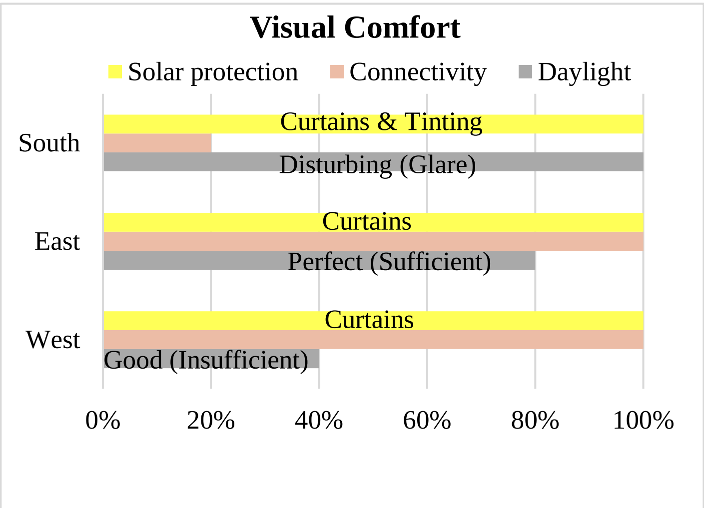


Figure 5.25: The visual comfort analysis.

Figure 5.26: A view from an office in Alizz tower 10:00am, 19th August 2020.

Regarding daylight intensity, the answers varied between "Good" which means the daylight intensity is good but not sufficient for tasks and need the aid of artificial lighting, "Disturbing" where the daylight causing glare, and "Perfect" that the daylight substitutes for the artificial lighting without causing glare. In general, the results showed that the office with the southern glazed façade suffers from high glare, where the daylight in the east and west facades have good or perfect intensity.

However, the contradiction between the daylight harvesting with the thermal comfort inside compelled to use the curtains or tinted glass for solar protection and shading, thereby diminish the daylight and required the aid of artificial lighting even there is sufficient daylight.

The interaction with the glazed façade varied between the employees according to their career and preferences. The context in the city center and main streets are crowded and noisy which causes confusion and disturbance besides there is no attractive view or greenery in the building context. Thus, some employees that have more concentrative thinking work don't prefer the connectivity with the outside and keep the curtains off even there is no glare.

► Schedules & Working environment

This section helps in the analysis and interpretation of the answers as well as in the case modeling.

5.1.2.2. Observation and Measurement Results

Among the buildings that had been questioned, an office had been chosen from the six offices that had been questioned in each building to be presented as a case for simulation and applying retrofit. These cases are:

A. Case 1: AlizzTower.

Located in Ain Sara street, opposite the Alhussien stadium. The glazed façade includes 28 offices on seven floors. The fans are used for cooling as it is difficult to install split units on the glazed façade. According to the measurements which were taken in six offices on the first, third and seventh floors, there was no temperature tangible difference across different floors.

Figure 5.27: Alizz Tower, 1st Oct. 2020

The curtain façade is made of double brown tint glass of 6mm panes and a 12 mm air layer. No external shading devices are used where internal curtains are used to cut off glare. The chosen office is on the third floor has a cellular plan as seen in Figure 5.30.

The field findings had been summarized in Table 5.4. In the questionnaire, the employee's moderate sensation in winter matches with the measurements of the inside temperature which was about 22 C°on 15th March as well as the daylight was measured 2300 lux correspond with the questionnaire where the employee answered that the daylight is excellent and sufficient without artificial lighting.

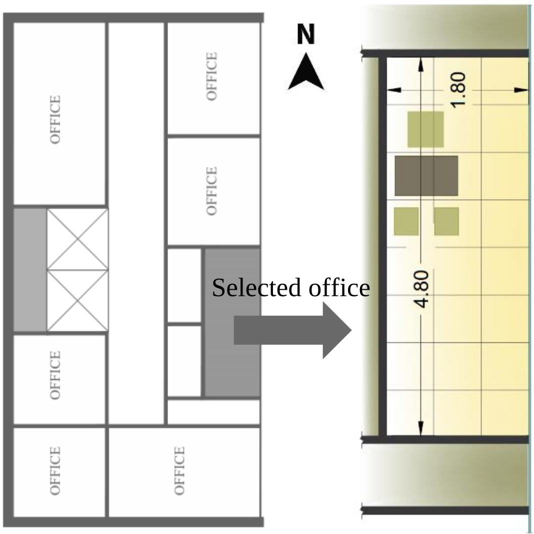


Figure 5.28: Plan of the selected office in Alizz Tower.

The same is for summer, as the employee sensation is very hot and the measured temperature on 19th August was 32 C°.

Table 5.4: Case studies datasheet. Case.1: Al Izz Tower.

OBSERVATION

Building	Elevation	Floor	Office Dimensions L*W*H (m)	Glazing Area (m^2)	No. Occupants	Activity	No. devices
Al Izz Tower	East	3^{rd}	4.8*1.8*2.5	12	1	teacher	0
	White painted ceiling, Porcelain tiles floors, Concrete un-insulated walls with stone cladding, and 20 cm cement block partitions. Crowded main square, 16 m offset from the opposing 3-story stadium.						

MEASUREMENTS

Parameter	Location	15/ March 10:00am	15/June 11:00am	19/August 10:00am
Temperature	Indoor	22 C°	27 C°	32 C°
	Outdoor	18 C°	25 C°	31 C°
Humidity	Indoor	61%	48.5 %	46%
	Outdoor	59%	45 %	43
Daylight	desk	2300 lux	2100 lux	15.5 k.lux

QUESTIONNAIRE

Employee Thermal satisfaction	Very hot in summer & moderate in winter. The most uncomfortable time is morning in summer and afternoon in winter.

Energy Consumption	Facility	Power (w/h)	No. opr. months	No. opr. hours/day	Setpoints/speed	Q (kW/h/year)
Cooling Loads	Fan	75	5	8	Higher speed	72
Heating Loads	Electrical heater	2000	3	6	Higher intensity	864

- Working days per month: 24
- Q: Energy
- opr.: operating
- Q = avg. no. operating hours* ((no. working days*no. operating months)-no. holidays) *facility operating power

Visual comfort	Solar protection	Curtains & tinted glass
	Connectivity	Prefer the connectivity with the outside.
	Daylight	Excellent sufficient without artificial lighting.
Schedules		8:00am-4:00pm

B. Case 2: The Golden Tower

Located in Ibn Rushd Square. The glazed façade includes 36 offices on nine floors. The building has curtains in the eastern façade and the southern façade. The last two floors are unoccupied. The curtain façade is made of a double Green reflective glass of 6mm panes and a 12 mm air layer. No external shading devices are used where internal curtains are used to cut off glare. The chosen office is on the seventh floor has a deep plan as seen in Figure 5.32.

Figure 5.29: The Golden Tower, 1st Oct. 2020

The field findings had been summarized in Table 5.5. The measurements were taken with HVAC are turned off and no heating or cooling aids, as well as the shading curtains inside, were opened.

In the questionnaire, the employee's moderate sensation in winter matches with the measurements of the inside temperature which was about 20 C°on 15^{th} March as well as the daylight was measured 700 lux as it was taken at the sunniest time during the day. This corresponds with the questionnaire where the employee answered that the daylight most times is good but insufficient without artificial lighting.

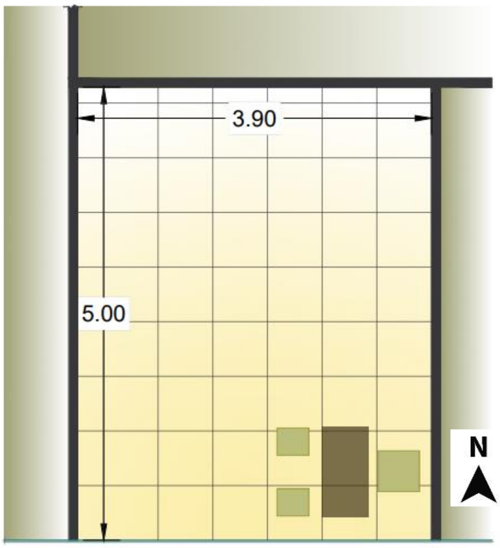


Figure 5.30: Plan of the selected office in Golden Tower.

Table 5.5: Case studies datasheet. Case.2: Golden Tower.

OBSERVATION

Building	Elevation	Floor	Office Dimensions L*W*H (m)	Glazing Area (m^2)	No. Occupants	Activity	No. devices
Golden Tower	South	7^{th}	4.8*3.6*2.5	12	1	Advocacy	1
	White painted ceiling, Porcelain tiles floors, Concrete un-insulated walls with stone cladding, and 20 cm cement block partitions. Crowded main street, 32 m offset from the opposing 3-7-story buildings.						

MEASUREMENTS

Parameter	Location	15/ March 12:30 pm	15/ June 12:00pm	19/ August 12:00pm
Temperature	Indoor	20 C°	25 C°	33 C°
	Outdoor	19 C°	27 C°	31 C°
Humidity	Indoor	55%	48.5 %	47 %
	Outdoor	59%	45 %	44 %
Daylight	desk	700 lux	350 lux	800 lux

QUESTIONNAIRE

Employee Thermal satisfaction	Hot in summer & moderate in winter. The most uncomfortable time is at noon in summer and afternoon in winter.

Energy Consumption	Facility	Power (w/h)	No. opr. months	No. opr. hours/day	Setpoints/speed	Q (k.W/h/year)
Cooling Loads	Split unit	3500	3	4	16 C°	840
Heating Loads	Split unit	3500	3	4	26 C°	840

- Working days per month: 24
- Q: Energy
- opr.: operating
- Q = avg. no. operating hours* ((no. working days*no. operating months)-no. holidays) *facility operating power

Visual comfort	Solar protection	Curtains & reflective glass
	Connectivity	Didn’t prefer the connectivity with the outside.
	Daylight	Good but insufficient without artificial lighting.
Schedules		8:00am-4:00pm

The same is for summer, as the employee sensation is hot and the measured temperature on 19th August was 33 C°.

Additionally, the employee used to keep the windows closed to avoid the noise from the outside as the building is located at a central street that caused overheating inside without ventilation where the highest floors often have good ventilation that can mitigate the overheating inside. As a result, the office requires excessive energy consumption and relied on mechanical cooling with a set point at 18C° to only provide a sense of only 22-25 C° in the hot summer period.

C. Case 3: Zuwwar Tower

The tower located in Ras Aljorah and consist of ten floors. The glazed façade facing the west orientation. Most of the offices depend on mechanical ventilation. Many floors are still unoccupied.

The curtain façade is made of a double blue reflective glass of 6mm panes and a 12 mm air layer. No external shading devices are used where internal shutters are used to cut off glare. The chosen office is on the seventh floor with an open plan as seen in Figure 5.34.

Figure 5.31: Zuwwar Tower, 1st Oct. 2020

The field findings had been summarized in Table 5.6. As the office is west oriented, the daylight had been observed to be insufficient during the working hours, (Figure 5.35), especially in the deep open plan make the artificial lightings adding extra heat inside, whilst the private enclosed two opposite offices have the highest daylight levels compared to the open plan. However, the employees feel hot each morning due to the office has been heated the previous day, they used to operate cooling in the morning and the afternoon. Besides, in winter, the employees feel cold as the sun doesn't strike their office until 1:00 pm.

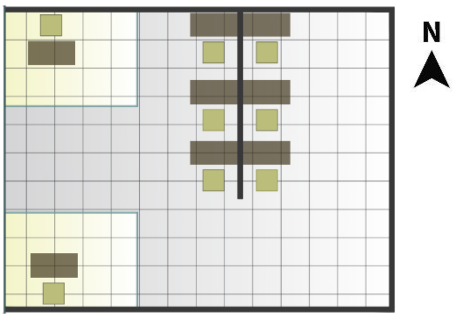


Figure 5.32: Plan of the selected office in Zuwwar Tower.

Figure 5.33: The office interior shots show the low daylight level at the midday in 19th August.

Table 5.6: Case studies datasheet. Case.3: Zuwwar Tower.

OBSERVATION

Building	Elevation	Floor	Office Dimensions L*W*H (m)	Glazing Area (m^2)	No. Occupants	Activity	No. devices
Zuwwar Tower	West	7th	6*5.4*2.75	16.5	6	Engineering	8
	White painted ceiling, Porcelain tiles floors, Concrete un-insulated walls with stone cladding, and 20 cm cement block partitions. Crowded main street, 18 m offset from the opposing 3-4 story-buildings.						

MEASUREMENTS

Parameter	Location	16/ March 2:00 pm	15/June 1:00pm	19/August 12:30pm
Temperature	Indoor	21 C°	27 C°	31 C°
	Outdoor	18 C°	25 C°	29 C°
Humidity	Indoor	57%	42 %	40 %
	Outdoor	59%	44 %	47 %
Daylight	desk	600 lux	350 lux	200 lux

QUESTIONNAIRE

Employee Thermal satisfaction	Very hot in summer & moderate to cool in winter. The most uncomfortable time is at noon in summer and afternoon in winter.					
Energy Consumption	Facility	Power (w/h)	No. opr. months	No. opr. hours/day	Setpoints/speed	Q (k.W/h/year)
Cooling Loads	Split unit	3500	5	4	16 C°	1400
Heating Loads	Split unit	3500	3	8	30 C°	1680

- Working days per month: 24
- Q: Energy
- opr.: operating
- Q = avg. no. operating hours* ((no. working days*no. operating months)-no. holidays) *facility operating power

Visual comfort	Solar protection	Curtains & reflective glass
	Connectivity	Didn't prefer the connectivity with the outside.
	Daylight	Good but insufficient without artificial lighting.
Schedules		8:00am-4:00pm

5.2. Simulation Results

After cases selection, a base model has been developed according to the data sheets presented in the previous section using DesignBuilder software, a simulation at the same time and day as the measurements had been taken inside these offices had been conducted for the base models to create base models as realistic as possible.

5.2.1. Creating Base Models

The results from the investigative survey and the simulation of the chosen cases base models were compared in terms of daylighting, relative humidity, and air temperature as follows:

A. Case 1: Alizz Tower

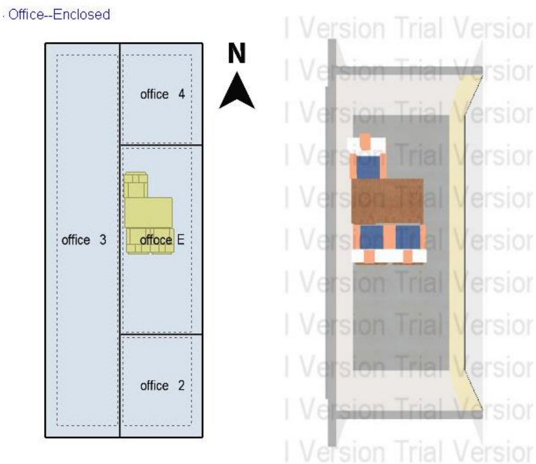


Figure 5.34: Case 1 model visualizing.

Table 5.7: The comparison between the measurements and the base model simulation results.

	Parameter	Location	15/ March 10:00am	15/June 11:00am	19/August 10:00am
MEASUREMENTS	Temperature	Indoor	22 C°	27 C°	32 C°
		Outdoor	18 C°	25 C°	31 C°
	Humidity	Indoor	61%	48.5 %	46%
		Outdoor	59%	45 %	43
	Daylight	desk	2300 lux	2100 lux	15.5 klux
SIMULATION	Temperature	Indoor	21 C°	28.8 C°	32 C°
		Outdoor	16 C°	23.7 C°	30 C°
	Humidity	Indoor	60%	48.8%	43%
	Daylight	desk	2022 lux	2118 lux	11154 lux

B. Case 2: Golden tower.

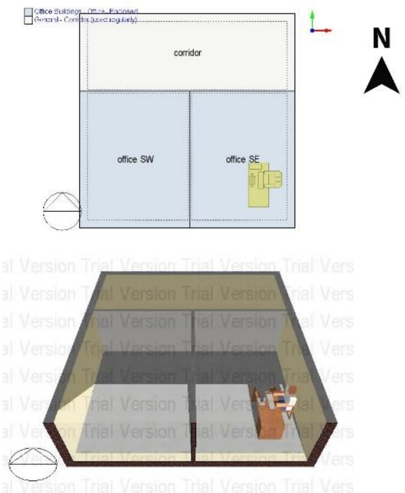


Figure 5.35: Case 2 model visualizing.

Table 5.8: The comparison between the measurements and the base model simulation results

	Parameter	Location	15/ March 12:30 pm	15/June 12:00pm	19/August 12:00am
MEASUREMENTS	Temperature	Indoor	20 C°	27 C°	33 C°
		Outdoor	19 C°	25 C°	31 C°
	Humidity	Indoor	55%	48.5 %	47%
		Outdoor	59%	45 %	44%
	Daylight	desk	700 lux	750 lux	800 lux
SIMULATION	Temperature	Indoor	22.8	26	32
		Outdoor	17	24.7	31
	Humidity	Indoor	56	49	44
	Daylight	desk	756	782	827

C. Case 3: Zuwwar Tower

Table 5.9: The comparison between the measurements and the base model simulation results

	Parameter	Location	16/ March 2:00 pm	15/June 1:00pm	19/August 12:30pm
MEASUREMENTS	Temperature	Indoor	21 C°	27 C°	31 C°
		Outdoor	18 C°	25 C°	29 C°
	Humidity	Indoor	57%	42 %	40%
		Outdoor	59%	44 %	47 %
	Daylight	On Desk	600 lux	350 lux	200 lux
SIMULATION	Temperature	Indoor	26	29	34.6
		Outdoor	16	25.5	32.3
	Humidity	Indoor	60	42	40.4
	Daylight	Working plane 0.75m	570	411	326

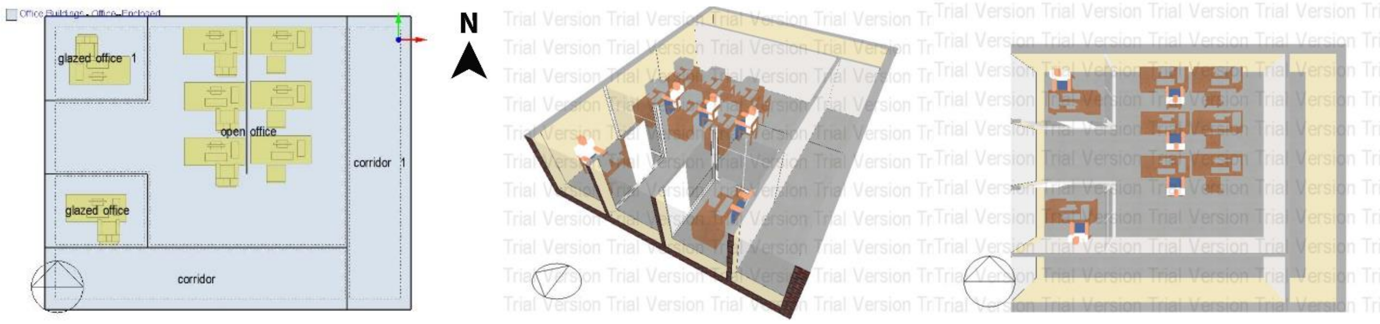


Figure 5.36: Case 3 model visualizing.

As shown above, in Tables 5.7, 5.8, and 5.9, the measured temperatures highly correspond with the simulation results. The deviation is calculated to be ±1.42 C° (Figure 5.39), this is mainly due to the use of simulation with not most updated weather data together with the accuracy of the sensors of the used thermometer (see appendix A: Sensors specification sheets, page 114). These deviations were the most in the third case which is west oriented.

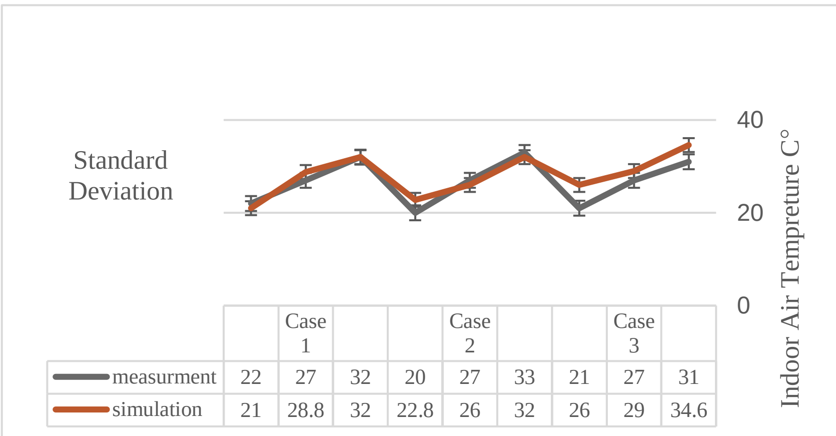


Figure 5.37: The standard deviation of the base models from the field measurements.

The daylight also showed difference and it's mainly due to that DesignBuilder deals with specific illuminations according to the weather data file were in the reality the illumination is differing for each moment during the day.

5.2.2. Retrofit Scenarios Results

Seven scenarios had been applied to each case; the detailed determination of these scenarios is attached in (appendix B, page 118). In this section, the results of the simulation of the applied retrofits are presented in terms of total energy savings of lighting, heating and cooling and costs savings besides the initial costs.

For case 1, the most energy savings result from scenario 1 which is to install four blades of 1.5m louvers as a shading device, and scenario 2 which is to replace the existing glazed façade with double low emissive electrochromic reflective colored glass. The highest savings reached only 46% by scenario 2, (Table 5.10).

Table 5.10: 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			
	Component	**Base case**	**Proposed case**	**Annual Energy Savings (kWh)**	**% savings**
Base case annual energy consumption kWh				1929	0%
Sc. 1	Shading system	Curtains & tinted glass	4 blades 1.5m louvers.	820	43%
Sc. 2	Glazing type	Tinted brown	Dbl. LoE Elec. Ref. Colored	886.45	46%
Sc. 3	Façade system	One skin	Double skin with a 90cm air gap.	586.5	30%
Sc. 4	The optimal shading & optimal glass type			541	28%
Sc. 5	Façade system & glass type			650	34%
Sc. 6	Façade system & Shading			716	37%
Sc. 7	Façade system & Shading & glass type			610	32%

* Point of comparison: Heating, Cooling & lighting loads.
* Sc.: scenario
* Dbl: double
* LoE: low emissive
* Elec.: electrochromic
* Ref.: reflective

For case 2, the most energy savings result from scenario 1 which is to install 1m louver with 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 reached only 38% by both scenarios 1 and 2 as shown in table 5.11.

Table 5.11: 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			
	Component	**Base case**	**Proposed case**	**Annual Energy Savings (kWh)**	**% savings**
Base case annual energy consumption kWh				2631	0%
Sc. 1	Shading system	Curtains & Ref. glass	1m louver+1m overhang+ side fins	999.5	38%
Sc. 2	Glazing type	Ref. blue	Dbl. LoE Elec. Ref. Colored	1012	38%
Sc. 3	Façade system	One skin	Triple skin with air gaps 0.6cm,0.3cm.	221.77	8%
Sc. 4	Shading & glass type			631.5	24%
Sc. 5	Façade system & glass type			400.23	15%
Sc. 6	Façade system & Shading			418.64	16%
Sc. 7	Façade system & Shading & glass type			466.3	18%

* Point of comparison: Heating, Cooling & lighting loads.
* Sc.: scenario.
* Dbl: double.
* LoE: low emissive.
* Elec.: electrochromic.
* Ref.: reflective.

For case 3, the most energy savings result 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 a good percentage of 81% by scenarios 5 and 6 as shown in table 5.12.

Table 5.12: Retrofit scenarios results of each case in terms of total energy savings of lighting, heating and cooling end uses

CASE 3: Zuwwar Tower		WEST orientation			
	Component	**Base case**	**Proposed case**	**Annual Energy Savings (kWh)**	**% savings**
Base case annual energy consumption kWhس				2993	0%
Sc. 1	Shading system	Shutters & Ref. glass	1m louver+1m overhang+ side fins	387	13%
Sc. 2	Glazing type	Ref. blue	Dbl. LoE Elec. Ref. Colored	1165	39%
Sc. 3	Façade system	One skin	Double skin with a 30cm air gap.	2340	78%
Sc. 4	Shading & glass type			613.7	21%
Sc. 5	Façade system & glass type			2424	81%
Sc. 6	Façade system & Shading			2422	81%
Sc. 7	Façade system & Shading & glass type			2221.8	74%

* Point of comparison: Heating, Cooling & lighting loads.
* Sc.: scenario.
* Dbl: double.
* LoE: low emissive.
* Elec.: electrochromic.
* Ref.: reflective.

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

The pricing sheet of the proposed retrofit scenarios is presented in Table 5.13 below which is based on local interviews with contractors and PV cells local pricing. The detailed pricing and interviews are attached in (Appendix C, page 126), where the resulted cost savings of the proposed scenarios based on the 1kwh electricity price in Hebron for the commercial sector equals 0.63 ILS and 0.19 in dollars (PIPA, 2019.).

Table 5.13: 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	1252.8 $
	Case 2		939.6 $
	Case 3		522 $
Sc. 3	Case 1	Double skin with a 90cm air gap.	1957.5 $
	Case 2	Triple skin with air gaps 0.6cm,0.3cm.	1493.5 $
	Case 3	Double skin with a 30cm air gap.	971.5 $
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	1687.8 $
	Case 2	Triple skin with air gaps 0.6cm,0.3cm. Dbl. LoE Elec. Ref. Colored	1519.6 $
	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 0.6cm,0.3cm.	2900 $
	Case 3	1m louver+1m overhang+ side fins Dbl. LoE Elec. Ref. Colored Double skin with a 30cm air gap.	1740 $

5.2.3. 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 as shown in tables 5.14, 5.15 and 5.16.

Table 5.14: 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 $	149.814	2.9036
Sc. 2	Glazing type	886.45	46%	1252.8 $	161.9544	7.73551
Sc. 3	Façade system	586.5	30%	1957.5 $	107.1536	18.26818
Sc. 4	Shading & glass type	541	28%	1595 $	98.8407	16.13708
Sc. 5	Façade system & glass type	650	34%	1687.8 $	118.755	14.21245
Sc. 6	Façade system & Shading	716	37%	2320 $	130.8132	17.73521
Sc. 7	Façade system & Shading & glass type	610	32%	3335 $	111.447	29.92454

Table 5.15: 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 $	182.60 $	3.18
Sc. 2	Glazing type	1012	38%	939.6 $	184.89 $	5.08
Sc. 3	Façade system	221.77	8%	1493.5 $	40.517 $	36.86
Sc. 4	Shading & glass type	631.5	24%	1450 $	115.37 $	12.57
Sc. 5	Façade system & glass type	400.23	15%	1519.6 $	73.122 $	20.78
Sc. 6	Façade system & Shading	418.64	16%	2030 $	76.485 $	26.54
Sc. 7	Façade system & Shading & glass type	466.3	18%	2900 $	85.193 $	34.04

Table 5.16: The case 3 optimizations.

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 $	70.70 $	6.15
Sc. 2	Glazing type	1165	39%	522 $	212.85 $	2.45
Sc. 3	Façade system	2340	78%	971.5 $	427.52 $	2.27
Sc. 4	Shading & glass type	613.7	21%	870 $	112.12 $	7.76
Sc. 5	Façade system & glass type	2424	81%	957 $	442.86	2.16
Sc. 6	Façade system & Shading	2422	81%	1363 $	442.50	3.08
Sc. 7	Façade system & Shading & glass type	2221.8	74%	1740 $	405.92	4.29

5.2.4. The Results of the Adopted Retrofits Improvements

Some improvements had been supposed to increase the percentage of the energy savings resulted from the optimized retrofits to reach more than 50%. These improvements include 1) Adding lighting sensors that control the artificial lighting intensity according to the daylight availability inside the office. Such a system reduces lighting loads. 2) Changing HVAC setpoints, as it observed the common setpoints reached 30-32 C° for heating and 16-18 C° for cooling, which is more than the required cooling and heating for a Mediterranean climate. According to the American Society of Heating, Refrigeration and Air-conditioning Engineering (ASHRAE), the temperature range for summer comfort is 23-26°C and for winter comfort 20-23°C (ASHRAE, 2017). However, comfort zone temperatures depend on climate and weather data. The acceptable setpoints for Hebron climate can be estimated according to the standard psychometric chart as their no specific psychometric chart for Palestine. The comfort zone is 2.5°C below and above the neutral temperature for 90% acceptability for naturally ventilated buildings, and are valid for activity levels of 1.1-1.4 met and for people wearing about 0.7 clo in summer and 0.9 clo in winter. (Eq. 5.2) (Auliciems and Szokolay, 2007).

$T_n = (17.8+0.31*T_{m.}) \pm 2.5C°$ (Eq. 5.2)

Where, T_n: neutral temperature, T_m: The average temperature for the month °C = $(T_{min} + T_{max})/2$

Taking August as summer design month, then the comfort zone temperatures are ranged between 24-29 C°. The same for January as Winter design month, the comfort zone temperatures are ranged between 19.64-24.64 C°. These ranges can be considered as the acceptable setpoints for Hebron city climate where occupants can feel comfortable.

However, changing setpoints just one degree had recorded good results and high energy savings. 3) using improved HVAC with higher efficiency and heat recovery property that allow reusing the heated or already cooled air by circulated it again which required less energy to reheat or cooled a new air from the outside, besides an economizer that control the inside setpoints according to the outside air temperature during the day. 4) Employing transparent PV cells, the detailed specifications are attached in (appendix D, page 129).

The system sizing based on the following procedure:

1. The system is determined to be on-grid (connected to the electric company).

2. Determination of the required devices such as inverter and PV module, panels type monocrystalline or polycrystalline and PV panels company. Then choosing the characteristics of the panel according to the requirements such as budget, available area, or the required produced electricity. In this research, the sizing is based on the glazed façade area and the panels were chosen from the Amerisolar company (Amerisolar, 2020).

3. After choosing appropriate PV panels and inverter, the number of the PV panels required are calculated according to the available façade area as follows:

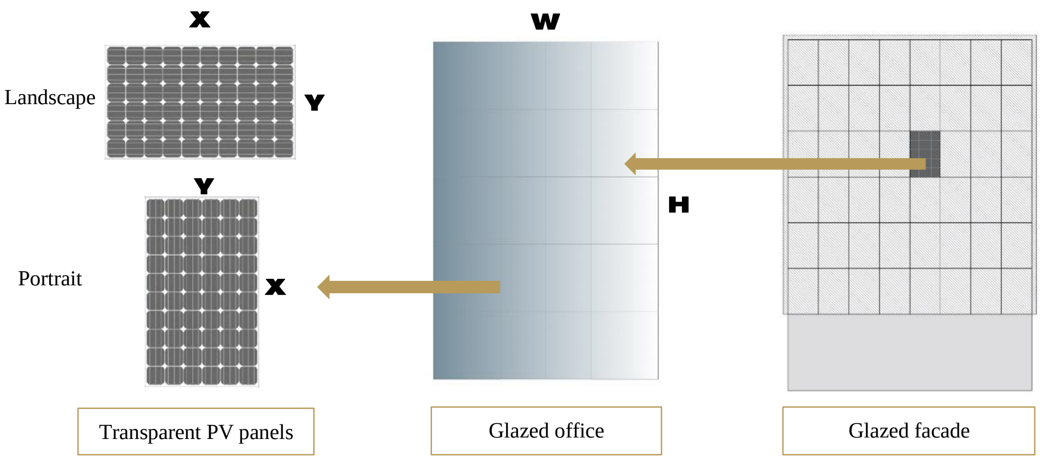


Figure 5.38: An illustration of PV panels arrangement.

- Supposing the arrangement of the panels in a landscape arrangement, (Figure 5.40). Then the allowed number equals:

  Panel number= W/X *H/Y, Where, W: Office façade width, X: PV panel length, H: Office façade height, Y: PV panel width

- Supposing the panels in a portrait arrangement, (Figure 5.40). The allowed panel number equals:

  Panel number= W/Y *H/X, where: W: Office façade width, X: PV panel length, H: Office façade height, Y: PV panel width

4. Calculating the generated energy according to the equation (Eq. 5.3):

$$P_{PV} * \text{number of panels} = E/\ SPH/\ \mu \qquad (\text{Eq. } 5.3)$$

Where:

P_{PV}: Photovoltaic panels power in Watt (W).
E: Generated electricity in kW.h/day
SPH: Sun Peak Hour, the average hours of sunshine during the day.
μ: system efficiency which equals (the efficiency of PV panels * the efficiency of the inverter).

5. Calculating the yearly yield of the generated electricity by multiplying the calculated E by 365 days.

6. Pricing the system:

- Cost= The chosen PV panel price * number of the panels + inverter price

- Local pricing: 0.90$/wp

The following tables 5.17, 5.18 and 5.19 show the results of the adopted retrofits improvements.

Table 5.17: Retrofits improvements results for case 1.

Case 1	Based case	Proposed case	Point of comparison	Energy savings (kWh/year)	Investment Cost ($)	Cost savings ($)/year	Energy savings	Payback period (year)
Scenario 1 Shading system	Curtains & tinted glass	4 blades 1.5m louvers.	Heating, cooling & lighting loads	820	435	149.81	43%	
Smart lighting	Without daylight sensors	With daylight sensors	Heating, cooling & lighting loads	854.8	150	156.17	44%	
HVAC setpoints	25 C° heating 26 C° cooling	24 C° heating 27 C° cooling	Heating & cooling loads	1007.6		184.09	52%	
Improved HVAC	Without heat recovery	With heat recovery + Economizer	Heating & cooling loads	1155.8	620	211.16	60%	5.71
PV cells	Electricity purchasing	Producing electricity with transparent PV cells	Energy savings	2027.1	1458	370.35	105%	
				Total	2663	370.35	105%	7.19

Table 5.18: Retrofits improvements results for case 2.

Case 2	Based case	Proposed case	Point of comparison	Energy savings (kWh/year)	Investment Cost ($)	Cost savings ($)/year	Energy savings	Payback period (year)
Scenario 1 Shading system	Curtains & Ref. glass	1m louver+1m overhang+ side fins	Heating, cooling & lighting loads	999.5	580 $	182.61	38%	
Smart lighting	Without daylight sensors	With daylight sensors	Heating, cooling & lighting loads	1044.9	259.2	190.90	40%	
HVAC setpoints	25 C° heating 26 C° cooling	24 C° heating 27 C° cooling	Heating & cooling loads	1169.9		213.74	44%	
Improved HVAC	Without heat recovery	With heat recovery + Economizer	Heating & cooling loads	1279.9	1071.36	233.84	49%	8.17
PV cells	Electricity purchasing	Producing electricity with transparent PV cells	Energy savings	1868.9	1458	341.45	71%	
				Total	3368.56	341.45	71%	9.86

Table 5.19: Retrofits improvements results for case 3.

Case 3		Based case	Proposed case	Point of comparison	Energy savings (kWh/year)	Investment Cost ($)	Cost savings ($)/year	Energy savings	Payback period (year)
Scenario 5	Façade system	One skin	Double skin with a 30cm air gap.	Heating, cooling & lighting loads	2340	957	427.52	78%	
	Glass type	Ref. blue	Dbl. LoE Elec. Ref. Colored	Heating, Cooling & lighting loads	2424		442.86	81%	
Smart lighting		Without daylight sensors	With daylight sensors	Heating, cooling & lighting loads	2425	60	443.05	81%	
HVAC setpoints		25 C° heating 26 C° cooling	24 C° heating 27 C° cooling	Heating & cooling loads	2495.6		455.95	83%	
Improved HVAC		Without heat recovery	With heat recovery + Economizer	Heating & cooling loads	2545.42	248	465.05	85%	0.53
PV cells		Electricity purchasing	Producing electricity	Energy savings	2839.887	729	518.85	95%	
					Total	1994	518.85	95%	3.84

The results in the tables above can be summarized as follows:

- Daylight sensors added a slight improvement in the energy savings for the three cases from 43% to 44% for case 1, 38% to 40% for case 2, and from 78% to 81% for case 3.

- Where changing HVAC setpoints by one-celsius degree for cooling and heating made a significant advantage for energy savings from 44% to 52% for case 1, and a slight improvement for case 2 and 3.

- The improved HVAC added significant energy savings for cases 1 and 2 from 52% to 60% and from 44% to 49% respectively. Whilst the case 3 had a slight improvement.

- Employing PV cells provide the best improvement by producing electricity to compensate for the consumed electricity, and in some cases (case 1), the resulted annual energy savings reached 2027.1 kWh/year which equals the average consumption of 1 Palestinian family for 6 months. Moreover, the energy savings reached 105% which means that the produced energy exceeded the office demand. In other cases, the savings reached 71% and 95% for case 2 and case 3 respectively. These percentages are cumulative savings from the retrofit scenario and all the added improvements.

- The payback period is reasonable and doesn’t exceed ten years in case 2, seven years in case 1 and four years in case 3. This means that the investment cost compensated by the energy cost savings in a short period that made the final adopted investments deemed to be successful.

The final results of the annual energy consumption for heating, cooling and lighting of the final optimized retrofits with improvements compared to the base models are presented in Figure 5.41 below.

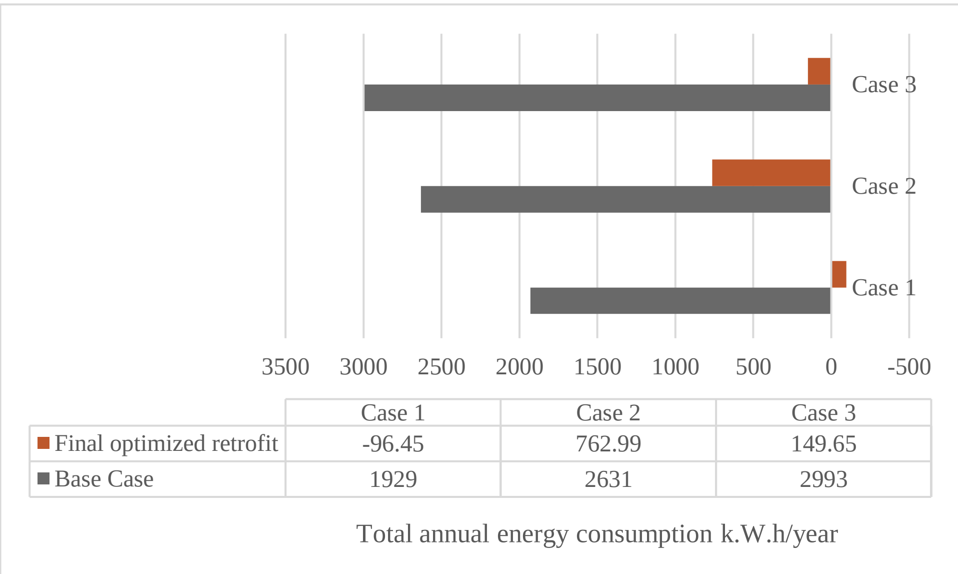


Figure 5.39: The total annual energy consumption of the base model compared to the final optimized retrofits.

5.2.5. Assessing the Environmental Benefits

The environmental assessment of the final retrofits for each case had been made in terms of carbon emissions reduction and indoor environment. The results in table 5.20 showed that the inside temperature had decreased for about 2-3.5 celsius degrees in summer when applying the final optimized retrofit with all improvements. Whilst the application of shades and retrofits does not significantly affect the amount of daylight indoor, but improves the daylight distribution whereby the average daylight factor and the illuminance intensity in areas closer to the glazed facades were reduced, providing a gentle daylit indoor, (Figures 5.42, 5.43, 5.44).

Table 5.20: The environmental assessment results.

Added benefits	Case 1	Case 2	Case 3
Temperature with no HVAC in summer	33.9- 30.5 C° minus 3.4 C°	36.76-34.55 C° minus 2.21	35-32.44 C° minus 2.56
Daylight: avg DF	2.8	2.866	1.33
CO^2 emissions reduction	910 kg CO^{2-e}	839 kg CO^{2-e}	1275.27 kg CO^{2-e}

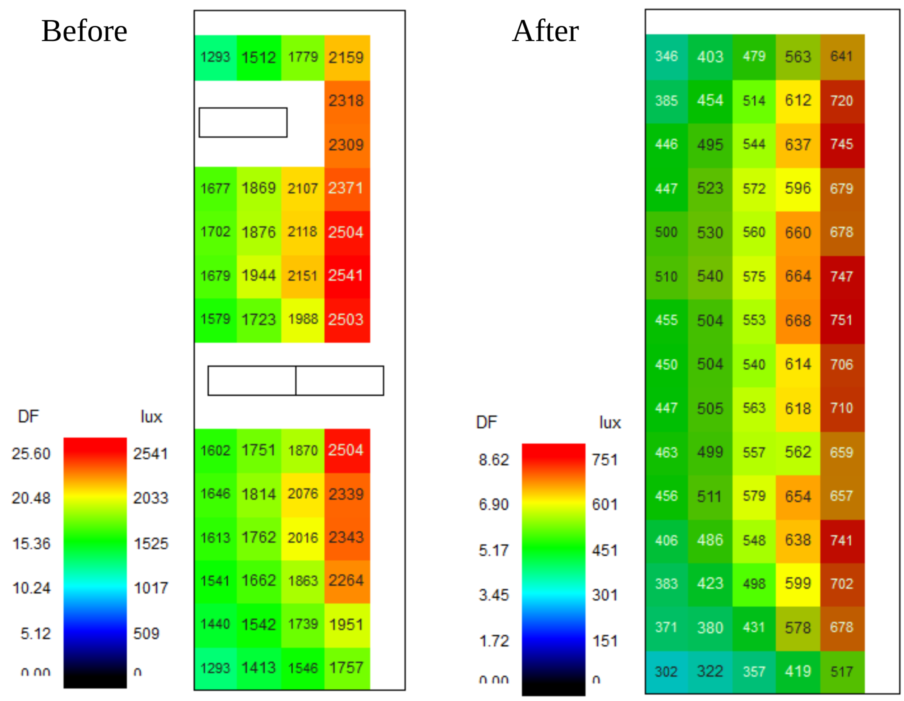


Figure 5.40: Daylight distribution of the case 1 base model compared to the final optimized model at 10:00 am on 22th March.

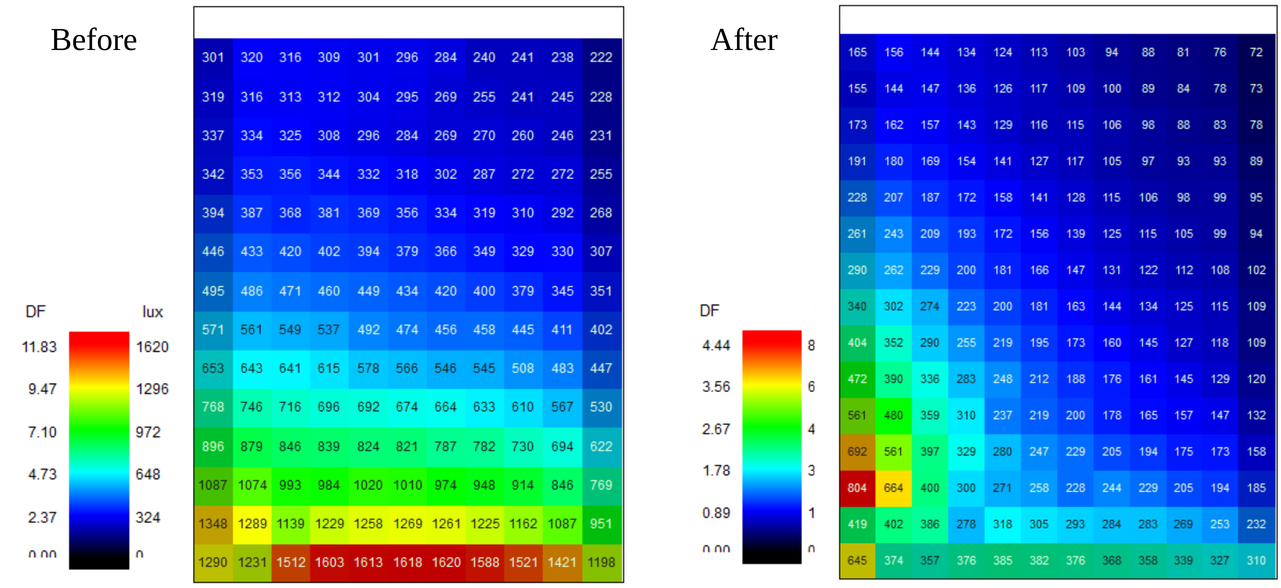


Figure 5.41: Daylight distribution of the case 2 base model compared to the final optimized model at 12:00pm on 22th March.

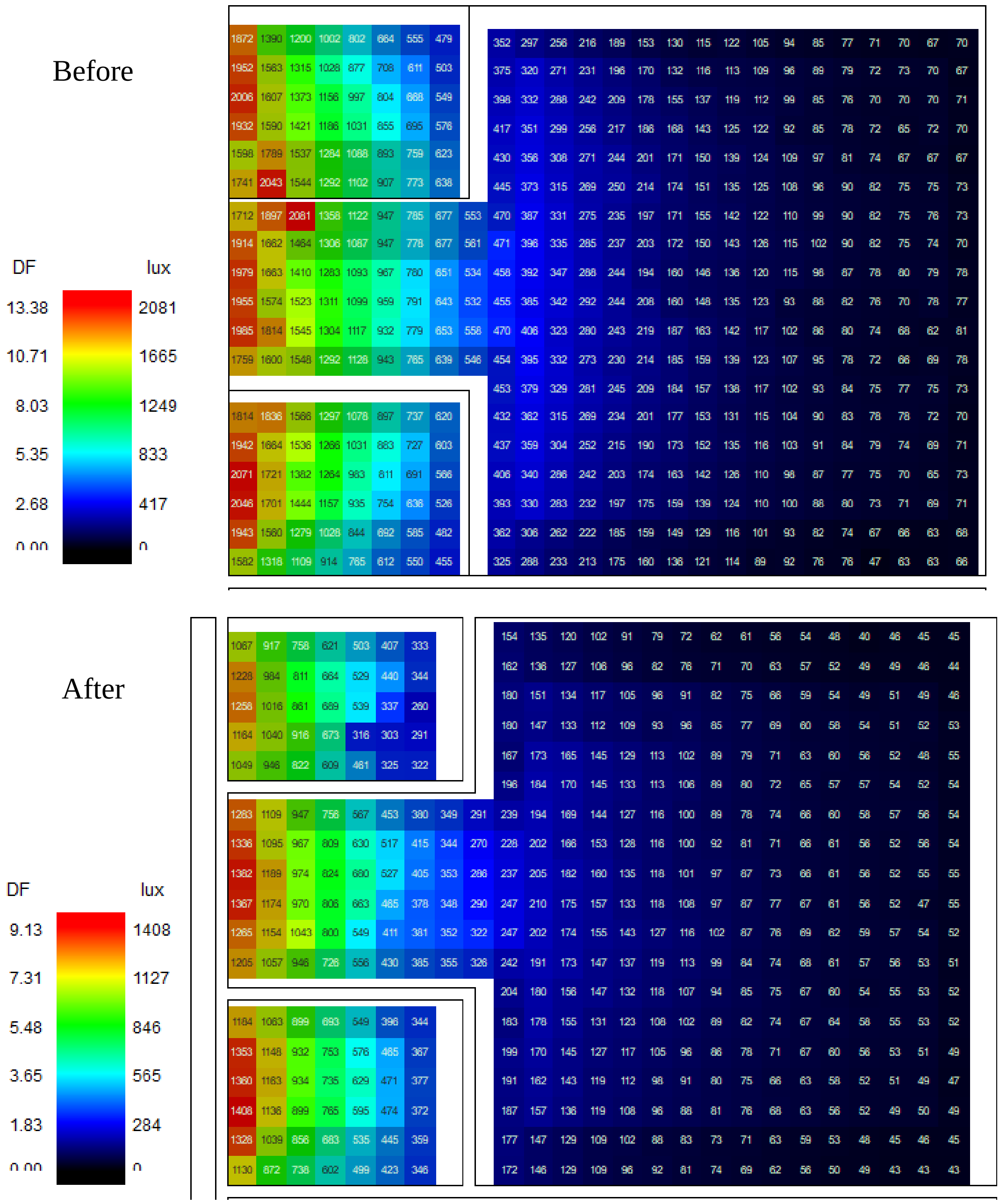


Figure 5.42: Daylight distribution of the case 3 base model compared to the final optimized model at 13:00pm on 22th March.

In addition to this, lifecycle assessment for the operation phase of the offices had been conducted in terms of carbon emissions reduction when applying retrofits to a case that consumes too much energy. The carbon emission had been calculated for the base case and then for the retrofitted model by conversion of the emissions resulted from the electric energy consumed for the heating, cooling and lighting. One kilowatt-hour (kWh) electric energy produces about 0.99 pounds* of carbon dioxide according to a study in 2018 in the United States that had estimated that the total electricity generation of 4.17 trillion kWh from all energy sources resulted in 1.87 billion tons of CO^2 emissions (EIA, 2020).

Another added benefit is that the cost savings after the payback period can contribute to the annual office renting payment in a significant portion for case 3 of about 92% from the payment. However, the other two cases haven't this significant contribution, (Table 5.21).

Table 5.21: Cost saving contribution to the annual office renting.

Added benefits	Case 1	Case 2	Case 3
The cost savings can cover the annual office renting cost after the payback period	975 $	1949.81 $	564 $
	37%	12%	92%

5.2.6. The Impact of Retrofits on the Whole Building

The final results were for one office in each of the three buildings, after that, it was supposed that if the building consists of similar offices to the retrofitted office in depth and dimension, etc. hence the results multiplied and the benefit extended to not only the whole building but also on the urban context as shown in table 5.22.

Table 5.22: The retrofit extension results.

		Energy savings (kwh)/year	**Reduction in carbon emissions (kg.CO^2)/year**	**Reduction in global warming potential**	**Cost savings ($)/ year**	**Social cost ($)/year**
Case 1	**An office**	2027.1	910.28		377.63	
	Building with same offices	56758.8	25488.17	2549	10369.83	1274.41
Case 2	**An office**	1868.9	839.2865		341.448	
	Building with same offices	33640.2	15107.16	1511	6146.065	755.36
Case 3	**An office**	2839.887	1275.269		518.8474	
	Building with the same offices	68157.288	30606.44	3061	12452.34	1530.32

* 1 Pound: 0.453592 kg.

The global warming potential GWP increased accordingly with the increasing carbon dioxide emissions which remains in the climate for thousands of years. One ton CO^2 reduction means that reduction of 1 GWP for 100 years and hence less heat island effect (EPA, 2017). Besides, the social cost of carbon is an indicator of the likely economic damages caused by an additional ton of carbon dioxide emissions on the global economy by affecting many sectors such as agriculture, forestry, fishing, tourism, insurance and health services as well as many utilities such as electricity, water and sanitation. It has been estimated by a U.S. government at $50 per ton of carbon dioxide in 2019 (Howard and Schwartz, 2017).

More added financial value is the increased profit by the increased workers' productivity which is estimated to be 100,000$ for every 100 workers per year. A study in 2018 studied the natural daylight impacts on the office workers and found that workers who are close to the windows with optimized daylight exposure reported a 2% increase in their productivity (Hedge, 2018). However, workers' productivity should be seen from more moral and humanitarian perspectives. The increasing of the workers' productivity, attendance pattern, increased concentration, and the reduction in some symptoms like eyestrain and headaches must be estimated and observed as indicators of their comfortability and satisfaction by a positive and successful change or retrofit occurred to their office indoor environment rather than be estimated as added profit.

Chapter 6

Conclusion and Recommendations

6.1 Highlights

This thesis aims to evaluate the potential energy-saving, and the feasibility of retrofitting office buildings with highly glazed façade 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, passive and active strategies, and the use of solar protection means with multi skin system in combination with the systems improvements. Seven retrofit scenarios had been applied to three cases that were carefully selected for an in-depth analysis, to provide a useful and convenient process for dealing with 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, the replacement of conventional glass in the glazed façade with an advanced one, adding multi skins that make up the building with a double- triple glazing system, and finally a combination of two or all scenarios and modifications.

The effectiveness of applying retrofit scenarios based on the reduction of the amount of electricity required to operate the mechanical HVAC system in a cost-effective manner. To identify whether the proposed retrofits and improvements address the aims and objectives of this research, the economic outcome and environmental aspects have been considered in each case compared to their base models. To assess the energy efficiency using an optimizing approach, a series of simulations were carried out by using the DesignBuilder software and the Energy Plus calculation program, which presented a three-dimensional building model, accompanied by all the available information regarding 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 chosen setpoints for the HVAC (section 5.1.2.), but also some key differences in the potential impact of diverse retrofitting scenarios applied to the three cases. After analyzing the simulation results and performing subsequent assessments, and according to the facade orientation, passive and active retrofit measures, the following subheadings explain this in light of energy consumption patterns, the research objectives which include: retrofit energy efficiency, retrofit cost-effectiveness, and the environmental consequences of the adopted retrofit scenarios.

1. The Energy Consumption Patterns of Highly Glazed Office Buildings

As observed in the research, the building orientation greatly affects energy consumptions. The case studies were intentionally selected as exemplars of the glazed offices with the highest glazing ratio and different orientations (see section 5.1.1.).

The energy consumptions for the Alizz tower office, a shallow plan office and east oriented, were found to be high in terms of thermal electric energy (section 5.1.2.). 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 caused a glare that makes the curtains are closed most of the time, thereby preventing employees from connectivity with the outdoors. However, less use of artificial lighting makes lower electric energy consumption.

The energy performance for the Golden tower was found to have a similar pattern. Due to a southern orientation that made the glazed façade exposed for a long time during the day, thus more solar gains and high indoor temperatures. However, the space benefits from acceptable daylight levels and better illuminance uniformity (section 5.1.2.).

The energy performance for Zuwwar tower was found to have a dissimilar pattern (section 5.1.2.). Due to a west orientation that made the glazed façade less exposed to the sun during working hours thus less solar gains and indoor temperatures. However, the west oriented glazed façade prevented adequate daylight penetration. As a consequence, an increased reliance on artificial lighting and electricity consumption. Besides, the heat losses in winter are higher than heat gains thus increasing heating loads.

The analysis found that the contradiction between cooling and heating demand made the cases similar in consumption as total consumption, but different in the potential impact of diverse retrofitting scenarios. This is due to that the case with higher cooling energy caused by high solar gains, it accordingly has lower heating energy and vice versa. However, by the performed analysis it had been found that cooling energy in the Mediterranean climate in Hebron for all cases is always the dominant and determining factor of the total energy consumption. Additionally, for the three cases, regarding the considerably required heating and cooling loads and according to the simulations performed, it is possible to conclude that the energy consumptions have been reduced with the increase of indoor comfort but at the expense of the indoor daylight (see sections: 5.1.2., 5.2.2. and 5.2.5.).

2. Retrofit Energy Efficiency

The passive retrofitting scenario has been assessed and has proved to be highly effective in providing the buildings with energy savings measures. In which it is necessary to adapt to the increased heat gains and losses through a glazed façade besides increased running costs of the mechanical ventilation. However, it had been found that it's not necessary that better energy saving is a better scenario where cost-effectiveness is the major determinant.

a. Passive Retrofit Strategies

External shading devices can be designed to shield the glazed facades from undesirable summer solar gains, without compromising the outdoor connectivity as shown in Figures 6.1 and 6.2. 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, also it can help to prevent glare. Changing glazing type showed also high effectiveness besides their ability to shade the building and prevent heat gains or losses through high insulative properties. The advantage of this scenario is that it keeps the all view through the glazing façade and doesn't affect the desired glazed façade appearance as with shading devices. However, the installation and maintenance of the changed glazing type are more expensive than of the shading devices.

Figure 6.1: The proposed louvres for case 1. The presented model shows the louvres effect on the east oriented office on 15 March at 8:00 am.

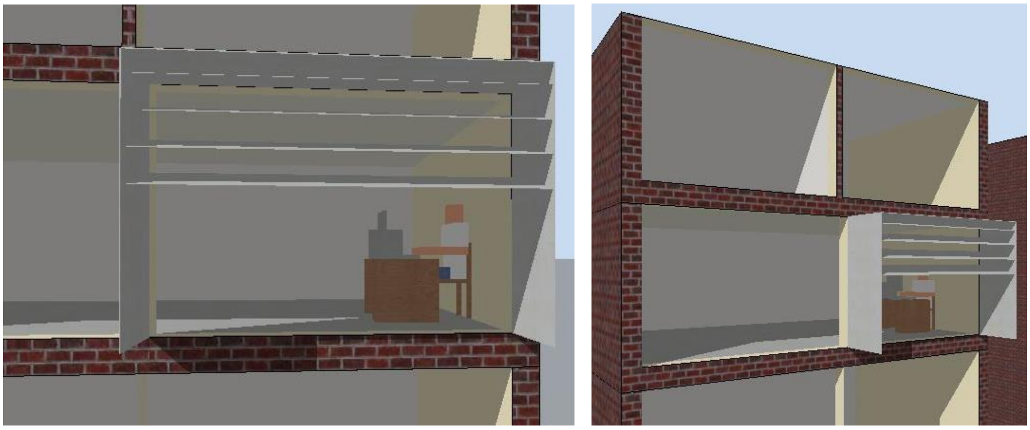


Figure 6.2: The proposed shading system composed of louvres, overhang and side fins for case 2. The presented model shows the shading effect on the south oriented office on 15 March at 13:00 pm.

Multi skin scenario was not at all effective retrofit for east and south facades, (section 5.2.2.), since multi skins are more effective for preventing heat losses in winter rather than shading effect in hot summer. Besides, without appropriate ventilation it can produce a greenhouse effect that warms up the adjacent spaces, thereby it has shown better results for the west case where heating loads were the highest, Figure 6.3.

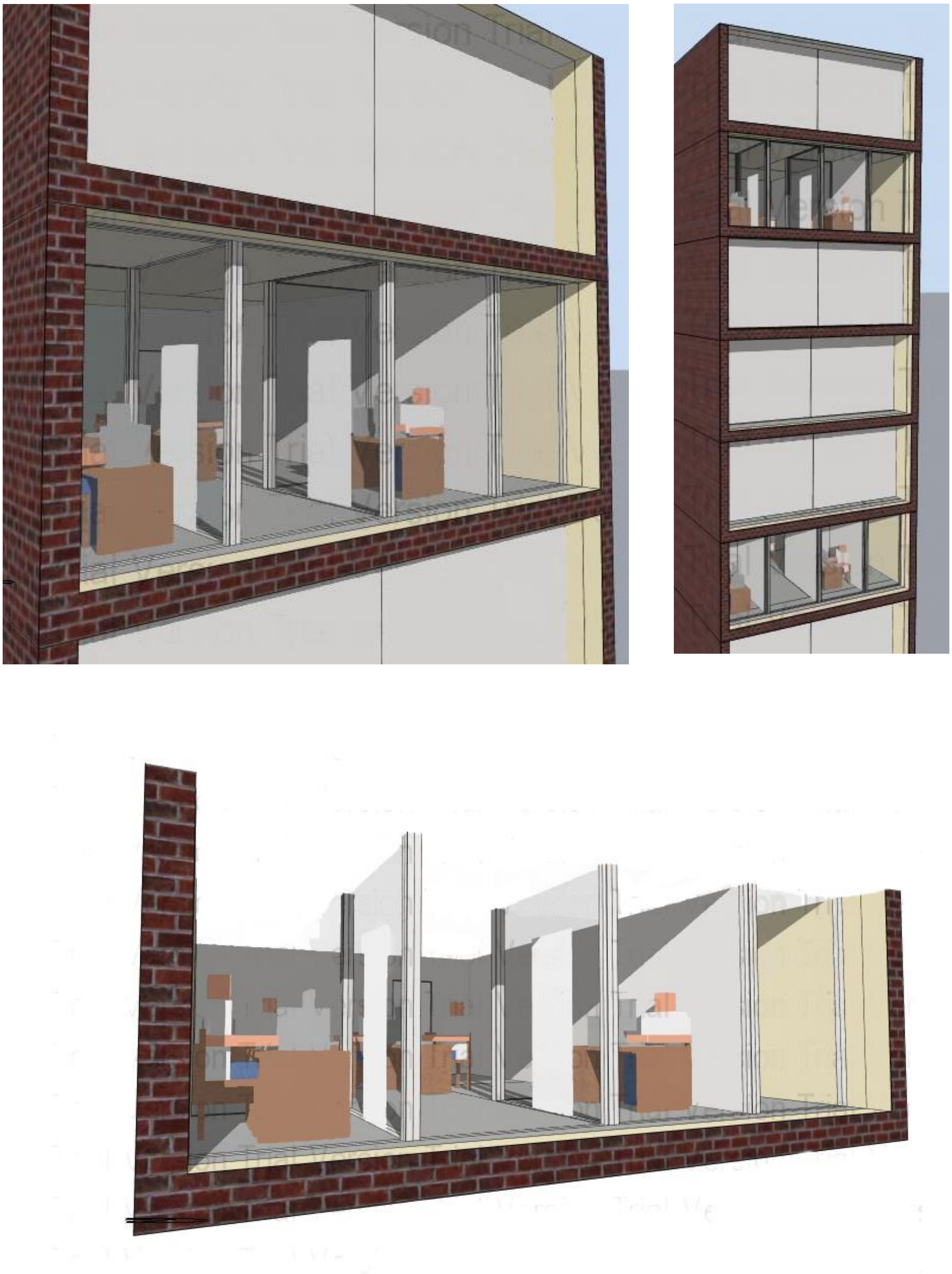


Figure 6.3: The proposed façade system composed of double skin with 30 cm air gap. The presented model shows the model of case 3 (west oriented office) on 15 March at 16:00 pm.

The impact of the retrofit on the daylight availability was significant in a positive way; since the adopted retrofits reduced glare and enhance daylight distribution and remain the average daylight in adequate limits (section 5.2.5.).

b. Improvements by Active Strategies

The retrofit with passive strategies found to be an effective retrofit strategy with satisfying achievements reached 46% and 38% energy savings for the east and south oriented cases and superlative savings of 81% for the west oriented (section 5.2.2.). However, adding improvements with some active strategies such as daylight sensors, using advanced mechanical devices, and changing setpoints showed remarkable outcomes and a dramatic jump in the energy savings for the east case and a slight enhancement for both south and west cases. Where the dramatic change was due to the installation of transparent PV cells that considered as pivotal improvement despite the costly initial investment, by generating electricity from solar radiation, the energy savings leveled up to 105% for the east case, 71% for the south case and 95% for the west case with short payback periods ranged between 3.5-9 years (section 5.2.4.).

The installation of daylight sensors is feasible for all cases regardless of a considerable initial investment. The cases can achieve a general decrease in lighting consumption on the condition the artificial lighting is provided to meet a minimum requirement according to the available daylight. Cases' retrofit chances are fairly unequal; a deep plan represents a serious constraint for the Zuwwar office that showed slight enhancement. This mainly due to that lighting load has little contribution to the total energy consumption compared to heating and cooling loads. However, changing setpoints for cooling and heating made a considerable change in energy-saving for all cases as well as using advanced HVAC with heat recovery and an economizer, which made significant savings for all cases.

3. Retrofit Cost-Effectiveness

For the east and south oriented glazed facades, the proposed scenario of shadings was found to be the 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 of each. A double skin system was found to have less impact on thermal efficiency than other alternatives. The shading scenario has proved to be very effective in reducing heat gains and also considered as a cost-effective passive retrofit strategy thus the most practicable option among all the retrofit scenarios for both Alizz tower and the golden tower as well. Whilst for the west oriented glazed facade, adding a second skin with advanced glazing type showed impressive results in energy savings of about 81% compared to the base model and very cost-effective since the payback was only two years (section 5.2.3.).

For solar exposed cases such as east and south orientations in general, and for the Golden tower office particularly, a strategy as a façade system of adding skins to the original façade showed not superlative results in terms of energy savings (5.2.3.).

All of these findings are summarized in the following Table 6.1.

Table 6.1: Summary of the final optimized retrofit scenarios.

Case	Orientation	Depth (m)	Optimal scenario	% Annual energy saving	Payback period year
1	EAST	1.8	Shading devices 4 blades 1.5m louvers.	43%	2.9
2	SOUTH	3.9	Shading devices 1m louver+1m overhang+ side fins	38%	3.18
3	WEST	5.4	Façade system double skin with 30 cm air gap & glass type Dbl. LoE Elec. Ref. Colored	81%	2.16

4. The Environmental Consequences of the Adopted Retrofit Scenarios

The annual evaluations of the performance of the alternative retrofits have been investigated. Economic and environmental assessments of the results were conducted to evaluate the effectiveness in terms of economic feasibility and the environmental impact of the retrofitting. The analysis showed that the shading devices, glazing type, and building improvements (daylight sensors and improved HVAC with higher setpoints) are the best options in terms of energy and environmental performance. However, in the economic assessments, the results promote the use of the PV cells, due to the extra energy savings (section 5.2.4.). Where the high cost of multi skin scenario played the main role in limiting the economic efficiency of the retrofit.

The benefits of the environmental retrofitting extended to not only the building indoor environment but also the urban context by reducing global warming potential, carbon dioxide emissions (section 5.2.6.).

6.2 Epilogue

In order to achieve the objectives within the time limits, the results were extracted as proving the success of such retrofit approaches. The cost-effectiveness of the proposed retrofitting strategies and scenarios is an essential consideration when evaluating the most appropriate retrofit carried out on an existing office building. In this regard, a cost-benefit analysis has been conducted using the simple payback period method to estimate economic performance which highlights the years required to offset the initial cost of an investment. The calculation of the payback period allows comparing each of the retrofit scenarios and improvements over the present state of the investigated office.

Thus, applying environmental retrofitting to office buildings with a highly glazed façade showed high effectiveness both on energy savings and in terms of economic aspect. On the other hand, a meaningful change resulted in the original glazed façade design and its' architectural appearance.

However, the benefit is not limited to energy and economic purposes, but also a wider environmental impact. Even any environmental investment is usually costly but it can be optimized to be cost-effective by balancing the initial costs with the resulted cost savings. Where the converse it's not necessarily true; when a work targeted a building or a certain sector or certain purpose such as economic, it can bring about some environmental benefits but it is still limited. Whilst when the environment improvement is the main target for any project it is then definitely will achieve all the sustainable anticipated results, e.g., if an environmental retrofit strategy becomes mandatory in a potential for enhancing the environment it would be a benefit to all; the investor, the owner, employees, and the urban context extended to the city at all.

Besides, the indoor environment enhancement can be reflected in the employees' comfort and productivity. Employee dissatisfaction can embrace the office's current situation and their acceptance for investigating their offices showed their desire and need for change, this can be seen from the first visit and telling them about the research objective.

6.3 Recommendations

The obtained recommendation can be addressed two important phases of the life cycle of offices with a glazed façade. The first is the preliminary design phase, it can be recommended to avoid the eastern and southern orientations when planning to design glazed facades since it had been proved that these two orientations had the highest energy consumption. Then it will require high shading which will, in the end, affect the appearance of the façade (Figures 6.4, 6.5) or use an advanced glazing type which is costly and it usually requires to be imported which adding 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 a careful study of the right proportions of space depth with the glazed area and ceiling height for lighting considerations.

Figure 6.4: On the left: The proposed shading devices for East oriented Alizz tower, in which the shading system covered the most of the glazed façade and affected the transparent appearance. On the right: A plan illustration and section a-a of the added shading consist of 1.5 m louvres with 4 vertical blades.

Figure 6.5: On the left: The proposed shading devices for South oriented Golden tower, in which the shading system covered the most of the glazed façade and affected the transparent appearance. On the right: A plan illustration and section b-b of the added shading consist of side fins, 1m overhang and 1 m louvre.

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, conditions of highly glazed buildings but with different supposed scenarios that fit the climatic conditions. From the literature review, the way of sourcing all and the recent information about glazed technologies and which 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 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 in keeping the curtain façade appearance and the daylight availability than shading devices. However, the study showed that the shading system is more effective in summer for eastern and southern facades, so the owner can take the advantage of multi skin with less energy and cost-effectiveness, (Figures 6.6 - 6.9).

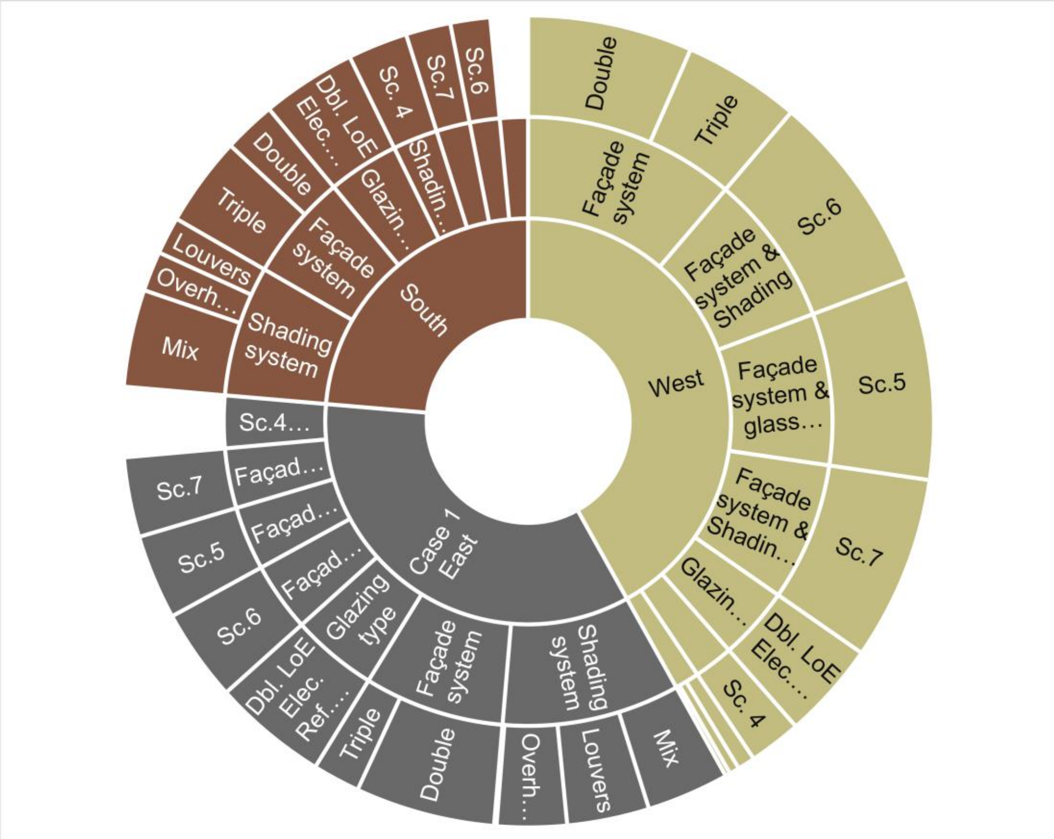


Figure 6.6: The summery wheel of the optimized retrofits for the three cases. The optimal retrofit according to energy saving is presented first and decreased gradually clockwise for each case.

Figure 6.7: The proposed second glazed façade for the west oriented Zuwwar tower, in which the new facade kept the desired transparent appearance.

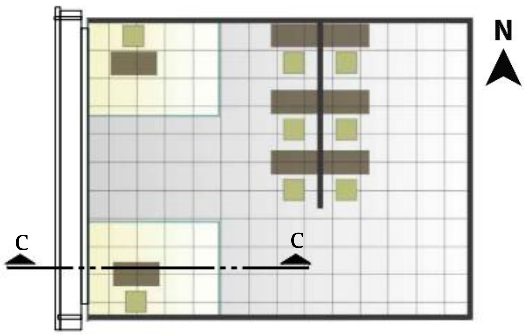


Figure 6.8: A plan illustration of the proposed second glazed façade for the west oriented Zuwwar tower.

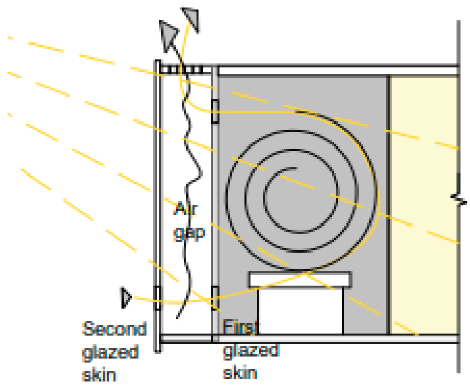


Figure 6.9: Section c-c shows the double-glazed façade with ventilated air gap.

6.4 Future Extension

Further extended studies are required to obtain holistic guidelines for both retrofit and preliminary design for 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:

- The social benefit of the proposed retrofitting strategies and scenarios is a vital consideration when evaluating the retrofit of an existing office building starting from the owner to the occupants. While the retrofitting strategies were presented briefly in terms of the indoor environment conditions, the social effects of each were not deeply investigated.

- Further research can be conducted to study the consequences of the environmental retrofits on the glazed facades' structure and the feasibility of applying the proposed shadings and multi skins in particular and the architectural pleasing appearance in general. Besides, the impact of the proposed transparent PV cells on daylight availability.

- As for the measures that have been discussed in the case studies, the potential retrofitting strategies have not included the use of dynamic façade technologies. While for the study area climate such a measure would potentially enhance the thermal performance and use all opportunities that the climate offer by tracking the benefits and avoiding the disadvantages, i.e., dynamic façade can be designed to increase solar gains in winter by allowing maximum solar penetration while preventing air leakages at the same time, and in summer it can prevent solar gains while allowing the required ventilation.

- The analysis showed that orientation and climatic constraints affected the proposed retrofits, limiting its effectiveness. The case studies have examined buildings that are located in a Mediterranean climate where the challenge is to prevent solar gains without affecting the daylight at the same time. It would be interesting to perform the simulations at different locations further Hebron city to estimate the different climatic conditions would bring about a considerable improvement in the performance. Since the three cases are in a similar climatic location, it would have been better, with more time and resources, to have extended the case study approach to a range of glazed buildings in different parts of Palestine.

- Additionally, all cases located at major streets were their large distance keeping them unshaded from the opposite so the shading factor was absent and doesn’t show the difference between floors. Hence, it will be better for further extension of investigating buildings that are partially shaded.

- 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.

- It’s recommended to consider the discount rate via using discount payback method instead of simple payback method for calculating the financial profitability.

- Finally, further research is required in terms of optimizing HVAC setpoints in Hebron offices according to the ASHRAE code of temperatures comfort ranges.

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APPENDICIES

APPENDIX A: FIELD WORK

"SENSORS SPECIFICATION SHEETS"

1. Digital illuminometer

Table A.1: Digital illuminometer specifications.

Brand	CEM
Model	DT-1309
Measuring range	40.000FC / 400.000lux
Accuracy	± 5% ± 10d
Power section	9V Battery size
Measuring rate	1.5/second

[Online]: https://ar.aliexpress.com/item/32763369151.html

Figure A.1: Digital illuminometer

2. Digital humidity and thermometer

Table A.2: Digital humidity and thermometer specifications.

Brand	CEM
Model	DT-321S
Humidity	0 - 100%RH, ±2%
Temperature	-30 to 100°C, ± 0.5°C
Dew-point Temp	-30 to 100°C, ± 0.5°C
Wet-Bulb Temp	0 to 80°C, ± 0.5°C

[Online]: https://www.cem instruments.in/product.php?pname=DT-321S

Figure A.2: Digital humidity and thermometer. [Online]: https://www.cem instruments.in/product.php?pname=DT-321S

General Specifications

Display	Large 4-1/2 dual digital LCD display with backlight
Sensor Type	A single chip relative humidity and temperature multi sensor module comprising a calibrated digital output.
Response Time	%RH : 10S (90% at +25°C still air)
Accuracy Note	Accuracy is specified for the following ambient temperature range : 64 to 82°F (18 to 28°C)
Sampling Rate	2.5 samples per second
Polarity	Automatic, (-)negative polarity indication
Over-range	"OL" mark indication
Low Battery Indication	The "[battery symbol]" is displayed when the battery voltage drops below the opera-ting level.
Operating Conditions	32 to 104°F (0 to 40°C); < 80% RH non-condensing
Storage Conditions	14 to 140°F (-10 to 60°C); <80% RH non-condensing
Auto Power Off	Meter automatically shuts down after approx.15 minutes of inactivity (Sleep Mode)
	Disable Option
Power	One standard 9V, NEDA1604 or 6F22 battery
Dimensions/Wt.	225 (H) x 45 (W) x 34 (D) mm/200g
Humidity / Temperature Measurement Range	
Humidity	0%~100%RH
Temperature	-30°C~ 100°C, -30°F~ 199°F
Resolution	0.01% RH, 0.01°C/F
Humidity Accuracy	± 2%RH (at 25°C, 20%~80% RH)
	± 2.5%RH (at other ranges)
Note : The measuring range is from 0% to 100%, but above 80% and below 20% the deviation is not specified	
Air Temperature Accuracy	± 0.5°C/± 0.9°F (at 25°C)
	± 0.8°C/± 1.5°F (all other ranges)

Figure A.3: Digital humidity and thermometer specifications. [Online]: https://www.cem instruments.in/product.php?pname=DT-321S

Figure A.4: Digital humidity and thermometer.

جامعة بوليتكنيك فلسطين / الخليل
عمادة الدراسات العليا
كلية الهندسة والتكنولوجيا
قسم الهندسة المعمارية

Palestine Polytechnic University

اســـتبانة لبحث علمي التـــاريخ:

تهدف هذه الاستبانة الى تقييم استهلاك الطاقة والراحة الحرارية والبصرية في مباني المكاتب ذات الواجهات الزجاجية في مدينة الخليل، لذا نرجو منكم التفضل بالاطلاع على هذه الاستبانة والاجابة على أسئلتها بكل دقة وموضوعية باختيار الاجابة التي ترونها مناسبة من وجهة نظركم وتعكس الوضع الفعلي في مكتبكم، وذلك من أجل خدمة البحث العلمي وتطويره بالشكل الأمثل ومن ثم خدمتكم، مع العلم بأن كافة البيانات والمعلومات المقدمة من قبلكم لن تستخدم الا لأغراض البحث العلمي فقط.

1. معلومات شخصية

الجنس	☐ ذكر	☐ أنثى		
العمر	☐ 20-30 عام	☐ 31-40 عام	☐ 41-50 عام	☐ أكثر من 51 عام
أوقات الدوام	☐ صباحي	☐ مسائي	☐ صباحي ومسائي	
الوظيفة				

2. الارتياح الحراري في فصل الصيف

▪ **درجة الحرارة**			
كيف تجد درجة الحرارة داخل المكتب صيفا (بدون استخدام أي وسيلة تكييف)؟			
☐ حار جدا	☐ حار	☐ حار قليلا	معتدل
أكثر وقت في الصيف يكون المكتب غير مريح بالنسبة لك: (يمكن اختيار أكثر من اجابة)			
☐ صباحا	☐ الظهيرة	☐ بعد الظهيرة	
▪ **التهوية الطبيعية**			
يتم فتح النوافذ في الصيف:			
☐ فتح بالكامل	☐ فتح جزئي	☐ اغلاق بالكامل	
كيف تشعر إزاء حركة الهواء داخل المكتب عند فتح النوافذ في فصل الصيف؟			
☐ مقبول	☐ غير مقبول		
إذا كانت الإجابة السابقة غير مقبول فالسبب يرجع الى كون الهواء؟			
☐ قوي	☐ ساكن	☐ قليل	
▪ **استهلاك الطاقة**			
وسائل التبريد المستخدمة:			
☐ تهوية طبيعية (شبابيك فقط)	☐ مراوح	☐ مكيف	☐ مزدوج (شبابيك ومراوح)

حدد الأشهر التي تستخدم فيها وسائل التبريد: (يمكن اختيار أكثر من اجابة)						
☐ قبل أيار	☐ أيار 5	☐ حزيران 6	☐ تموز 7	☐ آب 8	☐ أيلول 9	☐ بعد أيلول

حدد الأوقات التي تستخدم فيها وسائل التبريد (مراوح او مكيف): (يمكن اختيار اكثر من اجابة)				
☐ 8:00-10:00	☐ 10:00-12:00	☐ 12:00-2:00	☐ 2:00-4:00	
في حال استخدامك للمراوح تضبط المروحة على:				
☐ أقل سرعة	☐ سرعة متوسطة	☐ أعلى سرعة	☐ لا تستخدمها	
في حال استخدامك للمكيف حدد درجة حرارة ضبط المكيف:				
كيف تشعر أثناء استخدام وسائل التبريد؟				
☐ مريح جدا	☐ مريح	☐ راحة متوسطة (حياد)	☐ غير مريح قليلا	☐ غير مريح بتاتا
في حالة انقطاع التيار الكهربائي والشعور بأن الجو حار بالداخل ما هي الإجراءات التي تلجأ إليها:				
☐ فتح النوافذ والابواب	☐ شرب سوائل باردة	☐ الانتقال الى الخارج	☐ غير ذلك	
تعتقد أن الإجراءات البديلة:				
☐ كافية	☐ غير كافية			

3. الارتياح الحراري في فصل الشتاء

▪ **درجة الحرارة**			
كيف تجد درجة الحرارة داخل المكتب في فصل الشتاء؟			
☐ حار	☐ معتدل	☐ بارد قليلا	☐ بارد جدا
أكثر وقت يكون المكتب مريح في فصل الشتاء بالنسبة لك			
☐ صباحا	☐ الظهيرة	☐ بعد الظهيرة	
▪ **التهوية الطبيعية**			
كيف يتم تهوية المكتب عادة في فصل الشتاء؟			
☐ فتح النوافذ	☐ ميكانيكيا		
▪ **استهلاك الطاقة في فصل الشتاء**			
حدد وسائل التدفئة المستخدمة:			
☐ مدفأة كهربائية	☐ مكيف كهربائي Split Units	☐ تدفئة مركزية	☐ بدون (اشعة الشمس كافية)
حدد الأوقات التي تستخدم فيها وسائل التدفئة: (يمكن اختيار أكثر من اجابة)			
☐ 8:00-10:00	☐ 10:00-12:00	☐ 12:00-2:00	2:00-4:00
في حال استخدامك للمكيف حدد درجة حرارة ضبط المكيف: (في فصل الشتاء)			
في حالة الشعور بأن الجو بارد بالداخل ما هي الإجراءات التي تتخذها:			
☐ البقاء في مناطق الشمس	☐ ارتداء ملابس ثقيلة	☐ اقفال الفتحات	☐ شرب سوائل ساخنة
تعتقد أن الإجراءات البديلة عن التدفئة:			
☐ كافية	☐ غير كافية		

3. الارتياح البصري:

كيف تجد نسبة الإضاءة الطبيعية في المكتب بصفة عامة؟			
☐ ممتازة (تغني عن الاضاءة الصناعية)	☐ جيدة (لكن لا تغني عن الاضاءة الصناعية)	مزعجة (وهج عالي)	
كيف تحب أن تكون أشعة الشمس صيفا؟			
☐ أكثر تظليلا	☐ أكثر تشميسا	☐ دون تغيير	
من وجهة نظرك، هل يزيد الاتصال البصري مع الخارج، خلال الواجهة الزجاجية، من نشاطك وراحتك في العمل؟			
☐ نعم	☐ لا		
حدد الوسائل المستخدمة لتجنب الوهج العالي:			
☐ ستائر	☐ كاسرات شمسية	☐ الزجاج المعتم	☐ الأباجورات

نموذج لأخذ القياسات

معلومات عن المكتب

■ خصائص المبنى والبيئة المحيطة

الموقع	☐ مركز المدينة (كثافة عالية)			☐ كثافة متوسطة			☐ أطراف المدينة (كثافة قليلة)	
الطابق	☐ ارضي	☐ اول	☐ ثاني	☐ ثالث	☐ رابع	☐ خامس	☐ سادس	☐ سابع
عمر المبنى	☐ 5 سنوات أو أقل	☐ 6-10 سنوات	☐ 11-20 سنة	☐ 21-30 سنة	☐ 31-40 سنة	☐ أكثر من 40 سنة		
علاقة المبنى بالمحيط	☐ متصل (ملتصق)			☐ منفصل (مستقل)				

ارتفاعات المباني المواجهة للواجهة الزجاجية

☐ طابق ☐ طابقين ☐ ثلاث طوابق ☐ أربع طوابق ☐ خمسة طوابق ☐ ستة طوابق ☐ سبعة طوابق ☐ أكثر من سبعة

الارتدادات بين المبنى والمباني المحيطة به من جهة الواجهة الزجاجية

☐ اقل من 5م ☐ 5.1-6م ☐ 6.1-7م ☐ 7.1-8م ☐ 8.1-9م

■ خصائص الفراغ الداخلي

تصنيف المكتب	☐ مغلق			☐ مفتوح				
المساحة والابعاد								
عدد الموظفين								
أوقات الدوام								
طبيعة العمل								
مواصفات الغلاف ومواد العزل								
الجدران								
الأسقف								
الأرضية								
الزجاج								
مساحة الزجاج								
توجيه الزجاج	☐ شرق	☐ غرب	☐ جنوب	☐ شمال	☐ شمال شرق	☐ شمال غرب	☐ جنوب شرق	☐ جنوب غرب
وسائل التظليل:	☐ كاسرات شمس	☐ ستائر خارجية	☐ ستائر قماش داخلية	☐ عناصر خارجية أشجار، مباني ..	☐ زجاج معتم			

التاريخ:
الوقت:
درجة الحرارة الداخلية المقاسة:
درجة الحرارة في الخارج:
درجة الإضاءة الطبيعية الداخلية:
الإضاءة الصناعية :
الرطوبة النسبية في الداخل:
الرطوبة النسبية في الخارج:

APPENDIX B

"RETROFIT SCENARIOS & SIMULATION RESULTS"

– The base models' specifications of internals and their construction materials are detailed below (Table B.1), note that all cases have no ground floor, roof as they were between two slabs.

Table B.1: The base models construction materials and their specifications.

Component	**Layer: inside to outside**	**Thickness (mm)**	**Density ($kN/m3$)**	**Overall U value (W/m². K)**
Walls 0.75 m height	Plaster Cement block Concrete Stone	20 100 150 50	22 10 24 27	2.002
Partitions 3 sided partitions 2.75-3 m height	plaster Cement block Cement block Plaster	20 100 100 20	22 10 10 22	1.350
Ceiling	Plaster Cement block Topping Reinforced concrete	20 240 80	22 10 25	1.249
Glazing	**Layers**	**Glass type**		
	Outer Glazing pane Air gap Inner glazing pane	6 mm tinted glass 12 mm air 6 mm clear		2.690
Door	**Wooden door**			

– The base model simulation results, (Table B.2).

Table B.2: The base model simulation results.

Base Case	**Annual Energy (kWh)**				**R. Cost[1] ($)**
	Heating	Cooling	Lighting	Total	
Case 1: East	132	1220	577	1929	352.4283
Case 2: South	34	1384	1213	2631	480.6837
Case 3: West	468	2181	344	2993	546.8211

[1] R. Cost: Running costs of the used energy.

– SCENARIO 1: "Shading devices"

- Determination of the resulted annual cooling energy in kW.h of various shading devices with different projections.
- Choosing the shading device with the lowest annual cooling energy from each type of shadings, (Figure B.1).

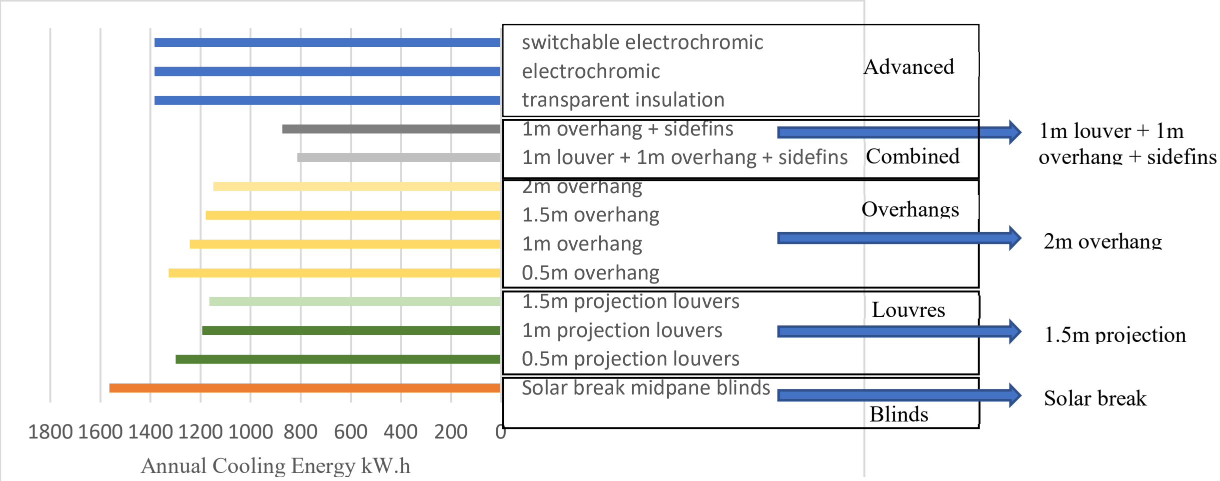


Figure B.1: The simulation results of the annual cooling energy of various shading devices.

- Choosing the appropriate shading devices for each case based on the lowest total energy of heating, cooling and lighting, (Table B.3).
- Generate scenario 1, (Table B.4).

Table B.3: The simulation results of the annual cooling and heating energy of the chosen shading devices.

	Blinds (solar break)			**Louvers** (1.5m)			**Overhang** (2m)			**Mix** (1m louver+1m overhang+ sidefins)		
	Heating	Cooling	Total	Heating	Cooling	Total	Heating	Cooling	Total	Heating	Cooling	Total
East	132	1220	1352	222	690	912	186	787	973	252	660	912
South	28	1564	1592	45	1165	1210	37	1149	1186	49	813	862
West	468	2738	3206	527	2016	2543	506	2082	2588	574	1895	2469

Table B.4: Generating scenario 1 for each case.

Scenario 1	shading devise	**I. Cost**	**Annual Energy** Heating	Cooling	Lighting	Total	**R. Cost**
East	1.5m louvers	435	222	690	197	1109	202.6143
South	mix	580	49	813	769.5	1631.5	298.0751
West	mix	435	574	1895	137	2606	476.1162

– SCENARIO 2: "Glazing type"

- Determination of various glass types with their properties in terms of solar heat gain coefficient, transmittance value, visual transmittance and cost per square meter, (Table B.7, page 119).
- Evaluate the effectiveness in terms of total annual energy consumption (includes heating, cooling and lighting loads) and cost payback period, (Table B.5).

Table B.5: Evaluating the simulation results of the glazing types.

				Case 1 EAST			**Case 2 SOUTH**			**Case 3 WEST**		
		VT	**I. Cost**	**Total Annual Energy**	**R. Cost**	**Payback period**	**Total Annual Energy**	**R. Cost**	**Payback period**	**Total Annual Energy**	**R. Cost**	**Payback period**
Lowest SHGC	Dbl LoE Elec Ref Colored	0.12	258	1043	190.56	1.48	1619	295.79	1.02	4158	759.67	1.68
Lowest U-value	Trp LoE Clr Arg	0.661	246	1702	310.96	4.52	1759	321.37	1.08	4782	873.67	6.18
	~~Quadruple LoE 3/8 Krypton~~	~~0.624~~	~~300~~									
	Base case			2000	365.4		3000	548.1		5000	913.5	

- Generate scenario 2, (Table B.6, B.7).

Table B.6: Generating scenario 2 for each case.

Scenario 2	Glass type	**I. Cost**	**Annual Energy** heating	cooling	lighting	total	**R. Cost**
east	Dbl LoE Elec Ref Colored	1252.8	201	634	207.55	1042.55	190.4739
south	Dbl LoE Elec Ref Colored	939.6	81	949	589	1619	295.7913
west	Dbl LoE Elec Ref Colored	522	497	3513	148	4158	759.6666

Table B.7: Glazing types with their properties.

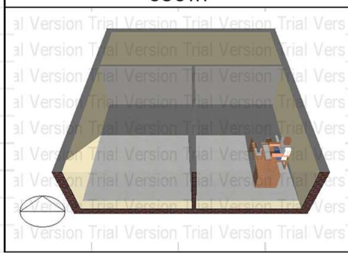
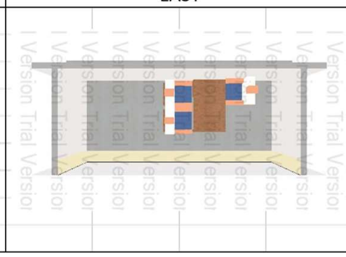
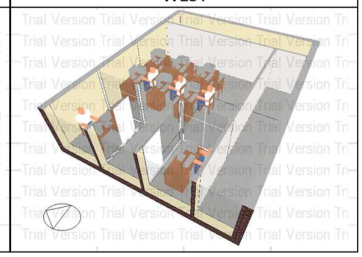
Glass type	SHGC	VT	U-Value w/m2 k	Cost $/m2
6mm/12mm				
Dbl Air Clr	0.703	0.781	2.665	184.5
Dbl Air Green	0.501	0.664	2.665	196.8
Dbl AirBlue	0.497	0.505	2.665	196.8
Dbl Air Grey	0.478	0.381	2.665	196.8
Dbl Air Bronze	0.497	0.473	2.665	196.8
Dbl Arg Clr	0.704	0.781	0.2511	221.4
Dbl Arg Green	0.499	0.664	0.2511	221.4
Dbl Arg Blue	0.494	0.505	0.2511	221.4
Dbl Arg Grey	0.476	0.381	0.2511	221.4
Dbl Arg Bronze	0.495	0.473	2.511	221.4
Dbl Elec Abs Bleached	0.742	0.752	1.761	258.3
Dbl Elec Abs Colored	0.168	0.114	1.761	258.3
Dbl Elec Ref Bleached	0.641	0.727	1.761	258.3
Dbl Elec Ref Colored	0.155	0.137	1.761	258.3
Dbl LoE Clr	0.568	0.745	1.761	196.8
Dbl LoE Tint	0.38	0.444	1.761	196.8
Dbl LoE Elec Abs Bleached	0.476	0.657	1.616	258.3
Dbl LoE Elec Abs Colored	0.128	0.099	1.616	258.3
Dbl LoE Elec Ref Bleached	0.426	0.634	1.616	258.3
Dbl LoE Elec Ref Colored	0.119	0.12	1.616	258.3
Dbl LoE Spec Sel Clr	0.421	0.682	1.628	196.8
Dbl LoE Spec Sel Tint	0.291	0.408	1.628	196.8
Dbl Ref A H Clr Air	0.234	0.181	2.412	196.8
Dbl Ref A H Clr Arg	0.228	0.181	2.233	233.7
Dbl Ref A H Tint Air	0.204	0.091	2.369	196.8
Dbl Ref A H Tint Arg	0.197	0.091	2.185	221.4
Dbl Ref A L Clr Air	0.137	0.073	2.216	196.8
Dbl Ref A L Clr Arg	0.131	0.073	2.014	221.4
Dbl Ref A L Tint Air	0.144	0.046	2.228	196.8
Dbl Ref A L Tint Arg	0.136	0.046	2.028	196.8
Thermochromic	0.569	0.578	2.13	221.4
Quadruple LoE 3/8 Krypton	0.466	0.624	0.781	369
6mm				
Sgl Clr	0.819	0.881	5.778	123
Sgl Blue	0.62	0.57	5.778	135.3
Sgl Green	0.623	0.749	5.778	123
Sgl Grey	0.602	0.431	5.778	135.3
Sgl Bronze	0.62	0.534	5.778	123
Sgl Ref A H Clr	0.321	0.201	4.975	147.6
Sgl Ref A H Tint	0.304	0.1	4.851	147.6
Sgl LoE	0.72	0.811	3.779	147.6
3mm/12mm				
Trp Clr Air	0.684	0.738	1.757	209.1
Trp Clr Arg	0.685	0.738	1.62	233.7
Trp LoE Clr Air	0.474	0.661	0.982	221.4
Trp LoE Clr Arg	0.474	0.661	0.78	246

– SCENARIO 3: "Multi skin system"

- Comparing the indoor temperature of the cases with different multi skins, (Table B.8 & Figure B.2).

Table B.8: The simulation results of indoor temperatures of the cases when applying multi skins.

	19-Aug	15-Mar	19-Aug	15-Mar	19-Aug	16-Mar
No. skins	**12:00**	**12:00**	**10:00 ص**	**10:00 ص**	**12:30**	**14:00**
One	32	22.8	32	21	34.6	26
Double	28	20	30	25	33	26
Triple	27	21	34	26	29	24.5
	SOUTH		EAST		WEST	

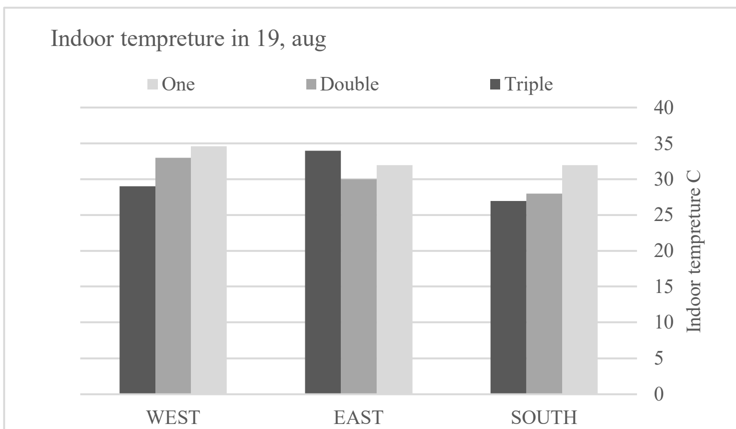


Figure B.2: The simulation results of the annual cooling energy of various shading devices.

- Evaluating the cooling & heating loads and solar heat gains & losses with different multi skins (Table B.9 & Figure B.3, B.4, B.5 and B.6).

Table B.9: The simulation results of cooling & heating loads and solar heat gains & losses of the cases when applying multi skins.

		Heating & cooling	with HVAC				
		summer design wee	winter design week	Kw.h			
		Summer	Winter	Summer	Winter	Summer	Winter
		jun-oct	**dec-feb**	**jun-oct**	**dec-feb**	**jun-oct**	**dec-feb**
One	COOLING	1384		1220		1080	
	HEATING		34		132		246
	SOLAR TRANS	91	-258	442	-196	-15	-218
Double	COOLING	1080		525		805	
	HEATING		32		70		80
	SOLAR TRANS	88	122	445	-85	292	-74.5
Triple	COOLING	845		1003		1339	
	HEATING		25		74		88
	SOLAR TRANS	79	63	225	-38	155	-37
		SOUTH		EAST		WEST	

● **Cooling setpoint 26 C°**	**-**	**heat loss**
● **Heating setpoint 25 C°**	**+**	**heat gain**
● **All units in Kw.h**	● **HVAC Ty**	**Split unit**

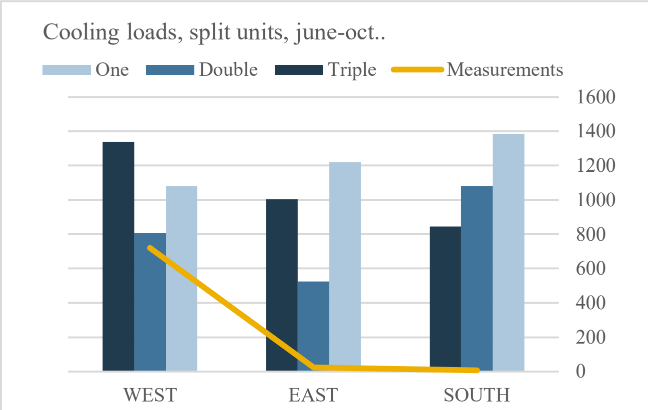


Figure B.3: The simulation results of the required annual cooling energy of the cases with different multi skins.

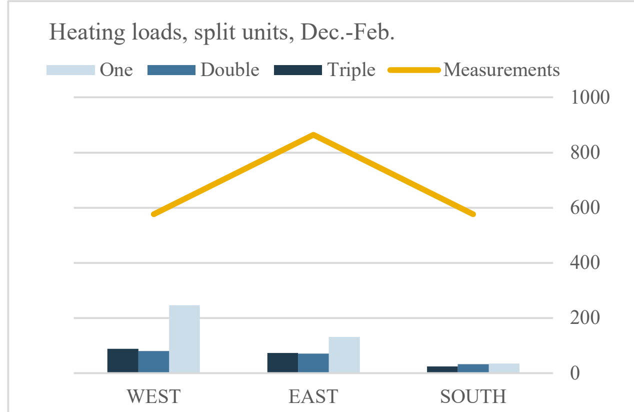


Figure B.4: The simulation results of the required annual heating energy of the cases with different multi skins.

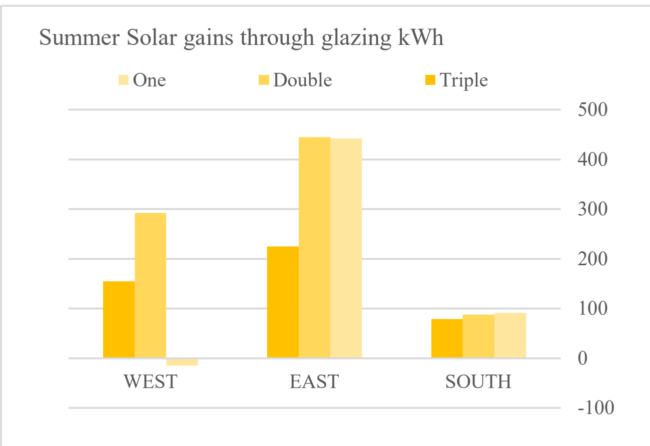


Figure B.5: The simulation results of the solar heat gains through glazed facade of the cases with different multi skins.

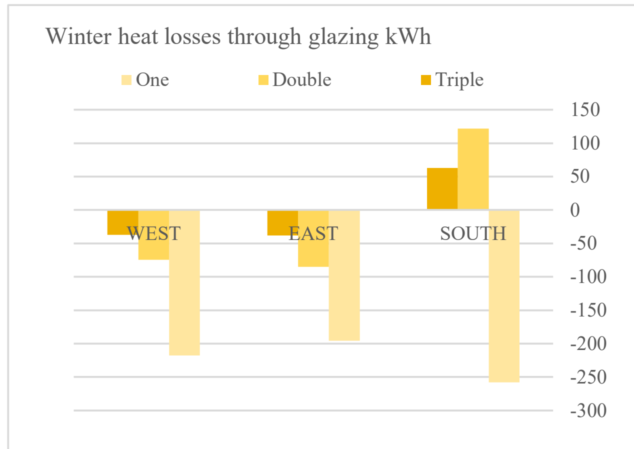


Figure B.6: The simulation results of the heat losses through glazed facade of the cases with different multi skins.

- Evaluating the visual performance in terms of daylight factor and uniformity ratio with different multi skins (Table B.10 & Figure B.7, B.8).

Table B.10: The simulation results of the visual performance of the cases with different multi skins.

		aug Clear day 12:00	Mar Overcast sky	aug Clear day 09:00 ص	Mar Overcast sky	aug Clear day 01:00 م	Mar Overcast sky
One	avg DF	7	4.8	22	9.7	9.8	7.2
	min DF	2.8	1.4	13.6	5.3	6.8	4.7
	Area to comply	**100%**	**77%**	**100%**	**100%**	**100%**	**100%**
	UR	0.4	0.29	**0.62**	**0.55**	**0.69**	**0.65**
Double	avg DF	5.7	3.7	17.3	6.8	6.4	4.9
	min DF	2.8	1.5	16.4	6.2	4 4	3
	Area to comply	**100%**	**73%**	**100%**	**100%**	**100%**	**100%**
	UR	0.49	0.41	0.95	0.91	0.63	0.61
Triple	avg DF	4	2.5	11.6	4.5	4.3	3
	min DF	2	1	7.9	3.3	2.8 2.8	1.8
	Area to comply	**100%**	**50%**	**100%**	**95%**	**100%**	**71%**
	UR	0.50	0.40	0.68	0.73	0.65	0.60
		S (Golden Tower)		E (AlIzz Tower)		W (Zuwwar Tower)	

*UR: Uniformity Ratio

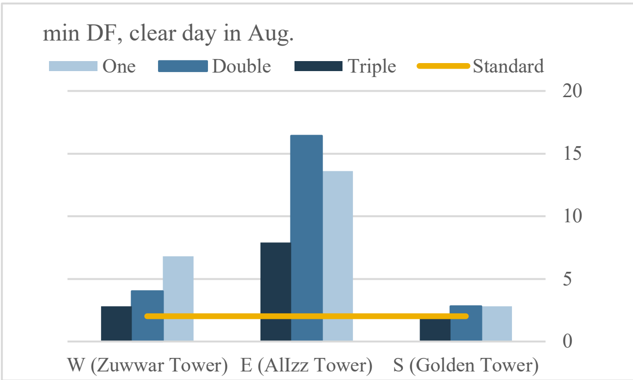


Figure B.7: The simulation results of the minimum daylight factor in a clear day in 24th August of the cases with different multi skins.

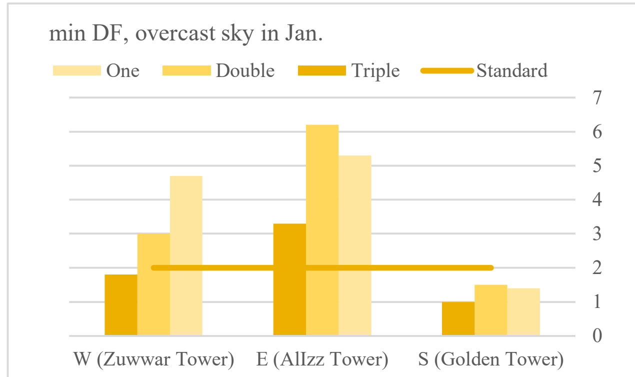


Figure B.8: The simulation results of the minimum daylight factor in an overcast day in 21th January of the cases with different multi skins.

- Rating the indoor environment of the cases with different multi skins, where the multi skin model with the highest total score demonstrated scenario 3 of each case (Figure B.9). See the rating system chapter 4, pages 54-55, Table B.11 below.

Table B.11: The rating system.

Points of comparison	The result	Rating points
▶Thermal environment ▶Daylight factor & uniformity ratio ▶Solar transmittance ▶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

		Case I		Case II		Case III	
		SOUTH		EAST		WEST	
DAYLIGHT		●	●●	○	●	○	●
Thermally	Summer	●	●●	●●	●	●	●●
	Winter	●	●	●●	●	○	●
Solar heat Gains	Summer	○	●	○	●	○	●
	Winter	●●	●	●	●●	●	●●
Loads	Cooling	●	●●	●●	●	●	○
	Heating	○	●	●	○	●	○
		Double	Triple	Double	Triple	Double	Triple
		6	10	8	7	4	7
		Triple		Double		Triple	

South → Triple
East, West → Double

Figure B.9: Rating the indoor environment of the cases with different multi skins.

- Determining the optimized air gap depth of the multi skins based on the lowest heating and cooling loads (Table B.12).

Table B.12: The simulation results of different depths of the air gap\ gaps for each case.

	system	0.3 m	0.6 m	0.9 m	1.2 m
east	double	3053	1030	693	705
west		470	2359	1370	1271
		.3/.3 m	.6/.3 m	.6/.6 m	.9/.3 m
south	triple	1217	1189	1180	1166
			↓ Less space		↓ More space

- Determining the position of the added skin for case 2 (Table B.13).

Table B.13: The simulation results of different position of the added triple skin for case 2.

Office space	position		heating	cooling	lighting	total	R.cost	annual cost saving ILS	annual area price ILS
17.28 m2	outside	triple .6/.3	5.23	1189	1215	2409.23	440.1663	139.7	100 JD\sq. m
15.12 m2	inside	triple .6/.3	9.4	975.5	1062	2046.9	373.9686	367.98	100 JD\sq. m

Losing 2.16 sq. m = 216 JD or 1483 ILS\year which is higher than the annual saved cost 367.98 ILS. Thus, the outside position is more reasonable.

- Generate scenario 3, (Table B.14).

Table B.14: Generating scenario 3 for each case.

scenario 3	system	**I.Cost**	**Annual Energy**				**R. Cost**
			heating	cooling	lighting	total	
east	double 0.9	1957.5	428	693	221.5	1342.5	245.2748
south	triple .6/.3	1493.5	5.23	1189	1215	2409.23	440.1663
west	double .3	971.5	127	470	56	653	119.3031

– Different scenarios: combinations of 1,2 and 3

- Generate scenario 4, (Table B.15).

Table B.15: Generating scenario 4 for each case

scenario 4	**shading devise**	**Glass Type**	**Annual Energy**				**R. Cost**	**I. Cost**
			heating	cooling	lighting	total		
east	1.5m louvers	Dbl LoE Ref Colored Air 6mm/12mm	239	899	250	1388	253.5876	1595
south	mix		81	828	1090.5	1999.5	365.3087	1450
west	mix		1147	2219	240.7	3606.7	658.9441	870

- Generate scenario 5, (Table B.16).

Table B.16: Generating scenario 5 for each case

scenario 5	system	Glass Type	Annual Energy heating	cooling	lighting	total	R. Cost	I. Cost
east	double 0.9	Dbl LoE Ref Colored Air 6mm/12mm	521	346	412	1279	233.6733	1687.8
south	triple .6/.3		19.77	996	1215	2230.77	407.5617	1519.6
west	double .3		262	215	92	569	103.9563	957

- Generate scenario 6, (Table B.17).

Table B.17: Generating scenario 6 for each case

scenario 6	shading devise	system	Annual Energy heating	cooling	lighting	total	R. Cost	I. Cost
east	1.5m louvers	double 0.9	524	352	337	1213	221.6151	2320
south	mix	triple .6/.3	19.36	978	1215	2212.36	404.1982	2030
west	mix	double .3	260	228	83	571	104.3217	1363

- Generate scenario 7, (Table B.18).

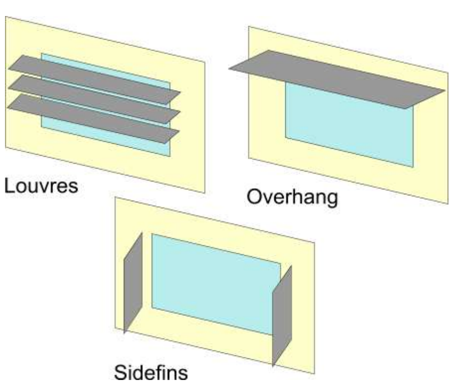
Table B.18: Generating scenario 7 for each case

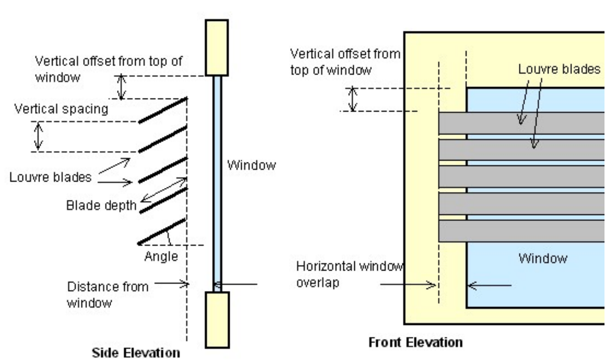
scenario 7	shading devise	Glass Type	System	Annual Energy heating	cooling	lighting	total	R. Cost	I. Cost
east	1.5m louvers	Dbl LoE Ref Colored Air 6mm/12mm	double 0.9	557	265	497	1319	240.9813	3335
south	mix		triple .6/.3	27.7	922	1215	2164.7	395.4907	2900
west	mix		double .3	276	373.5	121.7	771.2	140.8982	1740

A P P E N D I X C : Pricing sheets

The pricing sheets of the proposed retrofit scenarios based on local interviews with contractors and PV cells local pricing. In which, a phone interview conducted on 20 January 2020 with Eng. Riyad Abu Saada who discussed curtain walls design and glazing types pricing. Another personal interview conducted on 22 June 2020 in Hebron with Eng. Akran Zreiq Abu Ayash and Eng. Alaa Abu Ayash who discussed shading devices pricing, and multi skins structural feasibility and pricing.

	عمالة وتركيب	سعر المواد متر مربع	المواصفات		البند
					تركيب كاسرات شمس
		170\m2	المنيوم	النوع	1.5 m louvres
			1.2*4.8*0.002 م	الابعاد	
	15*3*14.5	170*4.8	4 blades	العدد	
ILS 1500	700	800	4.8*3= 14.4 sq.m	مساحة الزجاج	
			المنيوم	النوع	1m louvre
			0.7*3.6*0.002 م	الابعاد	
		160*3.6	4 blades	العدد	
ILS 1300	700	600	3.6*3	مساحة الزجاج	
			المنيوم	النوع	1m overhang
			0.7*3.6*0.002 م	الابعاد	
		40*6	1 blade	العدد	
		240	3.6*3	مساحة الزجاج	
			المنيوم	النوع	sidefines
			1*3*0.002 م	الابعاد	
mix		80*3	2	العدد	
2000 ILS		250	3.6*3	مساحة الزجاج	





البند	المواصفات	السعر شامل العمالة
استبدال واجهة زجاجية	استبدال الزجاج فقط *	
نوع الزجاج الجديد	دبل عاكس اقل انبعاثية 6ملم- 12 ملم هواء- 6 ملم Double low emissive reflective colored 6/12 mm	
مساحة الزجاج	م 4.8*3	**ILS 4320**
	م 3.6*3	**ILS 3240**
	م 2*3	**ILS 1800**
علما ان الزجاج الأصلي كان دبل معتم ازرق 12/6 ملم Double blue 6/12mm		

البند	المواصفات	السعر	
نوع الزجاج	دبل شفاف 6ملم- 12 ملم هواء- 6 ملم	الأصل 130 شيكل / متر مربع	
	Double clear 6/12 mm	170 مع العمالة والتركيب	
مساحة الزجاج	م 4.8*3	**2450**	6750
	م 3.6*3	**1850**	5150
	م 2*3	**1050**	3350
عقدة و أرضية حديد	م 4.8*0.9	**4000**	
	م 3.6*0.9	**3000**	
	م 2*0.3	**2000**	
فتحة grill في عقدة الحديد المضافة		**300**	
استبدال الواجهة الزجاجية المعتمة بزجاج شفاف			
نقل وتركيب الزجاج المعتم الموجود أصلا للواجهة الجديدة			

scenario 1	Case	ILS	$
1.5 m louver	east	**1500**	435
mix	south	**2000**	580
mix	west	**1500**	435
scenario 2		ILS	$
	east	**4320**	1252.8
	south	**3240**	939.6
	west	**1800**	522
scenario 3		ILS	$
	east double 90	**6750**	1957.5
	south triple 60-30	**5150**	1493.5
	west double 30	**3350**	971.5

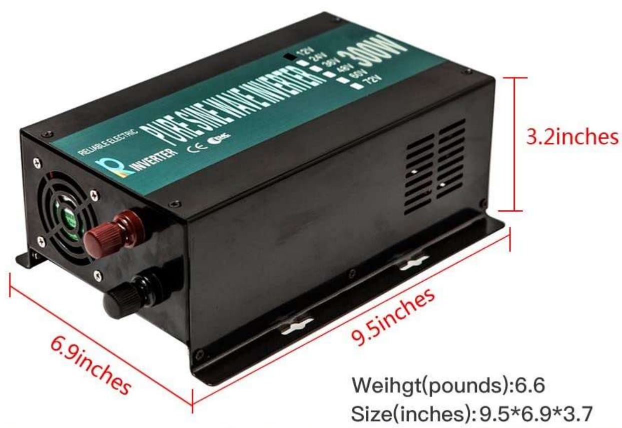
scenario 4	**shading devise**	**Glass Type**		ILS	$
east	1500	**4320**	5820	**5500**	1595
south	2000	**3240**	5240	**5000**	1450
west	1500	**1800**	3300	**3000**	870
Scenario 5		**Glass Type**	**System**	ILS	$
east		**4320**	1500	**5820**	1687.8
south		**3240**	2000	**5240**	1519.6
west		**1800**	1500	**3300**	957
scenario 6	**shading devise**	**system**		ILS	$
east	6750	1500	8250	**8000**	2320
south	5150	2000	7150	**7000**	2030
west	3350	1500	4850	**4700**	1363

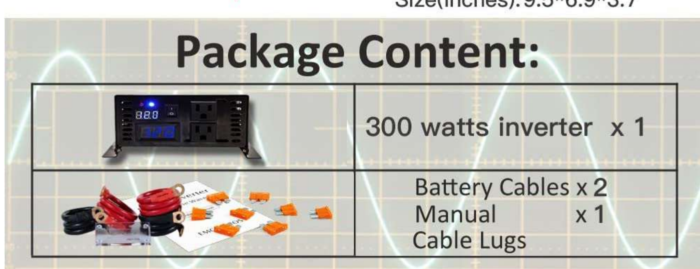
scenario 7	**shading**	**Glass Type**	**system**		ILS	$
east	6750	**4320**	1500	12570	**11500**	3335
south	5150	**3240**	2000	10390	**10000**	2900
west	3350	**1800**	1500	6650	**6000**	1740

Pricing Smart systems	
Smart lighting system	Added 15$\sq.m
Improved HVAC with economizer	Added 62$\sq.m

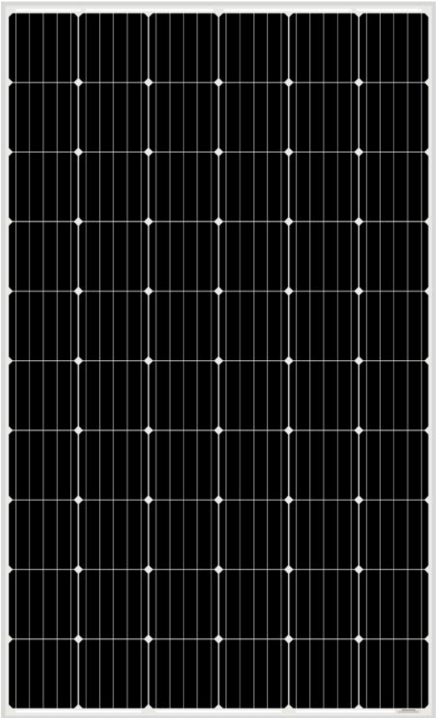
A P P E N D I X   D : PV system specifications

Inverter specifications: WZRELB 300W 12V DC to 120V AC Pure Sine Wave Solar Power Inverter. [Online]: https://www.amazon.com/WZRELB-RBP30012B1-Display-Power-Inverter/dp/B0792LLG3F/ref=sr_1_14?dchild=1&keywords=300+watt+solar+inverter&qid=1602614597&sr=8-14





AS-6M30-305W



MONOCRYSTALLINE MODULE

ADVANCED PERFORMANCE & PROVEN ADVANTAGES

- High module conversion efficiency up to 18.75% by using high efficient solar cells and advanced manufacturing technology.
- Low degradation and excellent performance under high temperature and low light conditions.
- Robust aluminum frame ensures the modules to withstand wind loads up to 2400Pa and snow loads up to 5400Pa.
- High reliability against extreme environmental conditions.
- Power tolerance: ±3%

CERTIFICATIONS

- IEC61215, IEC61730, CE, CQC, CGC, CEC(Australia), ETL(USA), JET(Japan), J-PEC(Japan), Kemco(South Korea), KS(South Korea), MCS(UK), FSEC(FL-USA), CSI Eligible(CA-USA), Israel Electric(Israel), InMetro(Brazil), TSE(Turkey)
- ISO9001:2008: Quality management system
- ISO14001:2004: Environmental management system
- OHSAS18001:2007: Occupational health and safety management system

Passionately

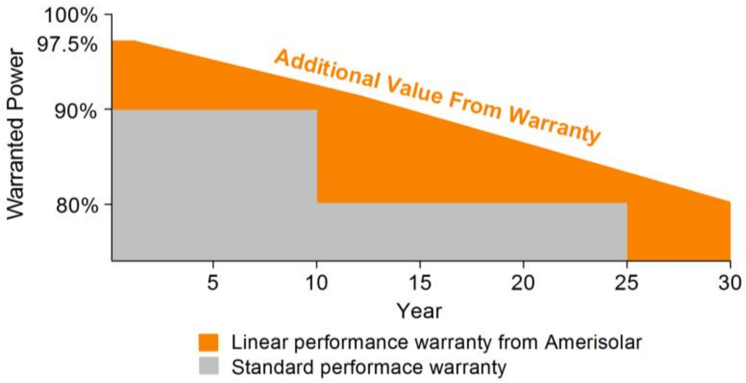
committed to

delivering innovative

energy solution

SPECIAL WARRANTY

- 12 years limited product warranty.
- Limited linear power warranty: 12 years 91.2% of the nominal power output, 30 years 80.6% of the nominal power output.



ELECTRICAL CHARACTERISTICS AT STC

Nominal Power (P_{max})	275W	280W	285W	290W	295W	300W	305W
Open Circuit Voltage (V_{OC})	38.6V	38.8V	39.0V	39.2V	39.4V	39.6V	39.8V
Short Circuit Current (I_{SC})	9.29A	9.37A	9.45A	9.53A	9.62A	9.70A	9.79A
Voltage at Nominal Power (V_{mp})	31.4V	31.6V	31.8V	32.0V	32.2V	32.4V	32.6V
Current at Nominal Power (I_{mp})	8.76A	8.87A	8.97A	9.07A	9.17A	9.26A	9.36A
Module Efficiency (%)	16.90	17.21	17.52	17.83	18.13	18.44	18.75
Operating Temperature	-40°C to +85°C						
Maximum System Voltage	1500V DC						
Fire Resistance Rating	Class C						
Maximum Series Fuse Rating	15A						

STC: Irradiance 1000W/m^2, Cell temperature 25°C, AM1.5

ELECTRICAL CHARACTERISTICS AT NOCT

Nominal Power (P_{max})	207W	211W	215W	218W	222W	226W
Open Circuit Voltage (V_{OC})	35.7V	35.9V	36.1V	36.3V	36.5V	36.7V
Short Circuit Current (I_{SC})	7.59A	7.65A	7.72A	7.79A	7.86A	7.93A
Voltage at Nominal Power (V_{mp})	28.8V	29.0V	29.2V	29.4V	29.6V	29.8V
Current at Nominal Power (I_{mp})	7.19A	7.28A	7.37A	7.42A	7.50A	7.59A

NOCT: Irradiance 800W/m^2, Ambient temperature 20°C, Wind Speed 1 m/s

MECHANICAL CHARACTERISTICS

Cell type	Monocrystalline 5BB 156.75x156.75mm (6x6inches)
Number of cells	60 (6x10)
Dimensions	1640x992x35mm (64.57x39.06x1.38inches)
Weight	18kg (39.7lbs)
Front cover	3.2mm (0.13inches) tempered glass with AR coating
Frame	Anodized aluminum alloy
Junction box	IP67, 3 diodes
Cable	4mm^2 (0.006inches^2), 1000mm (39.37inches)
Connector	PV-ZH202B(Manufacturer: Zhonghuan Sunter)

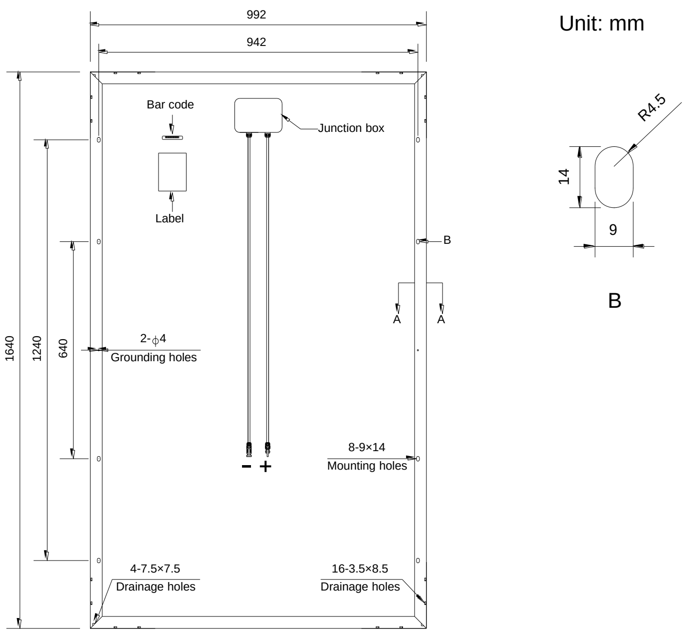
TEMPERATURE CHARACTERISTICS

Nominal Operating Cell Temperature (NOCT)	45°C±2°C
Temperature Coefficients of P_{max}	-0.39%/°C
Temperature Coefficients of V_{OC}	-0.29%/°C
Temperature Coefficients of I_{SC}	0.052%/°C

PACKAGING

Standard packaging	30pcs/pallet
Module quantity per 20' container	360pcs
Module quantity per 40' container	840pcs(GP)/924pcs(HQ)

ENGINEERING DRAWINGS

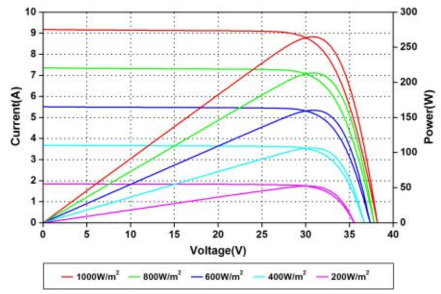


Rear View

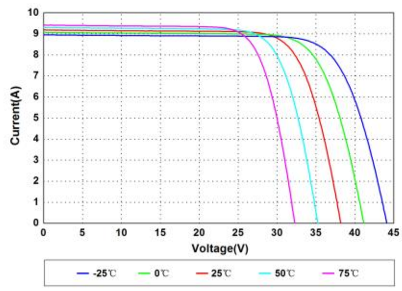
Section A-A

Specifications in this datasheet are subject to change without prior notice.

IV CURVES



Current-Voltage and Power-Voltage Curves at Different Irradiances



Current-Voltage Curves at Different Temperatures