Palestine Polytechnic University

Deanship of Graduate Studies and Scientific Research

Master of Architecture – Sustainable Design

Retrofitting strategies for enhancing natural daylight of the residential buildings in Hebron- Palestine

Lana M.Zuhdi Abu Munshar

Supervisor

Dr. Abdelrahman Halawani

Thesis submitted in partial fulfillment of requirements of the degree

Master of Architecture- Sustainable Design

July, 2021

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

Retrofitting strategies for enhancing natural daylight of the residential buildings in Hebron- Palestine

Lana M.Zuhdi Abu Munshar

in partial fulfillment of the requirements for the degree of Master in Renewable Energy & Sustainability.

Graduate Advisory Committee:

Dr. Abdelrahman Halawani

(Supervisor), University (PPU)

Signature: ______________________ Date: ______________

Dr. Fajer Tawayha

(Internal committee member), University (PPU).

Signature: ______________________ Date: ______________

Dr. Muhannad Haj Hussein

(External committee member), University (Al-Najah).

Signature: ______________________ Date: ______________

Thesis Approved by:

Name: ____

Dean of Graduate Studies & Scientific Research

Palestine Polytechnic University

Signature:……………...…………………

Date:…..……………...…………………

Retrofitting strategies for enhancing natural daylight of the residential buildings in Hebron-Palestine

Lana M.Zuhdi Abu Munshar

ABSTRACT

The concepts of green buildings rarely have been taken into account in Palestine, which environmental problems increased as well as the cost of operation and maintenance of buildings. Recently, some public buildings were constructed following the guidelines and principles of green concepts. However, no attention was given to the existing residential buildings, which form more than 80% of the building sector. The directions in architecture towards multi-story apartment buildings have also increased in the residential sector. This due to the high demand for housing in dense areas and rising land costs. Thus, flats shared side walls with neighboring units and sometimes have only one or two outer walls, which causes many problems. This thesis focuses on two main visual comfort problems :1-Limited access to daylight and low level of light in deep plan rooms. 2-High level of light and weak distribution of light (too glary).

This thesis aims to identify the way to enhance the natural daylight in multi-story residential buildings were built after 1993 in Hebron city by providing a local residential retrofit framework that helps support designers in pre-retrofit phases. It offers detailed guidance and retrofit strategies to enhance natural daylight in buildings, taking into account thermal comfort. The research methodology adopts a holistic method based on qualitative and quantitative research. A simulation of four multi-story buildings was performed to provide quantitative results and daylight analysis for each case before and after applying the passive retrofit strategies.

The results show that the few modifications in the existing buildings can improve considerable indoor daylighting. The result of enhancement after applying the proposed retrofit strategies ranges between (85% - 98%) for case 1, (80%- 98%) for case 2, (53%- 84%) for case 3 and (51% - 71%) for case 4. Some apartments reached adequate illumination, while in other apartments with the depth of a room more significant than 6 m (deep rooms), it did not reach adequate illumination. In most multi-story apartment buildings, it may not be feasible to rely solely on passive strategies. Consequently, to achieve optimal daylight, a combination of passive and active retrofit strategies needed. Furthermore, the study found that combining strategies (such as shading devices, light shelves, and blinds) can have an essential role in creating a desirable environment based on daylight quality and thermal comfort.

Keywords: Building envelope, retrofit strategies, multi-story residential buildings, façade retrofit, and spatial retrofit.

استراتيجيات تعديل المباني السكنية القائمة لتحسين الاضاءة الطبيعة في المباني السكنية في مدينة الخليل-فلسطين

لانا " محمد زهدي " أبو منشار

الملخص

نادرًا ما يتم أخذ مفاهيم المباني الخضراء بعين الاعتبار في فلسطين، مما أدى إلى زيادة المشاكل البيئية. في الآونة الأخيرة، تم تشييد بعض المباني العامة وفقًا لإرشادات ومبادئ المفاهيم الخضراء، ولكن لم يتم الاهتمام بالمباني السكنية القائمة والتي تشكل أكثر من 80٪ من قطاع البناء. ازدادت الاتجاهات في الهندسة المعمارية نحو العمائر السكنية ويرجع ذلك إلى عدة أسباب منها ارتفاع الطلب على المساكن في المناطق ذات الكثافة السكانية العالية، بإضافة الى ارتفاع أسعار الأراضي. كل طابق في العمارة السكنية يتم تقسيمة الى وحدات مستقلة (شقق)، بحيث تشترك الشقق في الجدران الداخلية مع الوحدات المجاورة، في بعض الأحيان يكون لكل شقة جدار واحد أو جداران خارجيان فقط، مما يسبب العديد من المشاكل. تركز هذه الأطروحة على مشكلتين رئيسيتين تتعلقان بالراحة البصرية: 1 -الوصول المحدود إلى الإضاءة الطبيعية وانخفاض مستوى الاضاءة في الغرف ذات التخطيط العميق. 2-ارتفاع مستوى الاضاءة (شديد اللمعان-الوهج).

تهدف هذه الأطروحة إلى تحديد طريقة لتحسين الإضاءة الطبيعية في المباني السكنية متعددة الطوابق التي تم بناؤها بعد عام 1993 في مدينة الخليل من خلال توفير إطار تعديلي سكني محلي يساعد في دعم المصممين في مراحل ما قبل اجراء التعديل على المباني. يتم تقدم إرشادات مفصلة واستراتيجيات تعديل المباني لتحسين أداء الإضاءة الطبيعية في المساكن، مع مراعاة الراحة الحرارية. تعتمد منهجية البحث على منهج شمولي قائم على البحث النوعي والكمي. حيث تم إجراء محاكاة لأربعة عمائر سكنية لتوفير نتائج كمية وتحليل نتائج ضوء النهار لكل حالة قبل وبعد تطبيق استراتيجيات التعديل.

تظهر النتائج أن تعديلات قليلة على المباني الحالية يمكن أن تحسن الإضاءة الطبيعية داخل المباني بدرجة كبيرة. تتراوح نتيجة التحسين بعد تطبيق استراتيجيات التعديل المقترحة بين (85٪ -98٪) للحالة الدراسية 1، (80٪ -98٪) للحالة 2، (53٪ - 84٪) للحالة 3 و (51٪ - 71) ٪) للحالة 4. وصلت بعض الشقق إلى الإضاءة الطبيعية الداخلية الكافية حسب وظيفة الغرفة، بينما في الشقق الأخرى التي يزيد عمق الغرفة فيها عن 6 أمتار (غرف عميقة)، لم تصل إلى الإضاءة الكافية. قد لا يكون من المجدي الاعتماد فقط على الاستراتيجيات السلبية وبالتالي لتحقيق الضوء الطبيعي الأمثل داخل الغرف، هناك حاجة إلى مزيج من استراتيجيات التعديل السلبي والنشط. كما وجدت الدراسة أن الجمع بين الاستراتيجيات (مثل أجهزة التظليل، ورفوف الإضاءة، والستائر) يمكن أن يكون له دور أساسي في خلق بيئة مريحة تعتمد على جودة الإضاءة الطبيعية والراحة الحرارية.

DECLARATION

I declare that the Master Thesis entitled" Retrofitting strategies for enhancing the performance of natural daylight of the residential 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.

Lana M.Zuhdi Abu Munshar

Signature: ______________________________ Date: ____________________

DEDICATION

This work is dedication to my parents who have been a great source of inspiration, supports and encouragement during my study .

This work is also dedication to Prof. Dr. Abdelrahman Halawani who encorgued me and shared his advice and help to accomplish this work.

ACKNOWLEDGEMENT

It is a pleasure to thank those who made this thesis possible. Foremost I would like to show my gratitude to my Prof. Abdelrahman Halawani for the continuous support, this thesis would not have been possible without his knowledge and help .

I am also very grateful for all survey and interview respondents, especially to Architects Razan Sharawi, Ayda kawasmi, Saad qawasmeh, M. Zuhdi Salhab, Sharif Maraqa and Ahmed abu kraifeh.

Finally, I would like to thank Hebron Municipality, Hebron engineering association, Palestinian civil defense and Engineering offices for their generosity in giving information and their cooperation.

Table of Content

List of Figures

List of Tables

Research Approach

Introduction

1.1. Background

The world is confronting significant challenges embodied in global warming and climatic change. According to the UNEP SBCI (Sustainable Buildings & Climate Initiative), buildings are responsible for more than 40 percent of global energy use and one-third of global greenhouse gas emissions, both in developed and developing countries. The building sector has the most considerable potential for delivering long-term, significant, and cost-effective greenhouse gas emissions. During the last years, most developed countries and many developing countries have already reduced greenhouse gas emissions from the building sector. On the other hand, reducing emissions from buildings will bring multiple benefits to both the economy and society.

The buildings in Palestine became uncomfortable and more depleted of natural resources with much internal heat disturbance. As a result, the running costs of the buildings and the consumption of energy increased significantly, thus increasing carbon emissions. In addition, the Palestinians have still treated the building as a structure, not as a living space that needs special attention to thermal comfort, good air quality, natural ventilation, and daylight (Alatawneh, Gramana and Corrao, 2015).

The green building sector has received much more interest in the last few years. Some projects were built based (green building ideas), considering saving energy by selecting suitable thermal insulation, using daylighting efficiently, natural ventilation, etc. Although (recently) there is an interest in green and sustainable development, specifically the efforts of the Higher Council of Green Building and the Engineers Association, the percentage of housing units established in 2017 in Palestine according to green construction standards and specifications are very marginal, almost zero. It is essential to point out that no attention was given to refurbishing existing buildings to be redesigned to apply the green building ideas. Therefore, this dissertation aims to present a way to enhance natural daylight in multi-story residential buildings by providing a local residential retrofit framework that helps support designers and decision-makers in pre-retrofit phases. It also offers detailed guidance and retrofit strategies to improve the performance of natural daylight, taking into account thermal comfort. This dissertation focuses on two main problems:

1. Limited access to daylight and low level of light in deep plan rooms
2. High level of light and weak distribution of light (too glary)

1.1. Problem Statement

The current trends in architecture towards multi-story apartment buildings in the residential sector, especially in Palestine, have increased due to the high demand for housing in densely populated areas and high land costs (ITMA, 2018). Many Palestinians build their houses without engineering consultancy, which increases random construction (Alatawneh, Gramana and Corrao, 2015). On the other hand, the clients and developers constantly tend to pressure architects to design multi-story residential buildings with maximum space utilization in the face of high land prices and rarity (Ahsan, 2009). Thus, apartments shared side walls with neighboring units and sometimes have only one or two external walls, which causes many problems. This configuration creates inner spaces without direct contact with outside natural light in terms of natural daylight. Deep plans are a common practice in multi-story buildings (Asfour and Al Shurafa, 2016), (Kristl and Krainer, 1999), (Ahadi, Saghafi and Tahbaz, 2019). The deep core areas of these buildings cannot be naturally illuminated by windows and depend entirely on electricity for illumination. On the other hand, neighboring buildings can reduce the chances of lighting reaching the building due to shadow effects.

In the early design phase, the building's energy performance is often prioritized over daylight utilization, resulting in negative consequences for indoor visual comfort (Vanhoutteghem et al., 2015). Thus, design solutions that balance daylight and energy performances in buildings are needed. Existing residential buildings also have many challenges, such as change essential services and building regulations.

Therefore, this thesis focuses on identifying how to enhance natural daylight in multi-story residential buildings by providing a local residential retrofit framework that helps support designers and decision-makers in pre-retrofit phases. It also offers detailed guidance and retrofit strategies to enhance natural daylight in buildings, taking into account thermal comfort.

1.2 Research Aims and goals

Research Aims:

- This thesis aims to **identify** a way to enhance natural daylighting in the existing multi-story residential buildings, taking into account thermal comfort.
- To **explore** the optimal retrofit solutions for existing multi-story residential buildings.
- To **provide** a local residential retrofit framework that helps support initial decisions.
- To **provide** detailed guidance and retrofit strategies to enhance natural daylight in multi-story residential buildings to create a high-quality living environment.
- To **propose** recommendations that help to enhance the natural lighting in exiting multi-story buildings in terms of quality and quantity.

1.3 Research Question

- Main question

1. What strategies and building retrofit technologies can enhance the natural daylight performance of existing multi-story residential buildings in Palestine?
2. How can the research outcomes be applied to enhance natural daylight in existing multi-story residential buildings?

1.4 Research Methodology

The methodology of this research is based on a holistic method based on qualitative research and quantitative research. Research methods outline, see figure 1.1

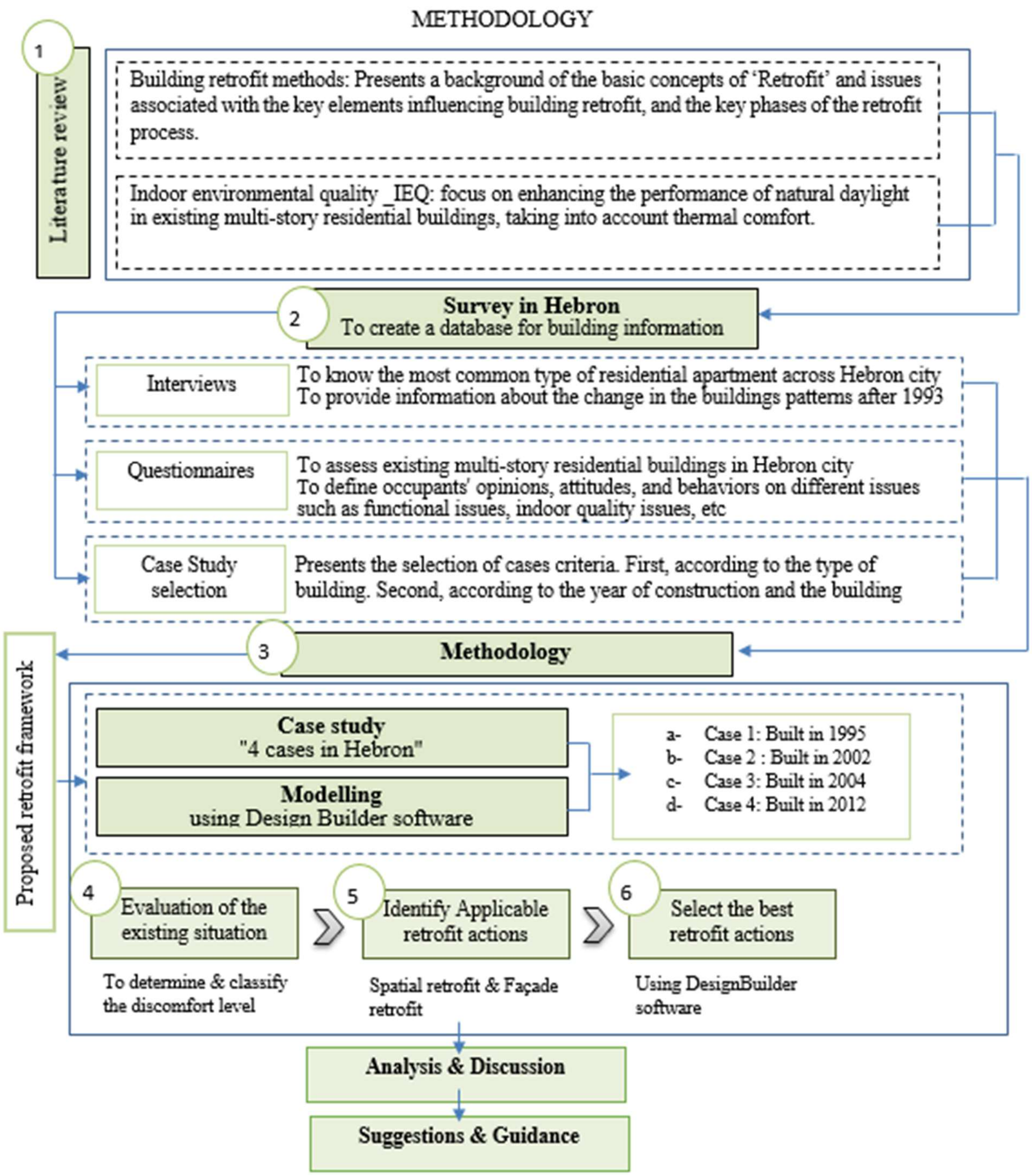


Figure1.1: Research methods outline

This dissertation subdivides into four tasks:

- Task 1: a literature review was conducted at the beginning of this research, which covers three fields:
  1. It provides a review of the literature relevant to an understanding of building retrofit methods.
  2. It covers a review of the literature on indoor environmental quality improvement, focusing on enhancing natural daylight in existing residential buildings.
  3. It provides a review of the literature related to retrofitting strategies of residential buildings to enhance the performance of indoor environmental quality (natural daylight) and improving building energy efficiency.

Depending on the literature review, a local residential retrofit framework for the multi-story buildings was proposed to identify, implement, and apply the most efficient retrofit scenarios that help decision-makers in the retrofit process.

- Task 2.1: Site surveys

A general study of the city of Hebron was conducted to establish a database of building information (including the main building characteristics of existing dwellings and changes in building patterns after 1993). The most common residential buildings in Hebron were classified according to vertical movement and light wells, which helped to determine the criteria for selecting the case study.

- Task 2.2: Interviews

The interviews were organized with experts to know the most common residential apartments in Hebron city and provide information about the change in building patterns after 1993.

- Task 2.3: Questionnaire

The sample of this study is all the multi-story residential buildings in Hebron city. The questionnaires were organized to assess existing multi-story residential buildings in Hebron city and to define occupants' opinions, attitudes, and behaviors on different issues. The majority of the questions were multiple-choice questions and included open-ended questions.

- Task 3: case studies

In this research, four typical multi-story residential buildings built after 1993 in Hebron city were selected. The case study examines the effectiveness of different combinations of natural daylight retrofit strategies.

- Task 4: Simulation

Simulations of four multi-story apartments were conducted to analyze daylight for each case before and after the optimization process. A 3D digital model was constructed using DesignBuilder (V6.1.0.6.), based on the actual building form and information on building materials collected during the fieldwork. The optimization process is used to investigate the impact of different parameters on daylight and determine the conditions that achieve optimal daylighting and the minimal energy consumption for heating and cooling.

Literature Review

Introduction

This chapter covers two fields; the first field provides a review of the literature relevant to an understanding of building retrofit methods. It presents a background of the basic concepts of ‘Retrofit’ and issues associated with the key elements influencing building retrofit, the key phases of the retrofit process, and building guidelines for an energy efficiency retrofit. While the second field presents a review of the literature on indoor environmental quality improvement, focusing on enhancing the performance of natural daylight in existing multi-story residential buildings, taking into account thermal comfort. This phase also include a detailed review for main daylight parameters that affect indoor environmental quality while identifying local standards related to visual comfort .Finally, it presents the general guidelines to use the proposed retrofit framework.

2.1. Building retrofit: drivers, reasons and application levels

Retrofitting means' providing a component or feature not fitted during manufacture or adding something that it did not have when first constructed '. When it comes to architecture and housing, the 'retrofit' and other terms such as refurbishment, renovation, restoration, etc., are used to describe physical changes at the building level to extend the lifetime of existing buildings (Eames et al., 2014). While (Rhoads, 2010) defined 'Sustainable retrofit' as incremental improvements in building fabric and systems with the primary objective of improving energy efficiency and reducing carbon emissions.

The buildings and construction sector rank first shares of carbon dioxide emissions and about two-thirds of global energy consumption occurs in buildings, according to a report by the United Nations Environment Program (UNEP)- 2018. Existing buildings represent a massive percentage of the building stock, compared to the current rate of new buildings, which is considered low (McArthur and Jofeh, 2015). Therefore, retrofitting existing buildings stock represents a sustained strategy that could improve energy efficiency and quality of life. As Phan pointed out, 'retrofitting offers many opportunities to improve the energy performance of residential buildings' (Schiano-Phan, 2010).
Retrofitting existing housing stocks to include sustainability initiatives will improve energy efficiency and reduce CO2 emissions and achieve many benefits in the environmental, social, and economic aspects (Zhang, 2018). For instance, the benefits on the social aspect include: fuel poverty mitigation, job creation, and improve occupant health & productivity. In contrast, the benefits on the economic aspect are reducing energy bills and public health spending and increase income and gross domestic product. In the environmental aspect, the benefits include: energy-saving, reduce CO2 emissions, natural resource-saving, and improve indoor environment quality.

During the last decade, one of the significant issues attracting many governments and international organizations around the world to investigate is improving energy performance. So that a considerable effort has been put towards improving the energy efficiency of existing buildings through policy guidance, financial assistance, and technical support to help expand local energy efficiency efforts and reduce energy use in existing buildings[1].

The retrofit of the buildings depends on the purpose of the intervention. Several retrofits can be classified as structural, energy, fire resistance, aesthetic, blast, etc. (Giebler et al., 2009). Four main domains or retrofit drivers have been identified, which motivate stakeholders to retrofit the energy performance of an existing building (Menassa and Baer, 2014): The first domain is social factors that include community impacts, human rights, etc. The second domain is the environmental factors that refer to reducing the environmental impacts of actions. The third domain is an economic factor that affects financial performance such as sales, profit, etc. Finally, the technical aspects include building façade retrofit, mechanical system, electrical system, and plumbing system retrofit.

There are three levels of application for energy retrofitting strategies: Firstly, stabilization strategy or minor retrofit. Secondly, substitution strategy or intermediate retrofit. Thirdly, restitution strategy or major retrofit (Jahed and Dino, 2018). The retrofit interventions are classified into two categories to determine the required comfort quality :(Jahed and Dino, 2018)

1. Spatial Retrofit (SR)
2. Facade Retrofit (FR)

Spatial interventions represent retrofit applicable to the interior parts and divided into internal and peripheral zones. The façade interventions form the basis of the façade retrofit framework.

[1] For example:

- The federal government of the United States has provided financial assistance to support existing building retrofits (DOE, 2009).
- In 2010, the UK government has provided strategies to improve the energy efficiency of 7.0 million British homes by 2020 intent to cut carbon emissions by 29% and it targets to meet an 80% reduction by the year 2050 (DECC, 2009).
- The UAE cabinet in 2011, started the application of Sustainable Building standards at government buildings and is expected by 2030 to reduce carbon emissions by 30% (UAE, 2011).
- The NEEAP for the Kingdom of Jordan has set targets for energy-saving until the year 2020, such as reduce energy efficiency by 20%. (Shakhashir, 2014)

Retrofit application levels		
Minor	Intermediate	Major
1. Stabilization action 2. Unmodified appearance 3. e.g adding insulation, changing lighting system	1. Substitution action 2. Modified components & appearance 3. e.g replacing window glazing, updating HVAC	1. Complete envelope transformation + preserved original building substance 2. Highly disruptive to occupants 3. e.g roof upgrading & renewable energy plants

Figure 2.1: Retrofit application levels (Jahed and Dino, 2018)

2.2 Key Elements Influencing Building Retrofit:

The success of retrofit projects depends on many issues. The essential elements that significantly impact building retrofits include policies and regulations, client resources and expectations, retrofit technologies, building-specific information, human factors, and other uncertainty factors (Ma et al. 2012),(Hong et al., 2019). See figure 2.2 below.

Figure 2.2: Key Elements Influencing Building Retrofit (Ma et al. 2012).

2.2.1 Policies and regulations

Policies and regulations are an effective instrument for addressing energy efficiency in buildings, which set minimum energy efficiency requirements for retrofitting existing buildings (UNESC, 2017). The government may provide policy guidance and financial assistance to assist building owners in achieving the required energy performance targets by implementing the energy retrofit of existing buildings.

2.2.2 Client resources and expectation

Client resources and expectations are other elements for a successful building retrofit measure. That pursues to define the project targets and goals, as well as the available economic budget. Thus, it determines the kind of retrofit technologies that should be used—these technologies impact energy savings. Therefore, the clients invest in technologies with higher energy savings potential to save costs and to abide to set standards and regulations (Harris, Anderson and Shafron, 2000), (Hong et al., 2019).

2.2.3 Retrofit technologies

The retrofit technologies correspond to the Energy Retrofit Measures (ERMs) used to promote buildings' sustainability and energy efficiency. Retrofit technologies vary from energy-efficient equipment, advanced controls, and renewable energy systems to energy consumption patterns changes (Ma et al., 2012).

2.2.4 Building specific information

A further key element for an effective retrofit is access to building information (Hong et al., 2019). Building geographical location, orientation, size, age, occupancy profiles, operation schedules, energy sources, and building fabric and envelope structures are the vital information that should be considered to propose the most appropriate ERMs. The interaction of this information will help provide the optimum retrofit package for any building (Ma et al., 2012).

2.2.5 Human factors

Human factors are other relevant elements for the success of building retrofits. The human factors include comfort needs, schedules (occupancy, maintenance, and management), activity, and access to controls (CIBSE, 2004). Changes in this factor will lead to changes in the energy use of buildings (Hong et al., 2019). Several studies showed that occupants' behavior and characteristics significantly affect building energy use. The changes in occupant behavior, occupant controls, and comfort range can produce substantial energy savings (Santin, 2011), (Ma et al., 2012).

2.2.6 Other uncertainty factors

Building retrofits are also affected by many uncertain factors, such as climate change, policy change, and occupant behavior change (Hong et al., 2019). Accurate estimation of building energy factors is essential to help select the best retrofit options to maximize building energy efficiency during its whole life span (Ma et al., 2012).

2.3. Roadmap and Energy Retrofit Process for Existing Building

2.3.1 Key phases of a building energy retrofit process

The problem with improving a building retrofit is to identify, implement the most cost-effective retrofit technology to achieve enhanced energy performance while maintaining satisfactory service levels and acceptable indoor thermal comfort. Thus, the overall process of retrofitting the building can be divided into phases.

According to (Ma *et al.*, 2012), there are five significant steps for building retrofit process, as shown in figure 2.3: 1) project setup and pre-retrofit survey, 2) energy auditing and performance assessment, 3) Identification of retrofit options, 4) Site implementation and commissioning, and 5) Validation and verification. While according to (Jahed and Dino, 2018), there are three steps for the energy retrofitting process: 1) Pre-retrofit process, 2) Retrofit, and 3) Post-retrofit. See figure 2.4r.

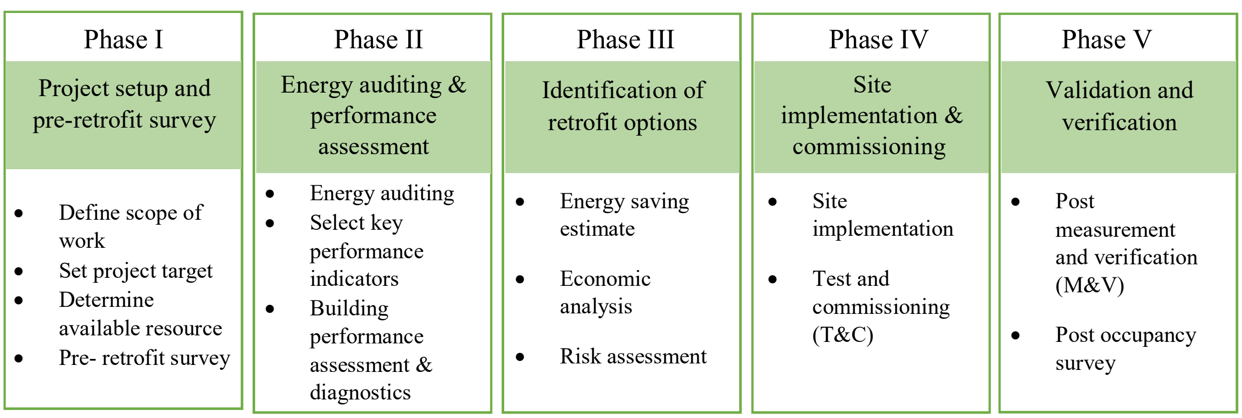


Figure.2.3: Key phases in a building retrofit programme (Ma et al., 2012).

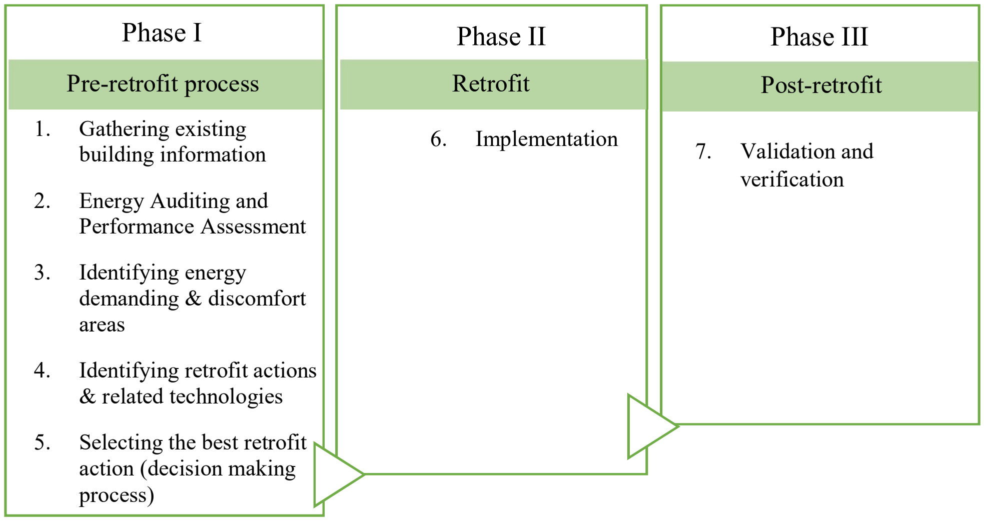


Figure 2.4: Key phases in a building retrofit programme (Jahed and Dino, 2018).

As previously discussed, the choice of retrofit strategies is complex and requires careful planning (Rabani et al., 2017). Therefore, the selection of design interventions for retrofitting cannot be considered separately. Specific parameters with various goals play essential roles in a single retrofit project—figure 2.5 shows all the stages of a retrofit process, considering three dimensions—first, environmental benefits in terms of energy savings and emission reduction. Second, linking social relevance with user requirements and finally, achieving financial viability (Rajapaksha et al., 2013), (Rey, 2004).

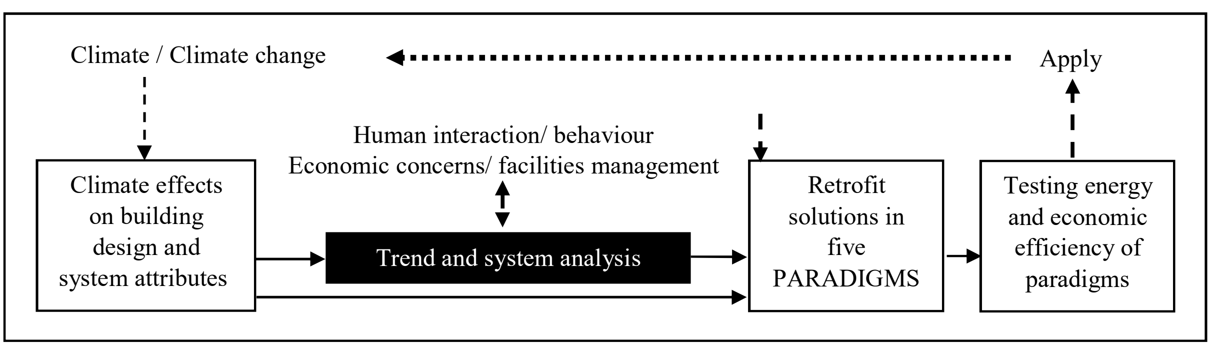


Figure 2.5: The stages of a total retrofit process (Rajapaksha et al., 2013).

2.3.2 Guidelines for building energy efficiency retrofitting

A lot of research has been done to develop energy efficiency to improve the energy performance of existing buildings. The results showed that energy consumption and greenhouse gas emissions of existing buildings could be reduced by retrofitting the buildings as one of the main approaches. Several retrofit guidelines have been developed in many countries around the world. Here are some retrofitting guidelines:

In the Indian guidelines, six main steps for energy efficiency buildings retrofit roadmap (The Energy and Resource Institute (TERI), 2013). First, an internal assessment is a preliminary analysis of energy use. The second step is to conduct a detailed energy survey with the help of the energy audit team to identify potential improvements. The third step is a technical analysis that studies the data from the energy survey. The next step is a cost-benefit analysis to choose the best retrofit option. This step is then followed by project implementation. The final step is operation and maintenance to ensure frequent energy savings from the modified building.

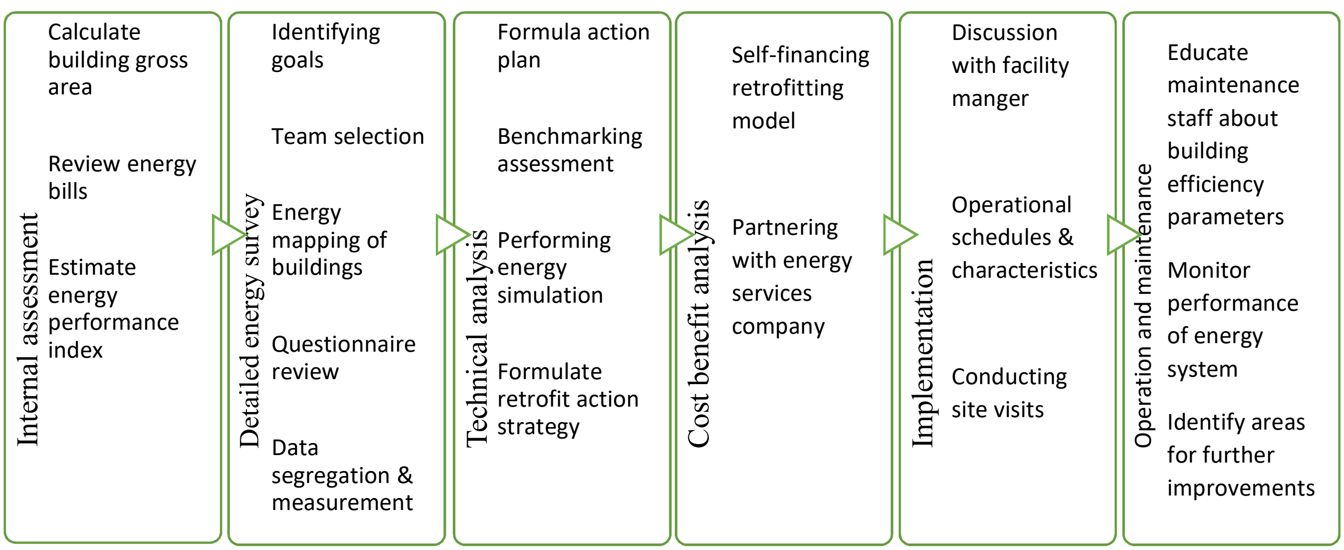


Figure 2.6: Building retrofitting roadmap India (The energy and resource institute (TERI), 2013)

In general, despite the increased awareness, the design phase of the refurbishment projects is often problematic. Decisions in the early stages of design determine the final result (Konstantinou and Knaack, 2011). Therefore, the building retrofit optimization framework aims to identify, implement, and apply the most efficient retrofit scenarios in energy and comfort improvements that help decision-makers and architects in the retrofit process.

2.4. Energy efficient building design.

Energy-efficient buildings are characterized by a good balance between passive strategies and high-efficiency equipment to minimize energy demand and energy consumption. Most of the building energy consumption is related to the maintenance of thermal and lighting comfort. As shown in figure 2.7, a low-energy building needs first to reduce its energy demands, reacting to its environmental conditions, having an appropriate envelope, and using passive design strategies. Moreover, high energy-efficiency systems and equipment need to be selected (Rodriguez-Ubinas et al., 2014).

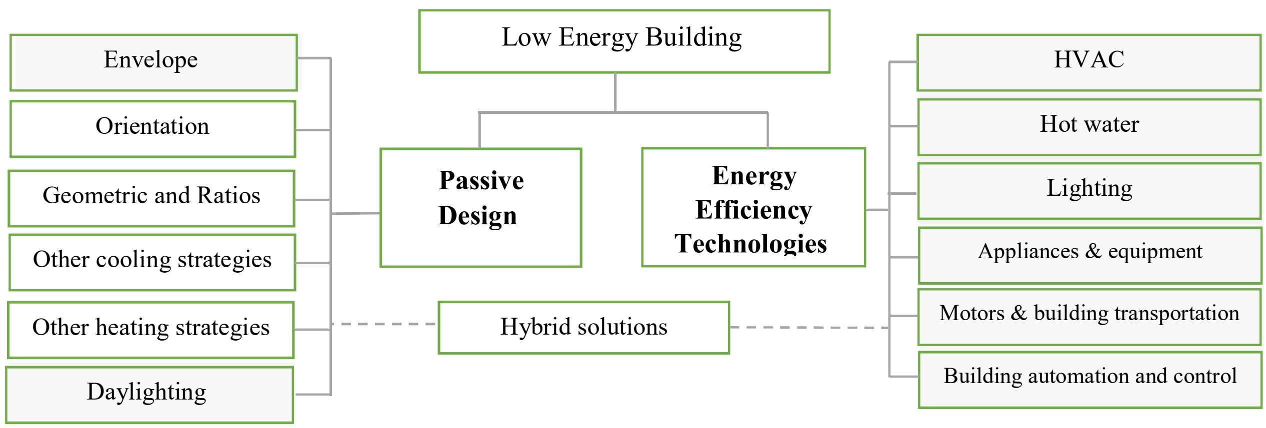


Figure 2.7: The keys for low energy buildings (Rodriguez-Ubinas et al., 2014)

The previous solutions can be performed for the new building design to decrease energy consumption. The energy efficiency technologies represent the possible actions that can be implemented on existing buildings. In addition, the building envelope and daylighting could be enhanced (Rodriguez-Ubinas et al., 2014).

Ma et al. proposed a possible classification of retrofit technologies in three categories: first, supply-side management, including renewable energy technologies and electrical system retrofits. Second, demand-side management, including heating and cooling demand reduction, energy-efficient equipment, and low energy technologies). Finally, change of energy consumption patterns includes human factors such as comfort requirement, as shown in the figure. 2.8 (Ma et al., 2012), (Mauro, 2015).

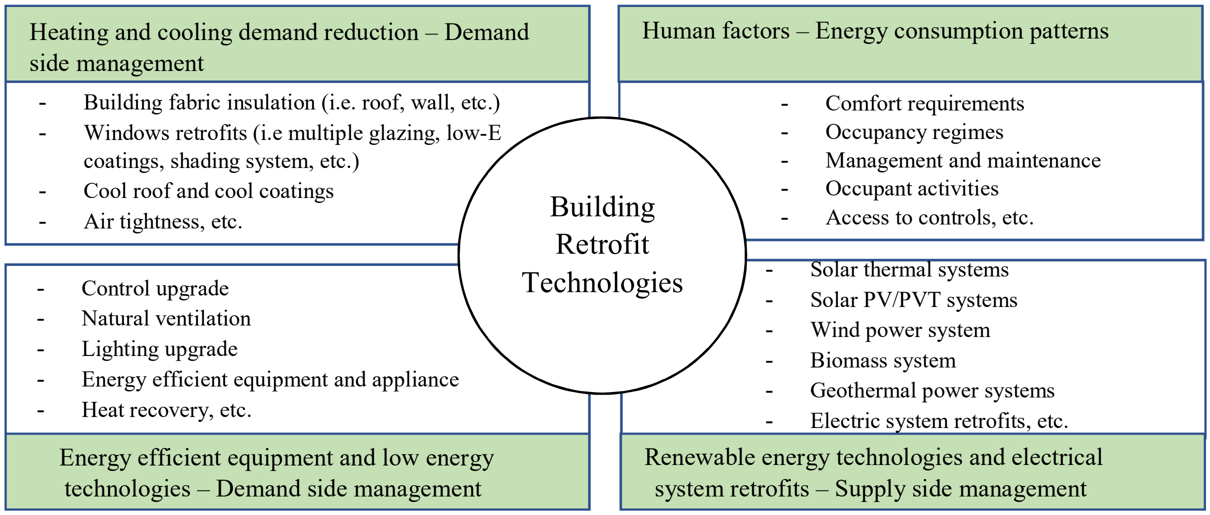


Figure 2.8: Main categories of building retrofit technologies (Ma et al., 2012)

2.5 Building envelope:

The building envelope consists of the structural elements and systems that physically separate the interior of the building from the exterior environment (Straube, 2006). Building envelope serves many functions that range from support and control to aesthetic values. A building envelope is considered a shelter from the weather. It controls solar, air quality, moisture, acoustics, access to daylight, fire resistance, and benefits such as aesthetics and views to the outdoors .

As shown in figure 2.9, the building envelope provides regulatory functions to decrease the environmental impacts on the indoor environment of buildings, and these functions interact with three parts of buildings: the exterior environment, interior environment, and the envelope system (Shamout, 2018).

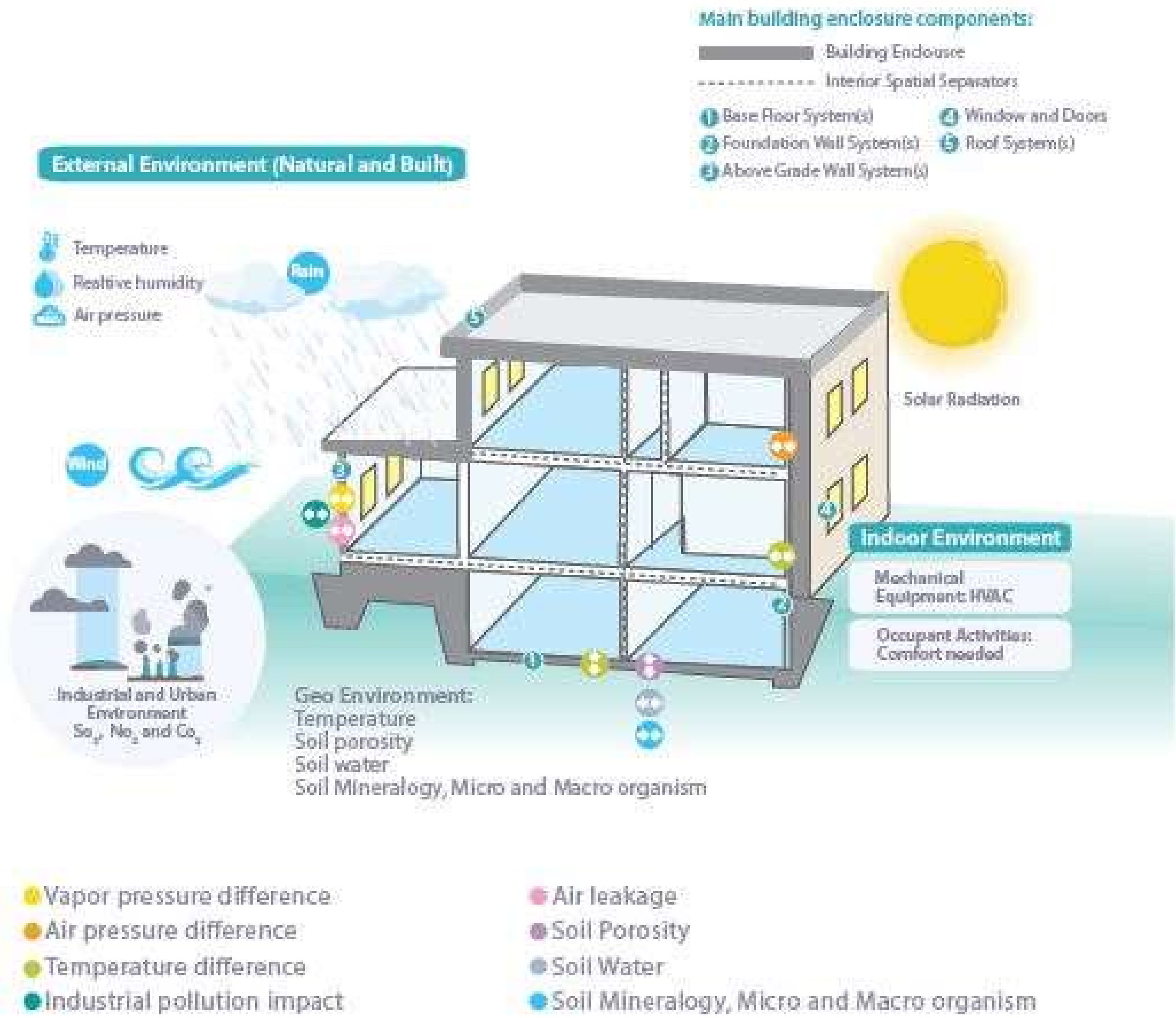


Figure 2.9: Environmental loads on the building envelope. Source:(Shamout, 2018)

The typical building envelope usually consists of essential elements, layers, and materials that comprise the foundation, external walls, roofing systems, ceilings, windows, doors, and any other penetrations. The interactions and connections between these elements are critical to ensure that the building envelope functions as intended (Straube, 2006).

The building envelope plays a key role in reducing energy consumption and determining the levels of thermal comfort, natural lighting, and ventilation. The building envelope determines the energy efficiency of the building through the rate of energy is lost, and the rate of energy is needed to maintain a comfortable indoor environment (Huovila et al., 2009). Accordingly, one of the key challenges of retrofit strategy is to optimize the building envelope's design and make it sustainable as a step to increase the thermal comfort and increase the quality of living spaces (Sozer, 2010).

The building envelope with sustainable design initiatives enhances the energy performance of building envelopment development. Furthermore, it records the highest energy efficiency performance score (Iwaro and Mwasha, 2013). The building energy performance and energy loss through the building envelope depend on building components and numerous factors such as building age and type, climate, geographic location, orientation, building materials, construction technique, and occupant behavior. The interactions between these factors are essential to consider when retrofitting buildings.

The retrofitting through some of the building envelope features affects human comfort and reduces energy consumption without compromising functional needs. The retrofitting of the building envelope optimizes energy use in the building, indoor air quality, and comfort needs (thermal comfort, visual comfort, and acoustic) (El-Darwish and Gomaa, 2017), (Fan and Xia, 2015).

2.6 Indoor Environmental Quality (IEQ) in residential buildings

The building envelope controls the indoor environment of the space. Therefore, indoor environmental quality factors must be taken into consideration when retrofitting the building envelope. Seven factors are affecting the indoor environment quality (IEQ) which are: 1) Thermal Comfort, 2) Indoor Air Quality, 3) Visual Comfort, 4) Acoustic Comfort, 5) building factors, 6) occupant factors, and 7) climate factors (Kamaruzzaman et al., 2017). These factors are closely related and cannot be addressed separately.

2.6.1 Visual Comfort and Daylighting

Visual comfort is one of the aspects that affect the indoor environment quality in buildings. Visual comfort factors affect human needs and the light environment, such as the amount of light (daylight/ artificial light), the uniformity of light, glare, view, and the rendering quality of light (Kamaruzzaman et al., 2017). The cause of discomfort in buildings can be an either too high or too low level of light, discomfort glare, low quality of color rendering, affecting the comfort and health of occupants (Carlucci et al., 2015).

Natural lighting has an essential role in architectural design. It replaces electric light during the daytime, reduces energy use for lighting, and influences both heating and cooling loads (Knoop et al., 2020). Providing a building with natural light is more than just the solution to energy consumption; more, even, than an aesthetic resource easily incorporated into the architecture. Natural light in architecture must be part of a more general philosophy that reflects a more respectful, sensitive attitude in human beings towards the environment in which they live (Serra, 1998).

Numerous studies have proved that daylight provides an array of health and comfort benefits that make it essential for buildings occupants (Ruck et al., 2000). Yet when we attempt to analyze the role of light in contemporary architecture, we find a significant challenge. Daylight is an important issue affecting the functional arrangement of spaces and occupants' comfort. Daylight is considered the best source of light for good color rendering. Also, its quality is the one that most closely matches human visual response. It gives a sense of cheeriness and brightness that can positively impact people (Knoop et al., 2020). The amount of daylight penetrating a building is mainly through window openings, allowing people to maintain visual contact with the outside environment. All of this makes people desire good natural lighting in their living environments (Li et al., 2006).

The natural light entering the building depends on internal and external factors. The internal factors that affect the daylight distribution include 1) size, position, and height of the window head, 2) the depth and shape of the rooms, 3) colors of the interior surfaces, 4) Shading devices, and 5) Glazing type (Nazer, 2019), (Kranti and Kranthi, 2019). External factors such as light reflected from the ground and opposite façades can be necessary for interior illumination (Asfour and Al Shurafa, 2016).

- The Daylight Factor Method

Many architectural design features affect the daylight factor and the indoor climate (Givoni, 1998). There are specific daylight factor values required in the building to create appropriate daylight and visual comfort. These factors depend on the function of the space and should be taken into consideration when designing the interior layout (Nazer, 2019).

The daylight factor method is considered one of the simplest ways to describe the amount of daylight received at a specific point in a room (Iversen et al., 2013). The daylight factor is the ratio between the interior illumination on a horizontal plane and the amount of daylight available outside from an overcast sky (Kubba, 2012). The following equation can express the daylight factor:

$$DF = (E\ indoor / E\ outdoor) \cdot 100\% \qquad (1)$$

Where:

DF: the daylight factor of the measured point (%)

E indoor: the interior illuminance at a point on a given plane (lux)

E outdoor: the outdoor illuminance measured at the same time under an unobstructed CIE standard overcast sky (lux)

There are different methods to measure the daylight factor. First, the measurement is done at a specific point in the room to determine DF levels for particular tasks. Second, the measurement of DF is done on a working plane or a specific floor area dependent on the room's function. The other method is to determine DF by simulating the defined grid-based measuring points in the studied floor area using daylight simulation engines such as Radiance and Design builder (Angeraini, 2016).

To conduct a reliable DF simulation, at the beginning must be defined the materials surface light reflectance value (LRV) and glazing light transmittance (LT) in the studied area according to the actual situation (Angeraini, 2016). The furniture is not considered in both the DF measurements and simulations (Ward and Mardaljevic, 1998).

As mentioned before, DF indicates a contrast between indoor and outdoor. Table 2.1 shows the minimum and average DF for different room types in residential buildings, according to the Jordanian code issued in cooperation with the Jordan green building council (Nazer, 2019).

Table 2.1: The minimum and average DF for different room types, Source: National Jordanian Building

Type of space	Average DF (%)	Minimum DF (%)
Dining room	5	2.5
Kitchen	2	0.6
Living room	1.5	0.5
Bedroom	1	0.3

- Natural daylight performance and deep plan problem

Most of the multi-story residential buildings are located in densely populated areas (Itma, 2018). As a result, the quality of natural lighting in residential buildings became questionable. On the other hand, the clients and developers tend to constantly pressure architects to design multi-story residential buildings with maximum space utilization in the face of rising land prices and rarity (Ahsan, 2009). Thus, flats shared side walls with neighboring units and sometimes have only one or two outer walls, which causes many problems. This configuration creates inner spaces with no direct contact with outside natural light in terms of natural daylight. Deep plans are a common practice in multi-story buildings (Asfour and Al Shurafa, 2016), (Kristl and Krainer, 1999), (Ahadi, Saghafi and Tahbaz, 2019). The deep core areas of these buildings cannot be naturally illuminated by side windows and depend entirely on electricity for illumination (Nazer, 2019). On the other hand, neighboring buildings can reduce the chances of lighting reaching the building due to shadow effects.

Artificial lighting has replaced the use of daylighting in some cases. Artificial lighting promoted growth in deep plan building design and construction because daylight illuminance usually is not possible in these buildings (Xue, Mak and Cheung, 2014). In the early design phase, the building’s energy performance is often prioritized over daylight utilization, resulting in negative consequences for indoor visual comfort (Vanhoutteghem et al., 2015).

Artificial lights can provide sufficient illumination levels; however, artificial lights cannot provide the occupant with natural light's physiological and psychological benefits. Artificial lighting has several direct and indirect harmful effects (i.e., unhealthy and infertile environments, non-energy-efficiency, and production of greenhouse gases, and use of non-renewable resources for the occupants of the building (Spoelstra et al., 2015). Therefore, current sustainable design developments have stirred efforts towards maximizing the use of this natural light source and providing healthy environments for people.

In general, the room depth affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by windows; the room will be darker at the back. Therefore, using the general rule in the earlier stage is one solution to ensure that windows provide adequate lighting in the space. Daylight role of thumb; the depth of penetration of daylight in a room is twice and a half the window's height. (Nazer, 2019).

Figure 2.10: Daylight role of thumb (Nazer, 2019)

2.6.2. Thermal comfort

This study focuses on enhancing natural daylight in existing multi-story residential buildings, taking into account thermal comfort. Thus, the challenge for the building envelope is to design it in such a way as to provide an ideal balance between sufficient daylight in the building and minimal heat transfer through the envelope. In addition, the energy-efficient building envelope significantly enhances indoor air quality as well as thermal comfort by using less energy.

Thermal comfort affects the level of occupant satisfaction toward building performance (Martellotta et al., 2016). The factors that must be considered to achieve a level of comfort are temperature, relative humidity, air movement or air velocity, and ventilation systems(Kamaruzzaman et al., 2017). A poor indoor thermal environment creates a variety of potential health risks for occupants. (Turunen et al., 2014) indicated that the ventilation rate plays a vital role in thermal conditions to avoid the temperature tending to be too high or too low. Therefore, improving the thermal insulation of the existing building envelope will reduce heat loss in winter and heat gain in summer, thus enhancing the thermal comfort of occupants.

2.6.3. Other factors affecting the Indoor Environment Quality (IEQ)

The building-related factors that affect the quality of the indoor environment are 1) building characteristics, 2) building envelope, 3) building condition (building age), 4) room interiors, 5) environmental control,6) building design, 7)building type, 8) building location, 8) building orientation, etc. Thus, building-related factors, if the building design is not taken into account, will destroy the visual, thermal, and acoustic comfort and indoor air quality (Kamaruzzaman *et al.*, 2017).

The indoor environment of a building is not only affected due to building-related factors, but it also depends on the occupants' factors (Martellotta et al., 2016). Occupant factors must be highlighted to design for control the indoor environment system of the buildings, application of appropriate building materials, and building design. Thus, occupant factors that need to take into consideration affecting the quality of the indoor environment are 1) occupant activities, 2) thermoregulation, 3) behavior/lifestyle, and 4) the thermal resistance of clothing, age, and country origin (Kamaruzzaman et al., 2017).

Climatic factors are a global factor affecting IEQ. As a result of climate change impacts, the indoor environmental quality was affected by the additional use of HVAC systems, increased airborne particles, chemical emissions, etc. Climate change also affects the health of building occupants (Kamaruzzaman et al., 2017). Finally, poor indoor environmental quality IEQ has been shown to affect residents' health conditions, satisfaction, comfort, well-being, performance, and productivity (Shamout, 2018). The building envelope, section, and form, are the main bioclimatic modifiers (Rajapaksha, Hyde and Groenhout, 2013).

1) It can reduce the negative influences from outdoor radiant heat and high air temperatures.
2) It can improve the cooling effects of ventilation in summer.
3) It can increase the internal heat loss from building interiors in summer.
4) It can reduce winter heat loss from building interiors.
5) It can improve daylight's effectiveness in indoor construction both in summer and winter to reduce interior loads of lighting.

2.7. Conclusions

In general, retrofitting existing buildings is a challenge because it needs to deal with many factors: 1- external factors, 2- internal factors, and 3- other factors such as the building envelope, building elements, material properties, and thermal processes.

In this thesis, one of the fundamentals comfort domains is natural daylight. The comfort framework is defined in five levels of discomfort problems: main goal, comfort domains, comfort criteria, performance criteria, and performance options. This formula helps the user arrive at applicable performance recommendations as solutions to the existing problems, see table 2.2 (Jahed and Dino, 2018).

Table 2.2: The comfort performance framework

Problem	Main goal	Comfort domains	Comfort criteria	Performance criteria
1. Too high or too low level of light **2. Low quality of color rendering** **3. Low view to out** **4. Too glare**	Comfort	Daylight- visual comfort	1. Visual transmittance 2. Shading coefficient (SC) 3. Window to wall ratio 4. Glass layers, thickness & color 5. Sunshades	1. Glare control 2. Access daylight 3. Access outside view

In light of the reviewed literature, user comfort can be achieved by: Firstly, the suitable spatial interventions to the interior parts —secondly, indicators of sources of discomfort caused by the poor performance of the building facade. Therefore, to determine the required comfort quality, the retrofitting interventions in this thesis were classified into two categories: 1) spatial modification and 2) facade retrofitting .

The three processes are taken into consideration to create the retrofit framework:

1. Building Scale: to define the characteristics of an existing building to improve energy performance and resident comfort.
2. Room Scale: to develop a spatial comfort framework, every room in the residential building has a particular requirement.
3. Facade Scale: organizing passive retrofitting actions.

In general, these three dimensions form the main approach to this thesis, which generates a holistic framework for the passive retrofit of existing multi-story buildings

In this research, a new retrofit guideline is proposed after reviewing available retrofitting guidelines adopted in different countries. Figure 2.11 below, this retrofit framework aims to identify, implement, and apply the most efficient retrofit scenarios in terms of energy and comfort improvements that help decision-makers in the retrofit process.

The retrofit process includes three main phases: the first phase is a pre-retrofit process, the second phase is a retrofit process, and the third phase is a post-retrofit process.

The first phases (pre-retrofit phase) include five steps:

Step 1: Define the scope of work and set the project target.

Four main domains or retrofit drivers have been identified, which motivate stakeholders to retrofit the energy performance of an existing building (Menassa and Baer, 2014): The first domain is social factors that include community impacts, human rights, etc. The second domain is environmental factors that indicate minimizing the environmental effects of the actions. The third domain is an economic factor that affects financial performance such as sales, profit, etc. Finally, the technical factors include building façade retrofit, mechanical system, electrical system, and plumbing system retrofit.

In this study, the main objective of the proposed retrofit framework covers some parts of the technology (building retrofits) and environmental domains. Also, in residential buildings, social domains cannot be ignored.

Step 2: Collect information about the characteristics of the existing building.

Step 3: Energy auditing, performance assessment, and diagnosis.

Step 4: Identifying discomfort area. This research focusing on visual comfort

Step 5: Identifying retrofit actions and solutions related to the specific problems.

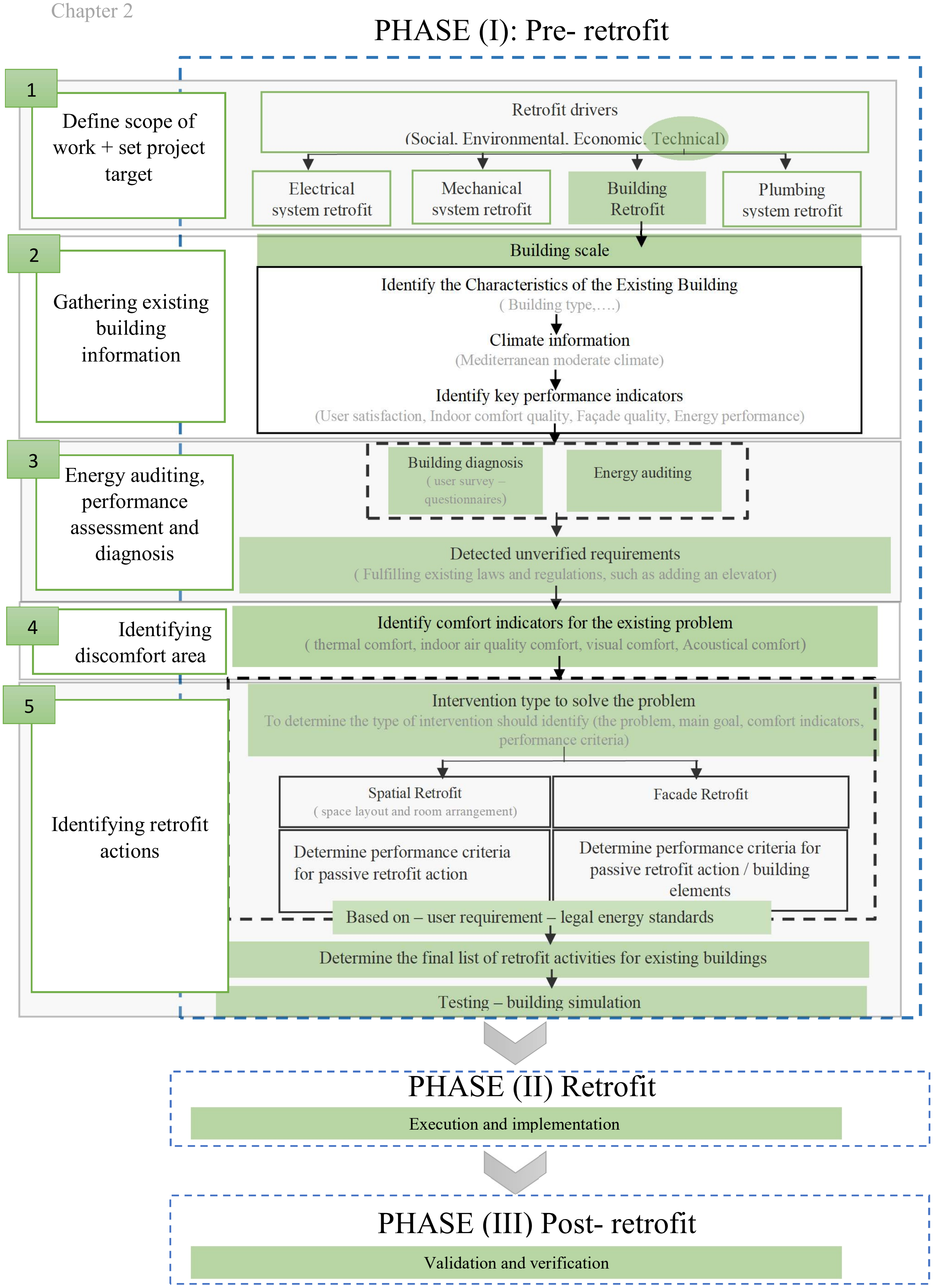


Figure 2.11: Proposed retrofit framework. Source: researcher

Retrofitting strategies in existing residential buildings

Introduction

This chapter reviews the current literature related to multi-story residential buildings' retrofitting strategies to enhance indoor environmental quality (natural daylight). Firstly, this chapter begins with an overview of the spatial retrofit strategies in residential buildings. Secondly, reviews facade retrofit strategies regarding natural daylight strategies, considering thermal comfort strategies to provide an ideal balance between sufficient daylight in the building and minimal heat transfer through the envelope.

Architectural decisions regarding a building's form and orientation affect daylight, passive ventilation, heating and cooling loads, and solar heat gain opportunities. For existing buildings, there is no possibility of any retrofit actions about orientation changes. Still, through decisions regarding appropriate retrofit techniques and strategies, the orientation should be considered since different building façades directions require different strategies in terms of daylight and views. The interdependence also between building form, facade design, and internal spatial arrangement should be investigated.

3.1 Energy efficiency and comfort retrofitting strategies

Retrofit strategies and building envelope performance affect human comfort and energy consumption, which is vital and must be considered. Furthermore, retrofit operations of the building envelope are complex, and the choice of a technological system could represent helpful support to achieve the goals of building retrofit. The selection of a technical system is based on previous experience or general assumptions.

The main action strategies considered in the retrofitting of the multi-story residential building in Cincello, Samo. First, the internal space and distribution quality to improve the building use and create new common areas. Second, the technological aspects through the use of prefabricated systems to enhance the envelope and building systems integration and the goals of architectural quality to enhance the perception of the aesthetic building quality. Therefore, the main action categories considered for the building retrofit were the story addition with shape continuity, facade addition through adding new volumes, and technical elements like solar shading systems and balconies. Also, envelope recladding through the addition of a second opaque skin applied on the existing walls (Pittau et al., 2017).

Another study conducted in Egypt. This study covered retrofit enhancement methods that significantly impact energy consumption, by using retrofit strategies such as solar shading, window glazing, airtightness strategies, and wall insulation strategies. This study noted that airtightness had little effect on energy reduction, and wall insulation had almost no effect (El-Darwish and Gomaa, 2017) .

In 2018, a guide to envelop retrofits for optimizing energy efficiency and thermal comfort was published in Jordan. The main action strategies taken into consideration in the retrofitting, thermal insulation, double-glazed windows, and shading device aim to improve thermal performance in the indoor environment and save energy. When combining the main proposed retrofit strategies, the results showed that the total cooling and heating energy use could reduce by around 50% in Amman and 47% in Aqaba for residential buildings (Shamout, 2018).

3.2 Spatial Retrofit strategies

3.2.1 Spatial comfort in residential buildings

The relationship between human behavior and the built environment has two sides: 1) Social conditions and 2) Spatial conditions. Social conditions are related to activities in which meet people and spend time in social interaction. Spatial conditions are associated with the physical properties of built environments such as space, area, size, locations of objects, and information (Kauser, 2018). See figure 3.1 below.

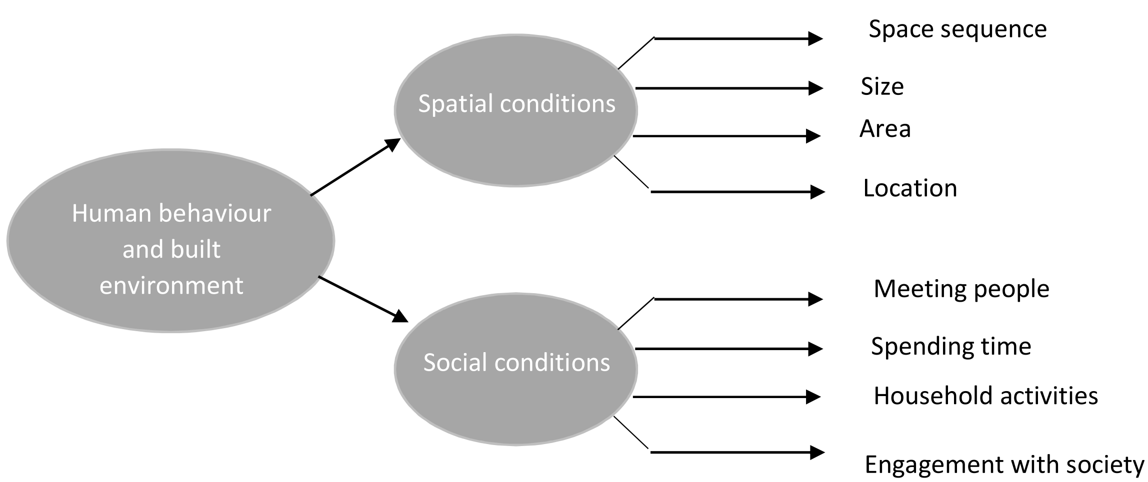


Figure 3.1 : Two sides of human behavior and the built forms (Kauser, 2018).

Residential satisfaction and housing quality are two related concepts in housing evaluation studies. According to the level of flexibility in terms of building type, there are two design models: 1) the ability to adapt without physical changes, and 2) the ability to interior changes according to zoning decisions (flexible, modular component architecture). Thus, satisfaction with the organization of the plan is considered one of the quality parameters in housing (Altaş and Özsoy, 1998).

According to predominant spatial arrangement concepts from past to present in residential buildings, the open floor plan uses large and open spaces and reduces the use of small, enclosed rooms. This organization weakens the boundaries between public and private.

Traditionally, the family living room was small and enclosed. The guest room is also somewhat isolated from the family living area to provide privacy. But the introduction of western technology and society created the desire for an open space allowing many activities at once (Ibrahim, 2012).

3.2.2 Energy efficiency and space layout design

Changing space layouts affect energy. Some studies have confirmed this, such as (Du et al., 2020) studied the effects of space layouts on energy use by changing space layouts. The results showed that by changing only space layouts, the energy use for space heating, space cooling, and lighting could be reduced significantly.

The energy-efficient space layout design is an overlapping area between space layout design and energy-efficient building design, as shown in figure 3.2 below.

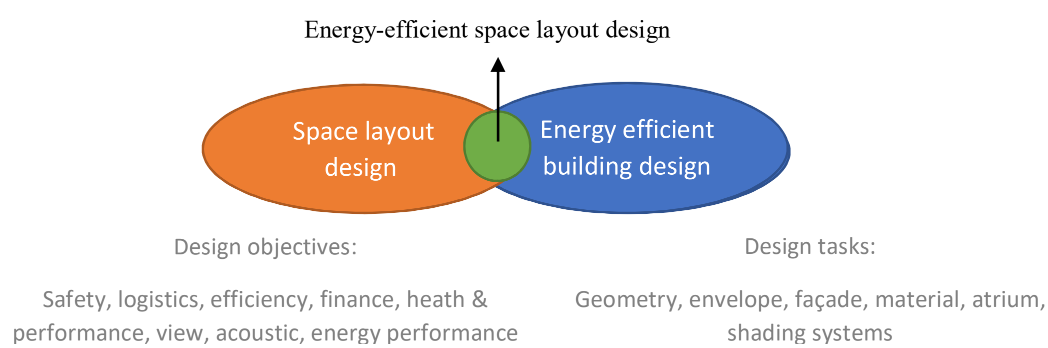


Figure 3.2: energy-efficient space layout design

The impact of space designs on building energy performance is presented below (Du et al., 2020), (du et al., 2019).

1. Daylighting

The effect of daylight on building energy performance can be clarified by the three points. First, different layouts bring different levels of light into the building. For example, by changing the shape, location, and dimension of atriums or courtyards, the performance of daylight for the whole building changes(Huang et al., 2015) (Freewan, 2011). Secondly, an appropriate space layout combined with the glazing design enhances the application of daylight inside the building. Third, the interior partitions also influence the application of light, taking into account the visual comfort of the occupants (Seo et al., 2012).

2. Control of the Heating, Cooling, Ventilation and Lighting System

The different space layouts are suitable for different types of control for space heating, cooling, ventilation, and lighting systems. With dynamic daylight control based on the available daylight and natural ventilation, the effects of space layouts on building energy performance are enhanced (du *et al.*, 2019), (Foster and Oreszczyn, 2001).

- Design Variables

Design variables affect building energy performance regarding their relationship with space layout design (Du et al., 2020). To study the effects of space layouts on the energy performance of the building should first keep the other design variables constant and only change design variables of space layouts to assess the isolated effects of space layouts on building energy performance, then add other design variables one by one and evaluate their impact on space layouts.

Table 3.1: Classification of design variables affecting building energy performance

Design Variable	1. Design space layout design	within a fixed boundary	Function allocation Space dimension Space form Interior partition Interior opening
		with a non-fixed boundary	Boundary dimension Boundary form Orientation
	2. Space properties	Functional requirements	Set-point temperature for heating Set-point temperature for cooling Lighting requirements (e.g., illuminance) Ventilation requirement (e.g. air flow rate) Control types
		Use of spaces	Occupancy, activity and schedule Internal gains from appliances and lighting Opening state of windows and doors
	3. Envelope design		Thermal transmittance Window area Window location Glazing type Shading type and effectiveness Air tightness

Room dimensions are essential to consider when designing energy-efficient buildings. Therefore, to get adequate natural daylight and natural ventilation, shallow plans are recommended. To ensure the implementation of optimum environmental strategies, follow the equation (Nazer, 2019).

$$\frac{L}{w}+\frac{L}{h}\leq\frac{2}{(1-R\partial\ )}$$

Where:

L= depth of room from window to back wall

W= width of room measured across the window wall

h = height of window head above floor

$R\partial$ = area-weighted average reflectance in the back half of the room (the value for a typical office is likely to be around 0.5)

3.2.3 Spatial retrofit proposed strategies

The first strategy is related to the quality of internal spaces and distribution to optimize the living spaces and create new common areas. Second, adding spaces to apartments, such as facade addition through the extension of indoor space and adding new spaces (adding new balconies, etc.).

Table 3.2: Spatial retrofit proposed strategies, source: researcher

Action category	Description
Optimize the quality of internal spaces and distribution	Optimize the living spaces, create new common areas.
Adding spaces to apartments; such as facade addition	Through the extension of indoor space and the addition of new spaces (adding new balconies, etc.).

3.3 Façade Retrofit Strategies

3.3.1 Natural daylight strategies

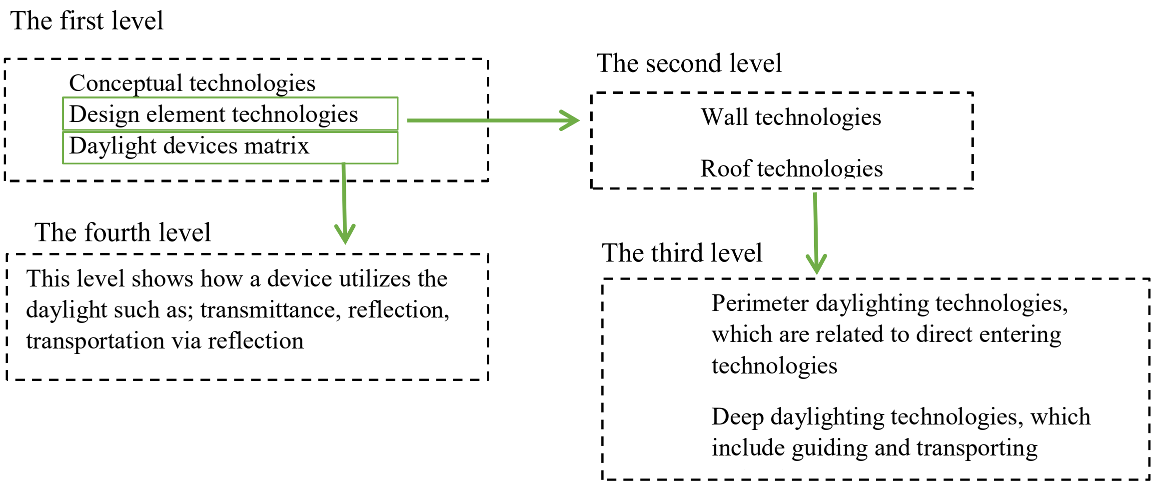
Daylighting is considered an intrinsic part of green and sustainable building design (Kibert, 2016). This has encouraged designers and researchers to create daylighting technologies to reduce dependence on electric lighting and to reduce using non-renewable energy sources (BEE, 2014). Thus, the use of daylight as the prime light source is being recognized as a valuable means of improving the energy efficiency of residential buildings .

Daylighting and architectural design strategies are inseparable (Ruck *et al.*, 2000). Daylight not only replaces artificial lighting, reducing lighting energy use but also influences both heating and cooling loads (Maier, 2016). Reducing heating and cooling loads requires an integrated view of the building design. Therefore, retrofitted building envelopes will be necessary to reduce energy consumption (El-Darwish and Gomaa, 2017), (Shamout, 2018). Sunlight is freely available, and maximizing its benefits to reducing heating and lighting needs is part of an integrated design.

A wide range of daylighting technologies has been developed to improve energy efficiency daylighting. Daylight technologies shifted from the simple improvement of the illuminance level in the perimeter zone to increased illuminance deep into spaces, improved uniformity, and glare control.

Several studies have focused on improving energy efficiency and daylight. For example, (Freewan, 2015) presented a new matrix of daylight devices to help designers choose the most appropriate device for a specific project or space at any design stage.

The new system matrix includes four levels for categorizing daylighting technologies (Freewan, 2015):



Thus, dividing daylighting technologies into groups helps architects choose the proper daylighting retrofit strategy that suits the building. As shown in Table 3.6 & Table 3.7, the solution could take two forms: 1) conceptual design based on daylighting, or 2) selecting a system for a problem that the designer faces while designing or retrofitting the building.

A. Conceptual technologies

At the conceptual stages in the design process, some technologies need consideration. These technologies directly affect the form, plan, and facade of the building being designed. Such as courtyard, atrium, light well, building layout, and orientation, see table 3.6. The following strategy is provided as an example:

- Light wells (Ahadi, Saghafi and Tahbaz, 2019)

The light well is an internal space within the volume of a building, reaching from the roof down several stories to the ground floor or basement level (Moore, 1991). Using open glazed spaces in the buildings with large areas helps illuminate lower floors (Al-shurafa, 2016). It is used to allow light and air to reach the dark or unventilated areas. Lightwell has a direct impact on how designers solve the issues of lighting and ventilation in intermediate spaces. Painting the interior walls of the shafts in the building with light colors helps to enter deeper through the spaces; As the light colors can reflect daylight (Nazer, 2019). (Freewan, Gharaibeh and Jamhawi, 2014) studied the improvement of daylight performance of light-wells in multi-story apartment buildings in Jordan. Many light-well variables had studied to optimize its performance and compare them to a base case. The results showed that the appropriate design of a light well's opening could increase daylight performance.

B. Design elements (Dr *et al.*, 2009).

Building elements include items installed into building surfaces such as walls, ceilings, and floors. 1) Entering technologies: used to utilize the space with daylight by using direct contact outside, such as windows. 2) Reflecting technologies: used to serve spaces by reflecting or redirecting light into space, such as light shelves (Elrayies, 2010). 3) Transporting technologies: transmit light over long-distance to deep spaces without direct contact outside, such as light pipes and light rods (Elrayies, 2010), (Freewan, 2015).

1. Wall element

1.1 Direct entry device

- Window

Daylight consider one of the main functions of windows. The window design determines light distribution to space (Mahdavi, Rao and Inangda, 2013). The facade configuration in terms of window-to-wall ratio, window factor, effective openings affects daylight levels and energy used in buildings (Saridar and Elkadi, 2002).

- Window to wall ratio

The window-to-wall ratio (WWR) is an indicator that is used to check the optimal balance between sufficient daylight and minimal heat transfer(Visser and Yeretzian, 2013) (Yang *et al.*, 2015).

The window to wall ratio measures the total area of all openings for transparent facades, excluding the frames, divided by the area of the exterior wall area (Alibaba, 2016), (Yang *et al.*, 2015). WWR is essential because it affects the amount of solar gain, controls the amount of daylight, and affects the efficiency of natural ventilation (Nazer, 2019).

WWR = Windows Area / (Total Wall Area)

According to the Jordanian codes, WWR should not be less than 15% in living areas and 10% in service areas. The WWR should be more specific to each orientation, as each orientation differs in sun and wind exposure. See figure 3.3 below

Figure 3.3: The WWR that required on each orientation. Source: National Jordanian Building Council, 2010

ASHRAE 90.1 (2007) has established that a Window to Wall Ratio (WWR) of 0.24 is ideal for optimum indoor daylight and natural ventilation. This does not mean that the higher of WWR, the better performance for the windows. The larger a window, the more heat or light will penetrate the room, which causes overheating and glare. Windows with a WWR of more than 0.30 will create overheating in the building. Table 3.3 shows a summary of the standard requirement for WWR.

Table 3.3: Standard requirement for WWR. Source: (ASHRAE 90.1, 2007)

WWR	**X <0.24**	**X =0.24**	**X >0.30**
Value	POOR	GOOD	OVERHEAT

- Window to Floor Area Ratio (WFR) and the daylighting.

Window to Floor Ratio (WFR) is a key parameter that is being used to assess the quantity of daylighting and affects the quality of interior design of buildings (Vaisi and Kharvari, 2019). The rational window size (Window to Floor ratio (WFR)) helps builders and architects in the design process and provides visual comfort and well-being for occupants (Phuong et al., 2019).

The rule of thumb is enshrined in many regional and local building regulations as a means of specifying the minimum glazing area for habitable rooms (Aries, Veitch and Newsham, 2010). Hopkinson argued that the 20% ratio yielded an adequate daylight factor of 2% at the rear of a room and a consequent task illumination of 100 lux (Hopkinson, 1963), (Ibrahim, 2006).

- The relationship between window glass, daylight and thermal comfort

The glass properties are essential in the design and retrofit stage. It affects the optimization of the building mechanical systems; a window can lose heat five times faster than a wall of the same area (He et al., 2019). So, it is essential to improve the thermal transmittance of window glazing by considering the U-value of the glass is low (Visser and Yeretzian, 2013). The color and visual transmittance of the glass affect the view outward and the occupants' sense of connection to the outdoors (Jonsson and Roos, 2010). The visible transmittance determines the amount of daylight that will be accepted when the window size is adjusted. The designer must assess the expected daylight levels before choosing the glass. If daylight levels are not satisfactory, choose alternative glass with different visible transmittance or increase the glazing area (Robinson and Selkowitz, 2013).

In the hot summer and cold winter zones, the window-to-wall ratio can be increased if the material type of external window is Low-E glass of high reflectivity and low emissivity (He et al., 2019) (Lee et al., 2013). Thus, installing the 6/12 mm double-glazing or the 6/12 mm low-E glazing on windows is better due to the energy performance (Yang et al., 2015). Jordan Green Building Guide requires the windows maximum U value and window to wall ratios. If the WWR was between (Nazer, 2019):

- 10-40% The U value of the glazing should not exceed 3.00 W/m2.K
- 40-70% The U value of the glazing should not exceed 2.00W/m2.K.
- More than 70% The U value of the glazing should not exceed 1.60 W/m2 .K

The windows maximum U value and a window to wall ratios required by JEEBC 2010. If the WWR was between:

Table 3.4: The windows maximum U value and a window to wall ratios source: National Jordanian Building Council, 2010

Window type	**Max U-value [W/m2K]**	**Maximum allowed window to wall ratio**
Windows with aluminum/steel frame, single glazing	5.70	20.1%
Window with aluminum/ steel frame, double glazing*	3.40	36.4%
Windows with a wooden/ plastic frame, single glazing	4.80	24.3%
Windows with a wooden/ plastic frame, double glazing*	3.10	40.7%
*with 6mm spacing between glass panes		

Therefore, several factors should be considered when retrofitting the building's glass surfaces(Shamout, 2018), such as:

1. Replacing single glazed surfaces with double-glazing Units (He *et al.*, 2019).

   Replacing single-pane windows and other glass surfaces such as skylights with double-glazed units could save up to 30% of the heating load. Also, double glazing contributes to reducing the heat transfer, which results in a lower cooling load (Visser and Yeretzian, 2013). Although triple-glazing units are more efficient, they are not cost-effective in the Jordan context regarding climate and cost.

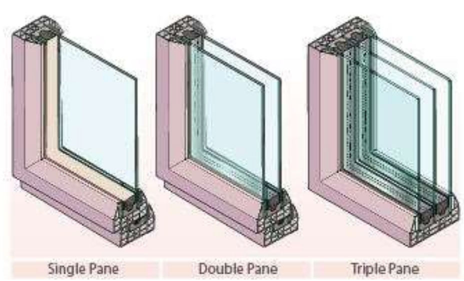


Figure 3.4: A Typical Single, Double & Triple Pane window, Sections

2. Choosing the type of glass with solar control properties

   The main types of glass are: See appendix D

   1. Clear glass 2. Tinted Glass 3. Coated Glass

   Several properties could be combined to have greater solar control, such as 1) spectrally selective characteristics, 2) reflective surface (mirror-like effect), 3) Low-E coated surface.

- Glazing properties (LOW E)

Low-e glass reduces the amount of infrared and ultraviolet rays that come through the glass without reducing the amount of light that enters. In a climate with a cooling dominance, the Low-E layer should be applied to the inner face of the external pane. But in a climate with heating dominant, the Low-E layer should be inside the front of the inner pane to reflect heat inside the space (He et al., 2019), (Shamout, 2018).

3. Choosing a glazed frame material that has a high thermal Resistance

Improving the frame's thermal resistance can contribute to the window's overall energy efficiency, especially the U factor. Vinyl, wood, fiberglass, and some composite frame materials offer greater heat resistance than metal. Aluminum window frames are the least efficient because they conduct heat and light. However, uPVC's low conductivity and the tight seals that uPVC windows provide make it the most energy-efficient type for buildings (Nazer, 2019).

Table 3.5: Different types of frames and glazing R-Values: source: level.org.nz, 2018

Window frame material	**Single Glazing**	**IGU with 4mm glass and 8mm air space**	**IGU with 4mm glass and 12 mm air space**	**IGU with 4mm glass and 12 mm air space and low-e pane**	**IGU with 4mm glass and 12 mm air space, low-e pane and argon gas fill**
Aluminium frame	R0.15	R0.25	R0.26	R0.31	R0.32
Thermally broken aluminium frame	R0.17	R0.30	R0.31	R0.39	R0.41
UPVC frame	R0.19	R0.34	R0.36	R0.47	R0.51
R – window total: the higher the R value, the better the thermal performance of the window IGU- Insulated Glazing Unit					

Other factors affect the thermal performance of glass surfaces, such as the orientation of the openings and the size of the windows. Previous studies have shown a relationship between cooling and heating load versus glass to wall ratio and glass thermal properties (Alkhalidi, Jarad and Juaidy, 2016). For example, (Muhaisen and Dabboor, 2013) have concluded that designing windows suitable for Gaza Strip buildings by environmental conditions can effectively reduce energy demand and meet thermal comfort requirements. The optimal window size for all facades is the minimum percentage of (10%)

from the total wall area. In addition, this study confirmed that the use of advanced glazing materials with low U values is an essential factor in reducing energy demand. Finally, the window shape (vertical or horizontal) does not affect the heating and cooling energy of the building.

1.2 Reflection technologies

- Light shelf (horizontal elements above eye level)

Providing daylight through the efficient use of windows is a challenge in allowing sufficient amounts of daylight to enter the space as deep as possible, with distributing within the space that is visually comfortable and does not cause glare. Light shelves can be classified according to their geometry (Kontadakis et al., 2018): (a) horizontal, (b) flat inclined, (c) curved, (d) active lighting shelves.

The higher the window, the deeper the daylighting zone. The daylight zone practical depth is typically 1.5 to 2 times the window head height. While, with a reflective light shelf, this area can be extended further. With standard window and ceiling heights (2.7 to 3 m), plan appropriate daylight within 6.1 m from the window. (Robinson and Selkowitz, 2013) See figure 3.5.

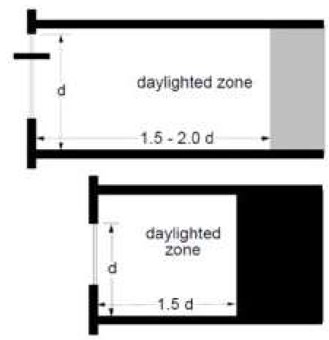


Figure 3.5: Typical daylight penetration rule-of-thumb

A light shelf is considered one of the daylight strategies that bring the light into the deep inside the space of the rooms with brilliant illuminance production and economic possibility through the introduction of natural lights (Kanwal et al., 2018). Also, it is considered one of the most efficient solutions for light energy issues in buildings.

Light shelves can improve illuminance distribution and reduce glare. External shelves are more useful than the interior but use both for the best year-round distribution. The best use of the light shelf is on the south side of the building in clear sky climate (Kontadakis et al., 2018). A light shelf can be applied following the rule of thumb below (Nazer, 2019).

(Selkowitz, Navvab and Mathews, 1983) suggested that under sunny skies, the maximum exterior light shelf depth (d ext light shelf, max) should be less than 1.5 times the height of the clerestory window (h clerestory) above it.

$$d_{ext\ light\ shelf,max} \leq 1.5 \times h_{clerestory}$$

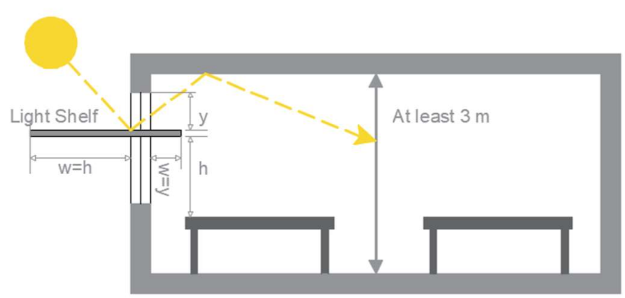


Figure 3.6: Light shelves to prevent glare - the rule of thumb (Nazer, 2019).

The light shelf could reduce the contrast between areas near the window and the back of the room. For example, (Ochoa and Capeluto, 2006) assessed visual comfort and performed a daylight analysis for three natural lighting systems for deep office buildings in climates with high solar radiation (Latitude: 32.5 N). One of these systems was: a horizontal light shelf. See figure 3.7. The result shows the illuminance values of the daylight zone were 1.5–2 times higher when compared with the reference case. In addition, the light shelf had maximum efficiency when the sun shines directly above it, while its effectiveness is reduced at distances of more than 6-7 meters from the window.

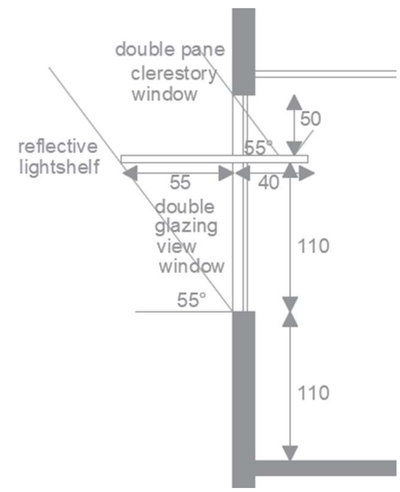


Figure 3.7: The main dimensions of the examined light shelf

- Louver (Shading device)

The shading device is used to control intense direct sunlight by allowing it to enter the building when it is needed for heating in winter and preventing sunlight from entering in summer(Shamout, 2018) (Visser and Yeretzian, 2013). Also, it is used to control glare to ensure comfortable interior spaces (Robinson and Selkowitz, 2013). When a relatively high window-to-wall ratio needs to access adequate daylight, the more the effect on the thermal performance of the building envelope (Shamout, 2018), the heat transfer through windows can be reduced by window shading. Thus, External window shading is an important measure to reduce the energy consumption of the building and has the highest payback period among all retrofit methods (Chen, Ji and Xu, 2012), (Visser and Yeretzian, 2013).

The shading device type and angle depend on the orientation and position of the sun during the year (Visser and Yeretzian, 2013).

1. South Shading

   Horizontal shading is using on southern facades to block solar radiation. External shading allows heat gain in winter when the sun is at a lower angle. Thus, external shading is the best strategy because of its efficient performance regarding energy and cost. It can reduce 25% of heating and cooling loads in Amman (Shamout, 2018). Figure 3.8 shown the southern shading design to achieve optimum efficiency following the rule of thumb (Nazer, 2019).

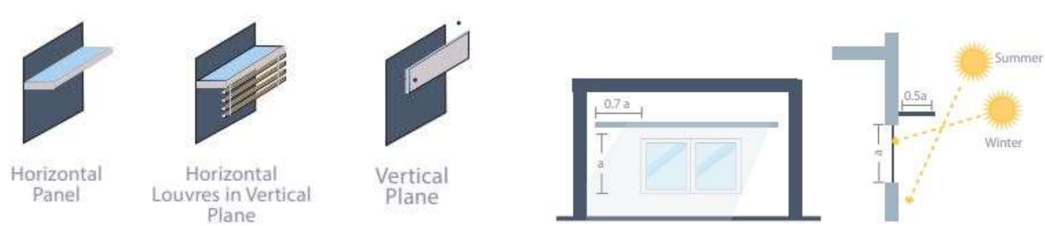


Figure 3.8: Southern shading design to achieve optimum efficiency following the rule of thumb

2. East and West Shading:

Fixed horizontal louvers set to the angle of mid-winter noon sun and spaced to allow winter heating and summer shading in locations with cold winters. (Nazer, 2019) .

Figure 3.9: East and west shading device

It is recommended not to install external shading devices if window-to-wall ratios are low of 10% or below and high-performance glass, due to minimal savings that can hardly recover the initial investment cost (Shamout, 2018).

2. Finishing, Top reflective surface and opening

Interior finishing should be part of the daylighting strategy. The reflection properties of the ceiling, walls, floor, and furniture influence the way daylight is distributed. According to the Illuminating Engineering Society recommendations, the desirable reflectance: ceilings >80%; walls 50%–70% (higher if wall contains window); floors 20%–40%; and furniture 25%–45%.

Table 3.6: Conceptual technologies

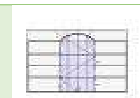
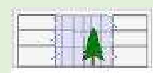
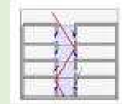
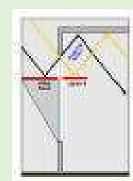
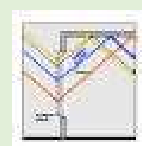
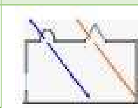
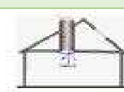
	Conceptual design elements				
	Basic elements		Design elements		
Relation of served area with outdoor environment	Perimeter zone		Perimeter and deep zone		
Working mechanism	Direct		Direct and indirect		
Served area	Perimeter		deep zone		
System or tool	Orientation	Layout and material	Atrium	Courtyard	Light well
Parameters and variables and climate	Quality of light, direct sun, diffuse light, time of Hight sun shine / climate any	Wall area, window area/ climate any	Wall area, shape, top design, materials height/ climate any	Wall area, shape, top design, materials/ climate any	Height, materials reflectance / climate any
Configuration					

Table 3.7: Design elements technologies

		Relation of served area with outdoor environment	Working mechanism	Served area	System or tool	Parameters and variables and climate	Configuration
Building elements	Wall elements	Direct contact / perimeter	Direct enter	Perimeter zone	Window	Shape, location, area/ climate any	
					Clerestory	Height, area, orientation/ climate any	
			Reflect – Deflect	Deep zone	Light shelf	Window, height, light shelf width, external and internal part, shape, reflectance/climate any	
					Louver	Width, shape, reflectance /climate any	
					HOE "Holographic Optical Element"	Climate any	
					LCP " Laser Cut Panel"	Cutting depth, distance between cuts, thickness/ climate any	
					Prismatic panel	Climate any	
		Indirect contact	Transport	Deep zone	Anidolic	Length, height, reflectance materials, opening, orientation	
					Micro guide system	Length, height, reflectance materials, opening, orientation/ climate any	
	Ceiling elements	Direct contact	Direct enter	Deep zone	Skylight	Shape, dimension, height, location/ climate any	
			Reflect	Deep zone	Top reflective surface and opening	Material, dimension, orientation	
		Indirect contact	Transport	Deep zone	Light pipe	Length, diameter, reflectance material/ climate any	

Daylight and materials are the only tools that impact all urban levels (city, district, building unit, and individual apartment) (Maier, 2016). The successful implementation of daylight retrofit strategies in all urban scales offers a significant shift towards an innovative approach when retrofitting the existing building stock to create improved living standards and increased property value.

Many studies examined the daylighting performance of apartment buildings, for example, in the Gaza Strip (31.52°N, 34.45°E) (Asfour and Al Shurafa, 2016) Examined the daylighting performance of apartment buildings and proposed some design recommendations to improve performance, the results concluded a relationship between the illuminance levels and space orientation, the wall-to-window ratio, and the reflectance of indoor surface materials. The light shelf also has a vital role in improving daylighting distribution in space.

3.3.2 Energy reduction by improving the building envelope

The challenge for the building envelope is to design it in such a way as to provide an ideal balance between sufficient daylight in the building and minimal heat transfer through the envelope (Visser and Yeretzian, 2013). There are three primary ways in which energy efficiency can be improved in residential, public, and commercial buildings (ESMAP, 2011): 1) through improved design and construction techniques that reduce heating, cooling, ventilation, and lighting loads 2) through building upgrades and energy replacement equipment used 3) by actively managing energy use.

Some studies have suggested energy retrofit programs to reduce energy consumption. (Bataineh and Alrabee, 2018) have investigated the effect of energy retrofit programs on existing residential buildings under the typical Jordanian climate. Detailed simulation analyses have been performed of three levels of energy retrofit programs are suggested.

LEVEL 1	LEVEL 2	LEVEL 3
No cost and low-cost energy efficiency measures	Medium cost energy efficiency measures	Implementation of capital-intensive measures
• Reducing heating set point temperature • Increasing cooling set point temperature • Weatherization of the building shell to reduce infiltration	• Replacing the current glazing type with an efficient type • Overhang shading installation • Replacing the lighting system with a more efficient system • Installation of roof and wall insulation	• Use double, low emissive technology (LOE) clear glazing • Replacing of old and inefficient HVAC system with an efficient system. By increasing the coefficient of performance (COP).

The results showed that implementing level 3 energy efficiency measures can save up to 43% of annual electricity consumption, save up to 842 MW on peak demand energy, and 2190 kilo-ton/year reduction of CO_2 emission. This equates to 3.37 TWh of electricity consumption compared to the base case.

- Energy reduction proposed strategies

The selection of the proposed initial retrofit options is based on previous studies in the same climate and their availability in the local market. Several studies have focused on improving the energy retrofit strategies for the building envelope. Such as:

Table 3.8: The proposed retrofit strategies to reduce energy

	Energy Efficiency Strategies	Proposed basic retrofit options	Reference
1	Adding thermal insulation to Improving the thermal performance of the building's External walls and Roof.	Insulation materials : Extruded Polystyrene boards (XPS) Polyurethane foam (PUR) Rock Wool boards (Rockwool) (with minimum thickness complying with Code) Wall insulation: 4cm polystyrene layer Roof insulation: 6cm polystyrene layer NOTE: • Finishing material such as gypsum boards, or wood panels, or plaster. (The suggested interior finish material is 15 mm thick Gypsum panel) • For The position of the insulation layer (external or internal) see table 14	Jordan (Shamout, 2018) Jordan (Bataineh and Alrabee, 2018)
2	Installing double or triple glazing windows and skylights to Improving the thermal performance of the building's transparent surfaces.	Double glazed windows (with 12mm spacer), low-e layer, and using UPVC frames. Double, LOE, clear, 13mm air	Jordan (Shamout, 2018) Jordan (Bataineh and Alrabee, 2018)
3	Improving the building fenestration geometry features like a: Window to wall ratio Window orientation Room width to depth ratio (Khattab, 2017)	Windows maximum U-values and window to wall ratios required by the JEEDC, see table 10	
4	Introducing shading devices to reducing heat gain in the building's envelope	Installing SHADING DEVICES on southern elevation (horizontal overhangs, 0.60 m depth). Overhang 1.5m	Jordan (Shamout, 2018) Jordan (Bataineh and Alrabee, 2018)
5	The double skin facade (DSF)		(Khattab, 2017)
6	The double photovoltaic (PV) façade technology		
7	Building finishes such as paint	Insulating paints based on Nanotechnology enable improved thermal performance within the building. These paints possess low conduction based on the color heat reflectivity compared to the conventional paints	

3.4 Conclusion

Retrofitting of the building's envelope can provide comfort without compromising functional needs and can reduce energy consumption. In this thesis, there are two action strategies for retrofit an existing multi-story building.

- First action

In the beginning, identifying the characteristics of the existing building and the unverified requirements should be detected. Then the optimal spatial retrofit strategies should be defined for improving energy performance and optimizing the quality of internal spaces and distribution. For example, it could be by adding spaces to apartments, such as facade addition through the extension of indoor space and adding a new space (adding new balconies, etc.). Also, it can be by fulfilling existing laws and regulations.

- Second action

Determination of technological aspects: retrofit technologies consist of strategies to improve the efficiency of windows, floors, walls, and roofs. This thesis focuses on facade retrofit strategies.

Daylighting strategies and architectural design strategies are inseparable. Daylight not only replaces artificial lighting, reducing lighting energy use but also influences both heating and cooling loads. A wide range of daylighting technologies has been developed to improve energy efficiency daylighting. For example, direct entry device (high-performance glazing), daylight redirection devices (light shelves, louvers), transport technologies (light pipe), solar shading devices, daylight-responsive electric lighting controls, daylight-optimized interior design (such as furniture design, space planning, and room surface finishes).

To provide an ideal balance between sufficient daylight in the building and minimal heat transfer through the envelope. There are some proposed solutions to reduce the energy consumption levels of existing buildings by using new materials such as new thermal insulation (such as polyurethane). Other technologies are suggested; triple-glazed and double-glazed windows, double skin facade (DSF), and double photovoltaic (PV) façade technology.

Finally, after developing the framework described in chapter 2, this framework will help support initial decisions through retrofit projects. This section provides detailed guidance through flow charts that take into account how the decision-maker uses this framework. This thesis proposed two main goals for visual discomfort problems:

1. Increasing daylight to achieve optimum interior lighting in the rooms that showed a low average daylight factor
2. Reducing glare and improving the distribution of daylight in the rooms that showed a high average daylight factor

The actions are provided into two contexts of facade retrofitting and spatial retrofitting. Detailed simulation analyses have been performed of three levels of application are suggested:

- Level 1 (Minor application): this level has an unmodified appearance, such as: using curtains or changes the material reflection.
- Level 2 (Intermediate): this level has modified components & appearance, such as: adding shading device, replacing window glazing, adding a light shelf.
- Level 3 (Major): this level has highly disruptive to occupants, such as: adjusting WWR.

After determining the best retrofit solution, thermal comfort should be tested to achieve an ideal balance between thermal comfort and daylight. After determining the best retrofit solution, thermal comfort should be tested to achieve an ideal balance between thermal comfort and daylight. Thus, by following visual comfort figure 3.10 to improve natural light performance, decision-makers can determine the required actions by defining the problem.

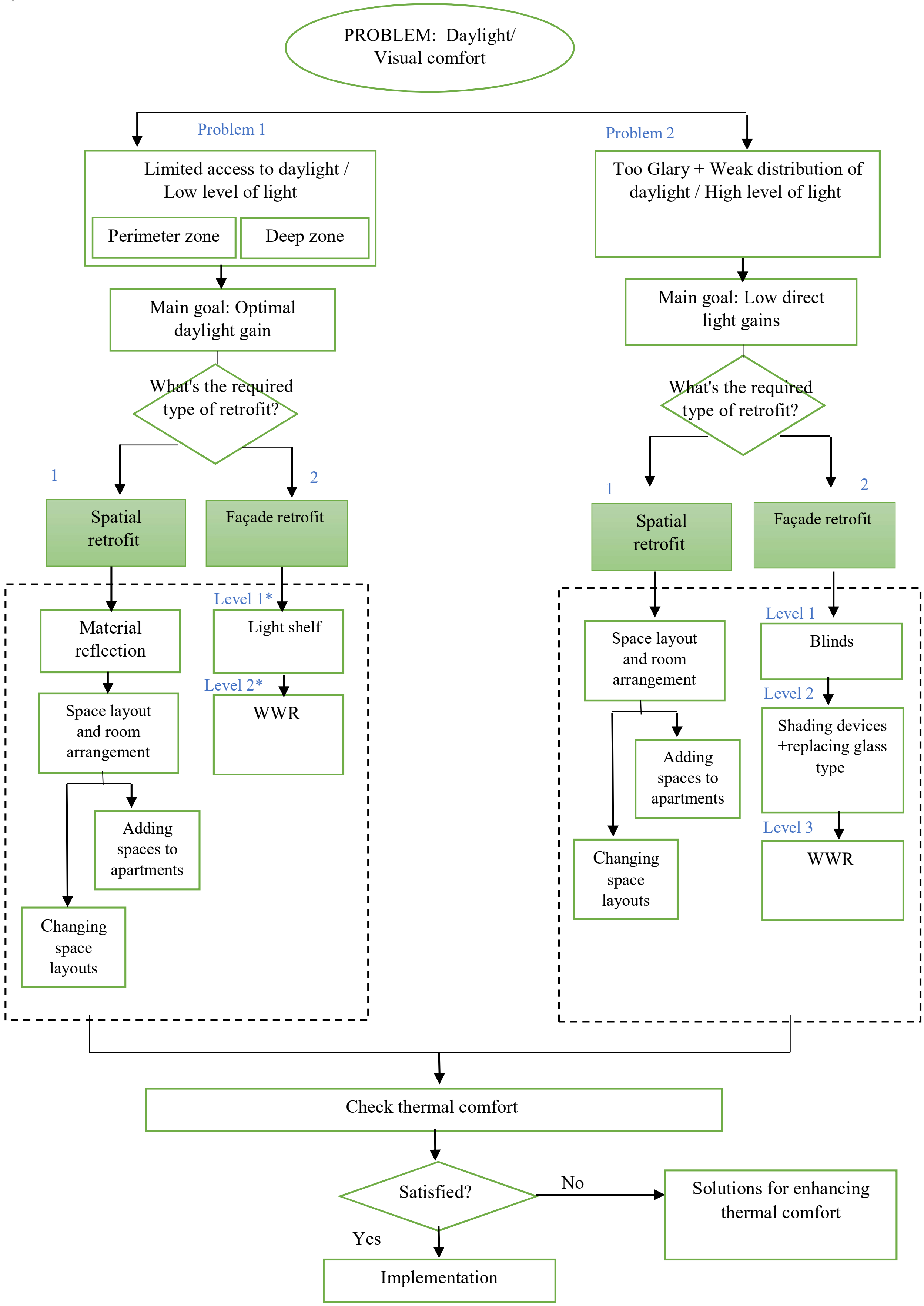


Figure 3.10: Visual comfort chart 1 – daylight

Research Methodology

Introduction

Chapter four explains the methodology used in this research to achieve the objectives and daylight analysis. This chapter first presents an overview of the research method employed and the analytical framework developed. Secondly, it discusses the methodology used in this thesis and the tools used during the study process to collect data and select case studies. Finally, the research framework and the simulation process are proposed for this research.

4.1 Details of the research methods used to achieve the thesis goals

This research examines passive retrofit strategies for enhancing the performance of natural daylighting in the existing multi-story residential buildings. This study is based on methodology-led research[1] that applies developed methodology to a new context. Therefore, in this research, the context was assumed a specific context (Hebron city) and the buildings built after 1993. The residential sector in Hebron faces many challenges. Most of the multi-story residential buildings are located in densely populated areas, which affects the quality of natural lighting in residential buildings. Also, there is no architectural planning for the city of Hebron. For example, streets, corridors, and setbacks between buildings did not consider the heights of the buildings and their overcrowding, which affects the quality of natural lighting inside the building.

The post-1993 period was chosen for several reasons: 1- the availability of architectural plans for buildings from engineering offices. 2- After the Oslo agreement, the Palestinian Authority (PA) assumed control over Area A and B, constituting 40% of the West Bank. A wide range of residential projects was implemented in area A. The land lots become very limited and expensive.

The study results may vary depending on the context, which may also modify the research method during the research process. The methodology of this research is based on a holistic method based on qualitative research and quantitative research. Four main phases are found necessary and will be carried out to form the research methodology as shown in the flow chart in figure 4.1.

[1] Methodology-led research means applying a relatively developed methodology in a new context, leading to new possibilities. The context is a changeable setting, leading to modification of the research method during the research process.

a) Qualitative research

Qualitative research emphasizes a holistic exploration of complex situations and contexts. It requires a study of the literature and fieldwork to understand the complete process of the retrofit projects and collecting data.

b) Quantitative research (simulation)

After collecting data through the survey approach and selecting the case studies, simulations were carried out for four multi-story apartment buildings. For each case, a 3D digital model was constructed using Design Builder software (V6.1.0.6.) to examine the daylight performance. The model was based on the actual building form and information on building materials collected during the fieldwork. In addition, the existing site information (such as latitude, longitude, altitude, the orientation of the building, etc.) was taken from the weather data for the Jerusalem region from the website of Energy Plus 8.9 for simulation .

After applying the retrofit strategies for enhancing the daylight performance in existing residential buildings, the optimization process was used to investigate the impact of different parameters on daylighting and determine the conditions that achieve optimal daylighting and the minimal energy consumption for heating and cooling well. Figure 4.1 below shows the research methods outline.

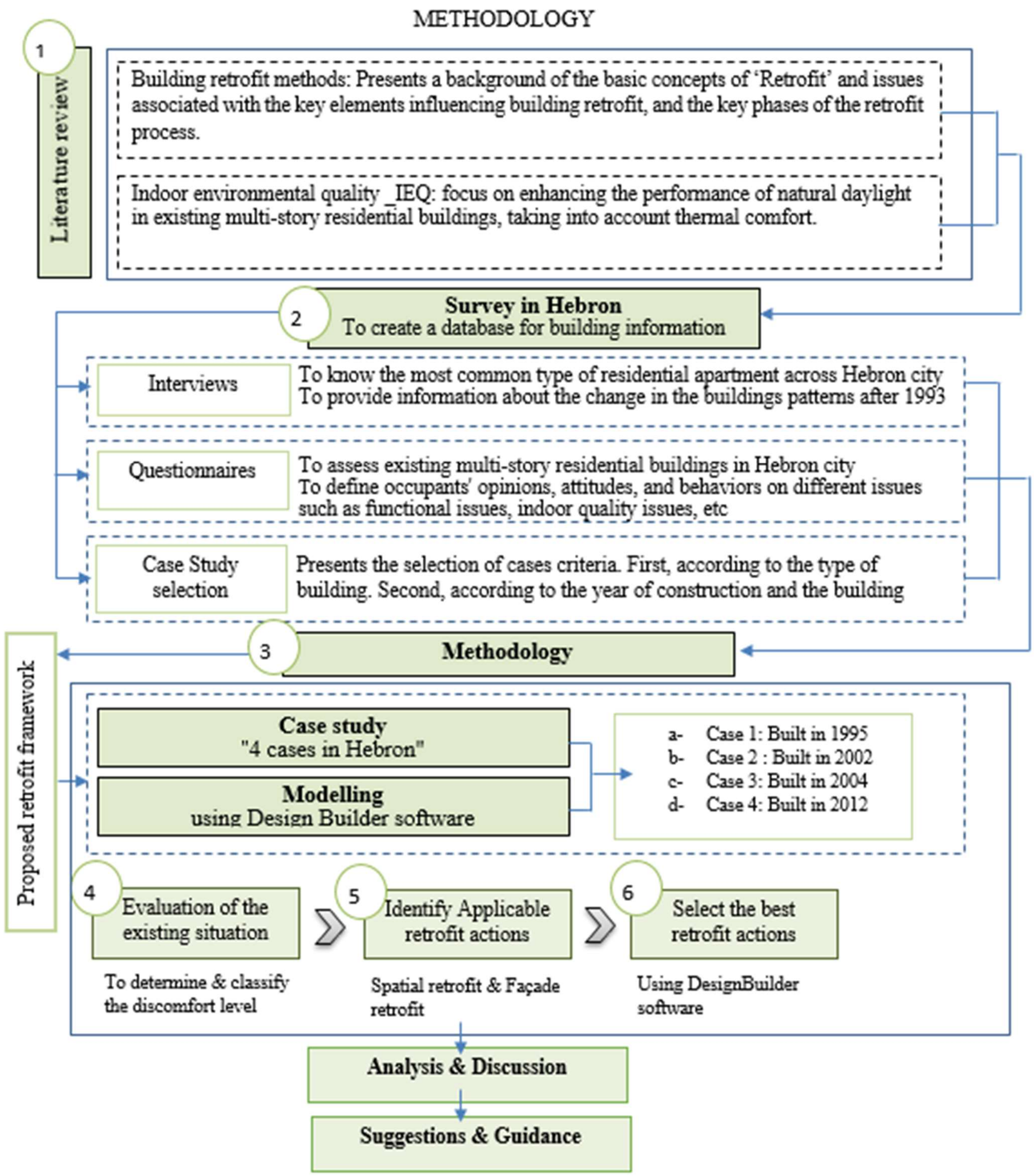


Figure 4.1: Research methods outline

The research is carried out using a holistic method based on qualitative research and simulation in the following steps:

4.2. Literature review

In this phase, the literature review was covered three fields, see figure 4.2 below:

1. The first field provides a review of the literature relevant to an understanding of building retrofit methods. It covers the background of the basic concepts of 'Retrofit' and issues associated with the key elements influencing building retrofit, the key phases of the retrofit process, and building guidelines for an energy efficiency retrofit .
2. The second field covers a review of the literature on Indoor Environmental Quality (IEQ) improvement, focusing on enhancing the performance of natural daylight in existing multi-story residential buildings. This phase also includes a detailed review of main daylight parameters that affect indoor environmental quality while identifying local standards related to visual comfort .
3. The third field provides a review of the literature related to retrofitting strategies of residential buildings to enhance natural daylight, taking into account thermal comfort strategies to offer an ideal balance between sufficient light in the building and minimal heat transfer through the envelope. The retrofit strategies include spatial retrofit strategies (interior parts) and facade retrofit strategies.

A retrofit framework is proposed after reviewed of available retrofitting guidelines adopted in different countries. This retrofit framework aims to identify, implement, and apply the most efficient retrofit scenarios in energy and comfort improvements that help decision-makers in the retrofit process.

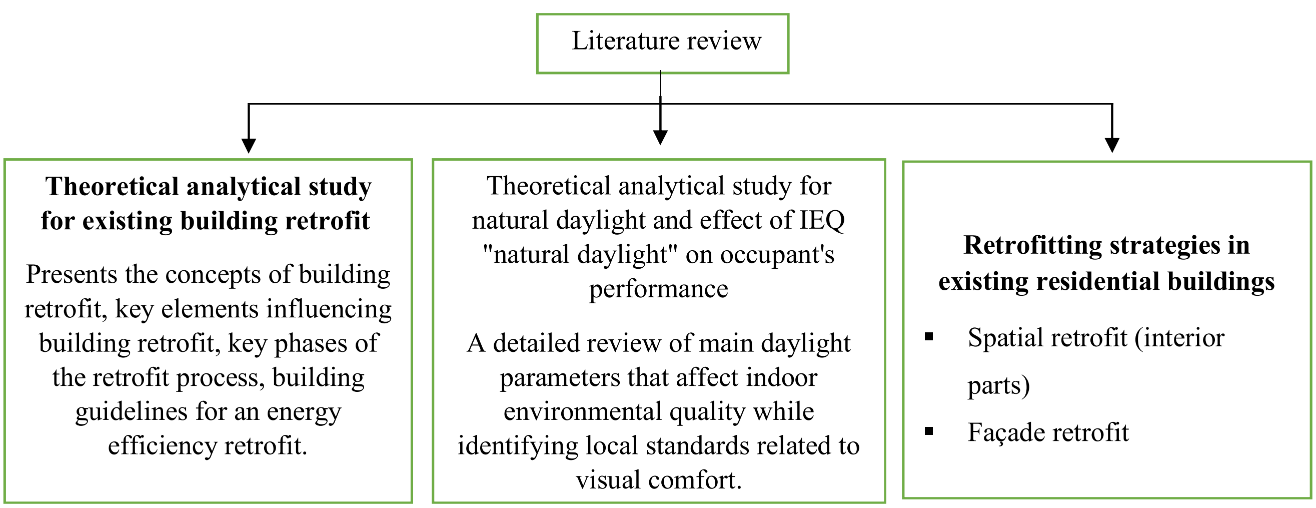


Figure 4.2: Outline of literature review

4.3 Data collection

4.3.1 A Survey in Hebron city

The survey research method is often used to collect information. In this research, the survey is used to evaluate the existing buildings and data collection. The general study was conducted to create a building information database in Hebron city, as shown below:

1. Construction characteristics of Hebron dwellings were collected and investigated
2. The main construction attributes of existing dwellings and changes in buildings patterns after 1993 were identified. (i.e. types, ages of construction, structure, floor area, No. of the apartments on each floor, building fabric, windows, external shadings, insulation, external walls, internal arrangement, etc.)
3. The typology outline was prepared. The most common residential buildings in Hebron were classified according to vertical movement and light wells. Lightwell was taken into account because it directly impacts how designers solve daylight problems in medium spaces.
4. Finally, case study selection criteria were determined.

4.3.2 Interviews

Interviews are an important method of obtaining research information from many design institutions, such as architects and building users (Lucas, 2016). In this research, interviews are all in the form of face-to-face, unstructured interviews, which generally start with some questions for each group and followed by free-flowing conversations.

The purpose of interviews is to know the most common type of residential apartments across Hebron city and provide information about the change in building patterns after 1993. Which helps to conduct a general study of the area to generate a building information database.

In this research, interviews are considered the best method because no previous studies or research was conducted for studying architectural styles (Hadid, 2002), (Bournas and Dubois, 2019). The interviews were conducted between January and June 2020 in two stages:

1. The first interviews were conducted between 9 and 23 of January 2020 with design institutions such as engineering offices, engineers association, municipality, and architects.
    a. The engineering offices and Hebron engineers association were interviewed to know the most common residential apartments and provide information about the change in building patterns after 1993.

b. Hebron municipality staff and Hebron engineer's association were interviewed to review building regulations, policies and to obtain statistical data on construction.

c. The civil defense staff was interviewed to review the changes in building regulations and policies.

The interview questions could be found in appendix A and the details of the interviewees are listed in Appendix C.

2. The second interview was conducted between 15 and 18 of June 2020 to obtain construction documents such as drawings to confirm the results of the interview.

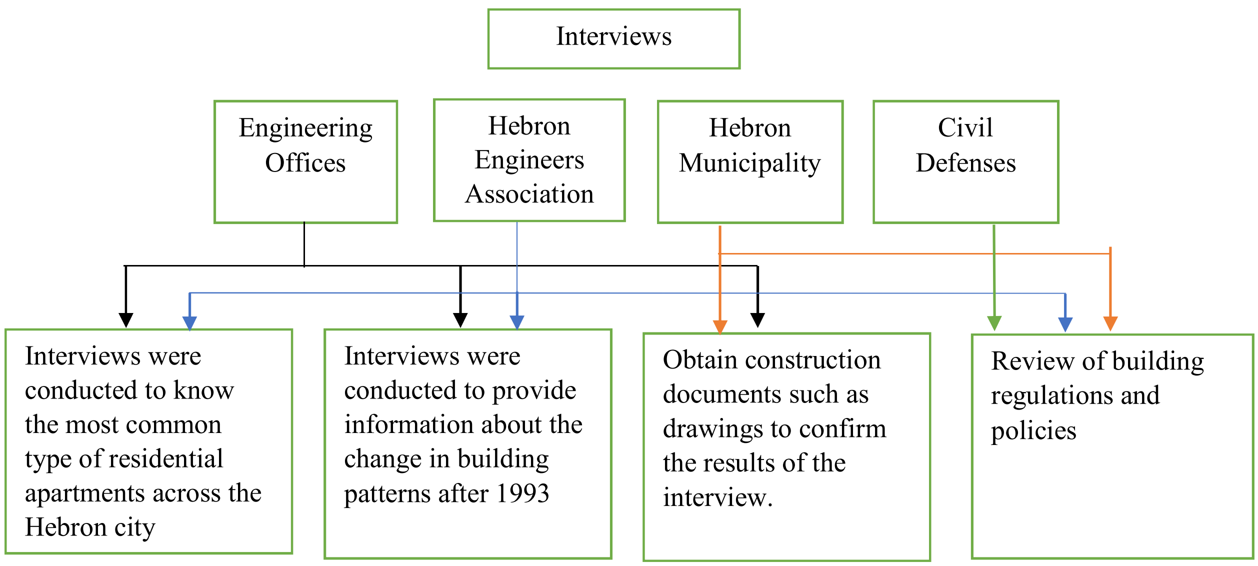


Figure 4.3: Outline of interviews

4.3.3 Questionnaire

The questionnaires were organized to assess existing multi-story residential buildings in Hebron city and to define occupants' opinions, attitudes, and behaviors on different issues such as functional issues, indoor quality issues, cultural issues, etc. The sample of this study is all the multi-story residential buildings in Hebron city.

The majority of the questions were multiple-choice questions and included open-ended questions. It covers one of the objectives and research questions of this study and helps to explore the optimal retrofit solutions for existing multi-story residential buildings:

"What strategies and building retrofit technologies can enhance the natural daylight performance of existing multi-story residential buildings in Palestine?"

The residents' opinion is critical. Therefore, before the retrofit process, a designer should communicate with the resident to understand the existing building (Gao and Zhang, 2011). Involved residents in a retrofit project's decision-making process help develop existing residential buildings and build a bridge between occupant needs and the proposed retrofit strategies (Ardda, 2017).

The questionnaire was organized into three parts:

1. The first part included the participants' general information such as gender, age, level of education, and monthly income, etc.
2. The second part involved objective questions about their physical living environments, such as floor level, orientation, the total area for their apartment, etc.
3. The third part was aimed to assess the current multi-story residential buildings situation. Also, it seeks to gather information about occupants' opinions, attitudes, and behaviors on different issues such as functional issues, indoor quality issues, cultural issues, etc.

4.4 Case study

The importance of the case study is to put the theory into practice. This allows the researcher to have practical experience applying the concept and an opportunity to monitor any anomalies or difficulties that may arise during application (Ayyad, 2017). For architectural research, case studies contain both contemporary and historical phenomenon and settings. Therefore, a case study is defined by an empirical inquiry that investigates a phenomenon or set (Groat and Wang, 2013).

In this research, four typical multi-story residential buildings built after 1993 in Hebron city were selected (case 1 was built in 1995, case 2 was built in 2002, case 3 was built in 2004, and case 4 was built in 2012). The selecting of cases was motivated by several factors. Firstly, these cases covered the most common types of multi-story residential buildings in Hebron city. Secondly, the selection was based on the year of construction and the building patterns.

The case study in this research aims to examine the effectiveness of different combinations of natural daylight retrofit strategies. Therefore, each case study was tested to assess the validity of the suggested daylight retrofit strategies. An environmental diagnosis conducts before applying the retrofit strategies to define the building's problems. Then, the solution for the retrofit process was proposed. Finally, the results of the cases are compared and discussed before and after retrofitting.

4.5 Simulation

Design-Builder (V6.1.0.6.) was used to examine the daylight performance of the case study buildings. A 3D digital model was constructed for each case based on the actual building information on building materials collected during the fieldwork. A simulation of four multi-story apartments was performed to provide quantitative results and daylight analysis for each case before and after retrofitting strategies were applied, which helps to evaluate the validity of the proposed retrofit strategies. The current site information (such as latitude, longitude, altitude, the orientation of the building, etc.) was taken from the weather data for the Jerusalem region from the website of Energy Plus 8.9 for simulation.

The selected residential buildings have geometric characteristics and building materials comparable to most residential buildings in Hebron. Several daylight strategies are proposed; retrofitting the building's envelope can provide comfort without compromising functional needs. The optimization process was used to investigate the impact of different parameters on daylighting and determine the conditions that achieve optimal daylighting and the minimal energy consumption for heating and cooling. Daylight analysis was performed for each case before and after applying retrofit strategies with a CIE standard overcast sky on 21st September (autumn equinox). The implications and contributions of the proposed strategies discussed for enhancing the performance of daylighting.

4.6. Conclusion

This proposed final framework helped support initial decisions in the retrofit process. This framework was focusing only on visual comfort (daylighting). Diagram 4.4 shows the first phases for retrofitting the building that was followed when analyzing the case studies. This framework includes five steps:

- Step 1: It begins with collecting information about the characteristics of the existing building and its performance
- Step 2: Diagnostics the building and identifying the main problems and discomfort sources, by user surveys .
- Step 3: Evaluation of the existing situation using design builder software to determine & classify the discomfort level at building-scale, room-scale, and facade scale
- Step 4: This phase requires a list of retrofit actions, the user comfort requirements determined based on the surveyed data. The conducted visual comfort chart 1 page 45 in this thesis can be used.
- Step 5: Select the best retrofit actions for each case using design builder software

Pre- retrofit process

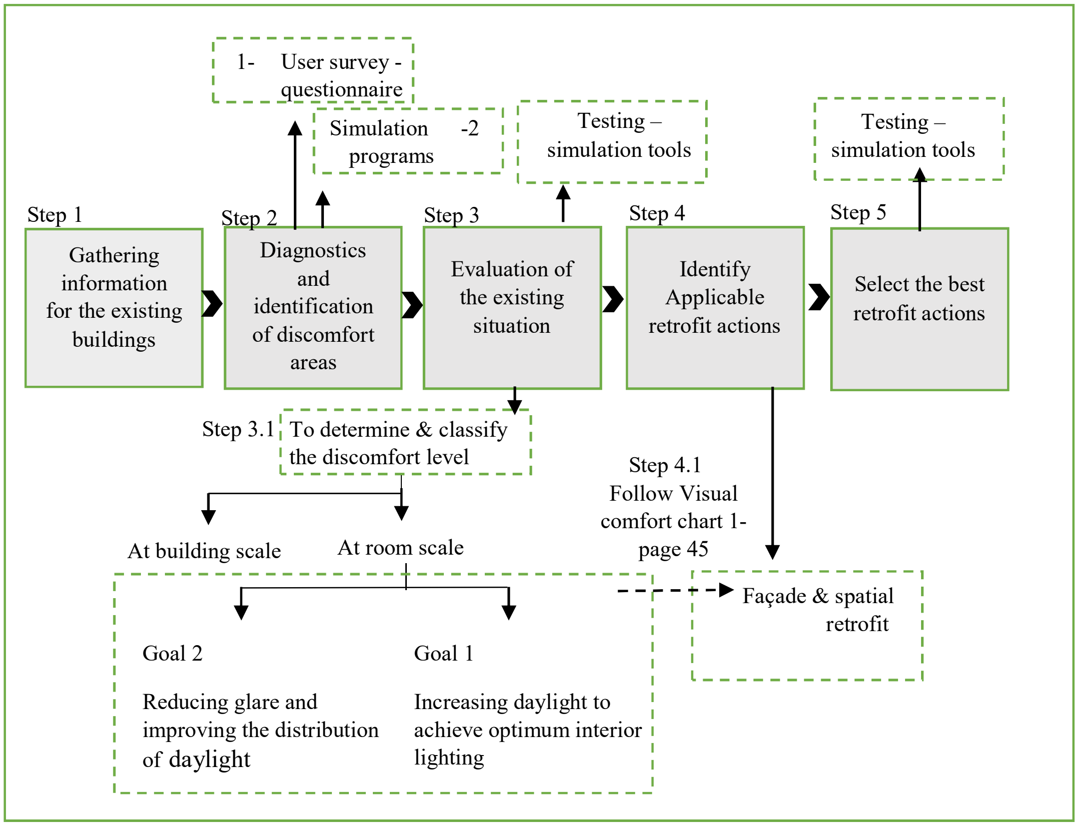


Figure 4.4 Diagram of visual comfort retrofit roadmap process (source- researcher).

Results from Interview and Data Collection

Introduction

This chapter presents the results of the interviews and data collected to create a database of building information about apartments in Hebron. In this study, the method and interview results were explained and analyzed. The purpose of interviews is to know the most common type of residential apartments across Hebron city, provide information about the change in building patterns after 1993, and review building regulations and policies.

5.1 Contemporary residential buildings, background

At the beginning of the 20th century, many changes occurred in the construction pattern in the West Bank, where many new building materials were imported. These changes result from a difference in lifestyle in social and economic terms and the entry of new building materials (Salameh, 2012), (Alsamamra and Said, 2019). During the second half of the 20th century, the number of multi-story buildings increased to overcome spatial limitations and increase demand for housing in the dense areas and continued to be widely used in the Palestinian cities.

Until the late 1980s, the architect was not the only designer. The construction process could pass even without the architect's signature. The construction process was influenced by an unstable political situation that caused chaos in architectural types' planning and development (Badawy, 2012).

In 1993, the Oslo Agreement was signed to divide the West Bank into three administrative areas, A, B, and C. In 1995, The Oslo II Interim Agreement and Paris Protocol Agreement formally established the Palestinian Authority (PA). The Palestinian Authority (PA) assumed control over Area A and B, constituting 40% of the West Bank (Alazza & al-Orzza, 2017). Through these agreements, the (PA) has acquired specific monetary, taxing, licensing, and policing authorities.

In the last decade, the Palestinian territories have witnessed a sudden transformation in the urban fabric. It was the beginning of the spread of contemporary buildings. Contemporary buildings differ from traditional residential buildings, the external walls of modern buildings are less thick, and the roofs of the building are turned into flat roofs. A wide range of residential projects was implemented in area A. In addition, most buildings lack thermal insulation, all of which have resulted in a low level of thermal comfort. The number of new buildings created between 1996 and 1997 reached about 200,000 in the West Bank and Gaza Strip (Ministry of Local Government, 2004).

Construction techniques in the West Bank developed to go with global development in the construction field (Salameh, 2012). According to the Palestinian Central Bureau of Statistics, the construction sector in 2010 recorded the highest growth rate of 36%, also showed an increase in the number of workers in the construction sector by 22% compared to 2009. But, conventional methods of building construction in the West Bank do not consider the sustainability of construction. Thus, the environmental problems in the West Bank will be uncontrolled and running costs will be higher.

5.2 Building sector in Hebron city

Housing is one of the most important subsectors of construction. The high demand for housing in dense areas, the increase in land cost, and the rapid population growth in Palestine played a significant role in the formulation of urban form (Abdelhamid, 2006). Thus, the relative distribution of households by type of housing unit showed that the 571,744 occupied housing units were apartments by 62.3% (PCBS, 2017). The GIS department in the Hebron municipality indicates the results of the housing and establishments censuses in March 2020, is about 21,747 buildings in Hebron, 50.0% of which are residential buildings and 33.0% for mixed-function buildings as shown in Table 5.1 below.

Table 5.1 - Number of Buildings Hebron city by Type of Building, March 2020- Source: GIS department in the Hebron municipality

Type of Building	Number of building	Percentage
Residential buildings	10,948	50.0%
Multifunctional buildings "shops with apartment building"	7,238	33.0%
Public buildings "Educational, Commercial, Industrial, Mosques"	3,561	16.0%

In general, the residential building takes a block shape that contains several floors that can reach eight floors "according to the building law for each region" (Kawasmi, 2020), (Alhrub, 2020). Figure. 5.1 clarifies classifications of residential buildings in Hebron City according to the number of floors. Single housing is the dominant typology followed by the apartment's building. Recently, a trend towards multi-story buildings is observed. The number of floors in multi-story buildings increased not only due to the spatial and economic limitations but also as a reflection on the importance of the extended family in the local culture (Al Qadi, et al., 2018).

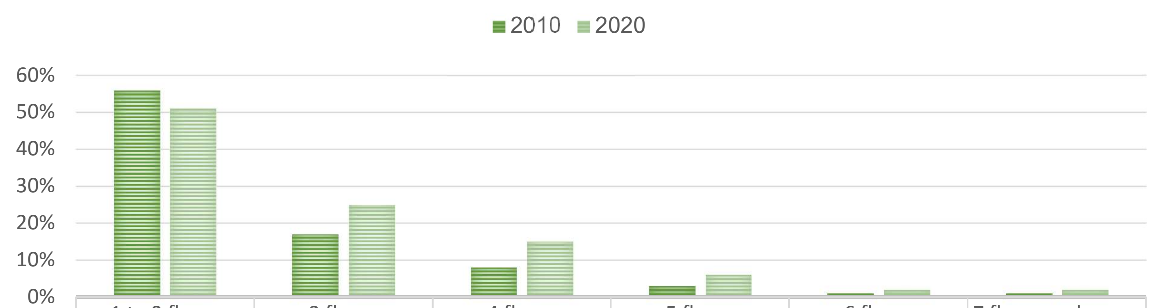
The main building materials used are natural stone, concrete, hollow blocks, and sometimes thermal insulation. There are different types of thermal insulation such as foams, and polyurethane, etc.

Recently, people have become more aware of insulation materials and their importance (Kawasmi, 2020).

The openings "windows and doors" have no standardization. In general, the width of the windows ranges from 1.00 to 1.50 m, while the height ranges from 1.25 to 1.50 m (Maraqa, 2020). No rules or characteristics have been specified for the minimum opening's height or size for lighting and ventilation. Residential building openings are more restricted than other buildings; the function forces the designer and the owner to reduce the sizes of openings for more privacy and to set furniture in a room (Hadid, 2002). Various types of glass have been found, such as single glass, double glass, mirrored glass, etc.

Table 5.2 - Number of Buildings in the city of Hebron by Number of building floors, March 2020 - Source: GIS department in the Hebron municipality

Number of building floors						
Residential and Multifunctional Buildings	1 to 2 floors	3 floors	4 floors	5 floors	6 floors	7 floors and more
Total - 2010	10295	3217	1496	464	118	96
Total - 2020	9325	4635	2738	1055	317	321
The variance between 2010 & 2020	-1.10	+1.44	+1.83	+2.27	+2.69	+3.34



	1 to 2 floors	3 floors	4 floors	5 floors	6 floors	7 floors and more
2010	56%	17%	8%	3%	1%	1%
2020	51%	25%	15%	6%	2%	2%

Figure: 5.1 - Number of Buildings in the city of Hebron by number of building floors, 2010-2020- source: GIS department in the Hebron municipality

5.3 Residential buildings typologies after 1993

Palestinian contemporary architecture was affected by many factors, not only new building materials and modern building techniques, but also economic and social factors (Hadi, 2013) (Qawasmeh, 2020). Contemporary buildings have become widespread since the mid-1995s (Badawy, 2012). People's social and cultural life is the main factor in defining architectural identity (Badawy, 2012), (Qawasmeh, 2020). There are many different types of plans that can be considered due to changing a social lifestyle. But, there are no previous studies or research conducted before to study architectural styles (Hadid, 2002).

According to (Hadid, 2002) (Badawy, 2012), the Palestinian contemporary architectural styles (types) consist of:

1. Residential Buildings and others (Educational, Commercial, Industrial, Mosques)
2. Contemporary Architectural Elements
3. Factors Affecting Architectural Styles
   A. Most common types of residential apartments

According to (Sharawi, 2020), (Kawasmi, 2020) multi-story residential buildings could be divided in Hebron city into:

1. Apartment buildings :

The apartment buildings can be classified as extended family residential buildings and investment residential buildings. The extended family residential buildings are the most common style in Hebron city; each floor consists of one, two, or three apartments at the same level. But the two apartments on each floor are the most common type, see figure 5.2. Whereas in " investment residential buildings," the most common style consists of four apartments on each floor (see figure 5.3.)

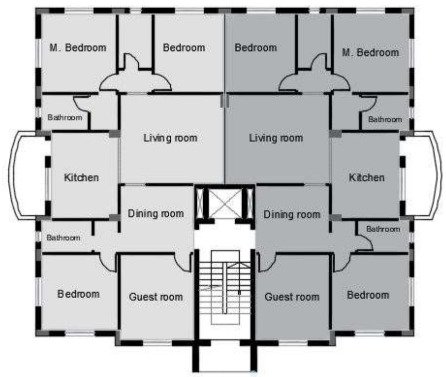


Figure 5.2: Multi-story residential building plan: each floor consists of two apartments – source : researcher

Figure 5.4: Multi-story residential buildings – Hebron city, source: researcher, 2020

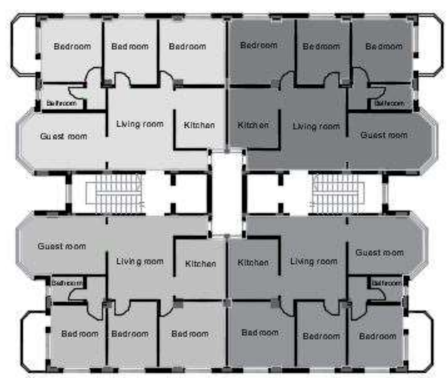


Figure 5.3: Multi-story residential building plan: each floor consists of four apartments – source: researcher

The areas of the apartments range from 120 m2 up to 180 m2. The apartments shared side walls with neighboring units and sometimes have only one or two outer walls. In large investment residential buildings, the number of floors can reach eight floors above the street line with 3 or 4 basements (Sharawi, 2020).

2. Mixed use building

This style (type) is very popular in Hebron city; it is usually a commercial "shops" in the lower levels "ground floor" and apartments on the upper floors which can reach four floors, each floor consist of one or two apartments as in the previous type. The height of the shops ranges from 3 m up to 6 m with a mezzanine level. It is allowed to build this building in commercial areas and main streets (according to the building law); see figure 5.5.

Figure 5.5: Mixed use building – shops and apartments- Hebron city

B. Contemporary architectural elements

The contemporary architectural design connects indoor and outdoor spaces. Contemporary design features selected to define the current modern building have depended on the types of elements expected to be seen in most of the building plans categorized under modern and contemporary design (Badawy, 2012). The factors affecting the internal climate of the building can be classified into two parts: the exterior and interior elements (Hadid, 2002):

1. Exterior Features

   Exterior features include a balcony, openings, and external walls, etc. Contemporary buildings and modern designs are usually defined by tall windows, unique shapes, etc.

2. Interior Features

   Interior features of modern building plans include open plans, high ceilings of the building, kitchen designs, marble, stainless steel and concrete counters, etc.

In this study, architects and engineering offices specializing in housing have been consulted in a reference group to determine this aspect. It is essential to analyze and understand the types of contemporary architecture. To determine the main building features of existing housing in Hebron city and changes in building style after 1993. See figure 5.6 below.

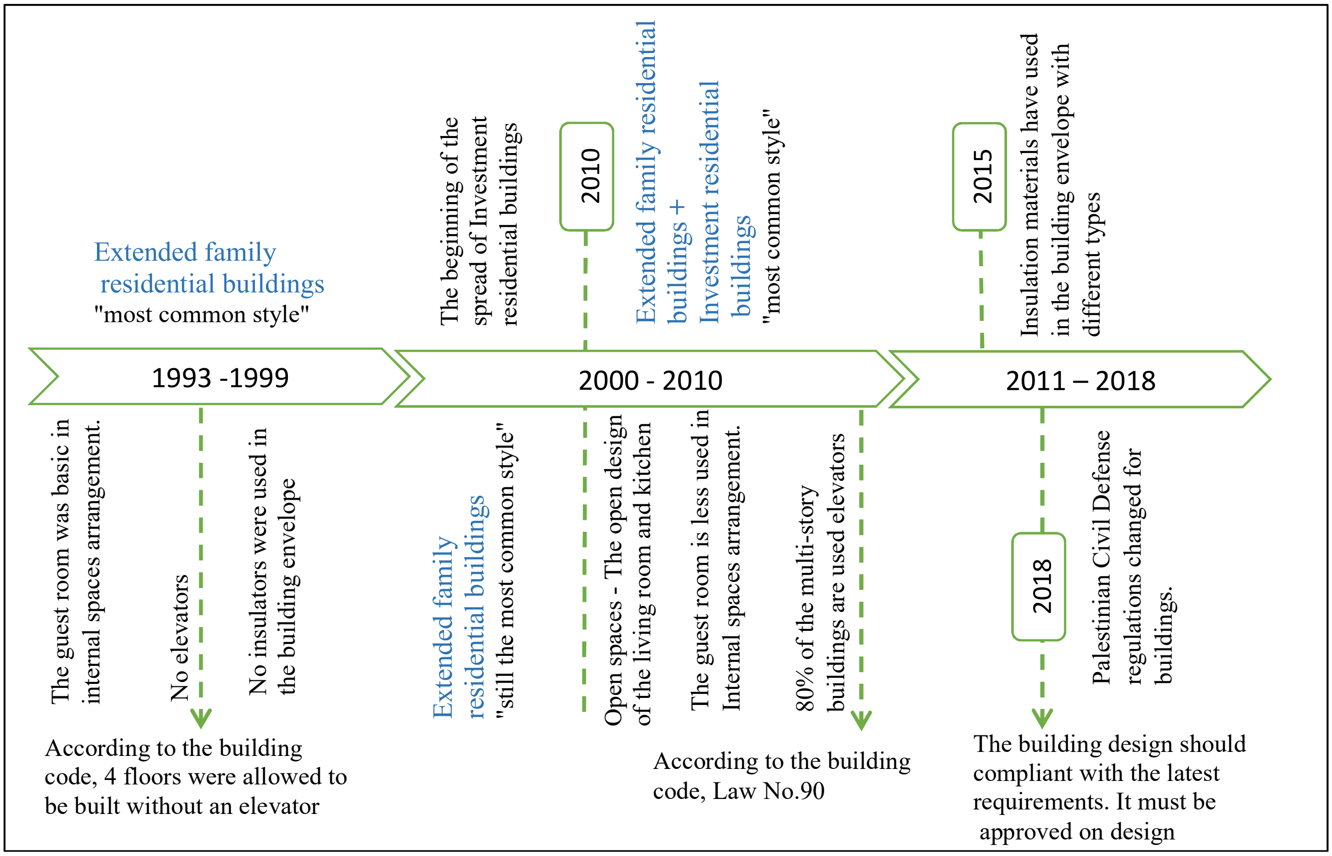


Figure 5.6: Changing in building patterns between 1993-2020/2021 in Hebron – Source: researcher

5.4 Current laws and regulations

The Palestinian Authority has modified building laws and by-laws instead of previous laws, "Jordanian laws in West Bank" to organize the building process without making any radical changes and considered temporary laws (ABOAMIR, 2014). Despite this, the Palestinian Engineers Association is still taking the Jordanian National Building Council code as a reference.

5.4.1 Building regulation codes

Building regulation codes have been formulated since 2011. Some of the current building laws are displayed below:

- According to the aesthetic aspects under Law No. 7 of the Building regulations codes, it is allowed to use any color to paint the facades of the external building. Still, the color should not exceed 20% of the facade area, which should be a natural stone color.

- In-laws No.79 and No.80, the buildings have to employ natural daylight and ventilation by windows opening to the outside. However, these provisions do not apply if the architectural design or technical reasons require mechanical ventilation or artificial lighting in the building.

5.4.2 Natural Daylight code - 1992

The Jordanian National Building Council issued these codes intending to increase awareness of the importance of daylight and methods of calculating light for optimal use in building lighting. In addition to providing visual comfort for the occupants, according to the type of activity. The Palestinian Engineers Association takes this code as a reference.

5.4.3 Fire Fighting Code

Fire code regulations and standards were reviewed and modified in 2018, meaning that the house's standards were built no longer compliant with the latest requirements. Therefore, upgrading work may require additional works on a large scale, such as adding stairs.

5.5 Conclusion

Multi-story buildings are a solution to overcome the problem of increased population and shortage of land. This research covered the most common types of multi-story apartment buildings, making it an excellent representative as a case study. Moreover, most multi-story residential buildings were built after 1993, which means that the standards according to which the house was built were less than today's goals, making it more difficult to retrofit.

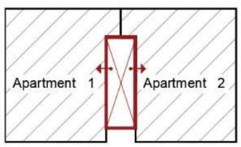
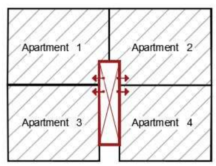
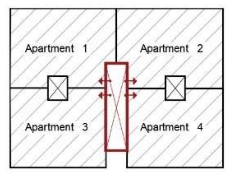
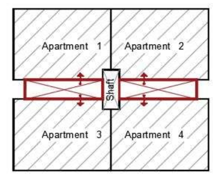
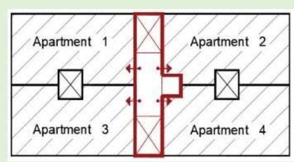
The design and layout vary depending on the number of apartments on the same floor. The arrangement of rooms depends on their function and time of use. It also depends on the area of the apartment and the occupants' needs .

In this research, the typology outline was prepared to determine the typical buildings, which helped to choose study cases. The most common residential buildings in Hebron were classified according to vertical movement, and light wells. Lightwell was taken into account because it has a direct impact on how designers solve daylight problems in medium spaces.

After obtained construction documents and analyzed. The interviews with engineering offices and engineers associations confirmed the typology outline. As shown in Table 5.3 below, there are four main typical types, type 1 for extended family residential buildings and other types for investment residential buildings.

The Palestinian Civil Defense regulations for buildings changed in 2018; two concrete staircases that lead to different levels should be existing. One for vertical circulation, the other is for emergency escape. Therefore, buildings type 5 has been resumed because the buildings are still under construction. Also, buildings built after 2016 were resumed because most of them are still not occupied.

Table 5.3: shows the five main typical types of the selected buildings sample sorted by vertical movement and light well- source: researcher.

<table>
<tr><th>Two apartments on each floor
"Extended family residential building"</th><th colspan="3">Four apartments on each floor
"Investment residential buildings"</th></tr>
<tr><td>Type 1</td><td>Type 2</td><td>Type 3</td><td>Type 4</td></tr>
<tr><td>
</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td rowspan="4">The staircase in the middle lead to different levels and apartments</td><td>• The staircase in the middle lead to different levels and apartments
• Without light wells</td><td>• The staircase in the middle lead to different levels and apartments
• Two main light wells</td><td>• Every two apartments are grouped around one staircase lead to different levels.
• One light well in the middle of the building</td></tr>
<tr><td colspan="3">Type 5</td></tr>
<tr><td colspan="3">
</td></tr>
<tr><td colspan="3">• Every two apartments are grouped around one staircase lead to different levels.
• One for vertical circulation, the other is for emergency escape.
Two main light wells</td></tr>
<tr><td colspan="4">Note: There are other types of buildings that can be classified according to vertical movement and light wells, but these types are more frequent.</td></tr>
</table>

Existing residential buildings evaluation- Questionnaires

Introduction

The questionnaires were organized to assess existing multi-story residential buildings in Hebron city and to define occupants' opinions, attitudes, and behaviors on different issues such as functional issues, indoor quality issues, etc. The questionnaire covers one of this study's objectives and research questions and helps to explore the optimal retrofit solutions for existing multi-story residential buildings. This chapter presents the results obtained from the questionnaire.

" What strategies and building retrofit technologies can enhance the natural daylight performance of existing multi-story residential buildings in Palestine?"

This chapter begins with an introduction, detailed information on the sampling process, and discusses the multiple issues extracted from the questionnaire results. The housing sector impacts the environment and the resident's health and well-being. It also affects the quality of life and considers as tied with the guarantee of human rights. Thus, the housing sector needs attention regarding the built environment (Ahmad and Thaheem, 2017). The residents' opinion is critical. Therefore, before the retrofit process, a designer should communicate with the resident to understand the existing building (Gao and Zhang, 2011). Involved residents in a retrofit project's decision-making process help develop existing residential buildings and build a bridge between occupant needs and the proposed retrofit strategies (Ardda, 2017).

6.1 Dimensions of the Questionnaire

The questionnaire was organized into three parts:

1. The first part included the participants' general information such as gender, age, level of education, and monthly income, etc.
2. The second part involved objective questions about their physical living environments, such as floor level, orientation, the total area for their apartment, etc.
3. The third part was aimed to assess the current multi-story residential buildings situation. Also, it seeks to gather information about occupants' opinions, attitudes, and behaviors on different issues such as functional issues, and indoor quality issues, etc.

Some issues should be assessed using a Likert scale. Mostly, the Likert scale is used to determine occupants' satisfaction and their opinions. A five-point Likert scale for measuring satisfaction is: (1) Very dissatisfied, (2) Dissatisfied, (3) Neither satisfied nor dissatisfied, (4) Satisfied, (5)Very satisfied.(Blog, 2020) The majority of the questions were multiple-choice questions, and this study also included open-ended questions. The example of questionnaires is presented in appendix B.

6.2 Sampling process

The sample of this study is all the multi-story residential buildings in Hebron city. According to GIS Management in the Hebron municipality, the results of the housing and establishments' censuses in March 2020 are about 21747 buildings in Hebron, among 18186 of which are residential buildings and multifunctional buildings. The number of multi-story buildings is about 3252. The size of the study sample was approximately 97560[1] person (Alreck et al., 1995). Thus, a sample size of 96[2] person or more is needed to have a confidence level of 95% that the real value is within ±10% of the surveyed value. A margin of error of ±10% is considered acceptable (Conroy, 2015).

6.3 Pilot study

A pilot study was conducted with a sample of 5 people to develop questions and verify that all questions are clear, accurate, and well understood. The results of the pilot study showed that most of the questions in the questionnaire were clear, but some questions need to be modified.

6.4 Questionnaire survey

The survey was conducted in June of 2020. Occupant responses were collected via online questionnaires in Arabic. Hard copies of questionnaires were distributed to increase the reliability of the survey results. The total number of occupants responding was 127 from both methods, which exceeds the required sample.

[1] 3252 (number of the multi-story buildings in Hebron city) * 5 (the number of floors) * 3 (number of apartments on each floor) * (2 assume two-person answer the questionnaire) = 97560 person

[2] Calculator.net: Free online calculators, this calculator computes the minimum number of necessary samples to meet the desired statistical constraints (calculator.net, 2021).

6.5 Results & Analysis

6.5.1 Demographic characteristics of the participants

Table 6.1: Demographic characteristics of the survey

Variable	Variable Definition	Percentage (%)
Gender	Male Female	**22.1%** **77.9%**
Age	Under 25 years old 25-35 35-45 Over 45 years old	**46.2%** **41.3%** **8.7%** **3.8%**
Education Level	Less than Bachelor's degree Bachelor's degree and above	**26.9%** **73.1%**
Family Monthly Income	1000-2000 NIS[3] 2000-3000 NIS More than 3000 NIS Undefined	**7.7%** **17.3%** **56.7%** **18.3%**
Homeownership	Rented Owned	**11.5%** **88.5%**

This part explains the demographic background of residential building occupants. The demographic variables included gender, age, level of education, average monthly income, and homeownership. Results from table 6.1 clarify that 77.9% of the respondents were female, and 22.1% were male. This could be due to Palestinian culture, as males work to provide income for the family, which could mean that they do not have time to answer this questionnaire.

87.5% of the respondents were under the age of 35. In terms of education level, 73.1% of the respondents obtained their bachelor's degrees and above. In terms of family monthly income, 56.7% of the respondents earned more than 3000 NIS. Among the 104 respondents, 88.5% were owners, and 11.5% were tenants. Consequently, owners can decide whether to conduct the environmental retrofitting of their existing residential buildings to remain comfortable in the future regardless of any prevailing changes related to their age, behaviors, environmental aspect, etc.

[3] NIS : New Israeli Shekel

6.5.2 The physical characteristics of the residential buildings

Table 6.2: Physical characteristics of the residential buildings

	Variable	Variable Definition	Percentage (%)
1	Apartment description	**A. The apartment level**	
		Ground floor	**30.8%**
		First floor	**26.0%**
		Second floor	**21.2%**
		Third floor	**11.5%**
		Fourth floor	**4.8%**
		Over fifth floor	**5.8%**
		B. Number of the apartment in each floor	
		One	**38.5%**
		Two	**38.5%**
		Three	**7.7%**
		Four	**10.6%**
		More than four	**4.8%**
		C. Open side	
		One side	**6.7%**
		Two sides	**18.2%**
		Three sides	**41.3%**
		Four sides	**33.6%**
		D. Number of window layers in the house	
		Single	**37.5%**
		Double	**62.5%**
2	Floor area in m2	Less than 120	**16.3%**
		120-140	**26%**
		140-150	**15.4%**
		170-180	**16.3%**
		More than 180	**26%**
3	Number of residents of the house	One – three	**19.2%**
		Four – six	**58.6%**
		Seven – nine	**19.2%**
		Ten – twelve	**2.8%**
4	Number of years lived in the house	Less than 5 years	**33.0%**
		5-10 years	**21.5%**
		11-15 years	**12.5%**
		16-20 years	**17.6%**
		More than 20 years	**14.7%**
	Year of construction	Before 1979	**6.7%**
		1980-1989	**19.2%**
		1990-1999	**25.0%**
		2000-2010	**19.2%**
		After 2010	**26.9%**
5	Daily hours	Less than 5 hours	**0.9%**
		5-10 hours	**25.0%**
		11-15 hours	**23.0%**
		16-20 hours	**20.0%**
		21-24 hours	**30.7%**

Table 6.2 results showed that 30.8% of respondents reside on the ground floor, 63.5% reside on the first and fourth floor, and only 5.8% of the occupants reside on higher floors. 66.2% of the respondents share the wall with their neighbors; the flats are positioned back to back and sometimes have only one or two outer walls. All this creates inner spaces without direct contact with the outside natural light; Where 53% of the respondents' answers range from very dissatisfied to neither satisfied nor dissatisfied with the natural ventilation and light that access the apartment. Respondents answered that they were very satisfied with natural lighting, although their apartments had only one or two outer walls; their apartments had directed to the east or south. While the respondents answered that they were very dissatisfied, their apartments had directed to the west or north. That means that the apartment building needs special treatment to create high-quality spaces.

As described in table 6.2, 26% of participants reside with a floor area is between 120 and 140 m2. Also, 26% of participants reside with a floor area of more than 180 m2; most of them reside in buildings with one or two apartments on each floor. The study revealed that 53.8% of the flats were partially insulated to heat and cold, and 62.5% of windows with double glazing. The result shows that partial insulation in the walls is common.

Participants were asked about the year the building was built on understanding the building stock. The results showed that 6.7% of the buildings were built before 1979, 19.2% between 1980–1989, 25% between 1990–1999, 19.2% between 2000–2010, and 26.9% were built before 2010.

It can be concluded that most of the buildings in this study were constructed after 1990, where 33% of the respondents lived in the buildings for less than five years, while 51.6% of them lived in buildings between five to twenty years. About 50.7% of respondents spend all of their time inside the house.

6.5.3 Results and Discussion

A. Functional issues

Figure 6.1 indicates that 41.3% of occupants were dissatisfied with the apartment layout, while 25% were neutral and about 33.6% were satisfied. Depending on the data collected, the results showed a percentage of user dissatisfaction with the room area or room location according to their daily use and activities. Consequently, the room spaces were inappropriate to meet its function and occupants'

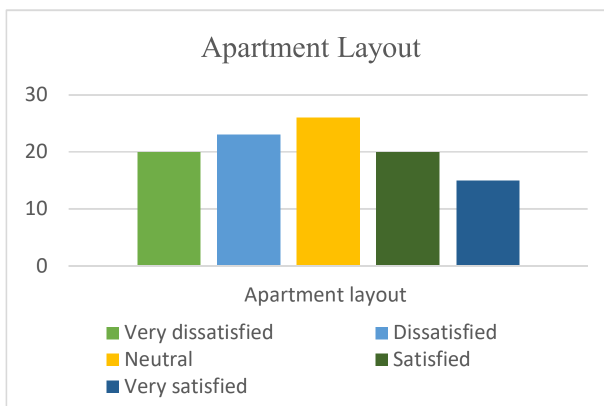


Figure 6.1: The respondents' satisfaction about the house layout

Some users need additional space to feel more comfortable, while other users need to deduct a space, especially from the guest room. Also, some rooms' location was unsuitable to meet the needs of natural daylight and ventilation. Results were plotted using the following graph in Figure 6.2.

Figure 6.2: The respondents' satisfaction with the internal spaces and room location

30.7% of the occupants had designed their apartments without restrictions from any designer. While 31.7% of them did not participate in the design of the apartment. 22.1% of them had no idea who designed the apartment. Some participants bought their house from the previous owner or were tenanted house.

Around 47% of the respondents believe that it is essential to implement changes in the house, whether changes in space use, physical or decorative changes. 13.5% of the occupants carried out changes in the use of space, while 11.5% carried out physical changes. Figure 26 shows the main reason for carried-out changes. Indoor house quality issues are basic in-house design, around 38.5% of respondents carried out changes in their houses to improve indoor air quality.

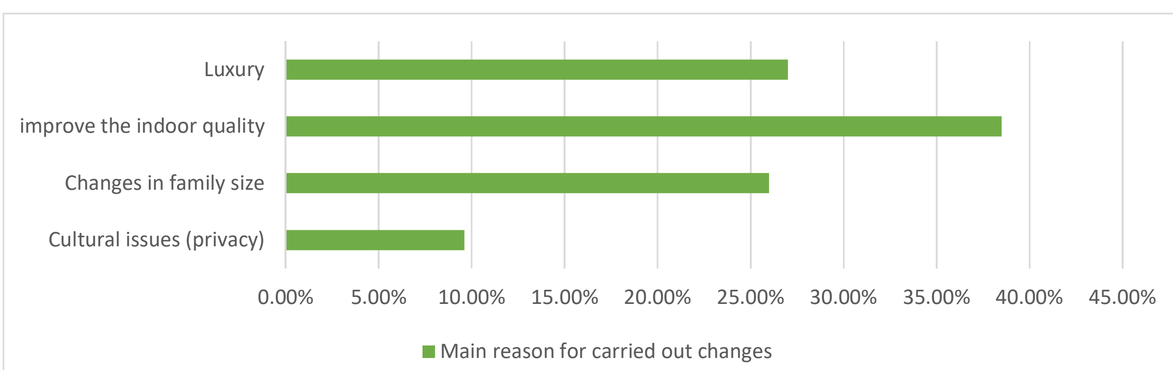


Figure 6.3: Main reason for carried out changes in houses

B. Environmental issues

Figure 6.4 shows indoor environmental quality satisfaction. Indoor environmental quality is one of the basic human needs and plays a vital role in human comfort. The study revealed that 24.15% of occupants reported having at least one indoor environmental quality problem.

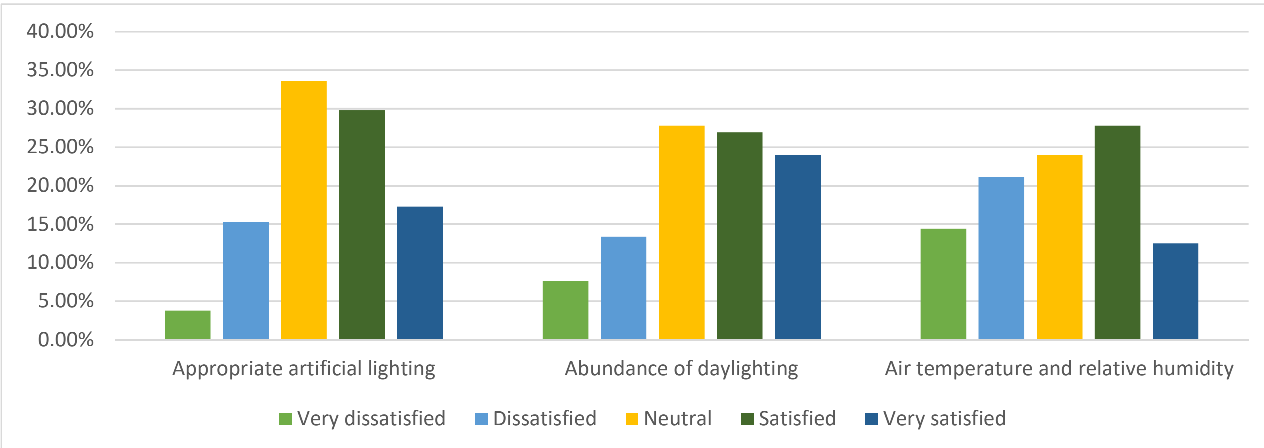


Figure 6.4: The respondents' satisfaction with indoor environmental quality

Most of the internal environmental quality problems were related to air temperature and relative humidity. About 72.1% of the respondents reported that they had mold and considered it a serious problem. It was investigated whether the internal arrangement influences the occurrence of indoor environmental issues. In general, residents were more satisfied with higher floors and rooms facing south or east.

In summer, 11.5% of respondents reported that they adjusted the internal temperature in hot weather using passive design only; by opening the windows or/and door to interior space. Some of them are satisfied with air temperature, relative humidity, air quality, and natural ventilation by using passive design only. From the data collected, it was noted that most of the satisfied population, their apartments were facing west. Thus, the possible reason is that their apartments had oriented to benefit from the summer wind "marine breezes" coming from the west and northwest to mitigate the heat. While 37.5% of respondents reported that they adjusted the internal temperature in hot weather using only active design, about 50.9% used active and passive design to improve the internal temperature.

In winter, 88.4% of respondents reported that they adjusted the internal temperature in winter weather using only active design. In contrast, 10.5% uses active and passive designs to improve the internal temperature. A possible reason for the high percentage of using the active design is that the weather has been colder than usual in recent years.

When participants were asked to assess the general daylight level in their houses - the time of filling out the questionnaire was summer, about 24.0 % of the occupants were very satisfied and about 26.9% of the occupants were satisfied with the natural daylight conditions. 27.3% of the respondents complained that there was no daylight in the living room spaces. Most of them were dissatisfied with the apartment's layout and the room's location, which may affect the regular access to daylight.

Between 17.3 and 29.8 % of the occupants reported that they are very satisfied or satisfied with the artificial lighting in their house. The use of artificial lighting depends on the season of the year .

The number of hours is the most appropriate behavior affecting illuminated comfort levels (Xue, Mak and Cheung, 2014). Consequently, it affects the number of hours spends without having to use artificial lighting in the daylight. In general, figure 6.5 below shows the hours respondents spend without using artificial lighting in the daytime. About 38.5% of respondents spend less than 5 hours a day without using artificial lighting. The use of artificial lighting for many hours a day indicates that natural daylight was insufficient and decreased luminous comfort.

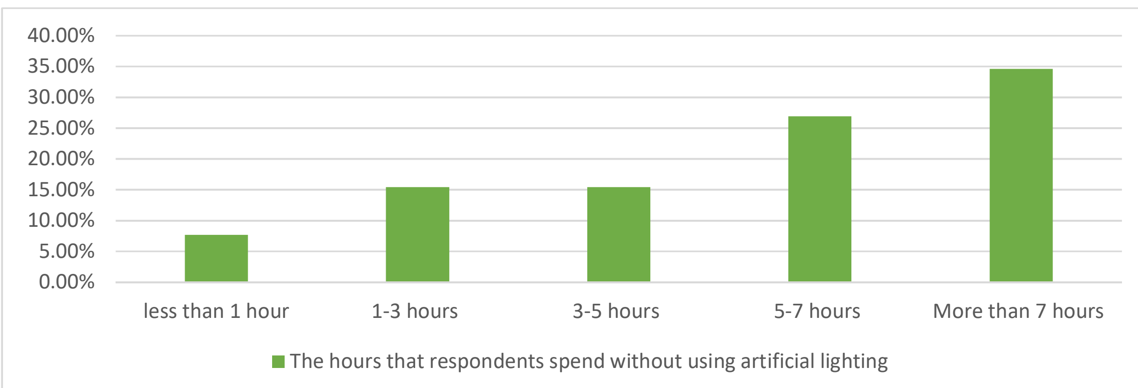


Figure 6.5: The hours that respondents spend without using artificial lighting in daytime

6.6 Conclusion:

Existing multi-story residential buildings in Hebron city were assessed, and occupants' opinions, attitudes, and behaviors on different issues were defined. Each building is a unique case requiring a complete understanding of the needs and problems of the building occupants before retrofitting.

Based on the analysis of the data, the following conclusion was:

- This study concludes that there is a proportion of user dissatisfaction with the room area or room location in terms of functional issues. The room spaces were inappropriate to meet its function and occupants' needs. Also, some rooms' location was unsuitable to meet the needs of natural daylight.

- Around 47% of the respondents believe that it is essential to implement changes in the house. Indoor house quality issues are very important in-house design, around 38.5% of respondents carried out changes in their houses to improve indoor air quality.

- Most of the internal environmental quality problems were related to air temperature and relative humidity, where the internal arrangement influences indoor environmental problems.

- Some of the respondents complained that there was no daylight in the living room spaces. Most of them were dissatisfied with the layout of the apartment and the location of the room, which may affect the normal access to daylight

- The use of artificial lighting (depending on the number of hours) is the most relevant behavior to influence luminous comfort levels. The use of artificial lighting for many hours a day indicates poor daylight conditions and reduced luminous comfort.

Finally, an open question about the changes that residents will make if allowed to feel more comfortable. Here are the residents' suggestions

- Most users need additional space to feel more comfortable, while other users need to change the apartment layout and room arrangements.
- Some residents need to increase window areas to increase their daylighting satisfaction level. In contrast, other residents need to combine the kitchen and living areas in open-plan designs to bring natural lighting and ventilation to the living room.
- Some residents were aware of energy consumption issues; some asked for better wall insulation, while others asked to change the type of glass. Thus, providing a good indoor climate while using as little energy as possible.

Case studies

Introduction

This chapter focuses on analyzing four existing multi-story residential buildings in Hebron city to assess the validity of the proposed visual comfort retrofit strategies. This chapter gives information about the selected cases: firstly, it begins with a brief overview of the climatic features of Hebron city. Secondly, an environmental diagnosis conducts to be able to define the building's problems precisely. Thirdly, it proposes solutions for the environmental retrofit process and simulates its results. Finally, the results of the cases are compared and discussed before and after retrofitting .

The importance of the case study is to put the theory into practice. This allows the researcher to have practical experience in applying the concept, and an opportunity to monitor any anomalies or difficulties that may arise during application (Ayyad, 2017).

7.1 Case studies of Hebron

A. The climate in Hebron city

Hebron is one of the largest Palestinian cities located in the southwestern part of the west bank, at the longitude of 35.8 east and latitude of 31.31. Palestine is located within the solar belt countries considered high solar potential energy countries; very sunny with average solar radiation on a horizontal surface of about 5.4 kWh/m2.day (Hussein and Albarqouni, 2010).

The city of Hebron is naturally mountainous, with an average city height of 972 meters above sea level. Therefore the city has a moderate Mediterranean climate with hot, dry summers and wet, cold winters. The average annual temperatures starting from a minimum temperature of 2° in winter to reach a maximum peak of around 31° in summer (Meteoblue weather, 2020).

The topography of Hebron city highly affects the wind speed reaching the city. The wind direction in Hebron is mostly from the West and North-Western. During the autumn and spring seasons, the western winds from the Mediterranean are humid. Whereas, during the summer, the prevailing winds come from the northwest, with an average speed of 10 km/hour during the day. The wind velocity reaches 35 km/hour in winter, mostly from the northwest (Applied Research Institute , 1995).

Rainfall in Hebron often occurs in January and February, exceeding 170mm, as spring rainfall may exceed 589mm (Meteoblue weather, 2020). On the other hand, the summer season is completely dry. As the amount of rainfall in 2018 was 621 mm/ year (PCBS, 2019).

Climate has a significant impact on the performance of the building and its energy consumption (Santamouris, et al., 2001). Climate analysis is the starting point for any design that can maximize comfort and minimize the energy consumption for heating and cooling loads.

B. Energy situation in Hebron city & the built environment

The energy sector in Palestine faces significant challenges. It relies on external sources for the supply of energy with exorbitant costs, in addition to many environmental risks arising from the use of traditional sources of energy (Kittanah, Hilow, & Hamouda, 2012). The energy sector in Palestine is affected by many factors, making it different from other Middle East countries; the limited natural resources, the high population density, and the unstable financial and political conditions are the main examples for them (Juaidi, Montoya, Ibrik, & Manzano-Agugliaro, 2016). Furthermore, the “Israeli” control and occupation over most areas of Palestine and the arbitrary procedures to close the borders and destroy the electricity facilities are hard challenges facing Palestinians in obtaining their electrical plants (Abu-Hafeetha, 2009).

Thus, like other cities in the West Bank, Hebron city depends almost entirely on “Israel” for its energy supply; this considers one of the reasons that led to obstructs the ability to develop the energy sector. In 2016, the Hebron municipality developed a strategy consistent with the Palestinian energy strategy and sustainable development needs. This strategy was structured around two parts: Firstly, reducing energy consumption across the board by around 20 to 25% through energy conservation and efficiency. Secondly, promoting energy production from local renewable resources and reducing Greenhouse Gas- GHG emissions by 20 % in 2020.

The results of the Baseline Emissions Inventory (BEI) of the Hebron municipality in 2014 showed that the transport and residential buildings sector represent the most enormous energy consumption, as shown in figure 7.1. The total energy consumption in Hebron city is estimated to be 839 GWh FE/year, which corresponds to about 4.15 MWh/person/year. While, the Global GHG emissions of Hebron city are estimated to be 448 ktCO2eq/year in 2014, which corresponds to about 2.22 tCO2eq/person/year. Also, gases and account for nearly 70% of Hebron’s emissions, as shown in figure 7.2

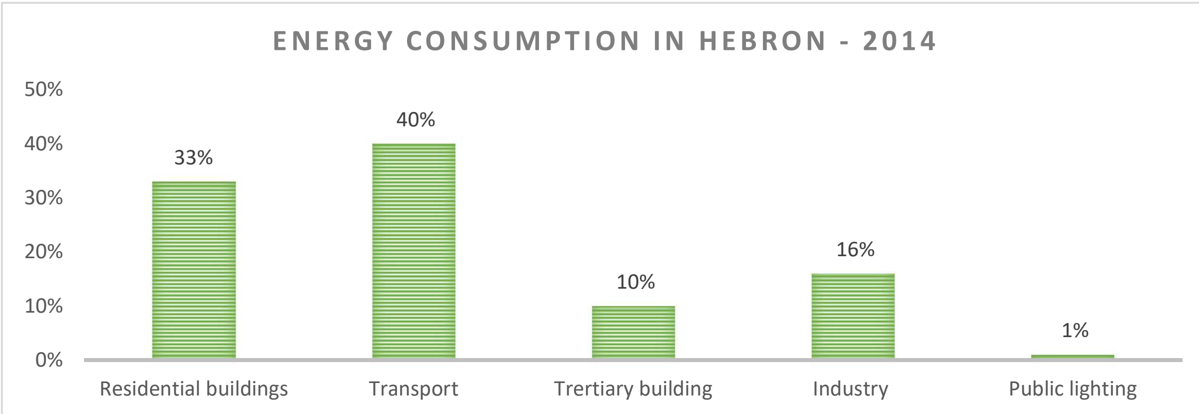


Figure 7.1: Energy Consumption by sector- 2014 – source : Hebron municipality

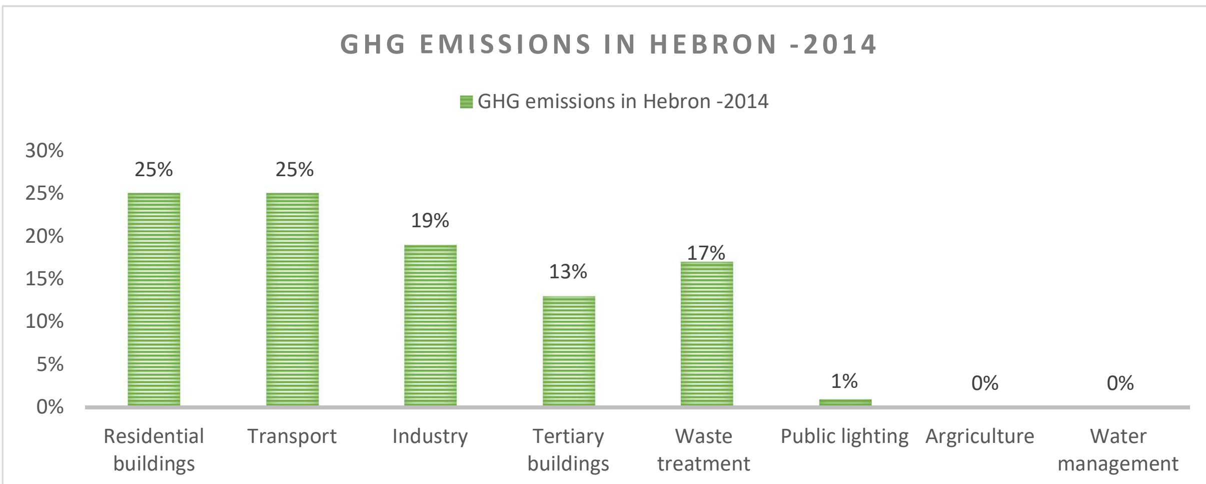


Figure 7.2: GHG emission by sector- 2014- source: Hebron municipality

C. Energy in residential and mixed use buildings

The residential and tertiary building sector ranks the first in energy consumption (43% with 357 GWh/year) and GHG emission (38% with 168 ktCO2eq/year). Therefore, in partnership with CHF / Global communities in 2016, the Municipal Council was designed an action plan for Hebron's urban area. This plan aims to raise public awareness on energy issues, inviting inhabitants to reduce their consumption and, as a consequence, cut their energy bills. Also, it seeks to develop an energy-retrofitting plan for housing and tertiary buildings. Table 7.1 below highlights the expected results of the action plan.

Table 7.1: The expected results of the action plan.

Energy in MW/year GHG in tCO2eq/year	Situation in 2014		Cut expected in 2020		Situation in 2020	
	Energy	GHG	Energy	GHG	GHG(BAU)	Cut/BAU
Residential & mixed use buildings	357,180	167,455	-63,584	-29,764	207,644	14,3%
Awareness to reduce consumption			-53,572	-25,118		12,1%
Housing renovation plan			-9,912	-4,646		2,2%

In Palestine, the building sector ranks the first consumption of electricity (75% of total consumption) (Njore & Mark, 2016). Therefore, this sector needs specific energy efficiency measures such as insulation of buildings, improvement instrument performance (especially for air conditioning), etc. Also, the main energy demand sources and GHG emissions are electricity for buildings, especially residential buildings, as shown in figure 7.3 and figure 7.4 below.

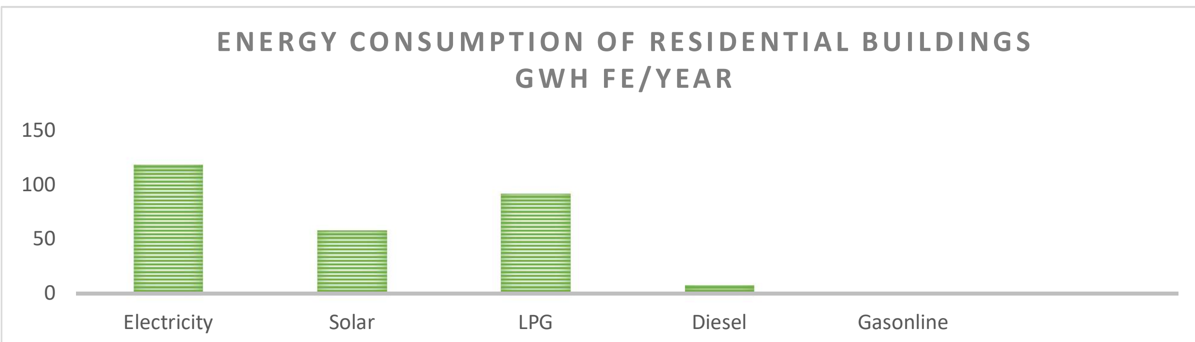


Figure 7.3: Energy consumption per energy in Hebron – 2014 source: Hebron municipality

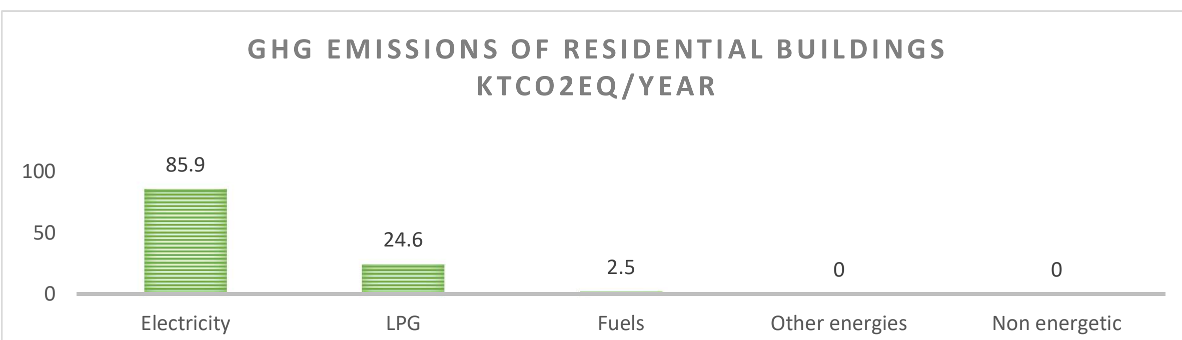


Figure 7.4: GHG emissions per energy in Hebron – 2014- source: Hebron municipality

7.2 Selected Cases in Hebron city

The selection of cases was based on two criteria. First, the type of building. Second, the year of construction and the building pattern. See figure 7.5 below.

A. Selection based on Building type

This study focused on multi-story residential buildings with over 20 meters according to the definition of a multi-story building in the Palestinian code. As mentioned before, current directions in architecture towards multi-story apartment buildings have increased in the residential sector, especially in Palestine. This due to the high demand for housing in dense areas and rising land costs (Itma, 2018). The results of the GIS Department in the Hebron municipality indicate the results of the housing and establishments censuses in March 2020, about 21,747 buildings in Hebron, among 18,186 residential and multifunctional buildings. The number of multi-story buildings is about 3,252.

B. Selection based on year of construction and the building pattern

The selection covered the most common multi-story apartment building, focusing on the period after 1993. Multi-story residential buildings can be divided into two types: an extended family residential building and investment residential buildings. The most common "investment residential buildings" are buildings that have four apartments on each floor. Still, buildings with two apartments on each floor are the most common style in extended family apartment buildings.

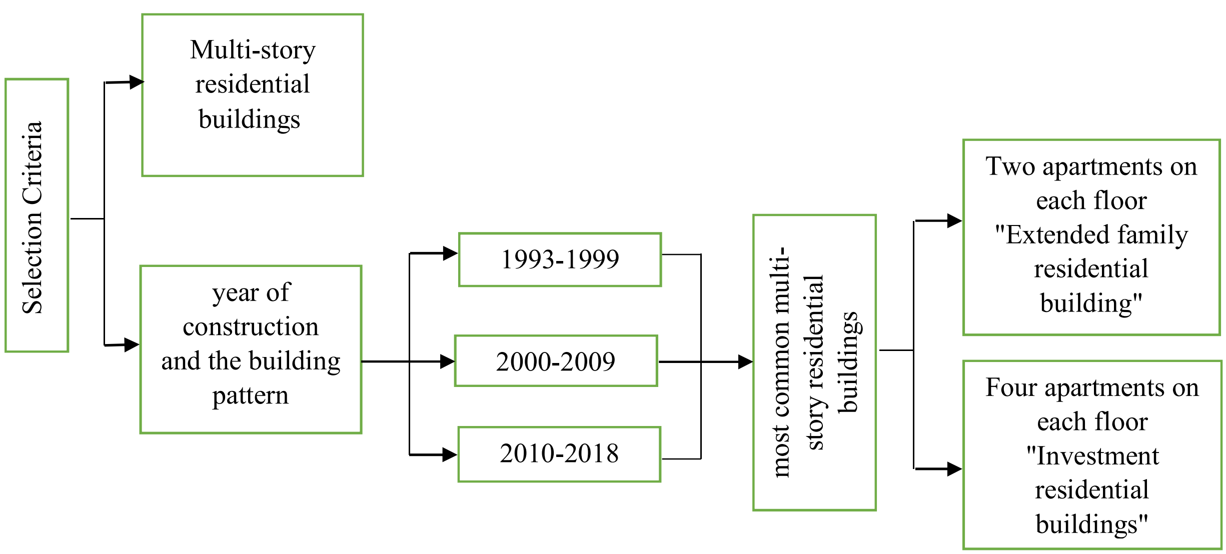


Figure 7.5: Building selection criteria- source: researcher

The case study in this research aims to examine the effectiveness of different combinations of natural daylight and energy efficiency retrofit strategies and technologies. In the case study, four typical multi-story residential buildings built after 1993 in Hebron city were chosen according to table 5.3 in chapter 5. Figure 7.6 below shows the position of selected cases in the map of Hebron city.

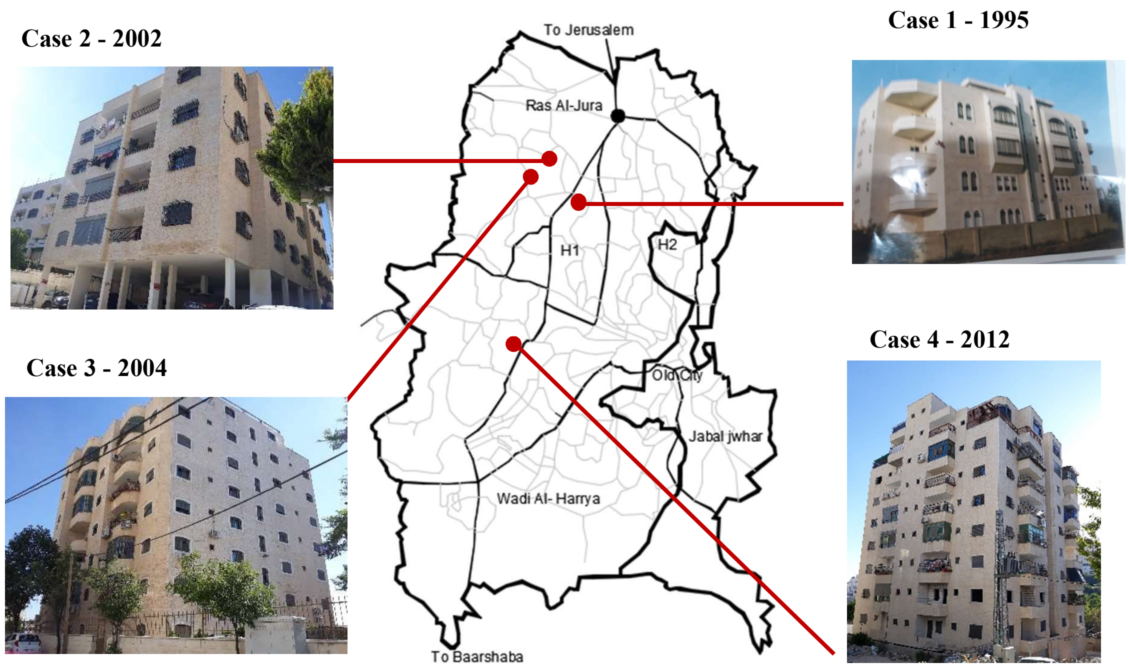


Figure 7.6: Selected cases in Hebron city- source: researcher

- Structure of the case studies

There are three parts of analysis for each case before examining the effectiveness of different natural daylight retrofit strategies and technologies, see figure 7.7 below:

- The first part describes the specific information for the selected case study.
- The second part contains the reason for choosing this case.
- The third part focuses on the environmental analysis of each case.

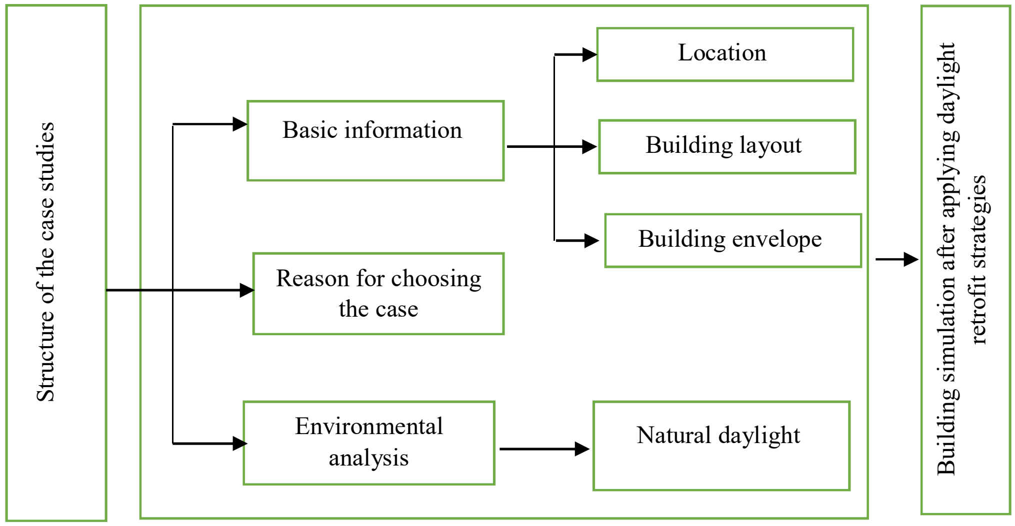


Figure 7.7: Structure of the case studies – source: researcher

Design-Builder (V6.1.0.6.) was used to examine the daylight performance of the case study buildings. Simulations were carried out for four multi-story apartment buildings:

1. The first building (Case 1) covered the extended family residential building built in 1995.
2. The second building (Case 2) covered the residential investment building type 3 (the four apartments are group around one staircase without an elevator, the building has two main light wells), this building constructed in 2002 .
3. The third case study building (Case 3), this investment residential building type 4 (every two apartments are group around one staircase leading to different levels, the building has one main light wells in the middle), was built in 2004.
4. The fourth building (Case 4) covered the investment residential building type 2 (the four apartments are group around one staircase without a light well); this building was built in 2012.

As a result, the selected residential buildings have geometric characteristics and building materials comparable to most residential buildings in Hebron. The daylight analysis was performed for each case before and after applying retrofit strategies with a CIE standard overcast sky on 21st September. The main parts of every retrofit project before verifying the effectiveness of solutions are examining and analyzing the current situation of the building, identifying the problems, and thus actions to be taken.

Therefore, an assessment of the existing daylight performance was conducted using a Design-Builder simulated model. After that, a comparison was made about whether the lighting requirements were compatible with the minimum and average daylight factor for different types of rooms in residential buildings (according to the Jordanian code issued in cooperation with the Jordanian Green Building Council) for adequate natural lighting. This helped to determine and classify the visual discomfort problems at room-scale. Follow visual comfort chart 1 in chapter 3.

7.3 Case Study 1:

7.3.1 General information

Location**:**

The building is located in the Hebron University neighborhood. It was built in 1995. The residential buildings surround the case study building in two directions: west and south. The long axis of the building is to the east and west direction. See the figure 7.8.

Figure 7.8: The site plan to the left shows the buildings. The red-marked building is our research case. The photo to the right shows the entrance façade. Source- researcher

The case study building consists of four floors with eight apartments. As shown in figure 7.9, each floor contains two apartments with an area of about 105 m² for each apartment. The two apartments are grouped around one staircase in the middle that leads to different levels, without an elevator . Every apartment consists of a master bedroom and another bedroom, a kitchen, bathroom, living room, two balconies, and a guest room with a toilet. In the selected residential building, only the master bedroom has windows on two different facades. Other rooms have windows only on one external facade.

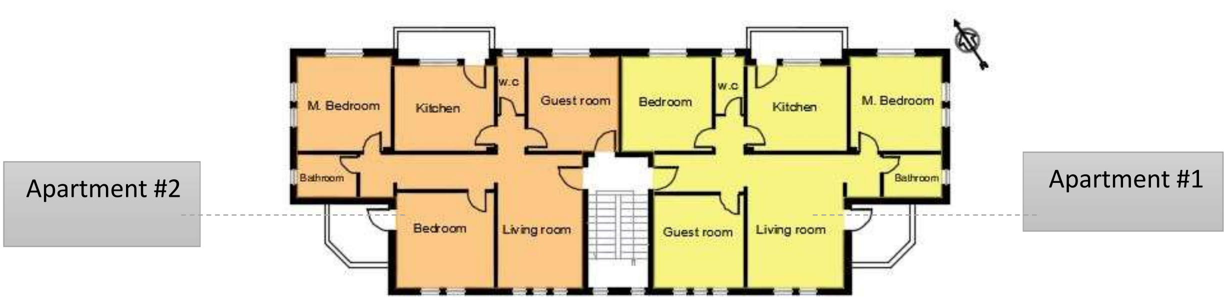


Figure 7.9: Represents the typical plan of the case study building

There is some difference between apartment layouts. One difference is that some apartments have balconies and other apartments have sunspaces. Therefore, in this case, assume that all apartments have the same plan to facilitate examining the effectiveness of different combinations of retrofit strategies.

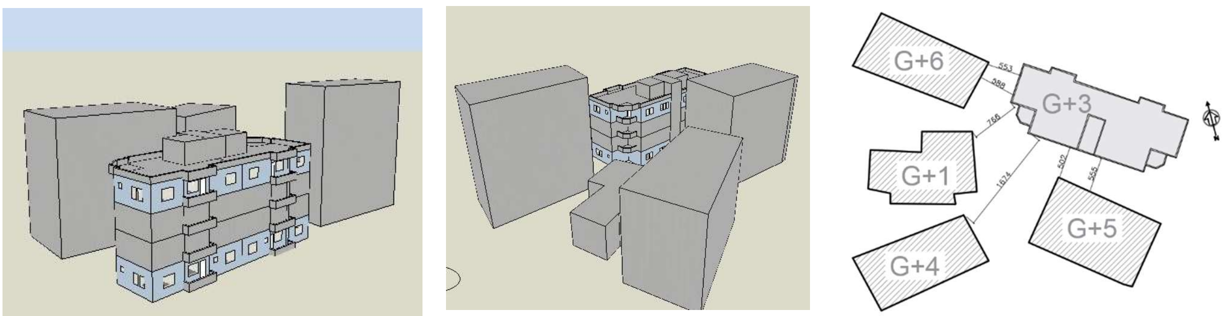


Figure 7.10: Modelled apartment building and its context.

Table 7.2: Basic information about buildings before renovation.

	Basic information about buildings before renovation	
1	Year of construction	1995
Building Layout		
1	Number of stories	4 stories
2	No. of apartment	8 apartments
3	No. of apartment in each floor and layout	Two
4	Structure	• 30cm Wall: 5cm Stone, 15cm Concrete, 3cm air gab, 7cm Hollow block wall, 2cm Plaster. • Slab: 28cm concrete
5	Window	Size: 0.8 * 1.30 0.6* 1.30 1.60 * 1.30
		Type :double glass Dbl Clr 3mm/6mm Air
		WWR: South Façade: 17.7% ~ 21.5% North Façade: 16.0% ~ 36.5% East + West Façade: 16.6%
6	Elevator	No elevator
7	HVAC System	Turned on
8	Light well	Without light well
Building envelope		
1	Thermal insulation	Non-insulation exterior wall
2	Reflection of the material before retrofitting (Design building software defaults)	Wall: 40% Ceiling: 40% Floor: 30%

7.3.2 Reason for choosing the case and residents opinions

The case had been selected due to the following reasons:

This case covered the extended family residential building type 1 mentioned in table 5.3 p.62; the two apartments are grouped around one staircase without an elevator. This building was built in the period between "1993-1999". The extended family residential buildings are the most common style in Hebron city in this period. Also, according to the building code, four floors were allowed to be built without an elevator in this period.

Before the retrofit process, a designer should communicate with the resident to understand the existing building. Involved residents in a retrofit project's decision-making process helped develop existing residential buildings and build a bridge between occupant needs and the proposed retrofit strategies. Therefore, three residents had been selected in this case to answer the questionnaire –see appendix B- to know the general satisfaction with the apartment, daylight level, daylight distribution, direct sunlight, view through windows, physical environment, and personal information.

Generally, no respondents reported that any room was too dark but that the lighting level was better before the surrounding buildings were constructed. Residents were satisfied with the apartment layout, but some users need extra space (another bedroom) to feel more comfortable. The residents will be move to another new apartment with a larger area. Consequently, the residents showed no desire to make any changes to the apartment's layout. In contrast, residents expressed their desire to install an elevator, to improve the living comfort of residents—especially the residents who live on the third and fourth floors.

7.3.3 Simulation of the Selected Apartment Blocks & Discussion

In this part, an assessment of the current daylight performance was conducted using a Design-Builder simulated model with a CIE standard overcast sky on 21st September. After that, compared to whether the lighting requirements were with the average daylight factor code - for adequate natural lighting- to achieve the required lighting level within the rooms. This helped to determine and classify the visual discomfort problems at room-scale, following visual comfort chart 1 in chapter 3 p.45

Due to the difference in flooring, it is essential to investigate daylight performance according to the building floor levels. In this case, the ground floor was considered the worst case, while the third floor was considered the best, which helps to compare the effectiveness of the proposed strategies at different levels. See figure 7.11 & 7.12 for simulation results before the retrofit.

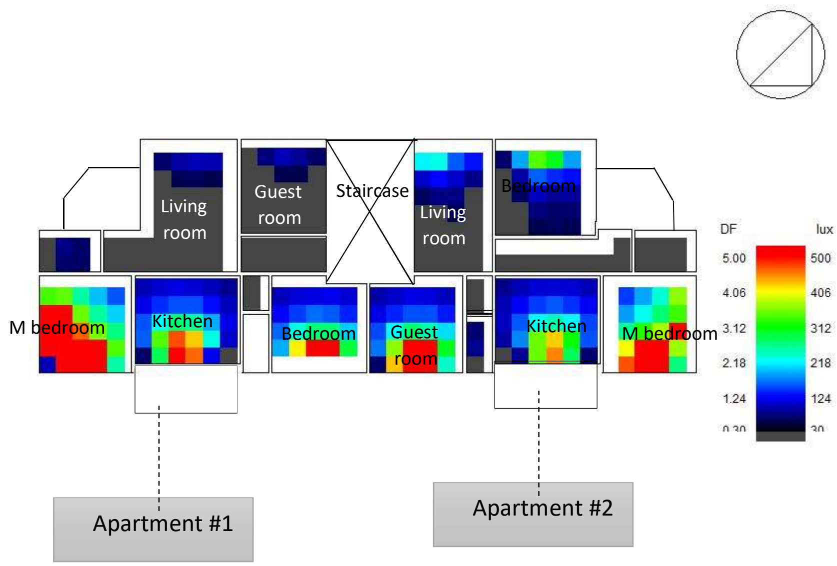


Figure 7.11: The ground-floor plan shows the results of the daylight simulation of the current situation

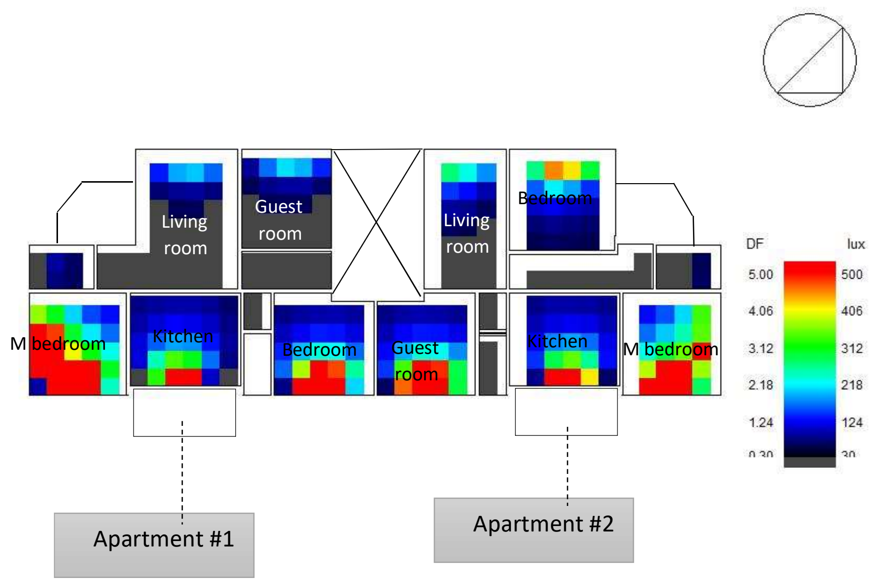


Figure 7.12: The third-floor plan shows the results of the daylight simulation of the current situation

- Master bedroom & Bedroom

The average DF for the master bedroom for apartments before retrofit was investigated and compared with different apartment floors (ground and third). As shown in figure 7.13, the average DF of the master bedrooms in all apartments shows a high level of light and too glary. This can be explained because the master bedroom has windows on two different facades. The windows are on the north and east sides of apartment #1. In contrast, the windows are on the north and west sides of apartment #2. Looking at table 2.1 p.19, no master bedroom meets the required level of average DF (Bedroom AV DF=1%).

Figure 7.14 presents the average DF for the bedroom. As shown, the bedroom in apartment #2 is oriented to the south, while the bedroom in apartment #1 is oriented to the north. The bedroom in apartment #2 (southern) shows a lower light level than the bedroom in apartment #1(northern). This is due to the closeness of adjacent buildings, which may cause shadow effects and minimize the chances of lighting from reaching south facades. While the simulation result shows a high level of illumination in all apartments, exclude apartment #2 on the ground floor, the results show an acceptable average DF that meets the required level of daylight factor (Bedroom AV DF=1%).

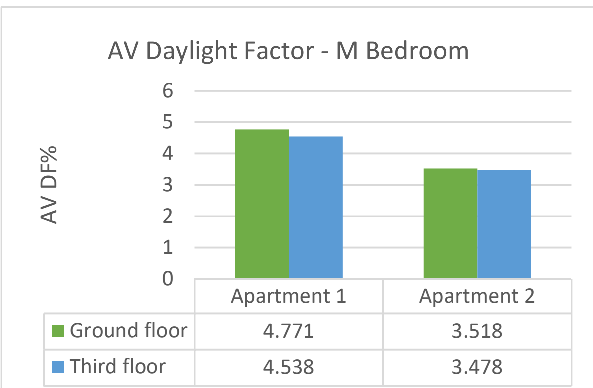


Figure 7.13: A comparison between the averages DF for the master bedroom

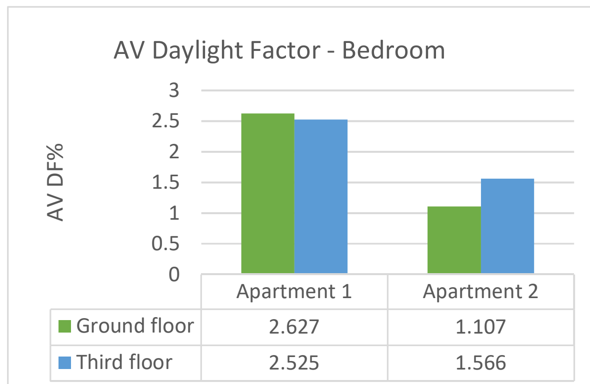


Figure 7.14: A comparison between the averages DF for the bedroom

- Kitchen

The results of the DF simulation for the kitchen are shown in figure 7.15. The kitchen in all apartments is oriented to the northeast with a balcony. The kitchen in apartment #1 on the ground floor meets the required level of daylight factor (Kitchen AV DF = 2%). The kitchen in apartment #2 on the ground floor also shows an acceptable average DF. In contrast, the average DF result shows a low level of light in apartments #1 and #2 on the third floor. This is due to the visible sky angle and obstruction angle for each window.

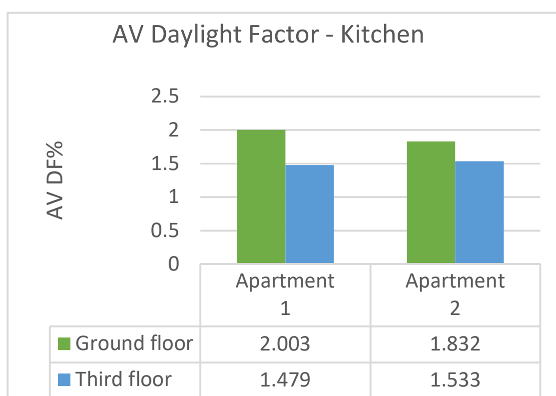


Figure 7.15: A comparison between the averages DF for the kitchen

- Living room & guest room

The average DF for the living room of apartments before retrofitting was investigated. As shown in figure 7.9, the living room in all apartments is oriented to the southwest. The simulation result, as shown in figure 7.16, presents a low level of light. This is due to the closeness of adjacent buildings, which may cause shadow effects and minimize the chances of lighting from reaching south facades. Where the residential buildings surround the case study in two directions - west and south - with different heights, the room depth also affects the natural illumination level. Thus, it is difficult to obtain sufficient daylighting by windows if the room depth exceeds 2.5 times the window height (see page No.20. In this case, daylight illuminance levels drop 4.375 meters away from side windows. Therefore, the living rooms consider a deep plan. Referring to table 2.1, page No.19, there is no living room in all apartments that meets the required level (living room AV DF=1.5%).

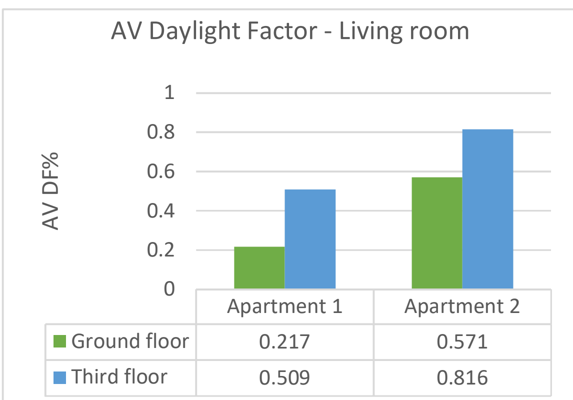


Figure 7.16: A comparison between the averages DF for the living room

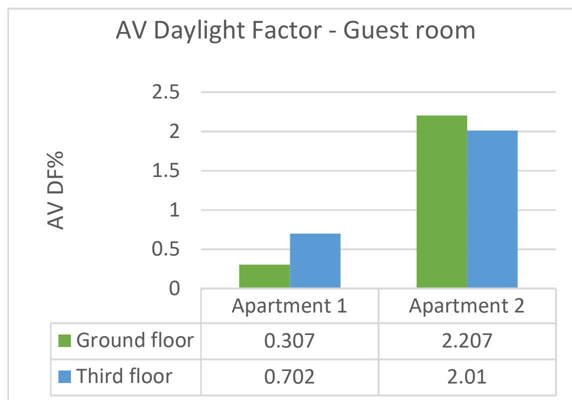


Figure 7.17: A comparison between the averages DF for the guest room

7.3.4 Simulation validity check

Daylight calculations were conducted in the studied areas to compare the results to the design-builder simulation results. The average daylight factor for the studied rooms was calculated by Crisp and Littlefairy using the formula below:

$$\overline{DF} = (\tau W \theta)/(A (1-R^2))$$

$\overline{DF}$= average daylight factor on the working plane.

τ= diffuse light transmittance of the glazing.

W = area of window.

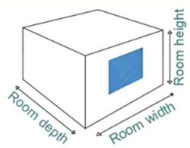
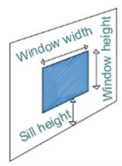
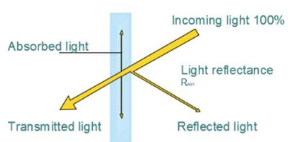
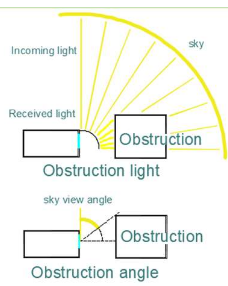
θ = vertical angle subtended at the centre of the window by the visible sky.

A = total area of room surfaces.

R = average reflectance of room surfaces.

This process aimed to check the validity of simulation results when compared with calculations. Table 7.2* shows the results of the daylight calculation and simulation of the same areas. Simulation results, as well as calculation results, are relatively closed with a 0.10% error.

Table 7.2*: Calculation and simulation results of the average daylight for bedroom in apartment #1- 3rd

Case 1/ Bedroom Apart.1 – 3rd floor		
	Room dimensions	
	Room width	3.85 m
	Room depth	4.00 m
	Room height	2.90 m
	Window dimensions	
	Sill height	0.86 m
	Window height	1.30 m
	Window width	1.60 m
	Properties of the window	
	Window light reflectance	0.1
	Window light transmittance	0.812
	Properties of room surface	
	Wall light reflectance	40%
	Ceiling light reflectance	40%
	Floor light reflectance	30%
	Obstruction outside the window	
	Obstruction outside the window	0
	Obstruction height	0
	Obstruction angle	
Average daylight factor - Calculation (1)	2.62%	
Average daylight factor - simulation – designbuilder	2.52%	
Error %	0.10%	

7.3.5 Evaluation of the existing situation

A preliminary analysis phase, if correctly performed, can provide a solid basis for an appropriate intervention plan commensurate with the needs of the occupants. In the beginning, the unverified requirements were detected, which help to fulfill existing laws, such as adding an elevator.

Evaluating the simulation results of the existing situation helps determine and classify the visual discomfort problems at room scale. Then, the main goals are identified for the current problems. In this case, there are two main goals:

1 Goal 1 : Increasing daylight to achieve optimum interior lighting for the kitchen, living room, and guest room in apartments #1 that showed a low average daylight factor

2 Goal 2: Reducing daylight and improving the distribution of daylight for master bedroom, bedroom, and guest room in apartments #2 that showed a high average daylight factor.

As explained above, there is a need to enhance daylight performance in buildings to maintain occupants' comfort and improve buildings' energy efficiency. Improving daylighting performance requires the control of several design variables expected to make a significant change. Therefore, detailed simulation analyses have been performed to investigate the effect of retrofit strategies on existing multi-story residential buildings.

7.3.6 Results and Discussion of Case 1 after retrofitting

The simulations were performed again after applying the retrofit strategies. The results of the different design conditions were compared and analyzed before and after using the retrofit strategies.

At the building scale, unverified requirements are revealed. In this case, a new elevator has been added that helped improve the quality of interior spaces. As shown in figure 7.18

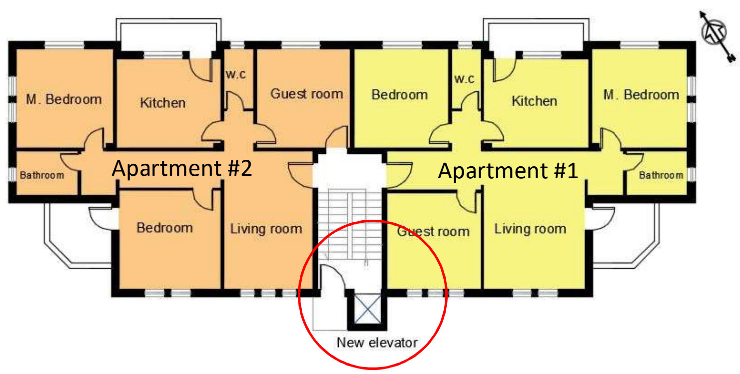


Figure 7.18: Represents the typical plan of the case study building type 1 after adding an elevator.

Simulation results after applying retrofit strategies and following visual comfort chart 1 page No. 45 are presented below:

- Master bedroom & Bedroom

Goal 2: Reducing daylight and improving the distribution of daylight

The bedrooms and master bedrooms in all apartments show a high level of average DF, as shown in figure 7.19 & 7.20

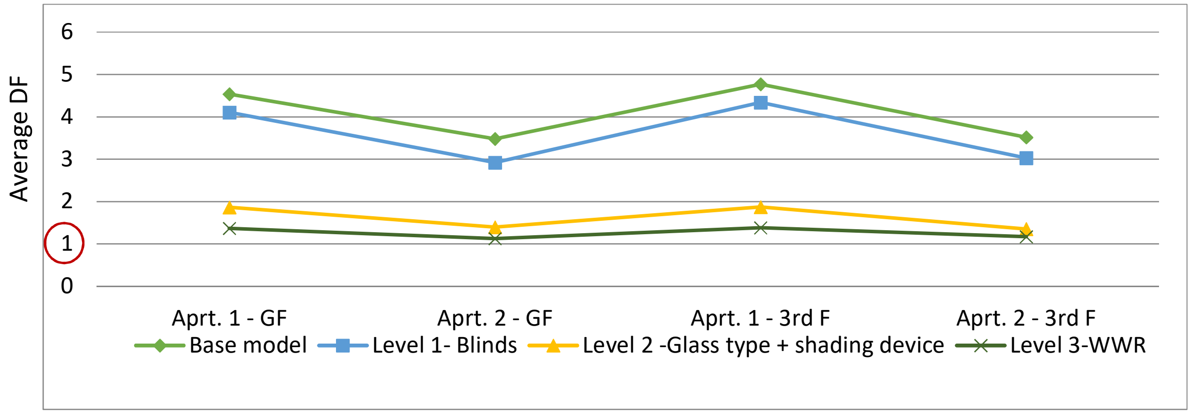


Figure 7.19: Average DF results in the master bedroom after applying retrofit strategies.

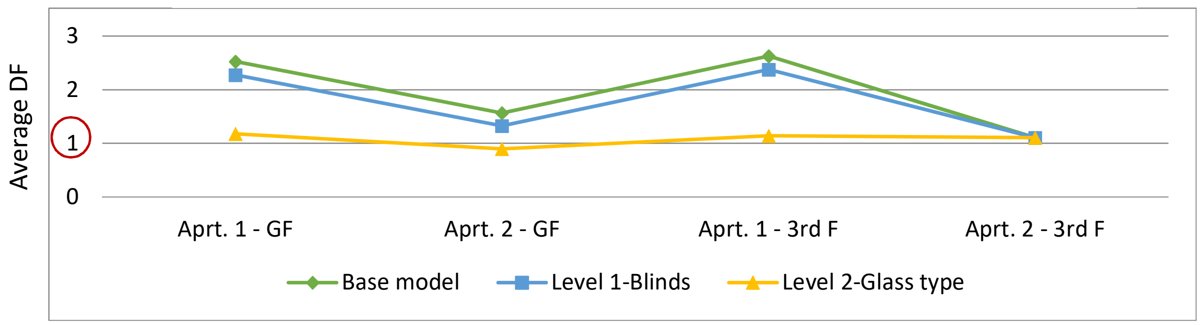


Figure 7.20: Average DF results in the bedroom after applying retrofit strategies.

1. After using blinds (blinds with low or medium reflectivity slats – curtains) that provide daylight free of glare, while allowing a partial view. The average DF was reduced and daylight distribution improved for bedrooms, but still did not meet the required standard. Table 7.3 shows the percentage of daylight enhancement after using blinds
2. The windows have also been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as needed. The illuminance level reduced systematically. As shown in figure 7.20, the average DF meets the required standards in bedrooms. Whereas, in the master bedroom, the average DF results still did not meet the required standard.

3. According to the visual comfort chart - p. 45, the facade retrofit level 2 (adding shading device) has been examined in the master bedroom in all apartments. Shading device has been added to the east and west windows, which used to control intense direct sunlight and control glare to ensure comfortable interior spaces. In this case, assumed the sidefins (SF) projection dimensions are 50cm. Table 7.3 shows the percentage of daylight enhancement after replacing glass type and adding shading device as needed.

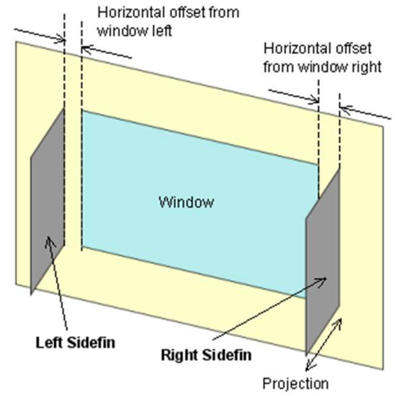


Figure 7.20*: East and west shading device- Source: DesignBuilding

4. The glass area also was modified, which affected the illumination level inside the rooms. As mentioned before the master bedroom has windows on two different facades. When the WWR was reduced in the west and east facade from 16.6% to 8.33% the illuminance level reduced systematically.

Finally as shown in the table 7.3, the average DF results approximately meet the required level (Bedroom AV DF = 1%).

Table 7.3: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement [1]			
		Apartment 1 Ground Floor	Apartment 2 Ground Floor	Apartment 1 Third Floor	Apartment 2 Third Floor
Master Bedroom	Base model	22.0% (DF 4.5%)	28.7 %(DF 3.4%)	20.9 %(DF 4.7%)	28.4 %(DF 3.5%)
	1 Using blinds	24.3 %(DF 4.1%)	34.0 %(DF 2.9%)	23.0 %(DF 4.3%)	33.0 %(DF 3.0%)
	2+3 replacing glass type + adding shading device	53.6 %(DF 1.8%)	71.6 %(DF 1.3%)	53.4 %(DF 1.8%)	85.4 %(DF 1.3%)
	4 Modifying WWR	73.0 % (DF 1.3%)	88.8 %(DF 1.1%)	72.5 %(DF 1.3%)	85.0 %(DF 1.1%)
Bedroom	Base model	39.6 %(DF 2.5%)	63.8 %(DF 1.5%)	38.0 %(DF 2.6%)	90.0 %(DF 1.1%)
	1 Using blinds	44.0 %(DF 2.2%)	75.4 %(DF 1.3%)	42.0 %(DF 2.3%)	
	2+3 replacing glass type + adding shading device	84.8 %(DF 1.1%)	99.9 %(DF 0.9%)	87.6 %(DF 1.1%)	

[1] Percentage of daylight enhancement is compatible with the average daylight factor for different types of rooms in residential buildings (according to the Jordanian code issued in cooperation with the Jordanian Green Building Council) for adequate natural lighting.

- Kitchen

Goal 1: Increasing daylight to achieve optimum internal daylighting.

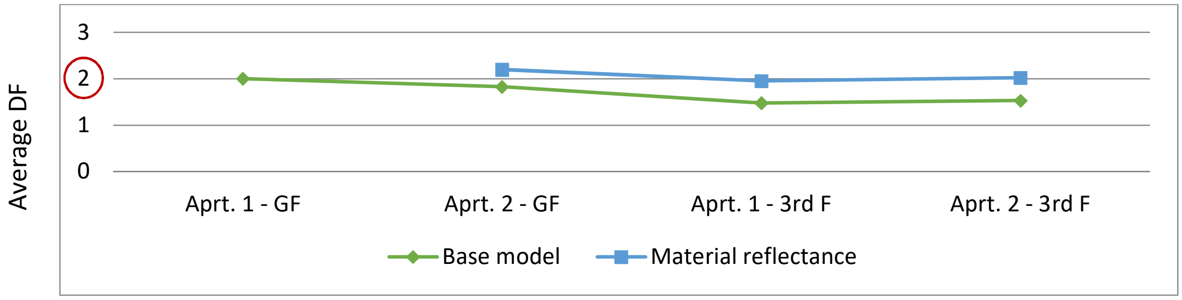


Figure 7.21 Average DF results for the kitchen after applying retrofit strategies.

To achieve an appropriate illuminance level, the material reflectance had been investigated. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, referring to page No.38. Then compared with the original base case before retrofitting.

Generally, the result indicated that the increase in the material reflectance helped improve the daylight environment in simulated space. The level of illuminance increased systematically. As shown in figure 7.21 and table 7.4, the average daylight factor results approximately met the required level (Kitchen AV DF - 2%)

Table 7.4: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**			
		Apartment 1 Ground Floor	Apartment 2 Ground Floor	Apartment 1 Third Floor	Apartment 2 Third Floor
Kitchen	Base model	99.9% (DF 2.0%)	91.6 %(DF 1.8%)	73.9 %(DF 1.4%)	76.6 %(DF 1.5%)
	Changing material reflectance		99.9 %(DF 2.1%)	97.7 %(DF1.9%)	99.9 %(DF 2.0%)

- Living room & Guest room

Living room

Goal 1: Increasing daylight to achieve optimum internal daylighting.

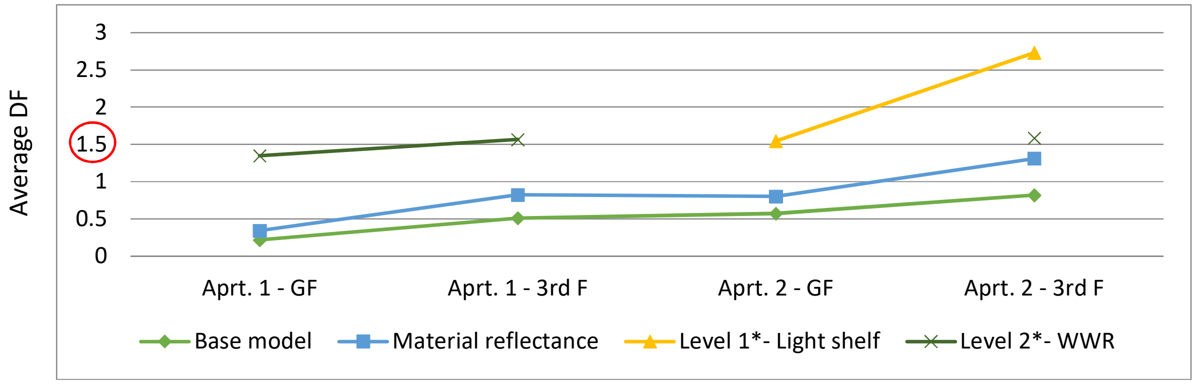


Figure 7.22 -Average DF results in the living room after applying retrofit strategies.

The depth of the room in living rooms affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by side windows if the room depth exceeds 2.5 times the window height. In the living room, daylight illuminance levels drop 4.375 meters away from windows. Visual Comfort chart 1 p.45 was followed to achieve an adequate level of illumination:

1. Material reflectance had been investigated. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, referring to p.38. Then it compared with the original base case before retrofitting. Figure 7.22 and table 7.5 shows how the average daylight factor in the living room was increased after the material reflectance was changed. The illuminance level increased in all apartments systematically but still did not met the required level.
2. The facade retrofit level 1* (adding light shelf) was applied.

   Essentially the main objective behind a light shelf is to reflect light into the building. Thus, when using a reflective light shelf, the daylight zone depth is extended. For the main dimensions of the examined light shelf see figure 3.7 p.37 .

   As shown in figure 7.22 the average DF in the living room in apartments #2 increased after the light shelves were added. In the previous simulation process, the illuminance level increased and met the required DF in apartment #2 on the ground floor. Whereas the living room in apartment #2 on the third floor shows a high level of daylight. The average DF increased in the living room in apartments #1 after adding the lighting shelves, but when compared to adjusting the window-wall ratio (WWR) or adding lighting shelves, the results of adjusting the WWR were closer to the desired target. See point 3 below.

3. The facade retrofit level 2* (Adjusting WWR) was applied in all living rooms except apartment #2 on the ground floor. The window area was increased in apartment #1, while the window area was decreased in apartment #2 on the third floor. Generally, the average daylight factor results in all rooms approximately met the required level (Living room AV DF = 1.5%). Table 7.5 shows the percentage of daylight enhancement after following visual comfort chart p. 45

Table 7.5: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**			
		Apartment 1 Ground Floor	Apartment 2 Ground Floor	Apartment 1 Third Floor	Apartment 2 Third Floor
Living room	Base model	14.4 %(DF 0.2%)	38.0 %(DF 0.5%)	33.9 %(DF 0.5%)	54.4 %(DF 0.8%)
	Changing material reflectance	22.7% (DF 0.3%)	53.5 %(DF 0.8%)	54.7 %(DF 0.8%)	87.4 %(DF 1.3%)
	Adding light shelf		99.9 %(DF 1.5%)		182.20 %(DF 2.7%)
	Adjusting WWR	89.9 %(DF 1.3%)		99.9 %(DF 1.5%)	99.9 %(DF 1.5%)

- Guest room

There are two goals to achieve an appropriate illuminance level in the guest room:

- Goal 1: Increasing daylight to achieve optimum internal daylighting in apartments #1.

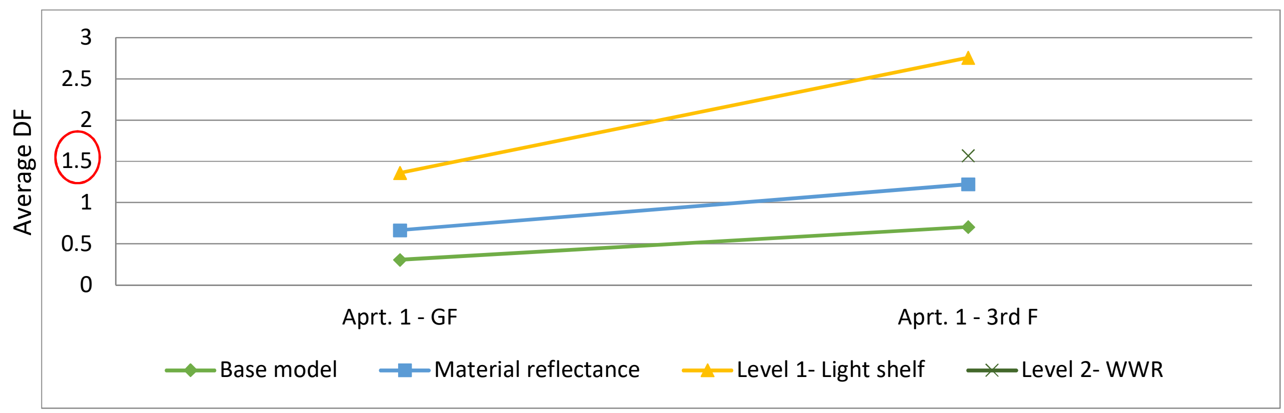


Figure 7.23 Average DF results in the guest room after applying retrofit strategies.

1. Material reflectance had been investigated. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, referring to p.38 then it compared with the original base case before retrofitting. Figure 7.23 and table 7.6 shows how the average daylight factor in the guest room was increased after the material reflectance was changed. The illuminance level increased systematically but still did not met the required level.

2. The facade retrofit level 1* (adding light shelf) was applied to the guest room in apartments #1, which helped to reflect light into the building and extended the daylight zone depth. Figure 7.23 shows how the average DF in the guest room in apartments #1 increased after the light shelves were added (for the main dimensions of the examined light shelf see figure 3.7 p.37). The simulation process showed that the illuminance level increased and met the required DF in apartment #1 on the ground floor. Whereas the guest room in apartment #1 on the third floor shows a high level of daylight. Thus the adjustment of the WWR in apartment #1 on the third floor was applied, see point 3 below.

3. The facade retrofit level 2* (Adjusting WWR) was applied in the guest room in apartment #1 on the third floor. When the WWR was reduced from 33.5% to 20.6% the illuminance level reduced systematically. Generally, the average daylight factor results in all rooms approximately met the required level (guest room AV DF = 1.5%)

Table 7.6: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement	
		Apartment 1 Ground Floor	Apartment 1 Third Floor
Guest room	Base model	20.4 %(DF 0.3%)	%46.8(DF 0.7%)
	Changing material reflectance	44.2 %(DF 0.6%)	81.5 %(DF 1.2%)
	Adding light shelf	90.6 %(DF 1.3%)	183.8 %(DF 2.7%)
	Adjusting WWR		99.9 %(DF 1.5%)

- Goal 2: Reducing daylight and improving the distribution of daylight

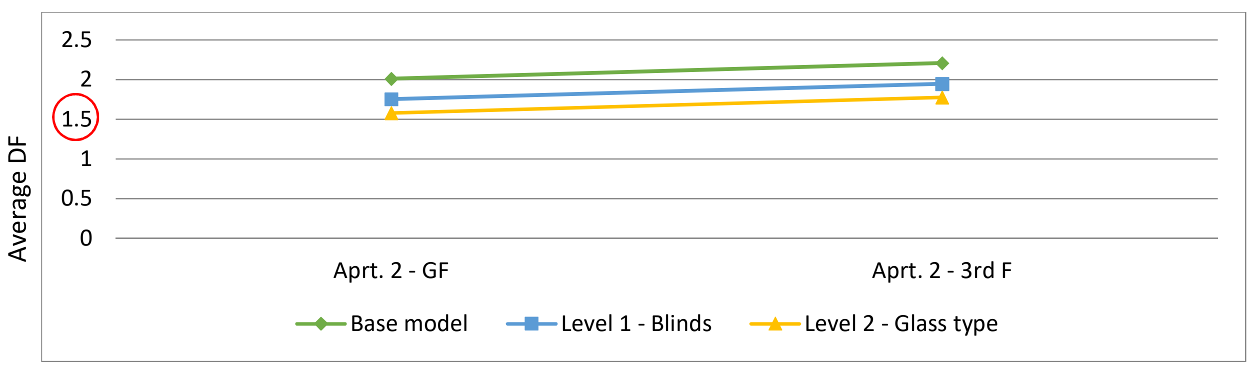


Figure 7.24 Average DF results in the guest room after applying retrofit strategies.

The guest room in apartments #2 shows a high level of average DF, as shown in figure 7.24 .

1. After using blinds (blinds with low or medium reflectivity slats – curtains) that provide daylight free of glare, while allowing a partial view. The average DF reduced and daylight distribution

improved for the guest room. Table 7.7 shows the percentage of daylight enhancement after using blinds

2. The windows have also been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as needed. Looking at figure 7.24, the illuminance level reduced systematically and the average DF results met the required level (Guest room AV DF = 1.5).

Table 7.7: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**		**The percentage of daylight enhancement**	
			Apartment 2 Ground Floor	Apartment 2 Third Floor
Guest room	Base model		74.6 %(DF 2.0%)	%67.9(DF 2.2%)
	1	Using blinds	84.5 %(DF 1.7%)	77.0 %(DF 1.9%)
	2	Replacing glass type	99.9 %(DF 1.5%)	84.7 %(DF 1.7%)

7.3.7 Conclusion

The local residential retrofit framework with proposed retrofit strategies has been tested to find the effect on enhancing the performance of natural daylight in multi-story buildings. The retrofit process and the results of natural daylight enhancements for case study 1 are shown below:

1. The process began with gathering information for the existing building .
2. To diagnostics and identification of discomfort areas:
   a) Firstly, Communication with the resident during the pre-retrofitting process was done to understand the existing building. In case study 1, three residents had been selected to answer the questionnaire to know the general satisfaction with the apartment .
   b) Secondly, simulation programs in the early stages of the pre-retrofit process were used to define the existing building problems, the results were shown in item 7.3.3.
3. Evaluation of the existing situation to determine and classify the visual discomfort problems.
   a) At building scale: The characteristics of the existing building and the unverified requirements were detected, which help to fulfill existing laws.
   b) At room scale: The main goals were identified for the existing problems. In this thesis, there are two main goals as mentioned in the visual comfort chart p.45. Therefore, in this case, goal 1 was increasing daylight to achieve optimum interior lighting for the kitchen, living room, and guest room in apartments #1 that showed a low average daylight factor, and goal 2 was reducing daylight and improving the distribution of daylight for master bedroom, bedroom, and guest room in apartments #2 that showed a high average daylight factor.
4. Identifying passive retrofit strategies and selecting the best retrofit action. In general, the results show that the following proposed passive retrofit strategies of the building creates spaces that meet the requirements of the code, as shown in the table 7.8 below.

Table 7.8: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement[2]			
		Apartment 1 Ground Floor	Apartment 2 Ground Floor	Apartment 1 Third Floor	Apartment 2 Third Floor
Master Bedroom	Base model	22.0% (DF 4.5%)	28.7% (DF 3.4%)	20.9% (DF 4.7%)	28.4% (DF 3.5%)
	After retrofitting	73.0% (DF 1.3%)	88.8% (DF 1.1%)	72.5% (DF 1.3%)	85.4% (DF 1.1%)
Bedroom	Base model	39.6% (DF 2.5%)	63.8% (DF 1.5%)	38.0% (DF 2.6%)	90.0% (DF 1.1%)

[2] Percentage of daylight enhancement is compatible with the average daylight factor for different types of rooms in residential buildings (according to the Jordanian code issued in cooperation with the Jordanian Green Building Council) for adequate natural lighting.

	After retrofitting	84.8% (DF 1.1%)	99.9% (DF 0.9%)	87.6% (DF 1.1%)	
Kitchen	Base model	99.9% (DF 2.0%)	91.6% (DF 1.8%)	73.9% (DF 1.4%)	76.6% (DF 1.5%)
	After retrofitting		99.9% (DF 2.1%)	97.7% (DF 1.9%)	99.9% (DF 2.0%)
Living room	Base model	14.4% (DF 0.2%)	33.9% (DF 0.5%)	38.0% (DF 0.5%)	54.4% (DF 0.8%)
	After retrofitting	89.9% (DF 1.3%)	99.9% (DF 1.5%)	99.9% (DF 1.5%)	99.9% (DF 1.5%)
Guest room	Base model	20.4% (DF 0.3%)	74.6% (DF	46.8% (DF 46.8%)	67.9% (DF 2.2%)
	After retrofitting	90.6% (DF 1.3%)	99.9% (DF 1.5%)	99.9% (DF 1.5%)	84.7% (DF 1.7%)

The outcome results show that the level of natural daylight was enhanced in apartments when implementing the proposed retrofit strategies. The result of enhancement ranges between 85% - 98%. From the experiments of simulating a multi-story residential building (Case 1), this research concluded the following:

(1) Daylight varies according to the floor levels (Ground floor, First floor, etc.) of the building with respect to orientation. The surrounding conditions was also another factor affecting the results, which the surrounding buildings as an obstruction on daylight access.

(2) The depth of rooms in all apartments is less than 4.375 except for the living room (it is considered a deep room). As shown, the depth of the room affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by side windows if the room depth exceeds 2.5 times the window height. In this case, daylight illuminance levels drop 4.375 meters away from side windows. Whereas, after following visual comfort chart 1, the living room met the requirements of the code.

(3) It is always important to consider and include proper external and internal solar shading in order to optimize visual and thermal comfort. Simulations of sunlight penetration with shading devices need to be conducted during the redesign stage to guarantee that occupants are protected from direct sunlight throughout the day. As shown in the master bedroom and bedroom, a vertical shading device has been added to the east and west window.

(4) The light shelf has effective results in improving the quality of the light distribution. At the same time, it is able to provide light penetration deeper into space and provide good shading from the sun. The living room is oriented southwest and is considered a deep room. When used a light shelf, the light level was improved.

(5) The type of glazing and window gives major significance to the performance of natural light and thermal performance of adjacent space. Therefore, the windows have been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as needed.
(6) The size and placement of windows must always be considered together with the building's total energy use and specific daylight requirements. Each window on each floor and orientation should have its own specific design from window to wall ratio. As shown in the guest room in apartment #1 on the third floor, when the WWR was reduced, the illuminance level systematically decreased. Whereas in the living room, the window area in Apartment # 1 has been increased, the lighting levels have been increased.
(7) It is observed that less reflective wall finishes reduced the reflectivity making the space more dull and dark

Few modifications in the existing building can improve considerable indoor daylighting. The results prove that applying the retrofit strategies enhances daylight performance by 85% for apartment #1, and 98% for apartment #2 on the ground floor. While on the third floor, daylight performance enhanced by about 92% for apartment #1 and 93% for apartment #2.

Excess glare and heat should be avoided. This can be achieved by controlling solar radiation using a shading device strategy. Therefore, this thesis concluded that a combination of strategies (such as shading device, light shelf, and blinds) can have an important role in creating a desirable environment based on daylight quality as well as thermal comfort. Furthermore, most people prefer daylight due to contact with the outside world which is provided by windows.

- Deep Plan

The living room is considered a deep plan. This room with a depth of more than 6 m. Thus it is difficult to obtain sufficient daylighting by windows. By applying a retrofit strategy (adding a light shelf), the illuminance level in the living room met the requirements of the code.

7.4 Case Study 2:

7.4.1 General information

Location:

The building is located in the Hebron University neighborhood. It was built in 2002, since the time of construction, no improvement has been made. The building is located in a dense area. Only the front facade is exposed to the road. Residential buildings surround the case study building in three directions: North, East, and West. The distance between the case study building and the neighbors according to building regulation codes see figure 7.25. The long axis of the building to the north-south direction- the longitudinal facade for apartments #1 and #3 to the west and apartments #2 and #4 to the east, see figure 7.26

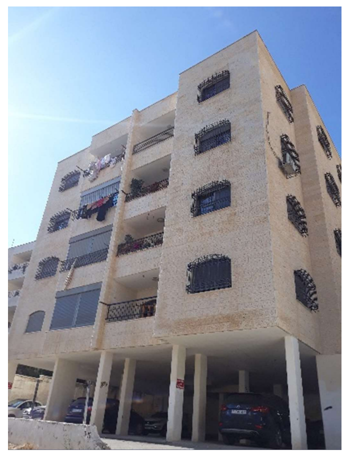


Figure 7.25 the site plan to the left shows the buildings. The red-marked building is our research case. The photo to the right shows the entrance façade- source: researcher

The building has a ground floor and four other floors. The ground floor is used an open parking. As shown in figure 7.26, each floor contains four apartments. The four apartments are grouped around one staircase in the middle leads to different levels. Also, this building has two main light wells; the light well provides daylight and ventilation for the facilities that overlook them. The symmetry plans forms for apartments are commonly used in multi-story residential buildings. In this case, every two apartments are symmetrical with an area of about 110 to 120 m².

The apartment in which area is 120 m² consists of a master bedroom, two bedrooms, a kitchen, bathroom, living room, balcony, and a guest room with a toilet. While, the 110 m² apartment consists of a master bedroom, one bedroom, kitchen, bathroom, a guest room is open to the living room and balcony

In the selected residential building, only the master bedroom has two windows in all apartments. The other rooms have only one window on the external facades, while the guest room has one window open on light well.

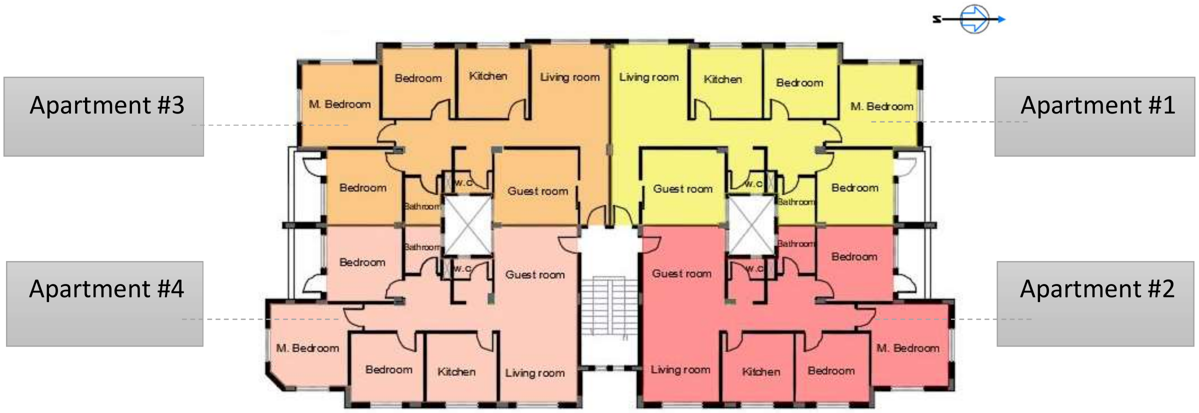


Figure 7.26: Represents the typical plan of the case study building type 3.

There is some difference between apartment layouts. One difference is that some apartments have balconies and other apartments have sunspaces. Other differences are the relocation of the kitchen to replace the bedroom. Therefore, in this case, assume that all apartments have the same plan to facilitate examining the effectiveness of different combinations of retrofit strategies.

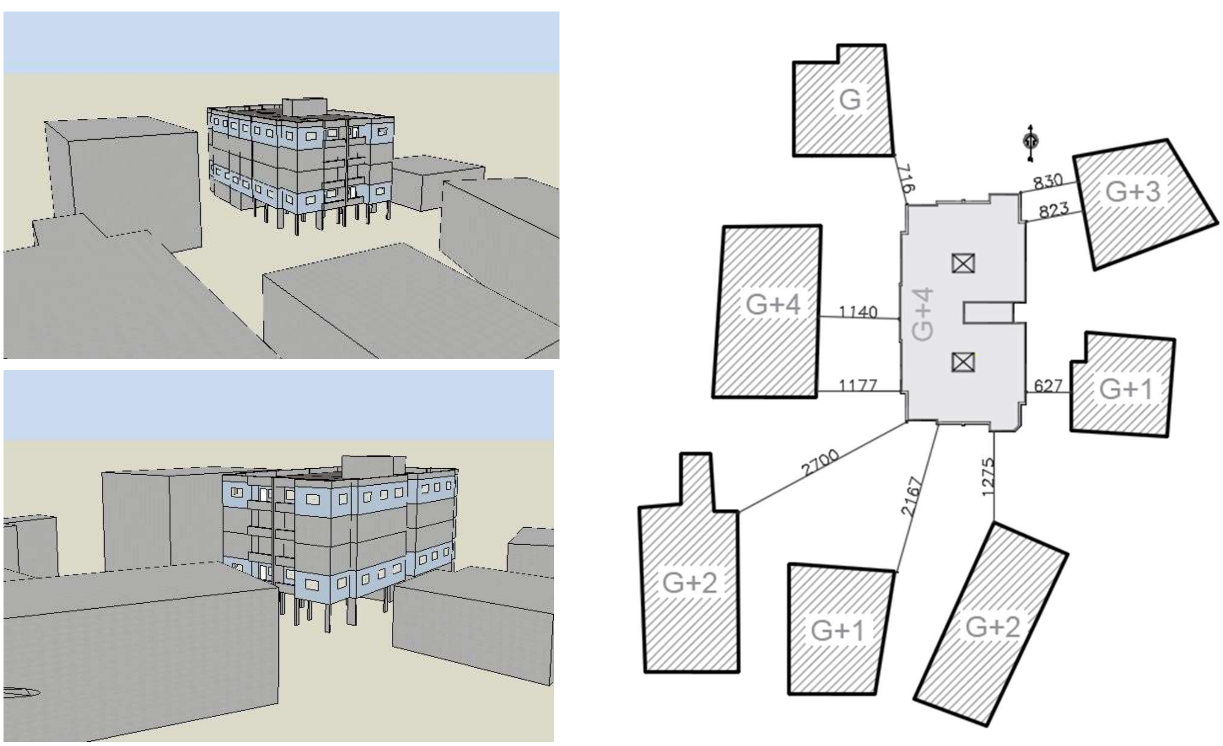


Figure 7.27 Modelled apartment building and its context.

Table 7.9 Basic information about buildings before renovation.

	Basic information about buildings before renovation	
1	Year of construction	2002
Building Layout		
1	Number of stories	5 stories: parking + 4 stories
2	No. of apartment	15 apartments
3	No. of apartment in each floor and layout	Four/Three
4	Structure	• 30cm Wall: 7cm Stone, 11cm concrete, 10cm Hollow block wall, 2cm Plaster. • Slab: 25cm concrete
5	Window	Size: 1.60 * 1.00 2.00* 1.00
		Type: single glass Sgl Clr 6mm
		WWR: South + North Façade: 11.8% East + West Façade: 13.6% Living room – West + East: 17%
6	Elevator	No elevator
7	HVAC System	Turned on
8	Light well	Two main light well Size: 2.9 * 2.30
Building envelope		
1	Thermal insulation	Non-insulation exterior wall
2	Reflection of the material before retrofitting (Design building software defaults)	Wall: 40% Ceiling: 40% Floor: 30%

7.4.2 Reason for choosing the case and residents opinions

The case had been selected due to the following reasons:

- This case covered the investment residential building type 3 as mentioned in table 5.3 p.62, the four apartments are grouped around one staircase without an elevator. Also, this building has two main light wells
- Another reason is that this building was built in the period between "2000-2010" and is located in a dense area. This helps to study the effect of surrounding buildings on the effectiveness of the proposed retrofit solutions to improve daylight. This type is popular in Hebron city. Therefore, environmental retrofit solutions for this kind of residences have great potential for multiplication. This building also built without an elevator.

Before the retrofit process, the designer should communicate with the resident to understand the existing building. Involved residents in a retrofit project's decision-making process helped develop existing residential buildings and build a bridge between occupant needs and the proposed retrofit strategies.

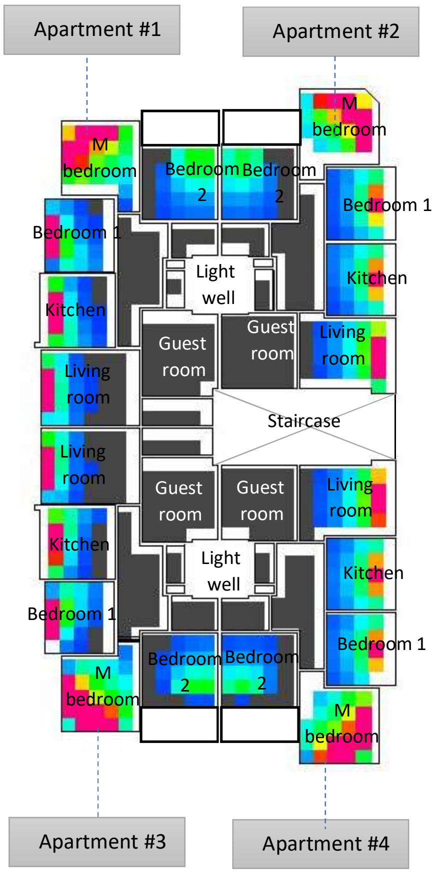
Therefore, four residents had been selected in this case to answer the questionnaire to know the general satisfaction with the apartment, daylight level, daylight distribution, direct sunlight, view through windows, physical environment, and personal information. The personal information collected about the respondents shows that most of the residents have jobs during the day and return home at 4:00 PM. Generally, respondents who lived on the first and second floors reported that the guest room was partially dark. Other residents reported that the illuminance level was better before the surrounding buildings were constructed. Residents were satisfied with the apartment layout; some users in apartments #3 and #4 need to combine the living room and guest room in an open plan design to bring natural lighting to the guest room.

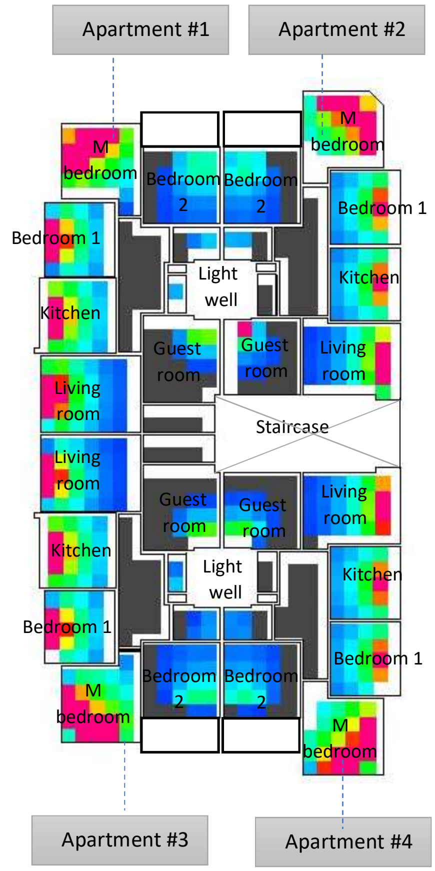
The residents expressed that the modification process should have a minimum inconvenience for all residents and prefer to remain in their apartment during construction work. Other residents have expressed a desire to install an elevator to improve the living comfort of residents—especially the residents of the third and fourth floors

7.4.3 Simulation of the Selected Apartment Block & Discussion

In this part, an assessment of the current daylight performance was conducted using a Design-Builder simulated model with a CIE standard overcast sky on 21st September. After that, compared to whether the lighting requirements were with average daylight factor code - for adequate natural lighting-achieved the required lighting level within the rooms. This helped determine and classify the visual discomfort problems at room-scale, following visual comfort chart 1 in chapter 3, page 45.

Due to the difference in flooring, it is essential to investigate daylight performance according to the building floor levels. In this case, the first floor was considered the worst case, while the fourth floor was considered the best, which helps to compare the effectiveness of the proposed strategies at different levels. See figure 7.28 & 7.29 for simulation results before the retrofit.





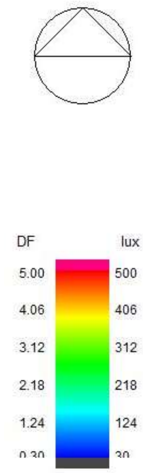


Figure 7.28 The first-floor plan shows the results of the daylight simulation of the current situation

Figure 7.29 The fourth-floor plan shows the results of the daylight simulation of the current situation

- Master Bedroom

The average DF of the master bedroom for apartments before the retrofitting was investigated and compared with different apartment floors (first and fourth floor). As shown in figure 7.30, the average DF of the master bedrooms in all apartments shows a high level of light and too glary. This can be explained may because the master bedroom has windows on two different facades. The windows on the north and west sides of apartment #1.While the windows are on the north and east sides of apartment # 2. In apartment #3 the windows on the south and west sides, in apartment # 4 the windows on the south and east sides. All apartments on the 4th floor show higher daylight factors than the 1st-floor apartments. Referring to table 2.1 p.19, there is no master bedroom that meets the required level of average daylight factor (Bedroom AV DF=1%)

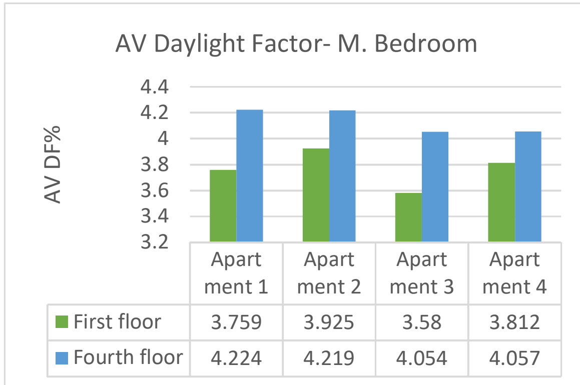


Figure 7.30- A comparison between the averages DF for the master bedroom

- Bedroom 1 & Bedroom 2

As shown in figure 7.31, the average DF in bedrooms 1 in all apartments shows a high level of light and too glary. Whereas, figure 7.32 shows a low level of the average DF in bedrooms 2 in all apartments. This is due to the closeness of adjacent buildings, which may cause shadow effects, as well as minimizing the chances of lighting from reaching building facades. As mentioned before, the building is located in a dense area, and the residential buildings surround the case study building in three directions with different heights. This explains the difference in the level of DF between the western and eastern apartments. Bedroom 2 also has a balcony facing south in apartments #1 and #2, while the balcony facing the north in apartments #3 and #4. Which also explain the low level of the DF.

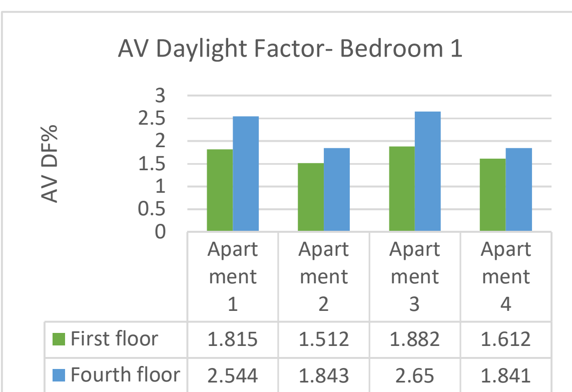


Figure 7.31 A comparison between the averages DF for the Bedroom 1

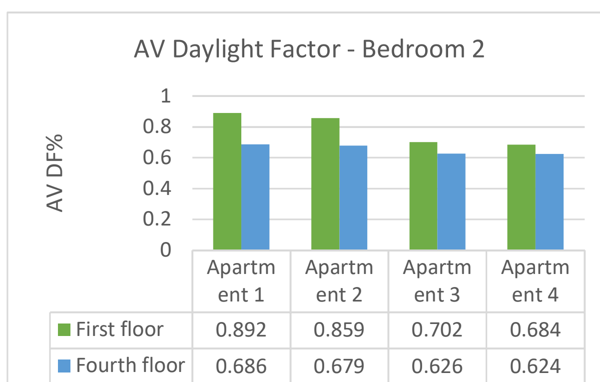


Figure 7.32 A comparison between the averages DF for the Bedroom 2

- Kitchen

The results of the DF simulation for the kitchen are presented in Figure 7.33, the average DF in all apartments on the 1st floor shows a low level of daylight. While the results show an acceptable average daylight factor in apartments #2 and #4 on the 4th floor. The results also show a high level of light in apartments #1 and #3 on the 4th floor. Referring to table 2.1 p.19, there is no kitchen in all apartments that meets the required level (Kitchen AV DF=2%)

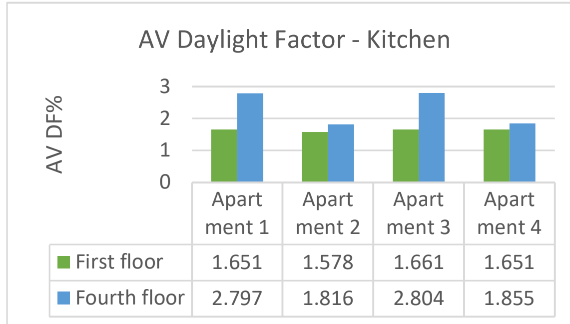


Figure 7.33 A comparison between the averages DF for the kitchen

- Living room & Guest room

The average DF for the living room of apartments before retrofitting was investigated. As shown in figure 7.34. The average daylight factors for the living room at apartments #1 and #3 on the 1st-floor show a low level of daylight. While apartments #1 and #3 on the 4th floor show a high level of daylight. The guest room in apartments #1 and #3 is separated from the living room with one window open on the light well. The guest room in apartments #1 and #3 on the 4th floor obtained higher daylight factors than the 1st floor, but still did not meet the required level as shown in figure 7.35 .

The open design of the living room and guest room were used in apartments #2 and #4. The room depth affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by side windows if the room depth exceeds 2.5 times the window height (see p.20. In this case, daylight illuminance levels drop 5 meters away from side windows. Therefore, the living rooms and guest rooms in apartments #2 and #4 consider a deep plan.

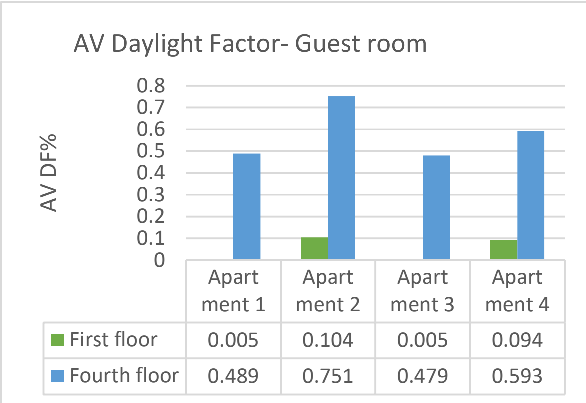


Figure 7.35 A comparison between the averages DF for the guest room

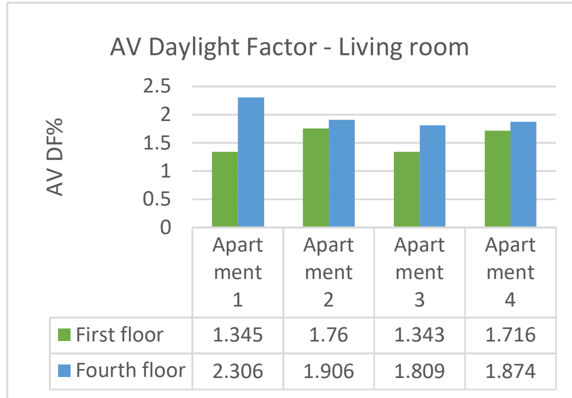


Figure 7.34 A comparison between the averages DF for the living room

7.4.4 Simulation validity check

Daylight calculations were conducted in the studied areas to compare the results to the design-builder simulation results. The average daylight factor for the studied rooms was calculated by Crisp and Littlefairy using the formula below:

$$\overline{DF} = (\tau W \theta)/(A (1-R^2))$$

$\overline{DF}$= average daylight factor on the working plane.

τ= diffuse light transmittance of the glazing.

W = area of window.

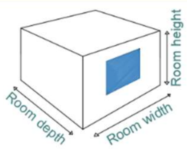
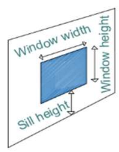
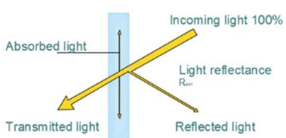
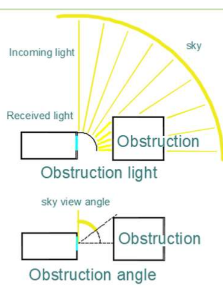
θ = vertical angle subtended at the centre of the window by the visible sky.

A = total area of room surfaces.

R = average reflectance of room surfaces.

This process aimed to check the validity of simulation results when compared with calculations. Table 7.9* shows the results of the daylight calculation and simulation of the same areas. The simulation results, as well as calculation results, are relatively closed with a 0.11% error for bedroom aprt.2 and a 0.03% error for bedroom apart.1 on 4th floor.

Table 7.9*: Calculation and simulation results of the average daylight for bedroom in apartment #1 & 3- 4th floor

	Descriptions	**Case 2 / Bedroom Apart.2– 4th floor**	**Case 2/ Bedroom Apart.1 – 4th floor**
	Room dimensions		
	Room width	3.60 m	3.60 m
	Room depth	3.40 m	3.40 m
	Room height	2.82 m	2.82 m
	Window dimensions		
	Sill height	1.00 m	1.00 m
	Window height	1.00 m	1.00 m
	Window width	1.60 m	1.60 m
	Properties of the window		
	Window light reflectance	0.1	0.1
	Window light transmittance	0.812	0.812
	Properties of room surface		
	Wall light reflectance	40%	40%
	Ceiling light reflectance	40%	40%
	Floor light reflectance	30%	30%
	Obstruction outside the window		
	Obstruction outside the window	0	11.26 m
	Obstruction height	0	15.75 m
	Obstruction angle		
Average daylight factor - using the formula (1)		1.96%	2.57%
Average daylight factor - simulation – design builder		1.843%	2.54%
Error %		0.117%	0.03%

7.4.5 Evaluation of the existing situation

A preliminary analysis phase, if properly performed, can provide a solid basis for an appropriate intervention plan, commensurate with the needs of the occupants. In the beginning, the unverified requirements were detected which help to fulfill existing laws, such as adding an elevator. According to the Jordanian code, WWR should not be less than 15% in living areas, and 10% in the service areas. Thus, the existing WWR in this case meets the requirements .

The evaluation of the simulation results of the existing situation helps to determine and classify the visual discomfort problems at room-scale. Then, the main goals are identified for the existing problems. In this case, there are two main goals:

1 Goal 1: Increasing daylight to achieve optimum interior lighting for bedroom 2, kitchen, guest room, and living room in apartment #1 and #3 on the first floor that showed a low average daylight factor

2 Goal 2: Reducing daylight and improving the distribution of daylight for master bedroom, bedroom 1, living room, and kitchen in apartments #1 and #3 on the fourth floor that showed a high average daylight factor .

As explained above, there is a need to enhance daylight performance in buildings to maintain occupants' comfort and improve buildings' energy efficiency. Improving daylighting performance requires the control of several design variables expected to make a significant change. Therefore, detailed simulation analyses have been performed to investigate the effect of retrofit strategies on existing multi-story residential buildings.

7.4.6 Results of Case 2 after retrofitting

The simulations were performed again after applying the retrofit strategies. The results of the different design conditions were compared and analyzed before and after using the retrofit strategies. At the building scale, unverified requirements are revealed. In this case, a new elevator has been added to improve the quality of interior spaces. As shown in figure 7.36

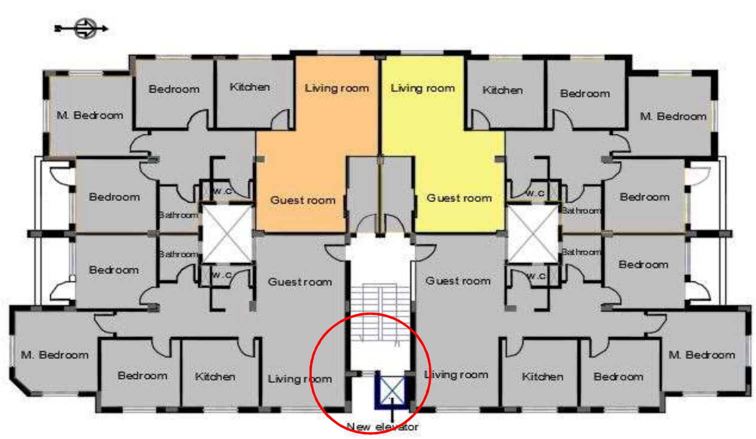


Figure 7.36 represents the typical plan of the case study building type 3 after adding an elevator.

Simulation results after applying retrofit strategies and following visual comfort chart 1 page No. 45 are presented below:

- Master bedroom

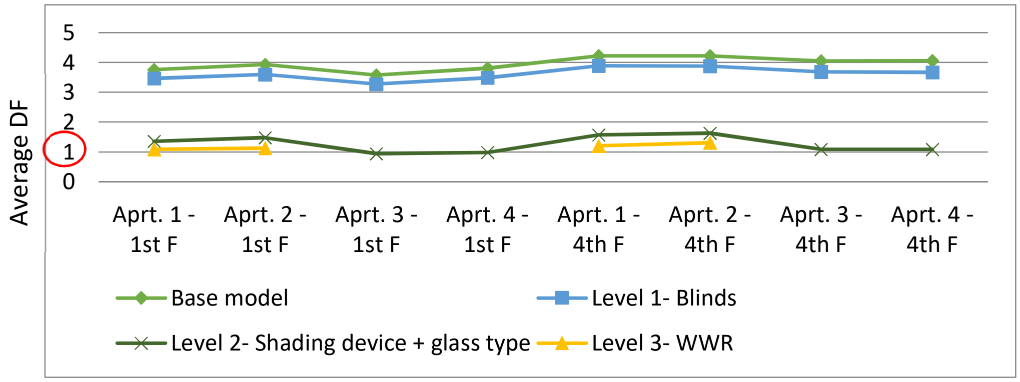


Figure 7.37 Average DF results in the master bedroom after applying retrofit strategies.

Goal 2: Reducing daylight and improving the distribution of daylight

The master bedrooms in all apartments show a high level of average DF, as shown in figure 7.37 .

1. After using blinds (blinds with low or medium reflectivity slats – curtains) that provide daylight free of glare, while allowing a partial view. The average DF was reduced and daylight distribution improved for the master bedroom, but still did not meet the required standard. Table 7.10 shows the percentage of daylight enhancement after using blinds
2. The windows have also been replaced with double glazed windows (with 13mm spacer), Low-E layer clear as required .
3. According to the visual comfort chart 1 p.45, the facade retrofit level 2 (adding shading device) has been examined for the master bedroom in all apartments. A shading device has been added to the east, west, and south windows, which used to control intense direct sunlight and used to control glare to ensure comfortable interior spaces. In this case, assumed the sidefins (SF) projection dimensions are 50cm for east and west windows. The overhang projection dimensions are 50cm for south windows. As shown in figure 7.37 the average DF met the required standard for master bedrooms for apartments #3 and #4. Whereas, in the master bedrooms for apartments #1 and #2 DF results still higher than the required standard. Table 7.10 shows the percentage of daylight enhancement after replacing glass type and adding shading device as needed.

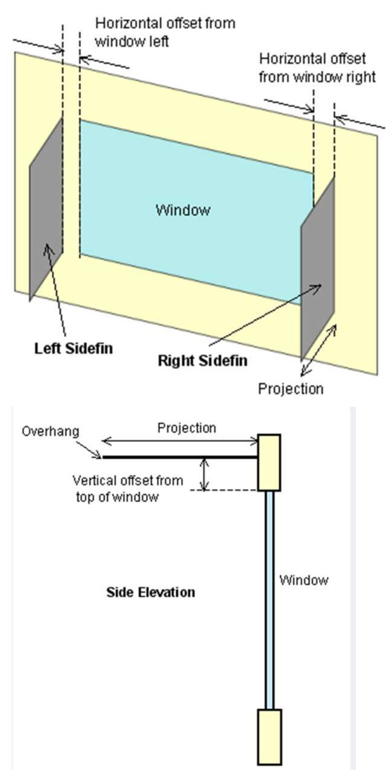


Figure 7.37* The photo on the top represent east and west shading device, the photo on the bottom represent south shading device

4. The glass area was modified for apartments #1 and #2, which affected the illumination level inside the rooms. As mentioned before the master bedroom has windows on two different facades. When the WWR was reduced in the west and east facade from 14.0% to 11.4% and reduced WWR in the south and north facade from 13.0% to 10.0% the illuminance level reduced systematically .

Finally as shown in the table 7.10, the average DF results approximately meet the required level (Master Bedroom AV DF = 1%).

Table 7.10: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement[3]							
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 1 4th F	Apartment 2 4th F	Apartment 3 4th F	Apartment 4 4th F
Master Bedroom	Base model	26.6% (DF 3.7%)	25.4% (DF 3.9%)	27.9% (DF 3.5%)	26.2% (DF 3.8%)	23.6% (DF 4.2%)	23.7% (DF 4.2%)	24.6% (DF 4.0%)	24.6% (DF 4.0%)
	1 Using blinds	28.8% (DF3.4%)	27.7% (DF 3.5%)	30.5% (DF 3.2%)	28.7% (DF 3.4%)	25.7% (DF 3.8%)	25.7% (DF 3.8%)	27.0% (DF 3.6%)	27.2% (DF 3.6%)
	2+3 replacing glass type + adding shading device	73.3% (DF 1.3%)	67.6% (DF 1.4%)	99.9% (DF 1.0%)	99.9% (DF 1.0%)	63.8% (DF 1.5%)	61.2% (DF 1.6%)	99.9% (DF 1.0%)	99.9% (DF 1.0%)
	4 Modifying WWR	91.9% (DF1.1%)	88.9% (DF 1.1%)			82.7% (DF 1.2%)	76.6% (DF 1.3%)		

- Bedroom 1

Goal 2: Reducing daylight and improving the distribution of daylight.

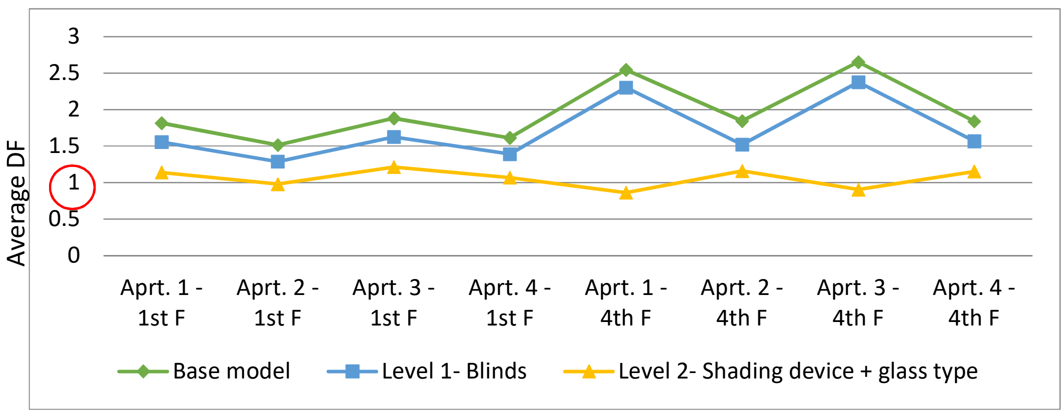


Figure 7.38 Average DF results for the bedroom 1 after applying retrofit strategies.

Bedrooms 1 in all apartments show a high level of average DF, as shown in figure 7.38.

[3] Percentage of daylight enhancement is compatible with the average daylight factor for different types of rooms in residential buildings (according to the Jordanian code issued in cooperation with the Jordanian Green Building Council) for adequate natural lighting

1. After using blinds (blinds with low or medium reflectivity slats – curtains) that provide daylight free of glare, while allowing a partial view. The average DF reduced and daylight distribution improved for Bedroom 1, but still did not meet the required standard. Table 7.11 shows the percentage of daylight enhancement after using blinds
2. The windows have also been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as required. The illuminance level reduced systematically, but it still did not meet the level required for the bedroom .
3. Therefore, the facade retrofit level 2 (adding a shading device) has been examined in the bedroom. A shading device has been added to the east and west windows apartments, which used to control intense direct sunlight and used to control glare to ensure comfortable interior spaces. In this case, assumed the side fins (SF) projection dimensions are 50cm for east and west windows. As shown in figure 7.38, the average DF results approximately met the required level (bedroom AV DF = 1%).

Table 7.11: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**							
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 1 4th F	Apartment 2 4th F	Apartment 3 4th F	Apartment 4 4th F
Bedroom 1	Base model	55.0% (DF 1.8%)	66.1% (DF 1.5%)	53.1% (DF 1.8%)	62.0% (DF 1.6%)	39.3% (DF 2.5%)	54.2% (DF 1.8%)	37.7% (DF 2.6%)	54.3% (DF 1.8%)
	1 Using blinds	64.2% (DF 1.5%)	77.7% (DF 1.2%)	61.5% (DF 1.6%)	71.8% (DF 1.3%)	43.4% (DF 2.3%)	65.6% (DF 1.5%)	42.1% (DF 2.3%)	63.8% (DF 1.5%)
	2+3 replacing glass type + adding shading device	87.8% (DF 1.1%)	102.0% (DF 0.9%)	82.4% (DF 1.2%)	93.7% (DF 1.1%)	116.1% (DF 0.8%)	86.3% (DF 1.1%)	110.8% (DF 0.9%)	86.8% (DF 1.1%)

- Bedroom 2

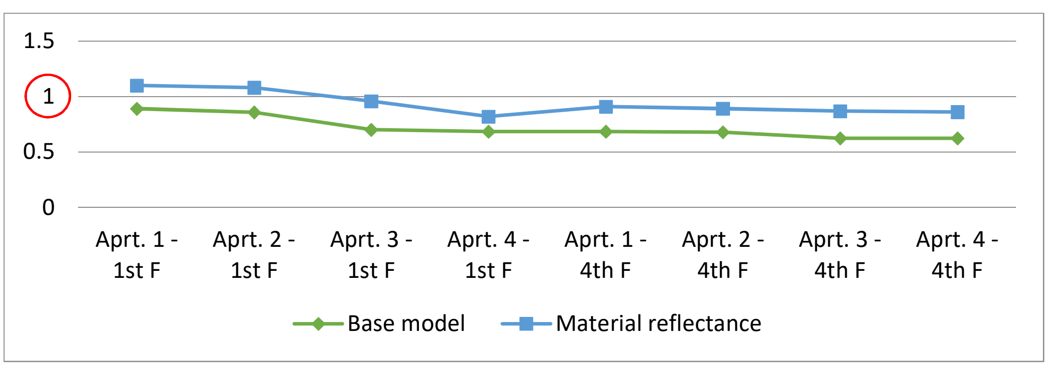


Figure 7.39 Average DF results for the bedroom 2 after applying retrofit strategies.

Goal 1: Increasing daylight to achieve optimum internal daylighting.

1. Material reflectance had been investigated. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, referring to p.38. Then it compared with the original base case before retrofitting. Figure 7.39 and table 7.12 shows how the average daylight factor in bedroom 2 was increased after the material reflectance was changed. Generally, the average daylight factor results in all rooms approximately met the required level (Bedroom AV DF = 1%)

Table 7.12: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**							
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 1 4th F	Apartment 2 4th F	Apartment 3 4th F	Apartment 4 4th F
Bedroom 2	Base model	89.2% (DF 0.8%)	85.9% (DF 0.85%)	70.2% (DF 0.70%)	68.4% (DF 0.68%)	68.6% (DF 0.68%)	67.9% (DF 0.67%)	62.6% (DF 0.62%)	62.4% (DF 0.62%)
	Changing material reflectance	110% (DF 1.1%)	108.1% (DF 1.08%)	96.0% (DF 0.96%)	82.0% (DF 0.82%)	91.0% (DF 0.91%)	89.0% (DF 0.89%)	87.0% (DF 0.87%)	86.0% (DF 0.86%)

- Kitchen

There are two goals to achieve an appropriate illuminance level in the kitchen:

- Goal 1: Increasing daylight to achieve optimum internal daylighting.

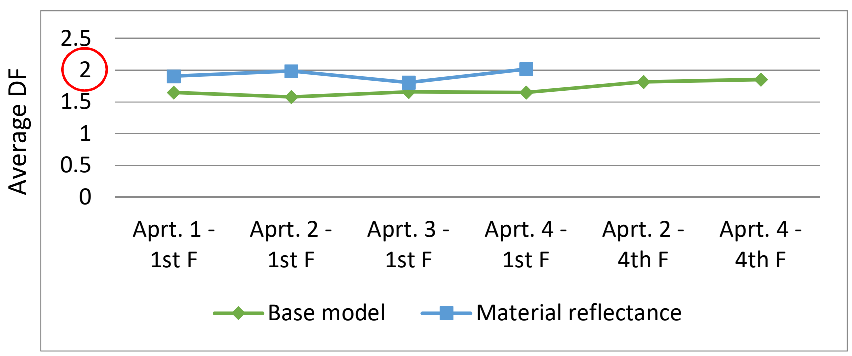


Figure 7.40 Average DF results in the kitchen after applying retrofit strategies.

1. Material reflectance had been investigated. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, see p.38. Figure 7.40 shows how the average DF in the kitchen was increased after the material reflectance was changed. Generally, the average DF results approximately met the required level (Kitchen AV DF = 2%).

Table 7.13: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement					
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 2 4th F	Apartment 4 4th F
Kitchen	Base model	82.5% (DF 1.65%)	78.9% (DF 1.57%)	83.0% (DF 1.66%)	82.5% (DF 1.65%)	90.8% (DF 1.81%)	92.7% (DF 1.85%)
	Changing material reflectance	95.2% (DF 1.90%)	99.2% (DF 1.98%)	90.2% (DF 1.80%)	101.0% (DF 2.02%)		

- Goal 2: Reducing daylight and improving the distribution of daylight

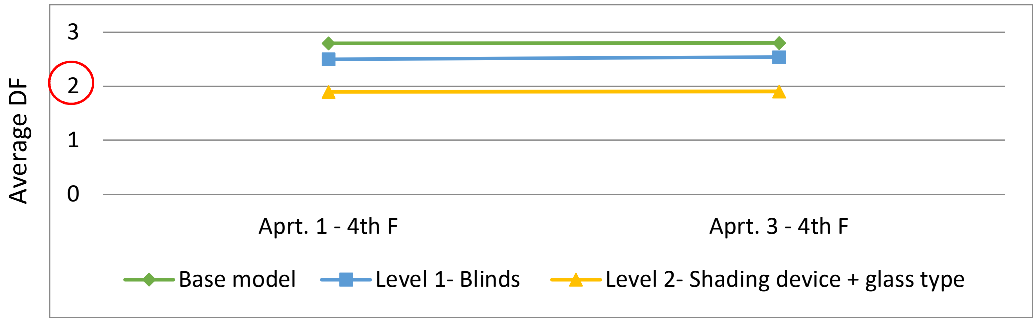


Figure 7.41 Average DF results in the kitchen after applying retrofit strategies.

The kitchen in apartments #1 and #3 on the 4th floor shows a high level of average DF, see figure 7.41.

1. After using blinds (blinds with low or medium reflectivity slats – curtains) that provide daylight free of glare, while allowing a partial view. The average DF reduced and daylight distribution improved for the kitchen, but still did not meet the required standard. Table 7.14 shows the percentage of daylight enhancement after using blinds.
2. The windows have also been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as required.
3. The facade retrofit level 2 (adding a shading device) has been examined in the kitchen. A shading device has been added to the west windows apartments, which used to control intense direct sunlight and used to control glare to ensure comfortable interior spaces. In this case, assumed the side fins (SF) projection dimensions are 50cm. As shown in figure 7.41, the average DF results approximately met the required level (kitchen AV DF = 2%)

Table 7.14: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement	
		Apartment 1 4th F	Apartment 3 4th F
Kitchen	Before retrofitting	71.5% (DF 2.79%)	71.3% (DF 2.80%)
	1 Using blinds	79.9% (DF 2.50%)	78.7% (DF 2.53%)
	2+3 replacing glass type + adding shading device	105.2% (DF 1.90%)	105.0% (DF 1.90%)

Living room and guest room

- Living room and guest room results of enhancements for Apartments # 2 & # 4

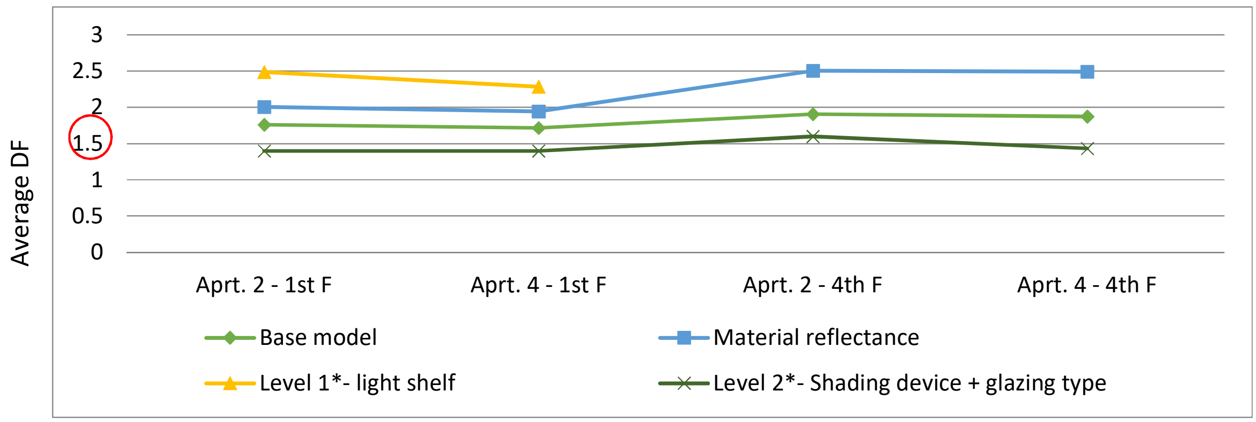


Figure 7.42 Average DF results in the living room after applying retrofit strategies.

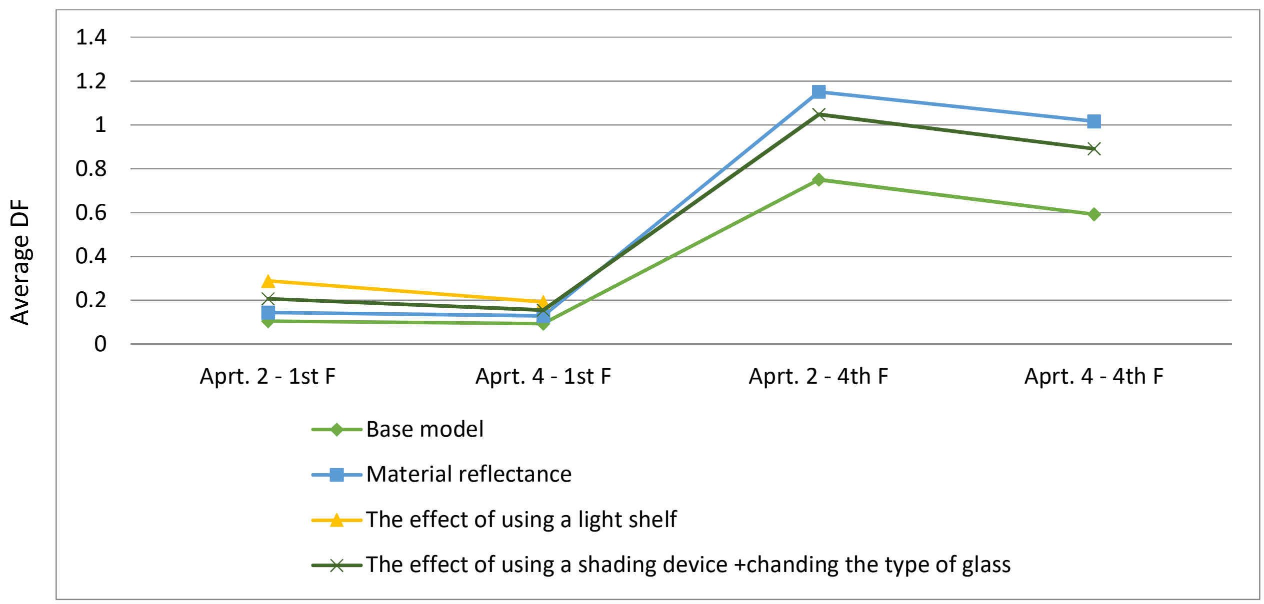


Figure 7.43 Average DF results in the guest room after applying retrofit strategies.

At apartments #2 and #4, there is an open design of the living room and guest room. The room depth affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by windows if the room depth exceeds 2.5 times the window height (see p.20. In this case, daylight illuminance levels drop 5 meters away from side windows. In deep-plan rooms, the room will be darker at the back. As shown in figures 7.42 & 7.43, the average DF simulation results show a low daylight level in the guest room. Thus to achieve a suitable illuminance level in a deep zone.

1. The material reflectance was examined. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, see p.38. Then compared with the original base case before retrofitting. In general, the average DF for the guest room was increased but still did not meet the required level. While the living room showed a higher level of daylight average compared to the base case.
2. According to visual comfort chart 1 the facade retrofit level 1* (adding a light shelf) was applied in the living room windows in apartment #2 and #4 on the 1st floor to achieve optimal daylight in the guest room. For the main dimensions of the examined light shelf see figure 3.7 p. 37 . This modification affected the illumination level in the guest room and daylight distribution increased a little, but the living room showed another high average DF.
3. The facade retrofit level 2* (adding a shading device) has been examined to achieve low direct light gains in the living room. A shading device has been added to the east windows, which used to control intense direct sunlight and used to control glare to ensure comfortable interior spaces. In this case, assumed the side fins (SF) projection dimensions are 50cm for east. As shown in figure 7.42, the average DF in the living room met the required level (Living room AV DF=1.5%). But the average DF for the guest room still did not meet the required level .

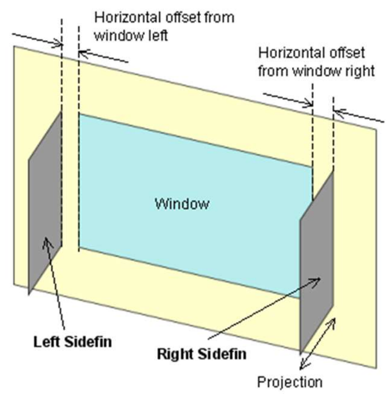


Figure 7.43*: East and west shading device- Source: DesignBuilder

As shown the change in the guest room in apartments #2 and #4 on the 1st floor is almost negligible. Therefore, it is preferable not to add a light shelf on the east side.

Table 7.15: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement			
		Apartment 2 1st F	Apartment 4 1st F	Apartment 2 4th F	Apartment 4 4th F
Living room	Base model	85.2% (DF 1.76%)	87.4% (DF 1.71%)	78.6% (DF 1.90%)	80.0% (DF 1.87%)
	Changing material reflectance	74.7% (DF 2.00%)	77.1% (DF 1.94%)	59.9% (DF 2.50%)	60.1% (DF 2.49%)
	Adding light shelf	60.2% (DF 2.48%)	65.7% (DF 2.28%)		
	Adding shading device	107.0% (DF 1.4%)	107.0% (DF 1.4%)	93.9% (DF 1.59%)	104.8% (DF 1.43%)
Guest room	Base model	6.9% (DF 0.10%)	6.2% (DF 0.09%)	50.0% (DF 0.75%)	39.5% (DF 0.59%)
	Changing material reflectance	9.6% (DF 0.14%)	8.6% (DF 0.12%)	76.7% (DF 1.15%)	67.8% (DF 1.01%)
	The effect of using light shelf	19.2% (DF 0.28%)	12.8% (DF 0.19%)		
	The effect of using shading device	13.8% (DF 0.20%)	10.3% (DF 0.15%)	69.8% (DF 1.04%)	59.4% (DF 0.89%)

- Living room and guest room results of enhancements for Apartments # 1 & # 3

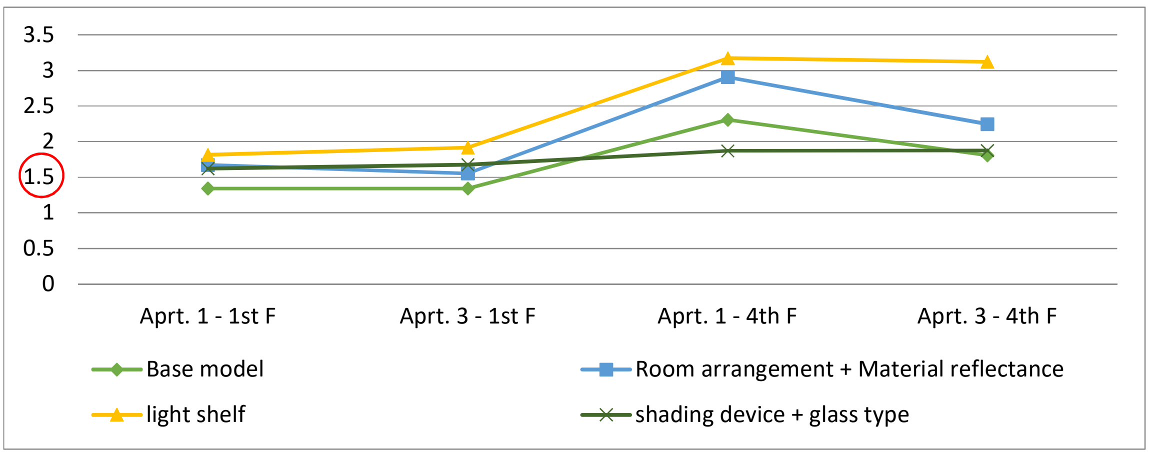


Figure 7.44 Average DF results in the living room after applying retrofit strategies.

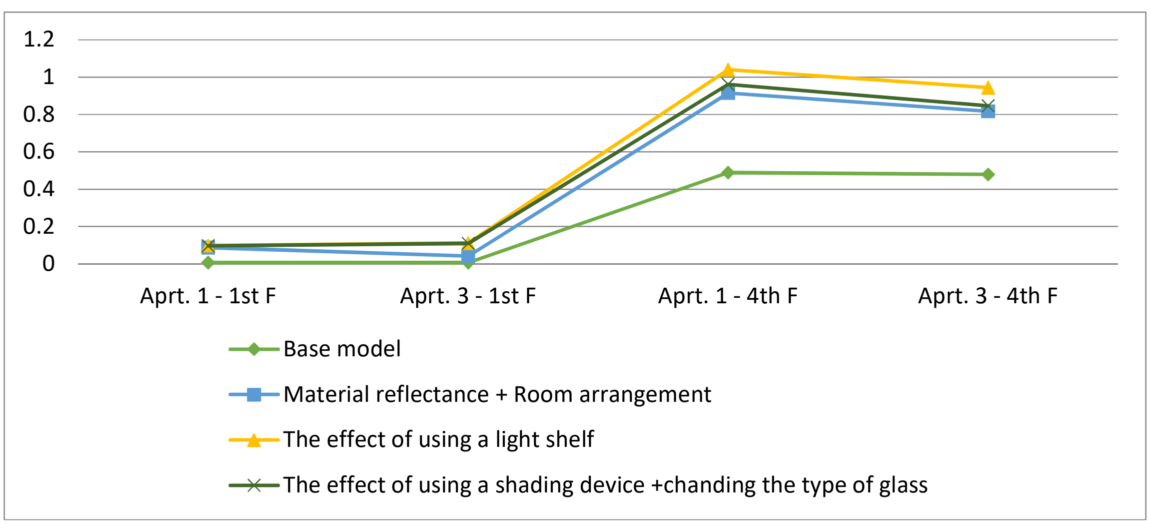


Figure 7.45 Average DF results in the guest room after applying retrofit strategies.

The guest room at apartments #1 and #3 are separated from the living room with one window open on the light well. In the retrofitting phase of the interior spaces, the interior layout was verified in terms of usability and flexibility to optimize the quality of internal spaces and distribution. The modifications on the floor plan were done. One of the significant modifications is to remove the block wall between the guest room and living room, then added a movable partition for privacy. Figure 7.36 shows the alternative internal distribution proposal that was evaluated.

The results of the average DF simulation show a low level of daylight. After the modification at apartments #1 and #3, there is an open design of the living room and guest room. In deep-plan rooms, the room will be darker at the back and cannot be naturally illuminated by side windows. As shown in Figures 7.44 & 7.45, the average DF simulation results show a low level of daylight in the guest room. Thus to achieve a suitable illuminance level in a deep zone:

1. The material reflectance was examined. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling. Then compared with the original base case before retrofitting. In general, the average DF for the guest room was increased but still did not meet the required level. While the living room showed a higher level of daylight average compared to the base case.
2. According to visual comfort chart 1, the facade retrofit level 1* (adding a light shelf) was applied in the living room windows to achieve optimal daylight again in the guest room. For the main dimensions of the examined light shelf see figure 3.7 p.37. This modification affected the illumination level in the guest room and daylight distribution increased a little, but the living room showed another high average DF.
3. The facade retrofit level 2 (adding a shading device) has been examined to achieve low direct light gains in the living room. A shading device has been added to the west windows. As shown in figure 7.44, the average DF in the living room approximately met the required level (Living room AV DF=1.5%). But the average DF for the guest room still did not meet the required level.

As shown the change in the guest room in apartments #1 and #3 on the 1st floor is almost negligible. Therefore, it is preferable not to add a light shelf on the west side

Table 7.16: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement			
		Apartment 1 1st F	Apartment 3 1st F	Apartment 1 4th F	Apartment 3 4th F
Living room	Base model	89.6% (DF 1.34%)	89.5% (DF 1.34%)	153.7% (DF 2.30%)	120.6% (DF 1.80%)
	Changing material reflectance + room arrangement	103.7% (DF 1.67%)	103.7% (DF 1.55%)	193.6% (DF 2.90%)	149.9% (DF 2.24%)
	Adding light shelf	121.2% (DF 1.81%)	127.8% (DF 1.91%)	211.6% (DF 3.17%)	208.1% (DF 3.12%)
	Adding shading device	108.1% (DF 1.62%)	111.8% (DF 1.67%)	124.8% (DF 1.87%)	125.0% (DF 1.87%)
Guest room	Base model	0.33% (DF 0.005%)	0.33% (DF 0.005%)	32.6% (DF 0.48%)	47.9% (DF 0.47%)
	Changing material reflectance+ room arrangement	5.8% (DF 0.087%)	2.73% (DF 0.041%)	61.0% (DF 0.91%)	54.5% (DF 0.81%)
	The effect of using light shelf	6.46% (DF 0.097%)	7.40% (DF 0.11%)	69.3% (DF 1.04%)	62.8% (DF 0.94%)
	The effect of using shading device	6.40% (DF 0.096%)	7.26% (DF 0.10%)	64.0% (DF 0.96%)	56.4% (DF 0.84%)

7.4.7 Conclusion

The local residential retrofit framework with proposed retrofit strategies have been tested to find the effect on enhancing the performance of natural daylight in multi-story buildings. The retrofit process and the results of natural daylight enhancements for case study 2 are shown below:

1. The process began with gathering information for the existing building .
2. To diagnostics and identification of discomfort areas:
    a) Firstly, Communication with the resident during the pre-retrofitting process was done to understand the existing building. In case study 2, four residents had been selected to answer the questionnaire to know the general satisfaction with the apartment .
    b) Secondly, simulation programs in the early stages of the pre-retrofit process were used to define the existing building problems, the results were shown in item 7.4.3
3. Evaluation of the existing situation to determine and classify the visual discomfort problems.
    a) At building scale: The characteristics of the existing building and the unverified requirements were detected, which help to fulfill existing laws. Therefore a new elevator was added to fulfill existing laws and resident requirements .
    b) At room scale: The main goals were identified for the existing problems. In this thesis, there are two main goals as mentioned in the visual comfort chart p.45. Therefore, in this case, goal 1 was increasing daylight to achieve optimum interior lighting for bedroom 2, kitchen, guest room, and living room in apartment #1 and #3 on the first floor that showed a low average daylight factor, and goal 2 was reducing daylight and improving the distribution of daylight for master bedroom, bedroom 1, living room,

and kitchen in apartments #1 and #3 on the fourth floor that showed a high average daylight factor.

4. Identifying passive retrofit strategies and selecting the best retrofit action. In general, the results show that the following proposed passive retrofit strategies of the building creates spaces that meet the requirements of the code, as shown in the table 7.17 below.

Table 7.17: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement[4]**							
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 1 4th F	Apartment 2 4th F	Apartment 3 4th F	Apartment 4 4th F
Master Bedroom	Base model	26.6% (DF 3.7%)	25.4% (DF 3.9%)	27.9% (DF 3.5%)	26.2% (DF 3.8%)	23.6% (DF 4.2%)	23.7% (DF 4.2%)	24.6% (DF 4.0%)	24.6% (DF 4.0%)
	After retrofitting	91.9% (DF 1.1%)	88.9% (DF 1.1%)	99.9% (DF 1.1%)	99.9% (DF 1.0%)	82.7% (DF 1.2%)	76.6% (DF 1.3%)	99.9% (DF 1.0%)	99.9% (DF 1.0%)
Bedroom 1	Base model	55.0% (DF 1.8%)	66.1% (DF 1.8%)	53.1% (DF 1.8%)	62.0% (DF 1.6%)	39.3% (DF 2.5%)	54.2% (DF 1.8%)	37.7% (DF 2.6%)	54.3% (DF 1.8%)
	After retrofitting	87.8% (DF 1.1%)	102.0% (DF 0.9%)	82.4% (DF 1.2%)	93.7% (DF 1.1%)	116.1% (DF 0.8%)	86.3% (DF 1.1%)	110.8% (DF 0.9%)	86.8% (DF 1.1%)
Bedroom 2	Base model	89.2% (DF 0.8%)	85.9% (DF 0.85%)	70.2% (DF 0.70%)	68.4% (DF 0.68%)	68.6% (DF 0.68%)	67.9% (DF 0.67%)	62.6% (DF 0.62%)	62.4% (DF 0.62%)
	After retrofitting	110% (DF 1.1%)	108.1% (DF 1.08%)	96.0% (DF 0.96%)	82.0% (DF 0.91%)	91.0% (DF 0.91%)	89.0% (DF 0.89%)	87.0% (DF 0.87%)	86.0% (DF 0.86%)
Kitchen	Base model	82.5% (DF 1.65%)	78.9% (DF 1.57%)	83.0% (DF 1.66%)	82.5% (DF 1.65%)	71.5% (DF 2.79%)	90.8% (DF 1.85%)	71.3% (DF 2.80%)	92.7% (DF 1.85%)
	After retrofitting	95.2% (DF 1.90%)	99.2% (DF 1.98%)	90.2% (DF 1.8%)	101.0% (DF 2.02%)	105.2% (DF 1.90%)		105.0% (DF 1.90%)	
Living room	Base model	89.6% (DF 1.34%)	85.2% (DF 1.76%)	89.5% (DF 1.34%)	87.4% (DF 1.71%)	153.7% (DF 2.30%)	78.6% (DF 1.90%)	120.6% (DF 1.80%)	80.0% (DF 1.87%)
	After retrofitting	108.1% (DF 1.62%)	107.0% (DF 1.4%)	111.8% (DF 1.67%)	107.0% (DF 1.4%)	124.8% (DF 1.87%)	93.9% (DF 1.59%)	125.0% (DF 1.87%)	104.8% (DF 1.43%)
Guest room	Base model	0.33% (DF 0.005%)	6.9% (DF 0.10%)	0.33% (DF 0.005%)	6.2% (DF 0.09%)	32.6% (DF 0.48%)	50.0% (DF 0.75%)	47.9% (DF 0.47%)	39.5% (DF 0.59%)
	After retrofitting	6.40% (DF 0.096%)	13.8% (DF 0.20%)	7.26% (DF 0.10%)	10.3% (DF 0.15%)	64.0% (DF 0.96%)	69.8% (DF 1.04%)	56.4% (DF 0.84%)	59.4% (DF 0.89%)

The outcome results show that the level of natural daylight was enhanced in apartments when implementing the proposed retrofit strategies. The result of enhancement ranges between 80.0% - 98.0%.

From the experiments of simulating a multi-story residential building (Case 2), this research concluded the following:

[4] Percentage of daylight enhancement is compatible with the average daylight factor for different types of rooms in residential buildings (according to the Jordanian code issued in cooperation with the Jordanian Green Building Council) for adequate natural lighting.

(1) Daylight varies according to the floor levels (Ground floor, First floor, etc.) of the building concerning orientation. In case 2, the fourth-floor apartments showed a higher level of light than the first-floor apartments. The variation of orientation and floor heights also showed a significant difference, especially on the east and west apartment rooms for the same floor height. This was caused by the conditions of the site with the surrounding buildings, where the surrounding buildings formed an obstruction on access daylight.

(2) The stage of spatial retrofit of the interior spaces was complex and depended on the needs of the residents and the architect's vision to solve the problems of discomfort.

(3) The depth of rooms in all apartments less than 5 except for the living room and guest rooms in apartments #2 and #4 (it is considered as a deep room). As shown, the depth of the room affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by side windows if the room depth exceeds 2.5 times the window height. In this case, daylight illuminance levels drop 5 meters away from side windows. There are rooms with great depth with windows opened on light well by applying the retrofitting strategies - optimizing the living spaces and creating new common areas- the quality of use of the apartments was improved. But in the rooms with a great depth of more than 6m did not meet the Code requirements

(4) A balcony and geometry are one of the most affecting parameters on the daylight conditions of the adjacent space. The balcony reduces the daylight in the adjacent space. Therefore, it is always essential to take into account all affecting aspects to have a well-performed space.

(5) It is always essential to consider and include proper external and internal solar shading to optimize visual and thermal comfort. Simulations of sunlight penetration with shading devices need to be conducted during the redesign stage to guarantee that occupants are protected from direct sunlight throughout the day. As shown in the master bedroom, bedroom 1, Kitchen in apartments #1& #3 on the fourth floor, and living room, a vertical shading device has been added to the east and west window. In contrast, a horizontal shading device has been added to the south.

(6) The light shelf has effective results in improving the quality of the light distribution. At the same time, it can provide light penetration deeper into space and provide good shading from the sun. As shown, the light shelves performed best when installed in southern facades. But when installed on the western or eastern facade, the performance is almost negligible.

(7) The type of glazing and window gives major significance to the performance of natural light and the thermal performance of adjacent space. Therefore, the windows have been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as needed.

(8) Each window on each floor and orientation should have its particular design from window to wall ratio. The size and placement of windows must always be considered together with the building's total energy use and specific daylight requirements. As shown in the master bedroom, when the WWR was reduced, the illuminance level systematically decreased.

(9) It is observed that less reflective wall finishes reduced the reflectivity making the space more dull and dark.

Few modifications in the existing building can improve considerable indoor daylighting. The results prove that applying the retrofit strategies enhances daylight performance by 85% for apartment #1, 87% for apartment #2, 80% for apartment #3, and 82% for apartment #4 on the first floor. While on the fourth floor, daylight performance enhanced by about 97% for apartment #1, 83% for apartment #2, 97% for apartment #3 and 87% for apartment #4.

Excess glare and heat should be avoided. This can be achieved by controlling solar radiation using a shading device strategy. Therefore, this thesis concluded that combining strategies (such as shading devices, light shelves, and blinds) could have an essential role in creating a desirable environment based on daylight quality and thermal comfort. Furthermore, most people prefer daylight due to contact with the outside world, provided by windows.

- Deep Plan

The living room and guest room with a depth of more than 6m (deep plan) make it difficult to obtain sufficient daylighting by windows. By applying retrofit strategies (adding a light shelf) and open spaces, the illuminance level in the guest room on first-floor apartments was enhanced but still did not meet the requirements of the code. In contrast, the guest rooms on fourth-floor apartments meet the requirements of the code. Although this room also with a depth of more than 6 m. This due to the light-wells, which gives a better daylighting performance in connected rooms to light-wells. Consequently, it might not be very feasible to rely only on passive strategies.

7.5. Case Study 3:

7.5.1. General information

Location:

The building is located in a residential district, Wadi Abu Kteelah Street. It was built in 2004, since the time of construction, no improvement has been made. The long axis of the building to the north-south direction- the longitudinal facade for apartments 3 and 4 to the east and apartments 1 and 2 to the west. See figure 7.46

Figure 7.46 The site plan to the left shows the buildings. The red-marked building is our research case. The photo to the right shows the entrance façade- source: researcher

The case study building consists of seven floors with 28 apartments. As shown in figure 7.47 each floor contains four apartments; every two flats are grouped around one staircase lead to different levels. There is one light well in the middle of the building. The light well provides daylight and ventilation for the facilities that overlook them. The symmetry plans forms for apartments are commonly used in multi-story residential buildings. In this case, every two apartments are symmetrical with an area of about 100 to 120 m².

The apartment in which area is 120 m² consists of a master bedroom, two bedrooms, a kitchen, bathroom, living room, dining room, balcony, and a guest room with a toilet. While, the 100 m2 apartment consists of a master bedroom, one bedroom, kitchen, bathroom, a living room is open to the dining room, a balcony, and a guest room with a toilet.

In the selected residential building, only the master bedroom has two windows in all apartments. The other rooms have only one window on the external facades, while the guest room in apartments #1 and #3 has one window open on light well. The living room in all apartments does not have windows.

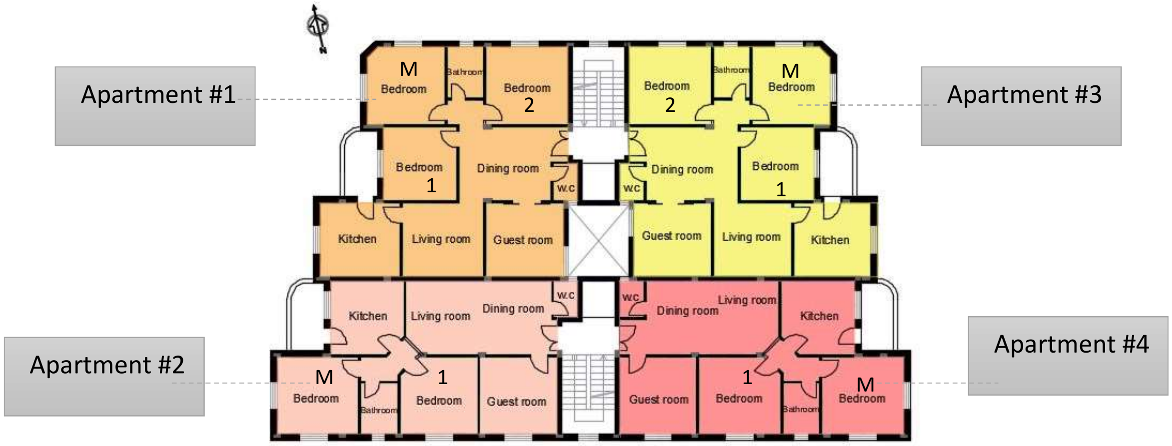
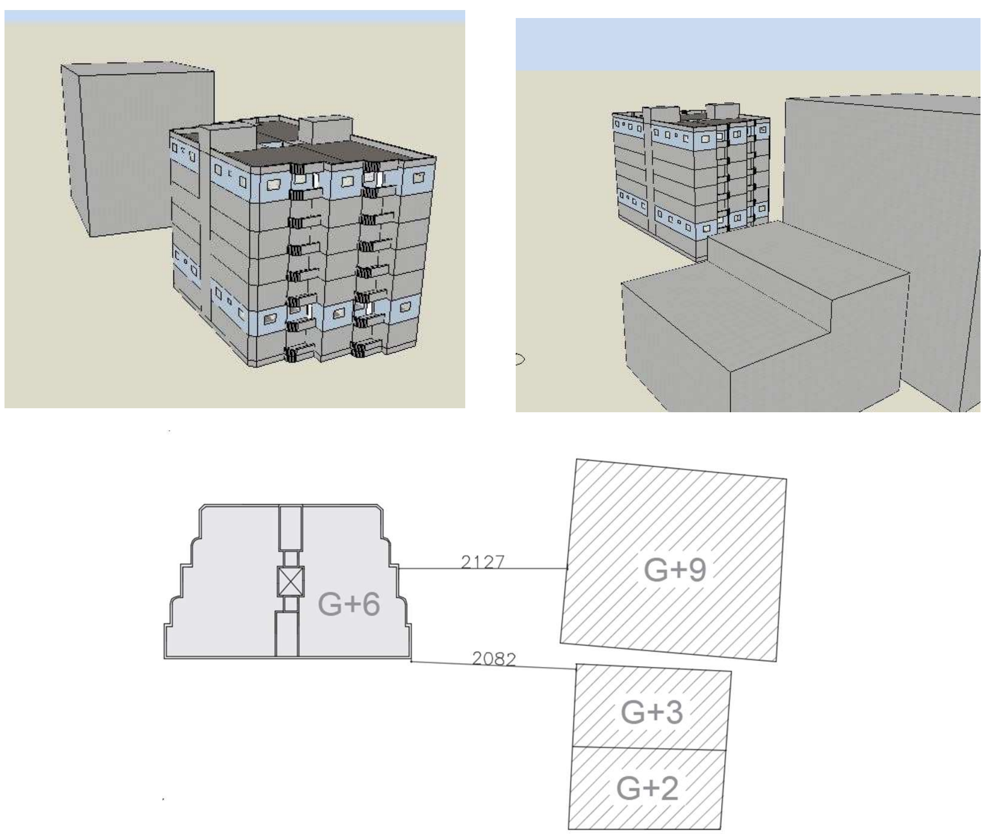


Figure 7.47-Represents the typical plan of the case study building type 4.

There is some difference between apartments layout. One difference is that some apartments have balconies and other apartments have sunspaces. In apartments #2 and #4, the guest room became a bedroom for kids. Therefore, in this case, assume that all apartments have the same plan to facilitate examining the effectiveness of different combinations of retrofit strategies.



-

Figure 7.48 Modelled apartment building and its context.

Table 7.18 Basic information about buildings before renovation.

	Basic information about buildings before renovation	
1	Year of construction	2004
Layout		
1	Number of stories	Seven stories
2	No. of apartment	28 apartments
3	No. of apartment in each floor and layout	four
4	Structure	• Wall: 5 Stone, 15concrete, 10hollow block wall, 2cm Plaster. • Ceiling: 25cm concrete
5	Window	Size: 1.40 * 1.00
		Type: Double glass Dbl Clr 3mm/6mm Air
		WWR: South façade:11.6% - 14.2% North façade: 11.6% - 12.2% East façade: 12.2% - 12.9% - 14.2% West façade: 12.2% - 12.9% - 14.2%
6	Elevator	Two elevators
	HVAC System	Turned on
7	Light well	One main light well Size: 3.00 * 3.50
Thermal insulation		
1	Envelope	Non-insulation exterior wall
2	Reflection of the material before retrofitting (Design building software defaults)	Wall: 40% Ceiling: 40% Floor: 30%

7.5.2. Reason for choosing the case and residents opinions

The case had been selected due to the following reasons:

- This case covered the investment residential building type 4 as mentioned in table 5.3 p.62, every two apartments are grouped around one staircase lead to different levels. Also, this building has one main light wells in the middle
- Another reason is that this building was built in the period between "2000-2010", this type is popular in Hebron city. Therefore, environmental retrofit solutions for this kind of residence have great potential for multiplication.

Before the retrofit process, the designer should communicate with the resident to understand the existing building. Involved residents in a retrofit project's decision-making process helped develop existing residential buildings and build a bridge between occupant needs and the proposed retrofit strategies.

Therefore, ten residents had been selected in this case to answer the questionnaire to know the general satisfaction with the apartment, daylight level, daylight distribution, direct sunlight, view through windows, physical environment, and personal information.

The personal information collected about the respondents shows that most of the residents have jobs during the day and return home at 4:00 PM. Generally, respondents reported the following:

1. The living room was dark and the level of light for the guest room in apartments #1 and #3 was ranging from dark to partially dark.
2. Residents were dissatisfied with the apartment layout, therefore some users need extra spaces (such as another bedroom and another balcony) to feel more comfortable with room arrangement and natural light.
3. Some residents need to combine the living room and kitchen in an open plan design in order to bring natural lighting to the living room

7.5.3 Simulation of the Selected Apartment Block & Discussion

In this part, an assessment of the current daylight performance was conducted using a Design-Builder simulated model with a CIE standard overcast sky on 21st September. After that, compared to whether the lighting requirements were with average daylight factor code - for adequate natural lighting- achieved the required lighting level within the rooms. This helped determine and classify the visual discomfort problems at room-scale, following visual comfort chart 1 in chapter 3 p 45.

Due to the difference in flooring, it is essential to investigate daylight performance according to the building floor levels. In this case, the first floor was considered the worst case, while the seventh floor was considered the best, which helps to compare the effectiveness of the proposed strategies at different levels. See figure 7.49 & 7.50 for simulation results before the retrofit.

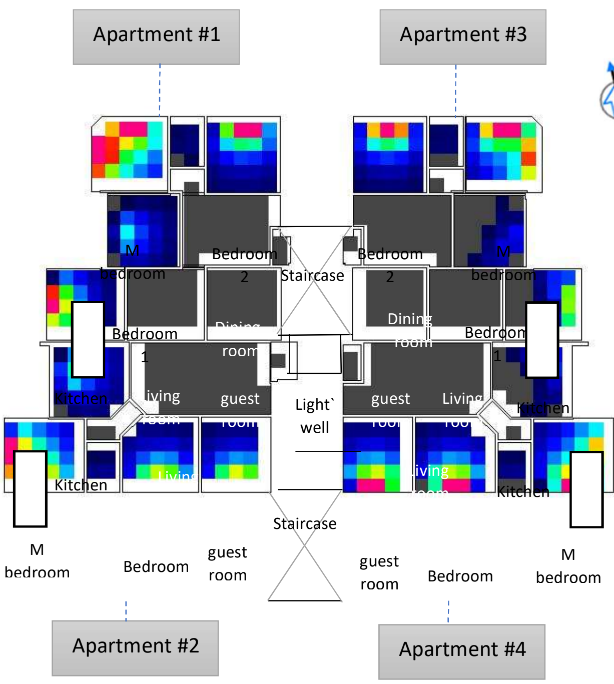


Figure 7.49 the first-floor plan shows the results of the daylight simulation of the current situation

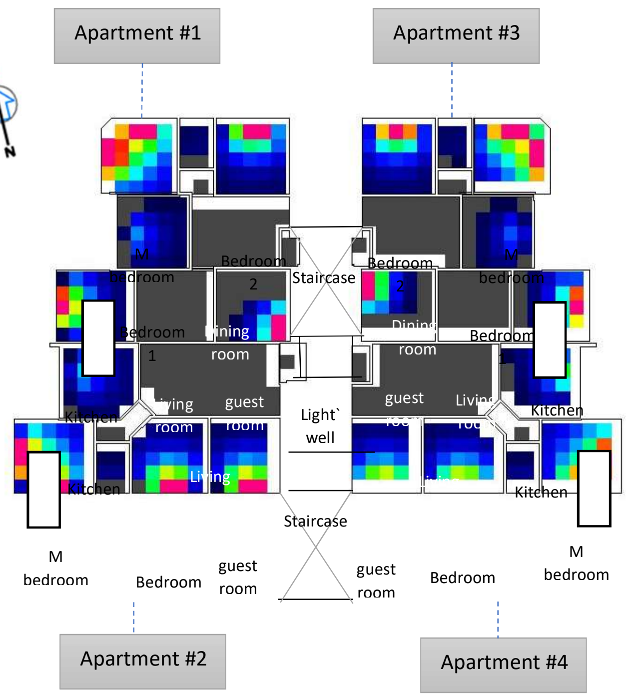
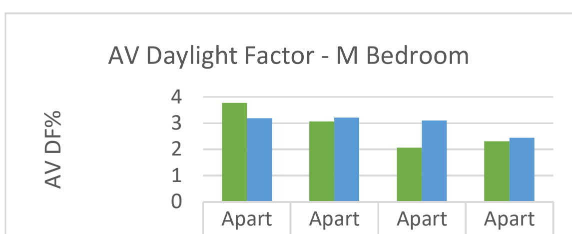


Figure 7.50 the seventh-floor plan shows the results of the daylight simulation of the current situation

- Master Bedroom

The average DF of the master bedroom for apartments before the retrofitting was investigated and compared with different apartment floors (first and seventh floor). As shown in figure 7.51, the average DF of master bedrooms in all apartment shows a high level of light and too glary. This can be explained may because the master bedroom has windows on two different facades. The windows on the north and west sides of apartments #1. While the windows are on the south and west sides of apartment # 2. In apartment #3 the windows on the north and east sides and on the south and east sides of apartment #4. Looking at figure 7.51, there is no master bedroom that meets the required level of average daylight factor (Bedroom AV DF=1%)



	Apartment 1	Apartment 2	Apartment 3	Apartment 4
First floor	3.776	3.068	2.06	2.312
Seventh floor	3.189	3.221	3.105	2.439

Figure 7.51 A comparison between the averages DF for the master bedroom

- Bedroom 1 & bedroom 2

Figures 7.52 & 7.53 presents the average DF for bedroom 1 and bedroom 2 respectively before the retrofitting. As shown in figure 7.52 Bedroom 1 has a balcony facing west in apartments #1, and a balcony facing east in apartments #3. Whereas bedroom 1 in apartments #2 and #4 has no balcony and facing south. Bedroom 2 is oriented to the north in apartments #1 and #3.

The simulation result for bedroom 1 shows a low level of light in apartments #1 and #3. This can be explained by the impact of the balcony that can cause a shadow, which minimizes the chances of lighting from reaching building facades. While the results in apartments #2 and #4 range from acceptable to high level of light. As for bedroom 2, the simulation result shows a high level of light in apartments #2 and #4. Referring to table 2.1 p.19, there is no bedroom that meets the required level of average DF (Bedroom AV DF=1%)

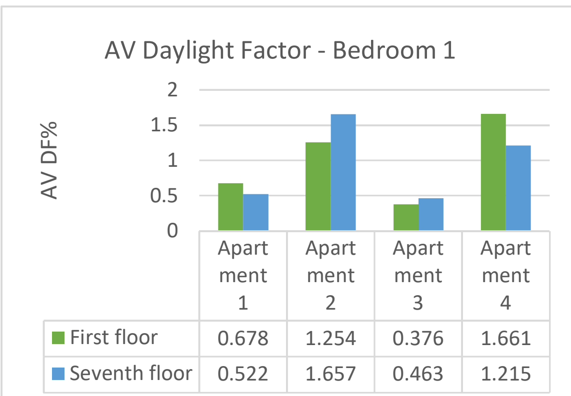


Figure 7.52 A comparison between the averages DF for the bedroom 1

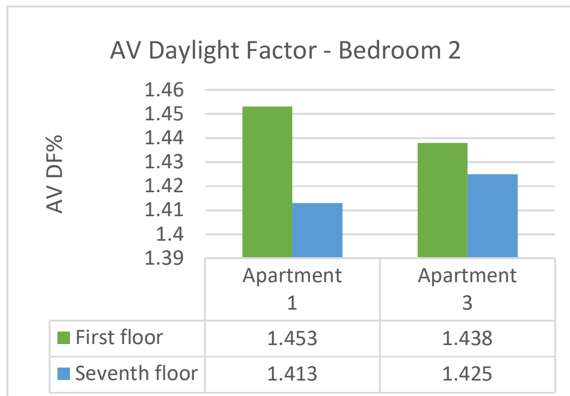


Figure 7.53 A comparison between the averages DF for the bedroom 2

- Kitchen

The following figure presents the average DF of the Kitchen for all apartments before retrofitting. As shown in figure 7.54 the kitchen in apartments #1 and #2 are oriented to the west with a balcony for apartments #2, while the kitchen in apartments #3 and #4 are oriented to the east with a balcony for apartments #4.

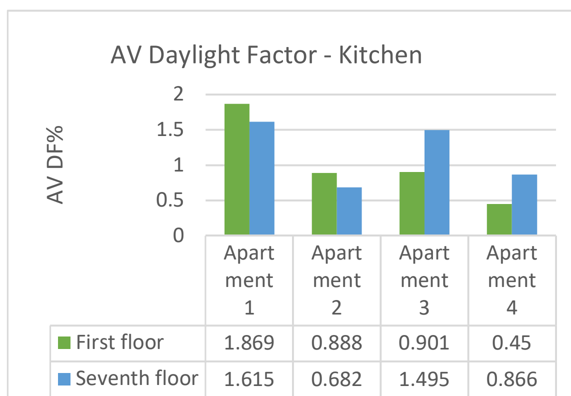


Figure 7.54 A comparison between the averages DF for the kitchen

The average DF of the kitchen in all apartments shows a low level of light and an acceptable average DF for apartment #1 on the 1st floor. The low-level daylight factor can be explained by the impact of the balcony that can cause a shadow. This is due to the closeness of adjacent buildings, which may cause shadow effects, as well as minimizing the chances of lighting from reaching building facades. As mentioned before, the residential buildings surround the case study building in east directions with different heights. Referring to table 2.1 p.19, there is no kitchen in all apartments that meets the required level (Kitchen AV DF=2%)**.**

- Living room & guest room

The average DF for the living room and guest room of all apartments before retrofitting was investigated. The guest room in apartments #1 and #3 has one window that opens on the light well. While the guest room in apartments #2 and #4 have windows on the external facade and facing south. The simulation result shows an average DF of guest rooms ranging from acceptable to low daylight factor in apartments #1 and #3. The guest room on the 7th floor obtained higher daylight factors than the 1st floor, but it still did not meet the required level. While the results in apartments #2 and #4 ranging from acceptable to high level of light. However, there is no guest room that meets the required level of average DF (AV DF=1.5%)

The living room in all apartments does not have windows. The open design of the living room and dining room were used in apartments #2 and #4. The room depth affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by side windows if the room depth exceeds 2.5 times the window height (see p20. In this case, daylight illuminance levels drop 5 meters away from side windows. Therefore, the living room and dining room in all apartments consider a deep plan. The living room in apartments #1 and #3 is separated from the dining room without windows. However, no living room meets the required level of average DF (AV DF=1.5%).

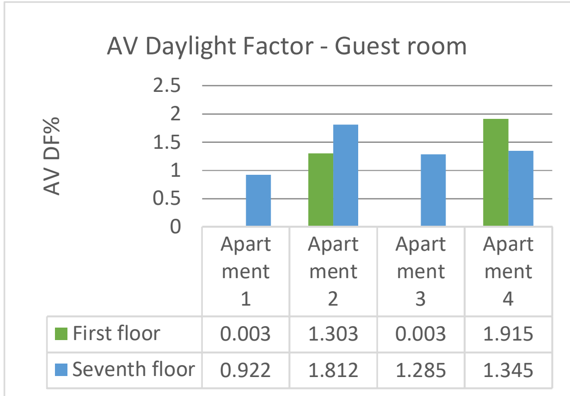


Figure 7.55 A comparison between the averages DF for the guest room

7.5.4. Simulation validity check

Daylight calculations were conducted in the studied areas to compare the results to the design-builder simulation results. The average daylight factor for the studied rooms was calculated by Crisp and Littlefairy using the formula below:

$$\overline{DF} = (\tau W \theta)/(A(1-R^2))$$

$\overline{DF}$= average daylight factor on the working plane.

τ= diffuse light transmittance of the glazing.

W = area of window.

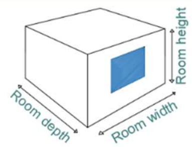
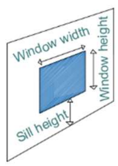
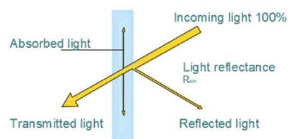
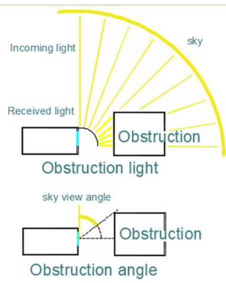
θ = vertical angle subtended at the centre of the window by the visible sky.

A = total area of room surfaces.

R = average reflectance of room surfaces.

This process aimed to check the validity of simulation results when compared with calculations. Table 7.18* shows the results of the daylight calculation and simulation of the same areas. The simulation results, as well as calculation results, are relatively closed with a 0.04% error for kitchen part.3 on the 7th floor and a 0.14% error for the kitchen apart.3 on the 3rd floor.

Table 7.18*: Calculation and simulation results of the average daylight for kitchen in apartment #3 & 3- 7th floor

	Descriptions	**Case 3 / Kitchen Apart.3 – 7th floor**	Case 3/ Kitchen Apart.3 – 3rd floor
	Room dimensions		
	Room width	3.80 m	3.80 m
	Room depth	3.60 m	3.60 m
	Room height	2.82 m	2.82 m
	Window dimensions		
	Sill height	1.07 m	1.07 m
	Window height	1.00 m	1.00 m
	Window width	1.40 m	1.40 m
	Properties of the window		
	Window light reflectance	0.1	0.1
	Window light transmittance	0.812	0.812
	Properties of room surface		
	Wall light reflectance	40%	40%
	Ceiling light reflectance	40%	40%
	Floor light reflectance	30%	30%
	Obstruction outside the window		
	Obstruction outside the window	22.4 m	22.4 m
	Obstruction height	26.7 m	26.7 m
	Obstruction angle	16	11
Average daylight factor - using the formula (1)		1.53%	1.05%
Average daylight factor - simulation – design builder		1.49%	0.901%
Error%		0.04%	0.14%

7.5.5. Evaluation of the existing situation

A preliminary analysis phase, if correctly performed, can provide a solid basis for an appropriate intervention plan commensurate with the needs of the occupants. In the beginning, the unverified requirements were detected, which help to fulfill existing laws. According to the Jordanian code, WWR should not be less than 15% in living areas and 10% in service areas. Thus, the existing WWR in the living room did not meet the requirements .

Evaluating the simulation results of the existing situation helps determine and classify the visual discomfort problems at room scale. Then, the main goals are identified for the current problems. In this case, there are two main goals:

1 Goal 1: Increasing daylight to achieve optimum interior lighting in the rooms that showed a low average daylight factor
2 Goal 2: Reducing daylight and improving the distribution of daylight in the rooms that showed a high average daylight factor .

As explained above, there is a need to improve daylight performance in buildings to maintain occupants' comfort and enhance buildings' energy efficiency. Improving daylighting performance requires the control of several design variables expected to make a significant change. Therefore, detailed simulation analyses have been performed to investigate the effect of retrofit strategies on existing multi-story residential buildings.

7.5.5. Results of Case 3 after retrofitting

The simulations were performed again after applying the retrofit strategies. The results of the different design conditions were compared and analyzed before and after applying the retrofit strategies.

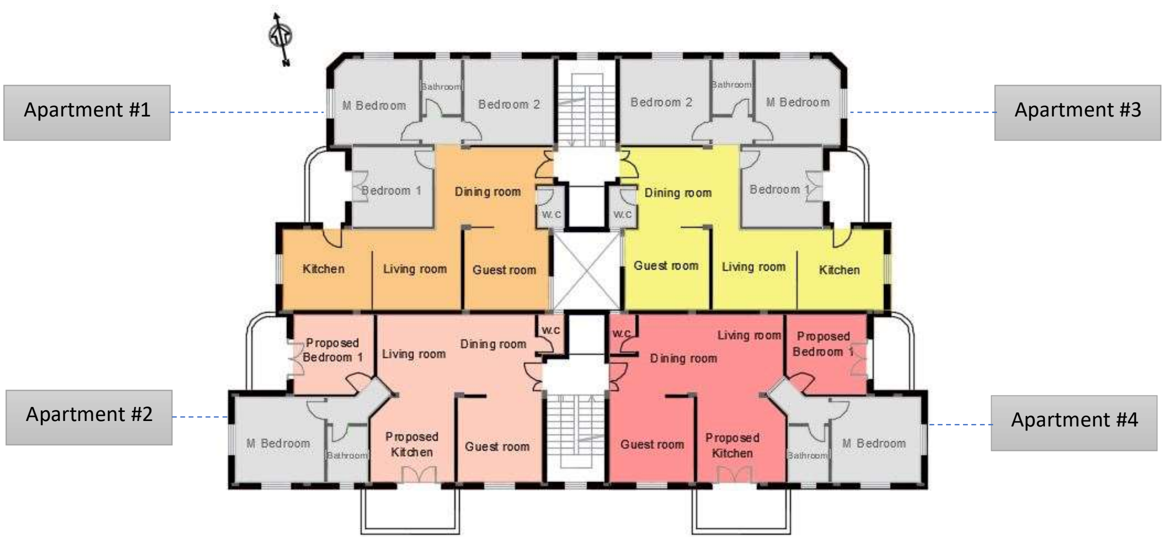


Figure 7.56-Represents the typical plan of the case study building type 4 after applying the retrofit strategies

As mentioned before, the living room and dining room are deep-plan rooms without windows in apartments #2 and #4. While the living room in apartments #1 and #3 is separated from the dining room without windows. Consequently, in deep plans, the rooms will be dark and cannot be naturally illuminated by external windows. Therefore, in the retrofitting phase of the interior spaces, the interior layout was verified in terms of usability and flexibility to optimize the quality of internal spaces and distribution. Initially, common areas were created, and new spaces were added to apartments, such as facade addition through the extension of indoor space and new spaces (adding new balconies). Figure 7.56 shows one of the alternative internal distribution proposals that was evaluated.

Initially, the adjustments were made to the floor plan. One of the significant modifications to achieve high-quality housing is to remove the hollow block wall between the kitchen and the living room in apartments #1 and #3. In addition, a part of the block wall between the guest room and dining room was removed, then a movable partition for privacy was added.

Other modifications were switching the kitchen and bedroom 1 in apartments #2 and #4. The block wall between the proposed kitchen and the living room was removed. Then, new spaces -balconies- have been added to the apartments at the request of occupants; see figure 7.59.

Simulation results after applying retrofit strategies and following visual comfort chart 1 page No. 45 are presented below:

- Bedroom 1 – Proposed Bedroom 1

Goal 1: Increasing daylight to achieve optimum internal daylighting

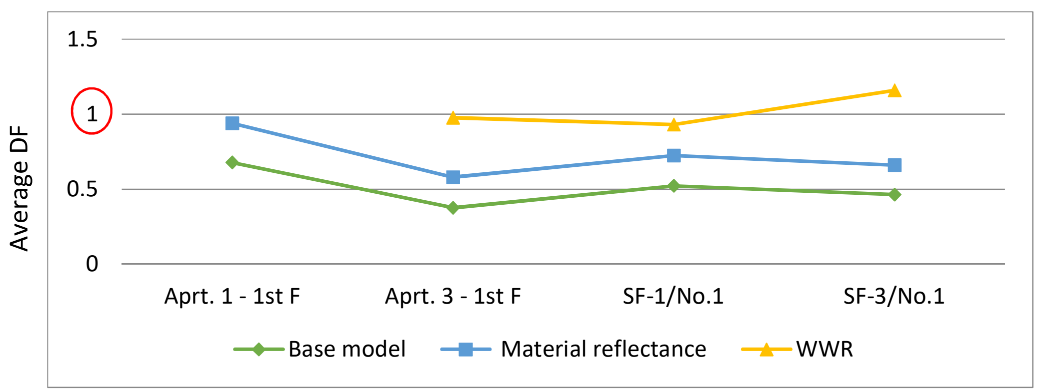


Figure 7.57 Average DF results in the bedroom 1 after applying retrofit strategies.

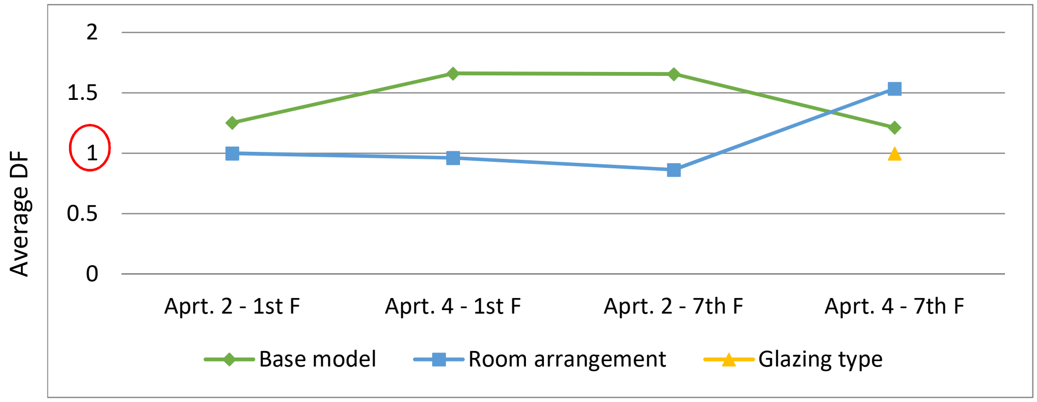


Figure 7.58 Average DF results in the proposed bedroom 1 after applying retrofit strategies.

1. Material reflectance had been investigated to achieve an appropriate illuminance level. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, see p.38. In general, the average DF was increased in bedroom 1 in apartments #1 and #3, as shown, the level of illumination has increased systematically but still did not meet the required standard except bedroom 1 for apartment #1 on the 1st floor .
2. The facade retrofit level 2* (WWR) was applied. The glazed area was modified which affected the illumination level inside the rooms. When the WWR was increased from 13% to 26% daylight distribution increased and the illuminance level increased systematically. The average DF results approximately met the required level in these apartments (Bedroom AV DF = 1%)
3. The facade retrofit level 2* (WWR) was applied in the proposed bedroom 1 for apartments # 4. When the WWR was increased from 13% to 35% the average DF results approximately met the required level except the proposed bedroom 1 for apartment #4 on the 7th floor.
4. In the proposed bedroom 1 for apartment #4 on the 7th floor, the window glass type was changed with double glazed windows (with 13mm spacer), Low-E layer clear or grey as required. The average DF was reduced and met the required level. As shown in figure 7.58 the average DF in the proposed bedroom1 for apartments #2 and #4 after modification floor plan.

In general, the average DF was reduced compared with the original base case before retrofitting. Referring to table 2.1 p19, in all proposed bedrooms 1 the average DF results approximately met the required level (Bedroom AV DF = 1%).

Table 7.19: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement[5]			
		Apartment 1 1st F	Apartment 3 1st F	Apartment 1 7th F	Apartment 3 7th F
Bedroom 1	Base model	67.8 %(DF 0.67%)	37.6 %(DF 0.37%)	52.2 %(DF 0.52%)	46.3 %(DF 0.46%)
	Changing material reflectance	93.9 %(DF 0.93%)	58.0 %(DF 0.58%)	72.4 %(DF 0.72%)	65.9 %(DF 0.65%)
	Adjusting WWR		97.6 %(DF 0.97%)	93.0 %(DF 0.93%)	115.9 %(DF 1.15%)

Table 7.20: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement			
		Apartment 2 1st F	Apartment 4 1st F	Apartment 2 7th F	Apartment 4 7th F
Bedroom 1	Base model	125.4 %(DF 1.25%)	166.1 %(DF 1.66%)	165.7 %(DF 1.65%)	121.5 %(DF 1.21%)
	Room arrangement	99.9 %(DF 0.99%)	96.4 %(DF 0.96%)	86.3 %(DF 0.86%)	153.6 %(DF 1.53%)
	Replacing glass type				99.9 %(DF 0.99%)

After adjusting the floor plan and creating new common areas, there was an open design of the kitchen and living room in apartments #1 and #3. The room depth affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by side windows if the room depth exceeds 2.5 times the window height (see p.20. In this case, daylight illuminance levels drop 5 meters away from side windows. Therefore, the kitchen and living room in all apartments consider a deep plan.

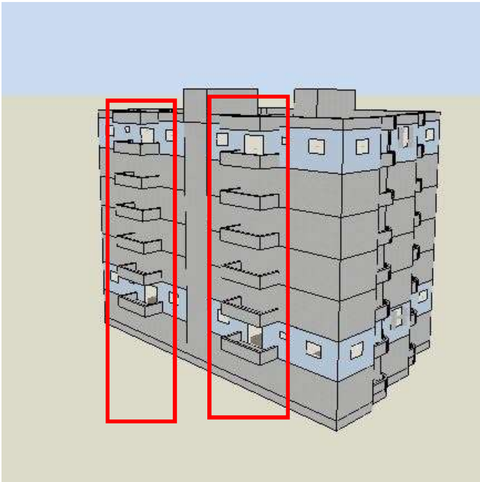


Figure 7.59-Represents the case study 4 after adding balconies

- Living room & Kitchen

Goal 1: Increasing daylight to achieve optimum internal daylighting

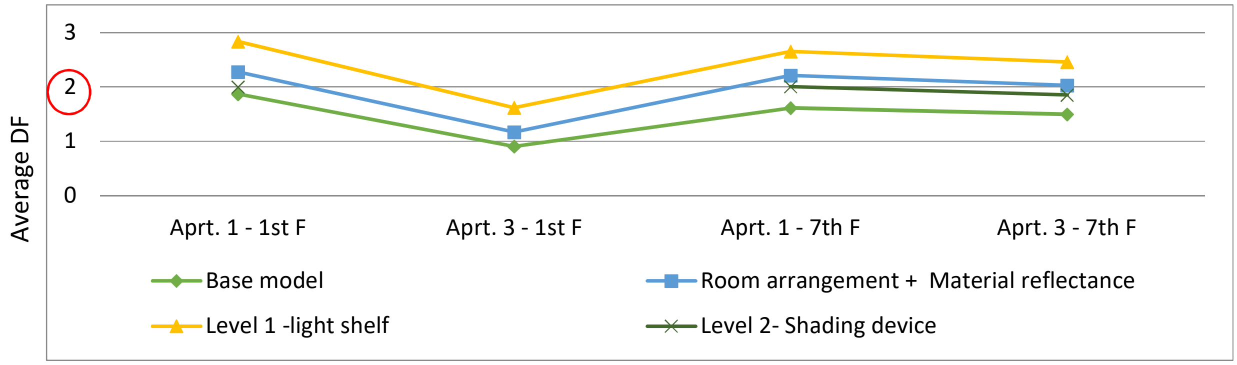


Figure 7.60-Average DF results in the kitchen after applying retrofit strategies.

[5] Percentage of daylight enhancement is compatible with the average daylight factor for different types of rooms in residential buildings (according to the Jordanian code issued in cooperation with the Jordanian Green Building Council) for adequate natural lighting

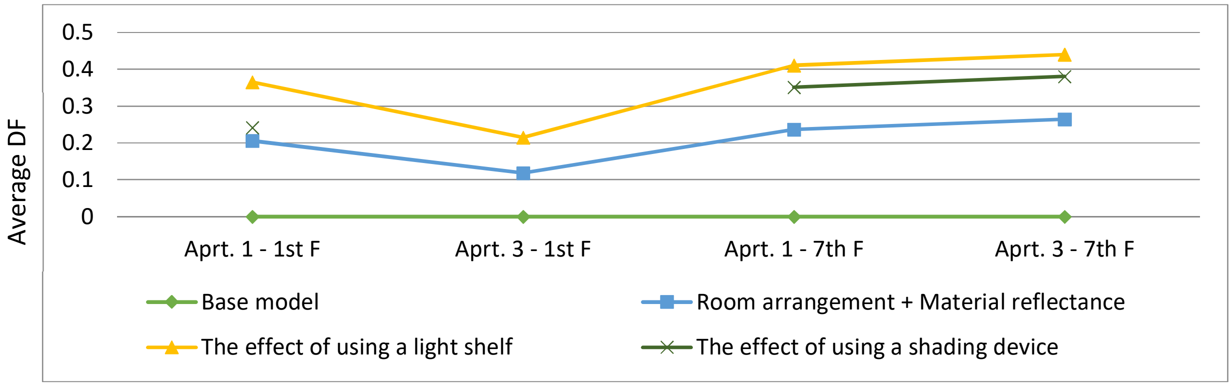


Figure 7.61-Average DF results in the living room after applying retrofit strategies.

1. Material reflectance had been investigated to achieve an appropriate illuminance level. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, see p.38. Figure 7.60 & 7.61 shows the average DF in the kitchen and living room after modification of the floor plan and changed material reflectance. In general, the average DF was increased in the kitchen. As a result, the illumination level was increased systematically in the living room in apartments #1 and #3 but still did not meet the required standard.
2. The facade retrofit level 1* (adding a light shelf) was applied in the kitchen windows in apartments #1 & #3 to achieve optimal daylight gain in the living room. This modification affected the illumination level in the living room and daylight distribution increased, but the kitchen showed a high average daylight factor .
3. The facade retrofit level 2 (adding a shading device) has been examined to achieve low direct light gains in the kitchen. A shading device has been added to the east and west windows, which used to control intense direct sunlight and used to control glare to ensure comfortable interior spaces. In this case, assumed the side fins (SF) projection dimensions are 50cm .

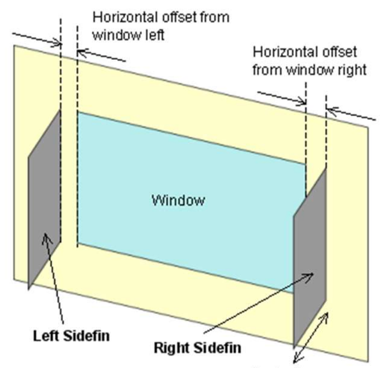


Figure 7.61*: East and west shading device-source: DesignBuilder

As shown in figure 7.60, the average DF in the kitchen for apartments #1 and #3 on the 7th floor was reduced and was approximately met at the required level. In the living room, the illuminance level has been reduced a little but still did not meet the required level, see figure 7.61.

Table 7.21: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement			
		Apartment 1 1st F	Apartment 3 1st F	Apartment 1 7th F	Apartment 3 7th F
Kitchen	Base model	93.4% (DF 1.86%)	45.0% (DF 0.90%)	80.7% (DF 1.61%)	74.7% (DF 1.49%)
	Changing material reflectance + room arrangement	114.0% (DF 2.28%)	58.5% (DF 1.17%)	110.5% (DF 2.21%)	101.3% (DF 2.02%)
	Adding light shelf	141.9% (DF 2.83%)	81.0% (DF 1.62%)	132.8% (DF 2.65%)	123.2% (DF 2.46%)
	Adding shading device	100.2% (DF 2.00%)		100.4% (DF 2.00%)	92.6% (DF 1.85%)
Living room	Base model	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)
	Changing material reflectance+ room arrangement	13.7% (DF 0.20%)	7.86% (DF 0.11%)	15.8% (DF 0.23%)	17.6% (DF 0.26%)
	The effect of using light shelf	24.3% (DF 0.36%)	17.9% (DF 0.21%)	27.4% (DF 0.41%)	29.3% (DF 0.44%)
	The effect of using shading device	16.1% (DF 0.24%)		23.4% (DF 0.35%)	25.4% (DF 0.38%)

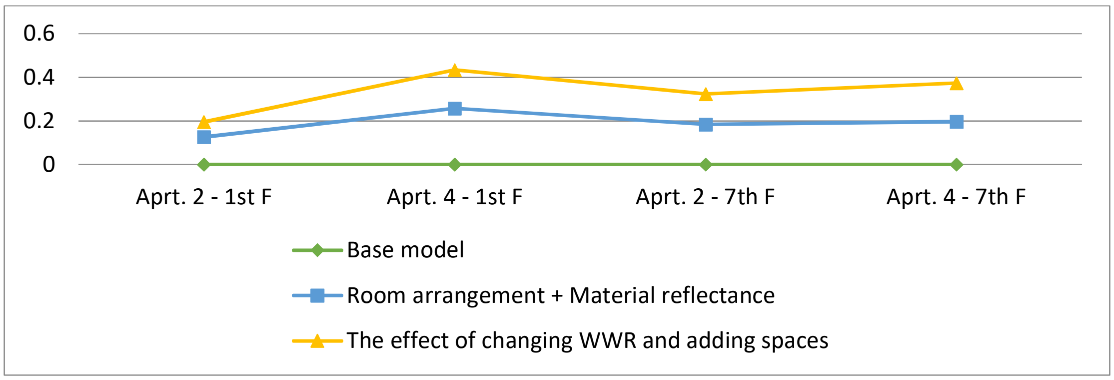


Figure 7.62-Average DF results in the living room after applying retrofit strategies.

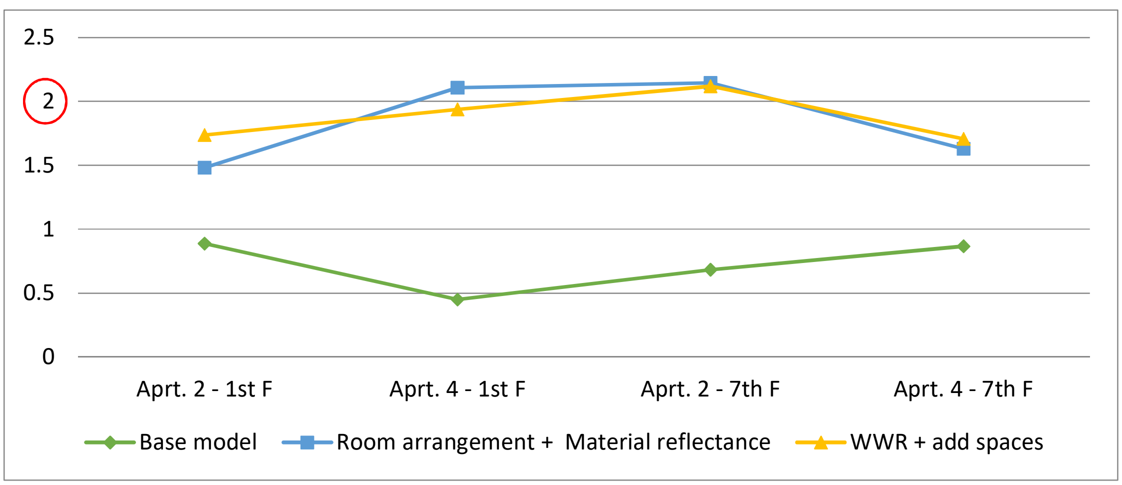


Figure 7.63 Average DF results in the proposed kitchen after applying retrofit strategies.

A new space -balconies- has been added to apartments # 2 and # 4 for the proposed kitchen and living room. The room depth affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by side windows if the room depth exceeds 2.5 times the window height, see p.20. In this case, daylight illuminance levels drop after 5 meters away from side windows. Therefore, the proposed kitchen and living room consider a deep plan.

Goal 1: Increasing daylight to achieve optimum internal daylighting

1. Material reflectance had been investigated to achieve an appropriate illuminance level. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, see p.38. Figure 7.62 & 7.63 shows the average DF in the proposed kitchen and living room after modifying the floor plan and changing the reflection of the materials. In general, the average DF in the proposed kitchen was increased and the required illumination level was met in apartment #4 on the 1st floor and apartment #2 on the 7th floor. As a result, the illumination level was systematically increased in the living room in apartments #2 and #4 but still did not meet the required standards .

The effect of adding new balconies to the proposed kitchen upon the residents' request was examined .

2. The level 2* facade retrofit (changing the WWR) has been applied. The glass area was modified, which affected the illumination level inside the rooms. When the WWR was increased from 11.6% to 35% daylight distribution increased and the illuminance level increased systematically. The average DF results approximately met the required level but in apartment #2 on the 1st floor and apartment # 4 on the 7th floor the DF still less than required (Kitchen AV DF = 2%).

This modification affected the illumination level inside the living rooms. The average DF has been increased in the living room but still did not meet the required level of illumination. (Living room) AV DF = 1.5%).

Table 7.22: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement			
		Apartment 2 1st F	Apartment 4 1st F	Apartment 2 7th F	Apartment 4 7th F
Proposed Kitchen	Base model	44.4% (DF 0.88%)	22.5% (DF 0.45%)	34.1% (DF 0.68%)	43.3% (DF 0.86%)
	Changing material reflectance + room arrangement	72.5% (DF 1.48%)	105.4% (DF 2.10%)	107.2% (DF 2.14%)	81.5% (DF 1.63%)
	Adjusting WWR + Add new space	86.8% (DF 1.73%)	96.8% (DF 1.93%)	105.9% (DF 2.11%)	85.4% (DF 1.70%)
Living room	Base model	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)
	Changing material reflectance+ room arrangement	8.4% (DF 0.12%)	17.2% (DF 0.25%)	12.2% (DF 0.18%)	13.1% (DF 0.19%)
	The effect of changing WWR + adding new space	13.0% (DF 0.19%)	28.9% (DF 0.43%)	21.5% (DF 0.32%)	24.9% (DF 0.37%)

- Guest room and dining room

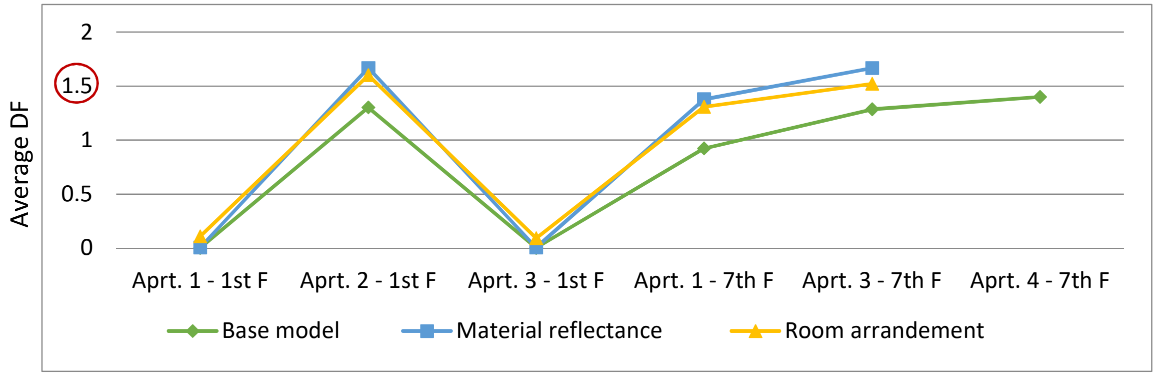


Figure 7.64-Average DF results in the guest room after applying retrofit strategies.

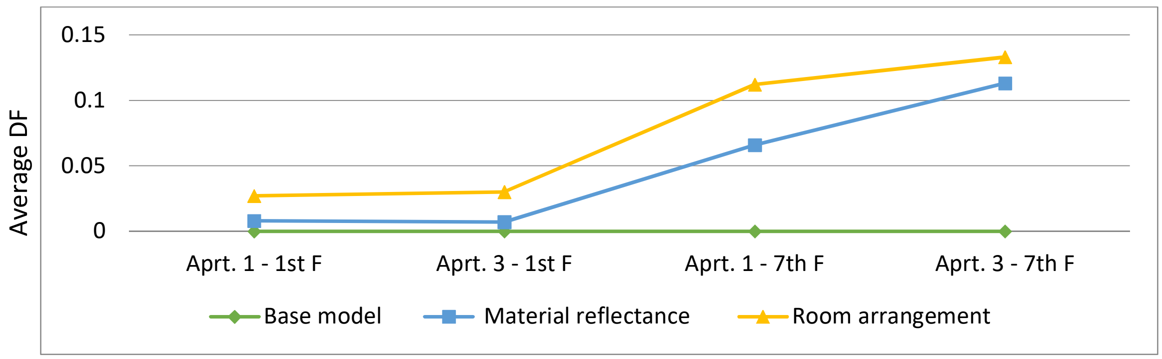


Figure 7.65-Average DF results in the dining room after applying retrofit strategies.

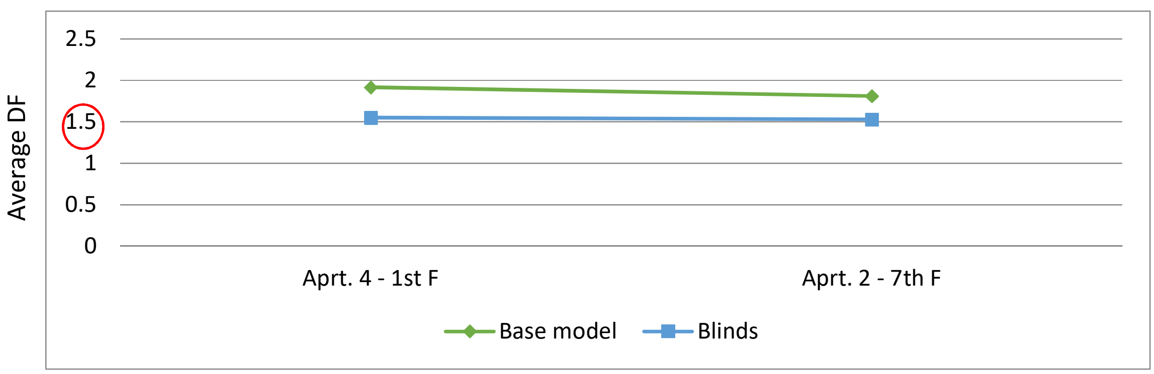


Figure 7.66-Average DF results in the guest room after applying retrofit strategies.

As a result of modifying the floor plan and removing part of the wall in apartments between the guest room and dining room. There was an open design of the guest room and dining room. As mentioned before, in deep-plan rooms with daylight on one side, this room cannot be naturally illuminated by side windows. The simulation result for the existing situation shows an average DF of guest rooms ranging from acceptable to low daylight factor in apartments # 1 and #3. While in apartment #2 on the 1st floor and apartment #4 on the 7th floor the simulation result shows an acceptable daylight factor .

Goal 1: Increasing daylight to achieve optimum internal daylighting.

1. Material reflectance had been investigated to achieve an appropriate illuminance level. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, see p.38. Figure 7.64 & 7.65 shows the average DF in the guest room and dining room after modifying the floor plan and changing the reflection of the materials. The DF average in guest room apartments # 1 and # 3 on the 1st floor still did not meet the required level. While average DF results in Apartment # 2 on the 1st floor and apartments # 1 and # 3 have almost fulfilled the required standard (AV DF = 1.5%). In general, the average DF in the dining room was increased but still did not meet the required level

Goal 2: Reducing daylight and improving the distribution of daylight

The guest room in apartments #4 on the 1st floor and #2 on the 7th floor show a high level of average DF. As shown in figure 7.66, by using blinds that provide glare-free daylight, while allowing a partial view. The average DF was reduced and the distribution of daylight for the guest room was improved.

Table 7.23: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**					
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 1 7th F	Apartment 3 7th F	Apartment 4 7th F
Guest room	Base model	0.2% (DF 0.003%)	86.8% (DF 1.30%)	0.2% (DF 0.003%)	61.0% (DF 0.92%)	85.6% (DF 1.28%)	93.3% (DF 1.4%)
	Changing material reflectance	0.26% (DF 0.004%)	111.2% (DF 1.66%)	0.33% (DF 0.005%)	91.9% (DF 1.37%)	111.1% (DF 1.66%)	
	Room arrangement	7.1% (DF 0.107%)	106.6% (DF 1.60%)	6.13% (DF 0.09%)	87.1% (DF 1.30%)	101.53% (DF 1.52%)	

Table 7.24: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**			
		Apartment 1 1st F	Apartment 3 1st F	Apartment 1 7th F	Apartment 3 7th F
Dining room	Base model	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)
	Changing material reflectance	0.16% (DF 0.008%)	0.14% (DF 0.007%)	1.32% (DF 0.06%)	2.26% (DF 0.11%)
	Room arrangement	0.54% (DF 0.027%)	0.6% (DF 0.03%)	2.2% (DF 0.11%)	2.66% (DF 0.13%)

Table 7.25: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement	
		Apartment 4 1st F	Apartment 2 7th F
Guest room	Base model	127.6% (DF 1.91%)	120.8% (DF 1.81%)
	Using blinds	103.3% (DF 1.55%)	102.0% (DF 1.53%)

- Bedroom 2

Goal 2: Reducing glare and improving the distribution of daylight

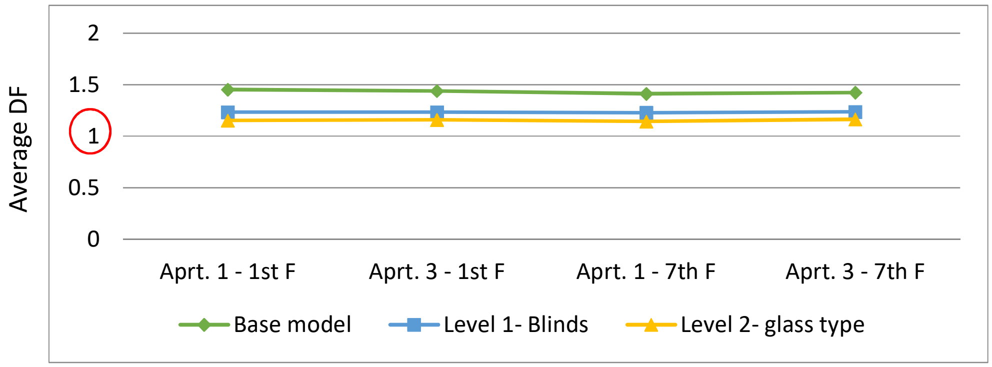


Figure 7.67-Average DF results in the bedroom 2 after applying retrofit strategies.

Bedroom 2 in all apartments shows a high level of average DF, see figure 7.67 .

1. After using blinds (blinds with low or medium reflectivity slats – curtains) that provide daylight free of glare, while allowing a partial view. The average DF reduced and daylight distribution improved for bedroom 2, but still did not meet the required standard. Table 7.26 shows the percentage of daylight enhancement after using blinds.
2. The windows have also been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as required.

Looking at figure 7.67, the average DF results in all bedrooms 2 met the required level (Bedroom AV DF = 1%)

Table 7.26: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement			
		Apartment 1 1st F	Apartment 3 1st F	Apartment 1 7th F	Apartment 3 7th F
Bedroom 2	Base model	68.8% (DF 1.45%)	69.5% (DF 1.43%)	70.7% (DF 1.41%)	70.1% (DF 1.42%)
	Using blinds	80.9% (DF 1.23%)	80.9% (DF 1.23%)	81.3% (DF 1.23%)	80.7% (DF 1.23%)
	replacing glass type	86.6% (DF 1.15%)	86.2% (DF 1.15%)	87.4% (DF 1.14%)	85.9% (DF 1.16%)

- Master Bedroom

Goal: Reducing glare and improving the distribution of daylight

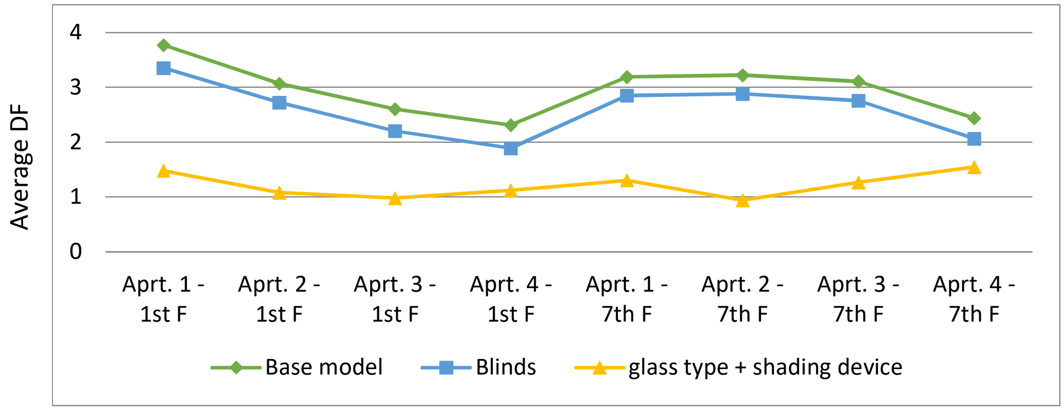


Figure 7.68 Average DF results in the master bedroom after applying retrofit strategies.

The master bedrooms in all apartments show a high level of average DF, as shown in figure 7.68.

1. After using blinds (blinds with low or medium reflectivity slats – curtains) that provide daylight free of glare, while allowing a partial view. The average DF reduced and daylight distribution improved for master bedrooms, but still did not meet the required standard. Table 7.27shows the percentage of daylight enhancement after using blinds.
2. The windows have also been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as required.
3. The facade retrofit level 2 (adding a shading device) has been examined in the master bedroom. A shading device has been added to the east, west, and south windows apartments, which used to control intense direct sunlight and used to control glare to ensure comfortable interior spaces. In this case, assumed the side fins (SF) projection dimensions are 50cm. The overhang projection dimensions are 50cm for south windows. As shown in figure 7.68 the average DF approximately met the required standard in master bedrooms (Bedroom AV DF=1%)

Table 7.27: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement							
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 1 7th F	Apartment 2 7th F	Apartment 3 7th F	Apartment 4 7th F
Master bedroom	Base model	26.5% (DF 3.76%)	32.5% (DF 3.06%)	38.4% (DF 2.60%)	43.2% (DF 2.31%)	31.3% (DF 3.18%)	31.0% (DF 3.22%)	32.2% (DF 3.10%)	41.0% (DF 2.43%
	Using blinds	29.8% (DF 3.35%)	36.7% (DF 2.72%)	45.4% (DF 2.20%)	53.1% (DF 1.88%)	35.0% (DF 2.85%)	34.7% (DF 2.88%)	36.2% (DF 2.75%)	48.4% (DF 2.06%)
	replacing glass type + adding a shading device	67.6% (DF 1.47%)	92.5% (DF 1.08%)	101.9% (DF 0.98%)	88.9% (DF 1.12%)	76.8% (DF 1.30%)	106.3% (DF 0.94%)	78.9% (DF 1.26%)	64.8% (DF 1.54%)

7.5.7 Conclusion

The local residential retrofit framework with proposed retrofit strategies have been tested to find the effect on enhancing the performance of natural daylight in multi-story buildings. The retrofit process and the results of natural daylight enhancements for case study 3 are shown below:

1. The process began with gathering information for the existing building .
2. To diagnostics and identification of discomfort areas:
   a) Firstly, Communication with the resident during the pre-retrofitting process was done to understand the existing building. In case study 3, 10 residents had been selected to answer the questionnaire to know the general satisfaction with the apartment .
   b) Secondly, simulation programs in the early stages of the pre-retrofit process were used to define the existing building problems, the results were shown in item 7.5.3.
3. Evaluation of the existing situation to determine and classify the visual discomfort problems.
   a) At building scale: The characteristics of the existing building and the unverified requirements were detected, which help to fulfill existing laws. Therefore a new elevator was added to fulfill existing laws and resident requirements. In addition, the optimal spatial retrofit strategies was defined for improving energy performance and optimizing the quality of internal spaces and distribution. In this case, rooms was joined together to create new common areas and a new balconies was added to fulfill the residents need.
   b) At room scale: The main goals were identified for the existing problems. In this thesis, there are two main goals as mentioned in the visual comfort chart p.45. Therefore, in this case, goal 1 was increasing daylight to achieve optimum interior lighting, and goal 2 was reducing daylight and improving the distribution of daylight.

4. Identifying passive retrofit strategies and selecting the best retrofit action. In general, the results show that the following proposed passive retrofit strategies of the building creates spaces that meet the requirements of the code, as shown in the table 7.28 below

Table 7.28: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement[6]**							
		Apartment 1 1^{st} F	Apartment 2 1^{st} F	Apartment 3 1^{st} F	Apartment 4 1^{st} F	Apartment 1 7^{th} F	Apartment 2 7^{th} F	Apartment 3 7^{th} F	Apartment 4 7^{th} F
Master bedroom	Base model	26.5% (DF 3.76%)	32.5% (DF 3.06%)	38.4% (DF 2.60%)	43.2% (DF 2.31%)	31.3% (DF 3.18%)	31.0% (DF 3.22%)	32.2% (DF 3.10%)	41.0% (DF 2.43%)
	After retrofitting	67.6% (DF 1.47%)	92.5% (DF 1.08%)	101.9% (DF 0.98%)	88.9% (DF 1.12%)	76.8% (DF 1.30%)	106.3% (DF 0.94%)	78.9% (DF 1.26%)	64.8% (DF 1.54%)
Bedroom 1	Base model	67.8% (DF 0.67%)	125.4% (DF 1.25%)	37.6% (DF 0.37%)	166.1% (DF 1.66%)	52.2% (DF 0.52%)	165.7% (DF 1.65%)	46.3% (DF 0.46%)	121.5% (DF 1.21%)
	After retrofitting	93.9% (DF 0.93%)	99.9% (DF 0.99%)	97.6% (DF 0.97%)	96.4% (DF 0.96%)	93.0% (DF 0.93%)	86.3% (DF 0.86%)	115.9% (DF 1.15%)	99.9% (DF 0.99%)
Bedroom 2	Base model	68.8% (DF 1.45%)		69.5% (DF 1.43%)		70.7% (DF 1.41%)		70.1% (DF 1.42%)	
	After retrofitting	86.6% (DF 1.15%)		86.2% (DF 1.15%)		87.4% (DF 1.14%)		85.9% (DF 1.16%)	
Kitchen/ proposed kitchen	Base model	93.4% (DF 1.86%)	44.4% (DF 0.88%)	45.0% (DF 0.90%)	22.5% (DF 0.45%)	80.7% (DF 1.61%)	34.1% (DF 0.68%)	74.7% (DF 1.49%)	43.3% (DF 0.86%)
	After retrofitting	100.2% (DF 2.00%)	86.8% (DF 1.73%)	81.0% (DF 1.62%)	96.8% (DF 1.93%)	100.4% (DF 2.00%)	105.9% (DF 2.11%)	92.6% (DF 1.85%)	85.4% (DF 1.70%)
Living room	Base model	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)
	After retrofitting	16.1% (DF 0.24%)	13.0% (DF 0.19%)	17.9% (DF 0.21%)	28.9% (DF 0.43%)	23.4% (DF 0.35%)	21.5% (DF 0.32%)	25.4% (DF 0.38%)	24.9% (DF 0.37%)
Guest room	Base model	0.2% (DF 0.003%)	86.8% (DF 1.30%)	0.2% (DF 0.003%)	127.6% (DF 1.91%)	61.0% (DF 0.92%)	120.8% (DF 1.81%)	85.6% (DF 1.28%)	93.3% (DF 1.4%)
	After retrofitting	7.1% (DF 0.107%)	106.6% (DF 1.60%)	6.13% (DF 0.09%)	103.3% (DF 1.55%)	87.1% (DF 1.30%)	102.0% (DF 1.53%)	101.53% (DF 1.52%)	
Dining room	Base model	0% (DF 0.0%)		0% (DF 0.0%)		0% (DF 0.0%)		0% (DF 0.0%)	
	After retrofitting	0.54% (DF 0.027%)		0.6% (DF 0.03%)		2.2% (DF 0.11%)		2.66% (DF 0.13%)	

The outcome results show that the level of natural daylight was enhanced in apartments when implementing the proposed retrofit strategies. The result of enhancement ranges between 53% - 84 %.

[6] Percentage of daylight enhancement is compatible with the average daylight factor for different types of rooms in residential buildings (according to the Jordanian code issued in cooperation with the Jordanian Green Building Council) for adequate natural lighting.

From the experiments of simulating a multi-story residential building (Case 3), this research concluded the following:

(1) Daylight varies according to the floor levels (Ground floor, First floor, etc.) of the building concerning orientation. In case 3, the seventh-floor apartments that oriented to the east & south showed a higher level of light than the first-floor apartments that oriented to the west & north. The variation of orientation and floor heights also showed a large difference, especially in the rooms oriented to the south in apartment #4. This was caused by the conditions of the site with the surrounding buildings, where the surrounding buildings formed an obstruction on access daylight.

(2) The stage of spatial retrofit of the interior spaces was complex and depended on the needs of the residents and the architect's vision to solve the problems of discomfort.

(3) As shown, the depth of the room affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by windows if the room depth exceeds 2.5 times the window height. In this case, daylight illuminance levels drop 5 meters away from side windows. The depth of rooms in all apartments less than 5 except for the living room and dining room, considered as a deep room without windows in apartments #2 and #4. While the living room in apartments #1 and #3 is separated from the dining room without windows). As shown by applying the retrofitting strategies - optimizing the living spaces and create new common areas- the quality of use of the apartments was improved. But in the rooms with a great depth of more than 6m, it did not meet the requirements of the Code.

(4) A balcony and geometry are some of the most affecting parameters on the daylight conditions of the adjacent space. The balcony reduces the daylight in the adjacent space. Therefore, it is always essential to take into account all affecting aspects to have a well-performed space.

(5) Simulations of sunlight penetration with shading devices need to be conducted during the redesign stage to guarantee that occupants are protected from direct sunlight throughout the day. It is always essential to consider and include proper external and internal solar shading to optimize visual and thermal comfort. As shown in the master bedroom and Kitchen, a vertical shading device has been added to the east and west window. In contrast, a horizontal shading device has been added to the south.

(6) The light shelf has effective results in improving the quality of the light distribution. At the same time, it can provide light penetration deeper into space and provide good shading from the sun. In this case, the kitchen and living room in apartments #1 & #3 are deep-plan rooms; by applying the light shelf in the kitchen windows, the illumination level in the living room and daylight distribution increased.

(7) The type of glazing and window gives major significance to the performance of natural light and the thermal performance of adjacent space. Therefore, the windows have been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as needed.

(8) Each window on each floor and orientation should have its particular design from window to wall ratio. The size and placement of windows must always be considered together with the building's total energy use and specific daylight requirements. As shown in bedroom 1, when the WWR was increased, the illuminance level systematically increased.

(9) It is observed that less reflective wall finishes reduced the reflectivity making the space more dull and dark

Few modifications in the existing building can improve considerable indoor daylighting. The results prove that applying the retrofit strategies enhances daylight performance by 53 % for apartment #1, 80% for apartment #2, 56% for apartment #3, and 83% for apartment #4 on the first floor. While on the seventh floor, daylight performance enhanced by about 67% for apartment #1, 84% for apartment #2, 72% for apartment #3 and 89% for apartment #4 .

Excess glare and heat should be avoided. This can be achieved by controlling solar radiation using a shading device strategy. Therefore, this thesis concluded that combining strategies (such as shading devices, light shelves, and blinds) could have an essential role in creating a desirable environment based on daylight quality and thermal comfort. Furthermore, most people prefer daylight due to contact with the outside world, provided by windows.

- Deep Plan

The kitchen and living room in apartments #1 & #3 are considered a deep plan. This room with a depth of is more than 6 m. Thus it is difficult to obtain sufficient daylighting by windows. By applying retrofit strategies (adding a light shelf) and open spaces, the illuminance level in the guest room on first-floor apartments was enhanced, but it still did not meet the requirements of the code .

The proposed kitchen and living room in apartments#2 & #4 are considered a deep plan—this room with a depth of more than 6 m. By applying retrofit strategies (adjusting WWR) and open spaces, the illuminance level was enhanced, but it still did not meet the code's requirements. Therefore, it might not be very feasible to rely only on passive strategies.

7.6 Case Study 4:

7.6.1 General information

Location:

The building is located in Al Haouz Street. It was built in 2012.

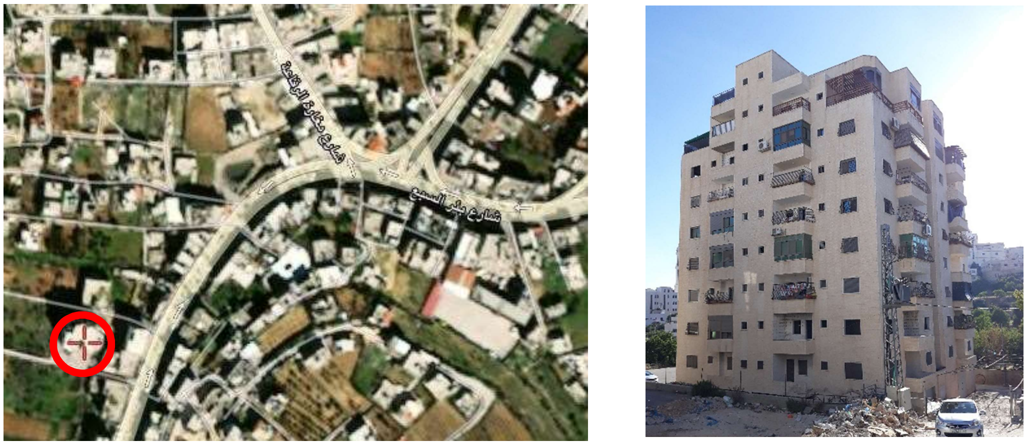


Figure 7.69 the site plan to the left shows the buildings. The red-marked building is our research case. The photo to the right shows the building.- source : researcher.

The case study building consists of eight floors with 32 apartments. As shown in figure 7.70, each floor contains four flats. The four apartments are grouped around one staircase in the middle leads to different levels. The symmetry plans forms for apartments are commonly used in multi-story residential buildings. In this case, the flats symmetrical in all directions with an area of about 120 m². The apartment in which area is 120 m² consists of a master bedroom, two bedrooms, a kitchen, bathroom, and the living room is open to the dining room, a balcony, and a guest room.

Figure 7.70 represents the typical plan of the case study building type 2.

In the selected residential building, only bedroom 2 has two windows in all apartments. The other rooms have only one window on the external facades. The living room and guest room in all apartments do not have windows. There is some difference between apartments layout. Therefore, in this case, assume that all apartments have the same plan to facilitate examining the effectiveness of different combinations of retrofit strategies.

Table 7.29 Basic information about buildings before renovation.

	Basic information about buildings before renovation	
1	Year of construction	2012
Layout		
1	Number of stories	Eight stories
2	No. of apartment	32 apartments
3	No. of apartment in each floor and layout	four
4	Structure	• Wall: 5 Stone, 15concrete, 10hollow block wall, 2cm Plaster. • Ceiling: 25cm concrete
5	Window	Size: 1.60 * 1.25
		Type: Double glass Dbl Clr 3mm/6mm Air
		WWR: South – North façade: 15.3% - 15.7% East – West façade: 14.5% - 23.8%
6	Elevator	One elevator
	HVAC System	Turned on
7	Light well	-
Thermal insulation		
1	Envelope	Non-insulation exterior wall
2	Reflection of the material before retrofitting (Design building software defaults)	Wall: 40% Ceiling: 40% Floor: 30%

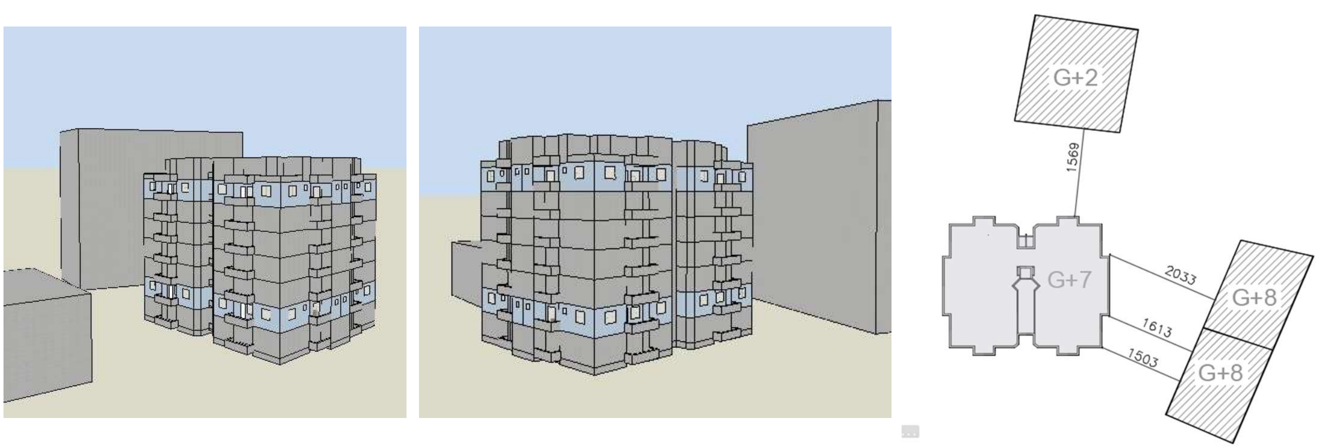


Fig 7.71 Modelled apartment building and its context.

7.6.2. Reason for choosing the case and residents opinions

The case had been selected due to the following reasons:

- This case covered the investment residential building type 2 as mentioned in table 5.3 p.62, the four apartments are grouped around one staircase without light well.
- Another reason is that this building was built after 2010. Also, this type is popular in Hebron city. Therefore, environmental retrofit solutions for this kind of residence have great potential for multiplication.

Before the retrofit process, the designer should communicate with the resident to understand the existing building. Involved residents in a retrofit project's decision-making process helped develop existing residential buildings and build a bridge between occupant needs and the proposed retrofit strategies. Therefore, six residents had been selected in this case to answer the questionnaire to know the general satisfaction with the apartment, daylight level, daylight distribution, direct sunlight, view through windows, physical environment, and personal information.

Generally, respondents reported the following:

1. The living room and the guest room was dark .
2. Residents were dissatisfied with the apartment layout, some users need to combine the living room and kitchen in an open plan design in order to bring natural lighting to the kitchen.

7.6.3. Simulation of the Selected Apartment Block & Discussion

In this part, an assessment of the current daylight performance was conducted using a Design-Builder simulated model with a CIE standard overcast sky on 21st September. After that, compared to whether the lighting requirements were with average daylight factor code - for adequate natural lighting- achieved the required lighting level within the rooms. This helped determine and classify the visual discomfort problems at room-scale, following visual comfort chart 1 in chapter 3 p.45.
Due to the difference in flooring, it is essential to investigate daylight performance according to the building floor levels. In this case, the first floor was considered the worst case, while the seventh floor was considered the best, which helps to compare the effectiveness of the proposed strategies at different levels. See figures 7.72 & 7.73 for simulation results before the retrofit.

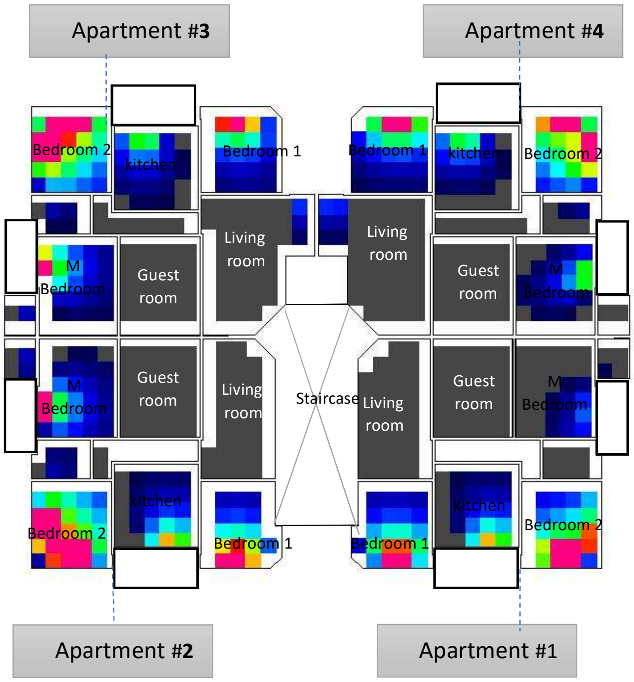


Figure 7.72- The first-floor plan shows the results of the daylight simulation of the current situation

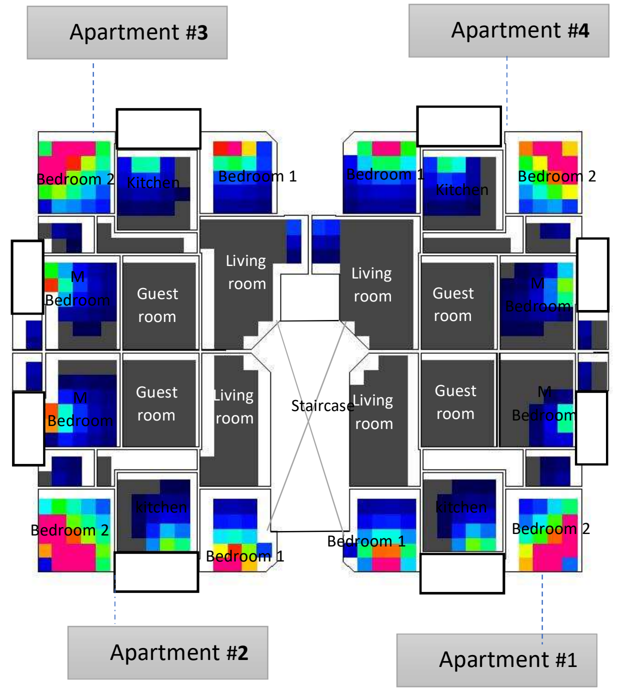


Figure 7.73- The seventh-floor plan shows the results of the daylight simulation of the current situation

- Master bedroom

The average DF of the master bedroom for apartments before the retrofitting was investigated and compared with different apartment floors (first and seventh floor). As shown in figure 7.74, the average DF of master bedrooms in apartments #1 and #4 shows a low level of light. While the simulation result shows an average DF of master bedroom ranging from acceptable factor to high daylight factor in apartments #2 and #3. The low level of light is due to the closeness of adjacent buildings, which may cause shadow effects, as well as minimizing the chances of lighting from reaching building facades

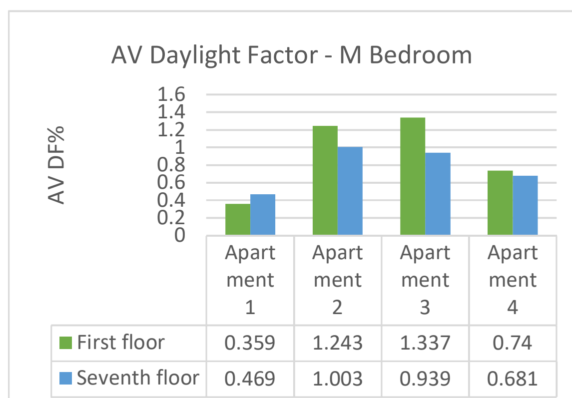


Figure 7.74 A comparison between the averages DF for the master bedroom

Master bedroom also has a balcony facing east in apartments #1 and #4, while the balcony facing the west in apartments #2 and #3. Which also explain the low level of the DF. Referring to table 2.1 p.19, there is no master bedroom that meets the required level of average DF except for master bedroom #2 and #3 on the 7th floor (Bedroom AV DF=1%)

- Bedroom 1 & bedroom 2

Figures 7.75 & 7.76 presents the average DF for bedroom 1 and bedroom 2 respectively before the retrofitting. As shown in figure 112, the average DF for bedroom 2 in all apartments shows a high level of light and too glary. This can be explained may because bedroom 2 has windows on two different facades. Windows on the south and east sides of apartments #1. While for apartments #2 the windows are on the south and west sides. The windows on the north and west sides of apartment #3 and the north and east sides of apartment #4. Figure 7.76 also shows a high level of light in bedroom 1 in all apartments.

Referring to table 2.1 p.19, there is no bedroom that meets the required level of average DF (Bedroom AV DF=1%)

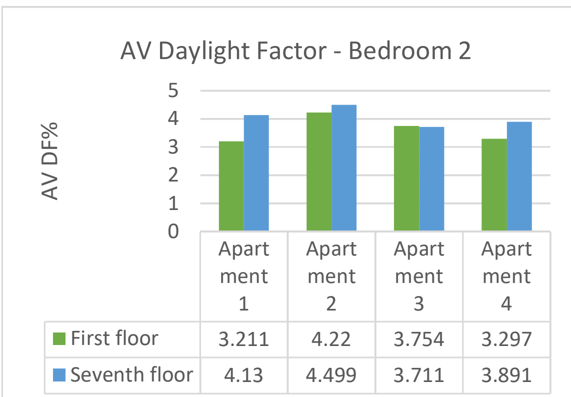


Figure 7.75 A comparison between the averages DF for the bedroom 2

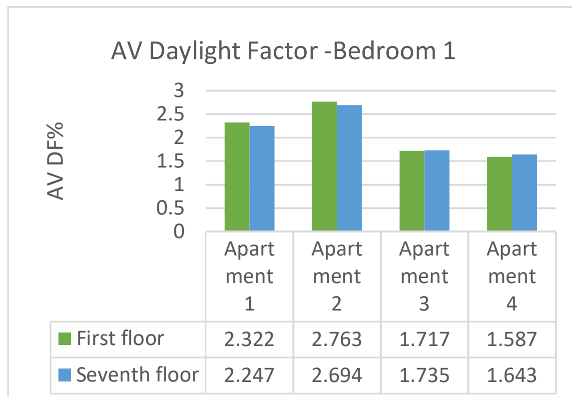


Figure 7.76 A comparison between the averages DF for the bedroom 1

- Kitchen

The following figure shows the average DF for the kitchen for all apartments before retrofitting. As shown in figure 7.77 the kitchen in Apartments #1 and #2 is oriented to the south with a balcony, while the kitchen in apartments #3 and #4 is oriented to the north with a balcony. The average DF for the kitchen in all apartments shows a low level of light. The low-level daylight factor can be explained by the impact of the balcony that can cause a shadow. Looking at table 2.1 p.19, there is no kitchen in all apartments that meets the required level (Kitchen AV DF=2%)

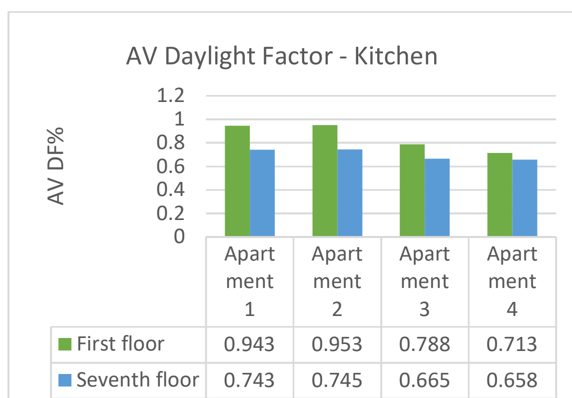


Figure 7.77 A comparison between the averages DF for the kitchen

- Living room and guest room

The following figure presents the average DF of the living room for all apartments before the retrofitting. As shown in figure 7.78, there is an open design of the living room and dining room in all apartments. In deep-plan rooms without windows, the room will be dark and cannot be naturally illuminated by windows. The open design of the living room and dining room were used in all apartments. The room depth affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by side windows if the room depth exceeds 2.5 times the window height (see p.20. In this case, daylight illuminance levels drop after 5.6 meters away from side windows.

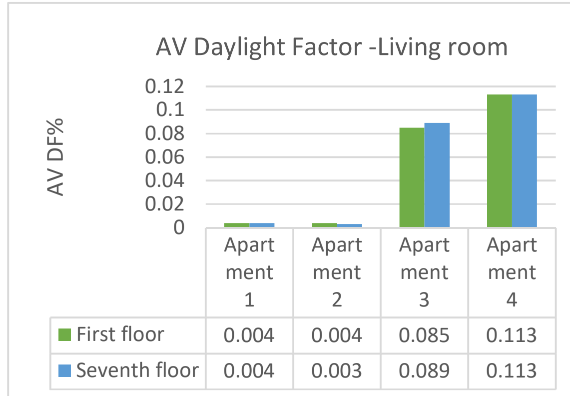


Figure 7.78 A comparison between the averages DF for the living room

Therefore, the living room and dining room in all apartments consider a deep plan. The guest room is without windows on the external facades. This explained the low level of daylight in all apartments. Looking at table 2.1 p.19, there is no guest or living room in all apartments that meet the required level (AV DF=1.5%)

7.6.4. Simulation validity check

Daylight calculations were conducted in the studied areas to compare the results to the design-builder simulation results. The average daylight factor for the studied rooms was calculated by Crisp and Littlefairy using the formula below:

$$\overline{DF} = (\tau W \theta)/(A (1-R^2))$$

$\overline{DF}$= average daylight factor on the working plane.

τ= diffuse light transmittance of the glazing.

W = area of window.

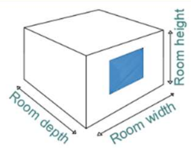
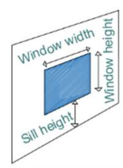
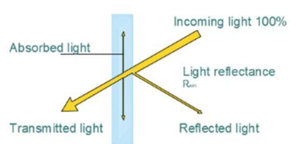
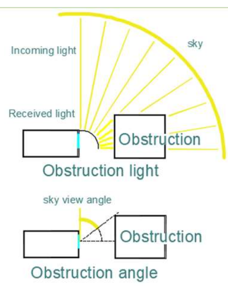
θ = vertical angle subtended at the centre of the window by the visible sky.

A = total area of room surfaces.

R = average reflectance of room surfaces.

This process aimed to check the validity of simulation results when compared with calculations. Table 7.29* shows the results of the daylight calculation and simulation of the same areas. The simulation results, as well as calculation results, are relatively closed with a 0.02% error.

Table 7.29*: Calculation and simulation results of the average daylight for bedroom 2 in apartment #4 - 7th floor

Case 4/ Bedroom 2 Apart.4 – 7th floor		
	Room dimensions	
	Room width	3.76 m
	Room depth	4.40 m
	Room height	2.82 m
	Window dimensions	
	Sill height	1.00 m
	Window height	1.25 m
	Window width	1.40 m
	Properties of the window	
	Window light reflectance	0.1
	Window light transmittance	0.812
	Properties of room surface	
	Wall light reflectance	40%
	Ceiling light reflectance	40%
	Floor light reflectance	30%
	Obstruction outside the window	
	Obstruction outside the window	0
	Obstruction height	0
	Obstruction angle	
Average daylight factor - using the formula (1)		3.87%
Average daylight factor - simulation – design builder		3.89%
Error %		0.02%

7.6.5. Evaluation of the existing situation

A preliminary analysis phase, if correctly performed, can provide a solid basis for an appropriate intervention plan commensurate with the needs of the occupants. In the beginning, the unverified requirements were detected, which help to fulfill existing laws. According to the Jordanian code, WWR should not be less than 15% in living areas and 10% in service areas. Thus, the existing WWR in the living area and guest room did not meet the requirements .

Evaluating the simulation results of the existing situation helps determine and classify the visual discomfort problems at room scale. Then, the main goals are identified for the current problems. In this case, there are two main goals:

1 Goal 1: Increasing daylight to achieve optimum interior lighting in the rooms that showed a low average daylight factor
2 Goal 2: Reducing daylight and improving the distribution of daylight in the rooms that showed a high average daylight factor .

As explained above, there is a need to improve daylight performance in buildings to maintain occupants' comfort and enhance buildings' energy efficiency. Improving daylighting performance requires the control of several design variables expected to make a significant change. Therefore, detailed simulation analyses have been performed to investigate the effect of retrofit strategies on existing multi-story residential buildings.

7.6.5. Results of Case 4 after retrofitting

The simulations were performed again after applying the retrofit strategies. The results of the different design conditions were compared and analyzed before and after applying the retrofit strategies

- Proposed Living room & Guest room

As mentioned before, the living room and guest room are deep-plan rooms without windows. Consequently, the rooms will be dark and cannot be naturally illuminated by external windows. Therefore, in the retrofitting phase of the interior spaces, the interior layout was verified in terms of usability and flexibility to optimize the living spaces and guest room, create new common areas. Figure 7.79 shows one of the alternative internal distribution proposals that was evaluated.

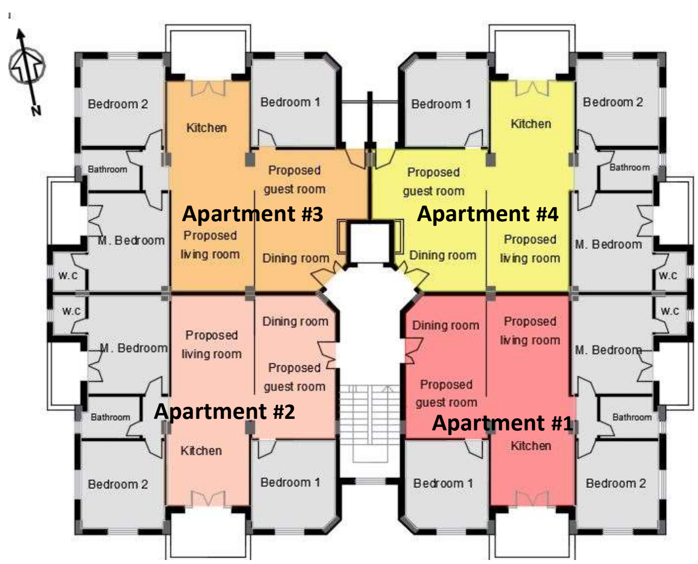


Figure 7.79-Represents the typical plan of the case study building type 2 after applying the retrofit strategies

Goal 1: Increasing daylight to achieve optimum internal daylighting.

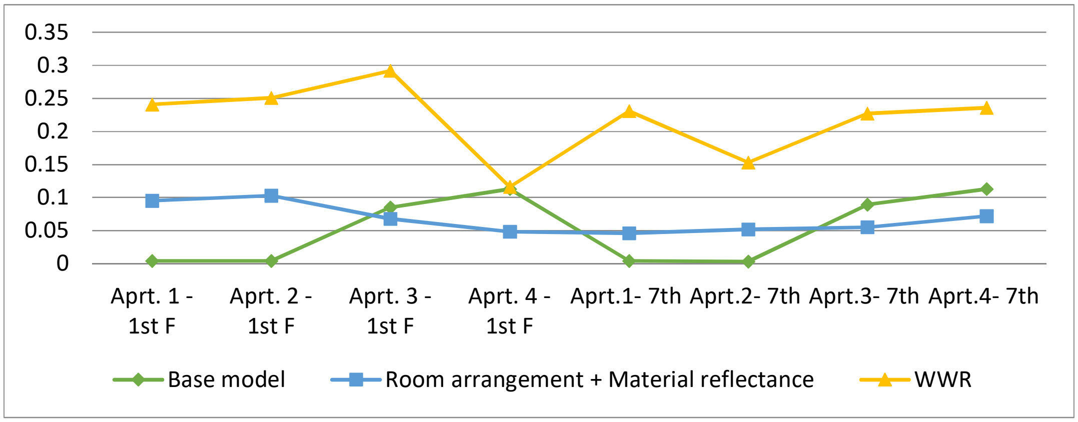


Figure 7.80 Average DF results in the proposed living room after applying retrofit strategies.

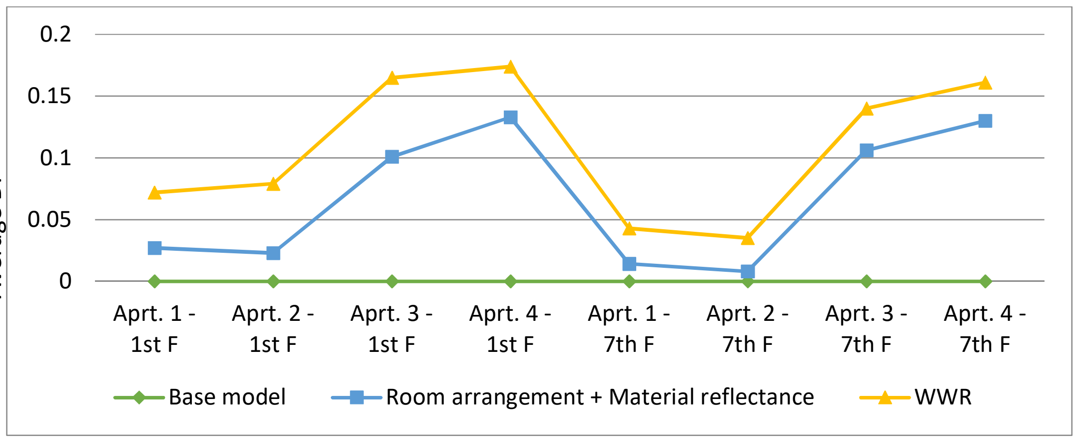


Figure 7.81 Average DF results in the proposed guest room after applying retrofit strategies.

Initially, the adjustments were made to the floor plan. One of the significant modifications to achieve high-quality housing is to remove the block wall between the guest room and the living room, then add a movable partition for privacy .

Other modifications were switching the location of the living room and guest room. Then, the block wall between the proposed kitchen and living room was removed, see figure 7.79.

Simulation results after applying retrofit strategies and following visual comfort chart 1 are presented below:

1. Material reflectance had been investigated to achieve an appropriate illuminance level. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, see p.38. The average DF results in the proposed guest room and proposed living room after modification floor plan and changed material reflectance are

presented in figures 7.80 & 7.81. In general, the average DF was increased in the proposed living room in apartments #1 and #2, but the average DF was decreased in apartments # 3 and # 4. On the other hand, the average DF was increased in all apartments in the proposed guest room. As shown, the level of illumination has increased systematically but still did not meet the required standard .

2. The facade retrofit level 2* (WWR) was applied in the kitchen. The glazed area was modified which affected the illumination level inside the proposed guest room and proposed living room. When the WWR was increased from 15% to 50% daylight distribution increased and the illuminance level increased systematically but still did not meet the required standard.

Table 7.30: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**[7]							
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 1 7th F	Apartment 2 7th F	Apartment 3 7th F	Apartment 4 7th F
Proposed Living room	Base model	0.26% (DF 0.004%)	0.26% (DF 0.004%)	5.6% (DF 0.08%)	7.5% (DF 0.11%)	0.26% (DF 0.004%)	0.20% (DF 0.003%)	5.93% (DF 0.08%)	7.53% (DF 0.11%)
	Changing material reflectance + room arrangement	6.33% (DF 0.09%)	6.86% (DF 0.10%)	4.53% (DF 0.06%)	3.2% (DF 0.04%)	3.06% (DF 0.046%)	3.46% (DF 0.05%)	3.66% (DF 0.05%)	4.8% (DF 0.07%)
	Adjusting WWR	16.0% (DF 0.24%)	16.7% (DF 0.25%)	19.4% (DF 0.29%)	7.7% (DF 0.11%)	15.4% (DF 0.23%)	10.2% (DF 0.15%)	15.13% (DF 0.22%)	15.73% (DF 0.23%)
Proposed guest room	Base model	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)
	Changing material reflectance+ room arrangement	1.8% (DF 0.027%)	1.5% (DF 0.023%)	6.7% (DF 0.10%)	8.8% (DF 0.13%)	0.93% (DF 0.01%)	0.53% (DF 0.008%)	7.06% (DF 0.106%)	8.6% (DF 0.13%)
	The effect of changing WWR	4.8% (DF 0.072%)	5.2% (DF 0.079%)	11.0% (DF 0.16%)	11.6% (DF 0.17%)	2.86% (DF 0.04%)	2.3% (DF 0.03%)	9.3% (DF 0.14%)	10.7% (DF 0.16%)

[7] Percentage of daylight enhancement is compatible with the average daylight factor for different types of rooms in residential buildings (according to the Jordanian code issued in cooperation with the Jordanian Green Building Council) for adequate natural lighting

- Kitchen

Goal 1: Increasing daylight to achieve optimum internal daylighting .

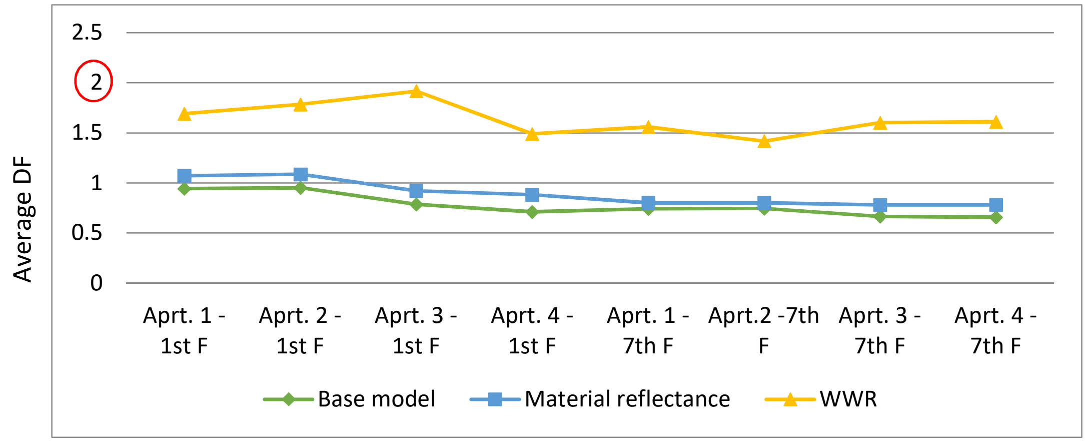


Figure 7.82 Average DF results in the kitchen after applying retrofit strategies.

1. Material reflectance had been investigated to achieve an appropriate illuminance level. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, see p.38. Figure 7.82 shows how the average DF in the kitchen was increased after the material reflectance was changed. The level of illumination increased systematically but still did not meet the required standard.
2. The facade retrofit level 2* (WWR) was applied in the kitchen. The glazed area has been affecting the level of illumination within the proposed guest room and the proposed living room. When the WWR was increased from 15% to 50% the daylight distribution increased and the luminance level increased systematically but still did not meet the required standard except for the kitchen in Apartment # 3 on the 1st floor. (Kitchen AV DF = 2%

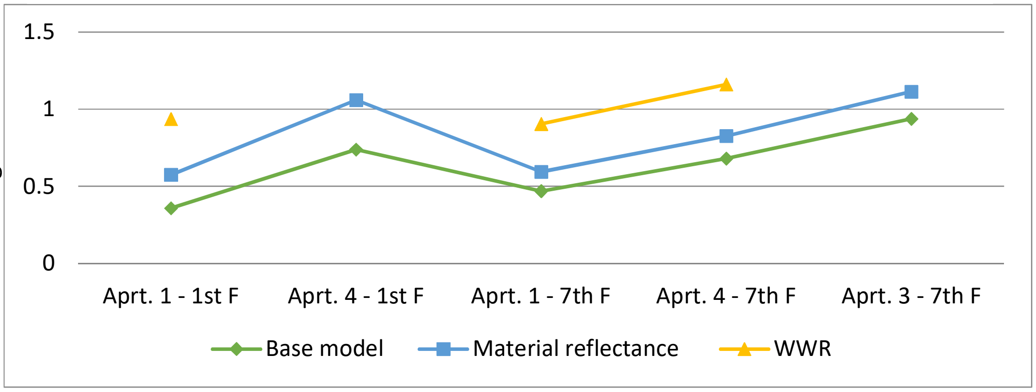
Table 7.31: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**							
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 1 7th F	Apartment 2 7th F	Apartment 3 7th F	Apartment 4 7th F
Kitchen	Base model	47.15% (DF 0.94%)	47.65% (DF 0.95%)	39.4% (DF 0.78%)	35.6% (DF 0.71%)	37.1% (DF 0.74%)	37.2 (DF 0.74%)	33.2% (DF 0.66%)	32.9% (DF 0.65%)
	Changing material reflectance	53.6% (DF 1.07%)	54.3% (DF 1.08%)	46.1% (DF 0.92%)	44.1% (DF 0.88%)	40.1% (DF 0.80%)	40.0% (DF 0.80%)	39.0% (DF 0.78%)	39.0% (DF 0.78%)
	Adjusting WWR	84.6% (DF 1.69%)	89.2% (DF 1.78%)	95.7% (DF 1.91%)	74.55% (DF 1.49%)	77.9% (DF 1.55%)	70.8% (DF 1.41%)	80.0% (DF 1.6%)	80.5% (DF 1.61%)

- Master Bedroom

Goal 1: Increasing daylight to achieve optimum internal daylighting .

Figure 7.83 Average DF results in the master bedroom after applying retrofit strategies.



1. Material reflectance had been investigated to achieve an appropriate illuminance level. The simulation was carried out by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, see p.38. Figure 7.83 shows how the average DF in the master bedroom in apartments #1 and #4 was increased after the material reflectance was changed. The illuminance level increased systematically but still did not meet the required level except for the master bedroom in apartment #4 on the 1st floor.
2. The facade retrofit level 2* (WWR) was applied master bedroom in apartments #1 and #4. The glazed area has been affecting the level of illumination within the master bedroom. When the WWR was increased from 23.8% to 48% the daylight distribution increased and the illuminance level increased systematically. Generally, looking at figure 7.83, in all rooms the average DF results approximately met the required level (Bedroom AV DF = 1%)

Table 7.32: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**				
		Apartment 1 1st F	Apartment 4 1st F	Apartment 1 7th F	Apartment 3 7th F	Apartment 4 7th F
Master bedroom	Base model	35.9% (DF 0.35%)	74.0% (DF 0.74%)	46.9% (DF 0.46%)	93.9% (DF 0.93%)	68.1% (DF 0.68%)
	Changing material reflectance	57.6% (DF 0.57%)	105.9% (DF 1.05%)	59.4% (DF 0.59%)	111.5% (DF 1.11%)	82.7% (DF 0.82%)
	Adjusting WWR	93.6% (DF 0.93%)		90.6% (DF 0.90%)		116.2% (DF 1.16%)

Goal 2: Reducing daylight and improving the distribution of daylight.

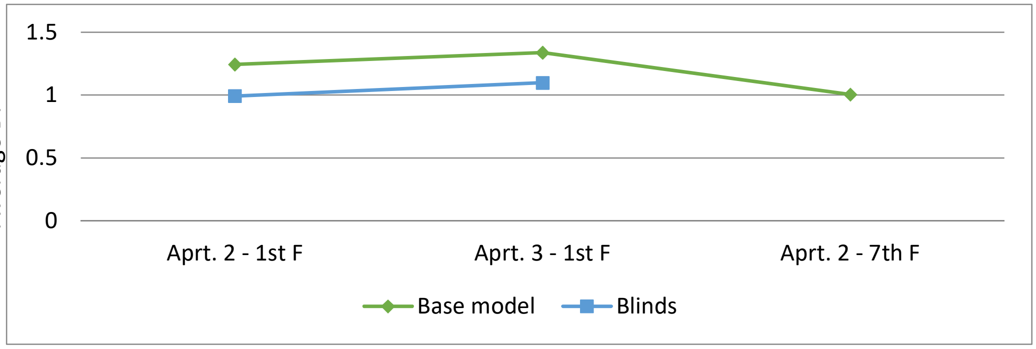


Figure 7.84: Average DF results in the master bedroom after applying retrofit strategies.

The master bedroom in apartments #2 and #3 on the 1st floor show a high level of average DF. As shown in figure 7.84, by using blinds that provide glare-free daylight, while allowing a partial view. The average DF was reduced and the distribution of daylight was improved.

Table 7.33: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**		
		Apartment 2 1st F	Apartment 3 1st F	Apartment 2 7th F
Master bedroom	Base model	80.4% (DF 1.24%)	74.7% (DF 1.33%)	99.7% (DF 1.00%)
	Using blinds	100.0% (DF 0.99%)	91.0% (DF 1.09%)	

- Bedroom 1

  Goal 2: Reducing glare and improving the distribution of daylight

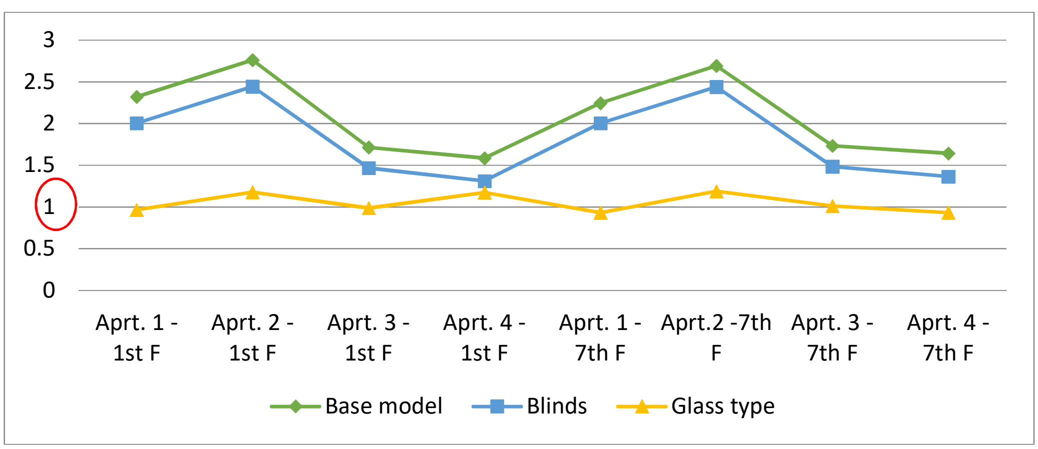


Figure 7.85: Average DF results in the bedroom 1 after applying retrofit strategies.

The bedroom 1 in all apartments shows a high level of average DF, see figure 7.85

1. After using blinds (blinds with low or medium reflectivity slats – curtains) that provide daylight free of glare، while allowing a partial view. The average DF reduced and daylight distribution improved for the bedroom 1, but still did not meet the required standard. Table 7.34 shows the percentage of daylight enhancement after using blinds.
2. The windows have also been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as required. As shown in figure 7.85, the average DF results approximately met the required level (bedroom 1 AV DF = 1%).

Table 7.34: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**							
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 1 7th F	Apartment 2 7th F	Apartment 3 7th F	Apartment 4 7th F
Bedroom 1	Base model	43.0% (DF 2.32%)	36.1% (DF 2.76%)	58.2% (DF 1.71%)	63.0% (DF 1.58%)	44.5% (DF 2.24%)	37.1% (DF 2.69%)	57.6% (DF 1.73%)	60.8% (DF 1.64%)
	Using blinds	49.9% (DF 2.00%)	40.8% (DF 2.44%)	68.1% (DF 1.46%)	76.2% (DF 1.31%)	49.9% (DF 2.00%)	40.9% (DF 2.44%)	67.2% (DF 1.48%)	73.2% (DF 1.36%)
	replacing glass type	103.4% (DF 0.96%)	84.8% (DF 1.17%)	101.2% (DF 0.98%)	85.1% (DF 1.17%)	107.2% (DF 0.93%)	84.1% (DF 1.18%)	98.6% (DF 1.01%)	107.2% (DF 0.93%)

- Bedroom 2

Goal 2: Reducing daylight and improving the distribution of daylight

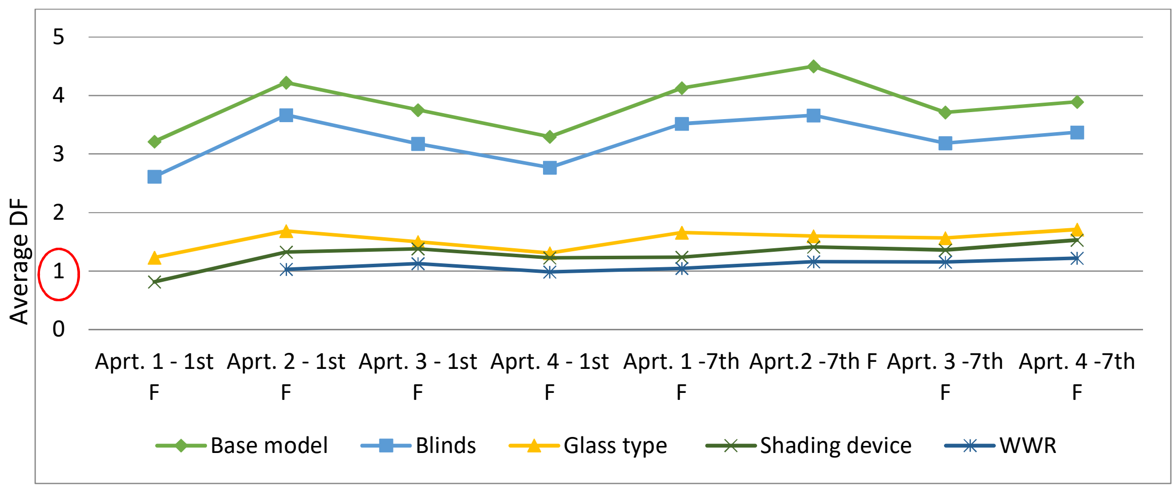
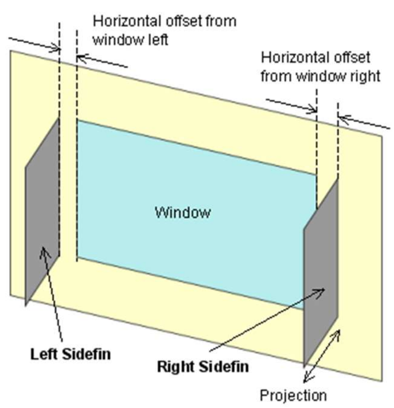


Figure 7.86: Average DF results in the bedroom 2 after applying retrofit strategies.

Goal 2: Reducing daylight and improving the distribution of daylight

The bedroom 2 in all apartments shows a high level of average DF, see figure 7.86.

1. After using blinds (blinds with low or medium reflectivity slats – curtains) that provide daylight free of glare, while allowing a partial view. The average DF reduced and daylight distribution improved for the bedroom 2, but still did not meet the required standard. Table 7.35 shows the percentage of daylight enhancement after using blinds.
2. The windows have also been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as required.
3. The facade retrofit level 2 (adding a shading device) has been examined in the bedroom 2. A shading device has been added to the west, east and south windows apartments. The shading device used to control intense direct sunlight and used to control glare to ensure comfortable interior spaces. In this case, assumed the side fins (SF) projection dimensions are 50cm for west and east windows. The overhang projection dimensions are 50cm for south windows. The illuminance level reduced systematically but still did not met the required level. Thus the adjustment of the WWR was applied, see point 4 below



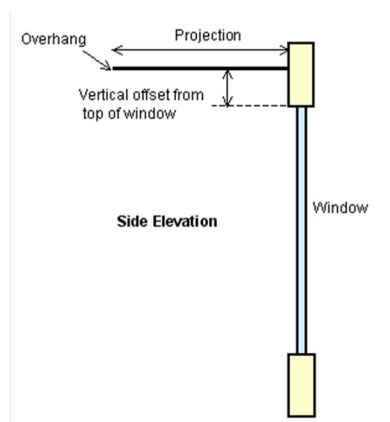


Figure 7.86*: Photo to the left represent east and west shading device. The photo to the right represent southern shading device.

4. The facade retrofit level 3 (Adjusting WWR) was applied in the bedroom 2. When the WWR was reduced from 16.3% to 14.0% and from 15.5% to 13.3% the illuminance level reduced systematically. Generally, the average daylight factor results in all rooms approximately met the required level (bedroom AV DF = 1%)

Table 7.35: The percentage of daylight enhancement

Room activities	Retrofit Strategies	The percentage of daylight enhancement							
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 1 7th F	Apartment 2 7th F	Apartment 3 7th F	Apartment 4 7th F
Bedroom 2	Base model	31.1% (DF 3.21%)	23.6% (DF 4.22%)	26.6% (DF 3.75%)	30.3% (DF 3.29%)	24.2% (DF 4.13%)	22.2% (DF 4.49%)	26.9% (DF 3.71%)	25.7% (DF 3.89%)
	Using blinds	38.1% (DF 2.61%)	27.2% (DF 3.66%)	31.4% (DF 3.17%)	36.0% (DF 2.77%)	28.4% (DF 3.51%)	27.3% (DF 3.66%)	31.3% (DF 3.18%)	29.6% (DF 3.37%)
	replacing glass type	81.1% (DF 1.23%)	59.3% (DF 1.68%)	66.7% (DF 1.49%)	76.4% (DF 1.30%)	60.3% (DF 1.65%)	62.6% (DF 1.59%)	63.8% (DF 1.56%)	58.4% (DF 1.71%)
	Adding shading device	122.5% (DF 0.81%)	75.4% (DF 1.32%)	72.5% (DF 1.37%)	81.4% (DF 1.22%)	80.8% (DF 1.23%)	70.9% (DF 1.41%)	73.4% (DF 1.36%)	65.3% (DF 1.53%)
	Adjusting WWR		97.1% (DF 1.02%)	88.5% (DF 1.13%)	101.4% (DF 0.98%)	95.7% (DF 1.04%)	86.4% (DF 1.15%)	86.7% (DF 1.15%)	81.7% (DF 1.22%)

7.6.7. Conclusion

The local residential retrofit framework with proposed retrofit strategies have been tested to find the effect on enhancing the performance of natural daylight in multi-story buildings. The retrofit process and the results of natural daylight enhancements for case study 4 are shown below:

1. The process began with gathering information for the existing building .
2. To diagnostics and identification of discomfort areas:
   a) Firstly, Communication with the resident during the pre-retrofitting process was done to understand the existing building. In case study 4, six residents had been selected to answer the questionnaire to know the general satisfaction with the apartment .
   b) Secondly, simulation programs in the early stages of the pre-retrofit process were used to define the existing building problems, the results were shown in item 7.6.3.
3. Evaluation of the existing situation to determine and classify the visual discomfort problems.
   a) At building scale: The characteristics of the existing building and the unverified requirements were detected, which help to fulfill existing laws. In this case, the existing WWR in the living area and guest room did not meet the requirements, according to the Jordanian code, WWR should not be less than 15% in living areas, and 10% in the service areas. In addition, the optimal spatial retrofit strategies were defined for improving energy performance and optimizing the quality of internal spaces and distribution. In this case, rooms were joined together to create new common areas.
   b) At room scale: The main goals were identified for the existing problems. In this thesis, two are three main goals as mentioned in the visual comfort chart p.45. Therefore, in

this case, goal 1 was increasing daylight to achieve optimum interior lighting, and goal 2 was reducing daylight and improving the distribution of daylight.

4. Identifying passive retrofit strategies and selecting the best retrofit action. In general, the results show that the following proposed passive retrofit strategies of the building creates spaces that meet the requirements of the code, as shown in the table 7.36 below

Table 7.36: The percentage of daylight enhancement

Room activities	**Retrofit Strategies**	**The percentage of daylight enhancement**[8]							
		Apartment 1 1st F	Apartment 2 1st F	Apartment 3 1st F	Apartment 4 1st F	Apartment 1 7th F	Apartment 2 7th F	Apartment 3 7th F	Apartment 4 7th F
Proposed Living room	Base model	0.26% (DF 0.004%)	0.26% (DF 0.004%)	5.6% (DF 0.08%)	7.5% (DF 0.11%)	0.26% (DF 0.004%)	0.20% (DF 0.003%)	5.93% (DF 0.08%)	7.53% (DF 0.11%)
	After retrofitting	16.0% (DF 0.24%)	16.7% (DF 0.25%)	19.4% (DF 0.29%)	7.7% (DF 0.11%)	15.4% (DF 0.23%)	10.2% (DF 0.15%)	15.13% (DF 0.22%)	15.73% (DF 0.23%)
Proposed guest room	Base model	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)	0% (DF 0.0%)
	After retrofitting	4.8% (DF 0.072%)	5.2% (DF 0.079%)	11.0% (DF 0.16%)	11.6% (DF 0.17%)	2.86% (DF 0.04%)	2.3% (DF 0.03%)	9.3% (DF 0.14%)	10.7% (DF 0.16%)
Kitchen	Base model	47.15% (DF 0.94%)	47.65% (DF 0.95%)	39.4% (DF 0.78%)	35.6% (DF 0.71%)	37.1% (DF 0.74%)	37.2 (DF 0.74%)	33.2% (DF 0.66%)	32.9% (DF 0.65%)
	After retrofitting	84.6% (DF 1.69%)	89.2% (DF 1.78%)	95.7% (DF 1.91%)	74.55% (DF 1.49%)	77.9% (DF 1.55%)	70.8% (DF 1.41%)	80.0% (DF 1.6%)	80.5% (DF 1.61%)
Master bedroom	Base model	35.9% (DF 0.35%)	80.4% (DF 1.24%)	74.7% (DF 1.33%)	74.0% (DF 0.74%)	46.9% (DF 0.46%)	99.7% (DF 1.005%)	93.9% (DF 0.93%)	68.1% (DF 0.68%)
	After retrofitting	93.6% (DF 0.93%)	100.0% (DF 0.99%)	91.0% (DF 1.09%)	105.9% (DF 1.05%)	90.6% (DF 0.90%)		111.5% (DF 1.11%)	116.2% (DF 1.16%)
Bedroom 1	Base model	43.0% (DF 2.32%)	36.1% (DF 2.76%)	58.2% (DF 1.71%)	63.0% (DF 1.58%)	44.5% (DF 2.24%)	37.1% (DF 2.69%)	57.6% (DF 1.73%)	60.8% (DF 1.64%)
	After retrofitting	103.4% (DF 0.96%)	84.8% (DF 1.17%)	101.2% (DF 0.98%)	85.1% (DF 1.17%)	107.2% (DF 0.93%)	84.1% (DF 1.18%)	98.6% (DF 1.01%)	107.2% (DF 0.93%)
Bedroom 2	Base model	31.1% (DF 3.21%)	23.6% (DF 4.22%)	26.6% (DF 3.75%)	30.3% (DF 3.29%)	24.2% (DF 4.13%)	22.2% (DF 4.49%)	26.9% (DF 3.71%)	25.7% (DF 3.89%)
	After retrofitting	122.5% (DF 0.81%)	97.1% (DF 1.02%)	88.5% (DF 1.13%)	101.4% (DF 0.98%)	95.7% (DF 1.04%)	86.4% (DF 1.15%)	86.7% (DF 1.15%)	81.7% (DF 1.22%)

The outcome results show that the level of natural daylight was enhanced in apartments when implementing the proposed retrofit strategies. The result of enhancement ranges between 51% - 71%.

[8] Percentage of daylight enhancement is compatible with the average daylight factor for different types of rooms in residential buildings (according to the Jordanian code issued in cooperation with the Jordanian Green Building Council) for adequate natural lighting.

From the experiments of simulating a multi-story residential building (Case 4), this research concluded the following:

(1) Daylight varies according to the floor levels (Ground floor, First floor, etc.) of the building with respect to orientation. In case 4, sometimes the seventh-floor apartments that oriented to the east & south showed a higher level of light than the first-floor apartments that oriented to the west & north. This was caused by the site's conditions with the surrounding buildings, where the surrounding buildings formed an obstruction on access daylight. The stage of spatial retrofit of the interior spaces was complex and depended on the needs of the residents and the architect's vision to solve the problems of discomfort.

(2) As shown, the depth of the room affects the natural illumination level inside. Thus, it is difficult to obtain sufficient daylighting by side windows if the room depth exceeds 2.5 times the window height. In this case, daylight illuminance levels drop 5.6 meters away from side windows. The depth of rooms in all apartments less than 5.6 except for the kitchen and proposed living room, considered as a deep room. The dining room and proposed guest room are also considered deep rooms without windows. As shown by applying the retrofitting strategies - optimizing the living spaces and create new common areas- the quality of use of the apartments was improved. But in the rooms with a great depth of more than 6m, it did not meet the requirements of the code.

(3) Simulations of sunlight penetration with shading devices need to be conducted during the redesign stage to guarantee that occupants are protected from direct sunlight throughout the day. (1) It is always essential to consider and include proper external and internal solar shading to optimize visual and thermal comfort. As shown in bedroom 2, a vertical shading device has been added to the east and west window. In contrast, a horizontal shading device has been added to the south.

(4) A balcony and geometry are one of the most affecting parameters on the daylight conditions of the adjacent space. The balcony reduces the daylight in the adjacent space. Therefore, it is always essential to take into account all affecting aspects to have a well-performed.

(5) The type of glazing and window gives major significance to the performance of natural light and the thermal performance of adjacent space. Therefore, the windows have been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as needed.

(6) The size and placement of windows must always be considered together with the building's total energy use and specific daylight requirements. Each window on each floor and orientation should have its particular design from window to wall ratio. As shown in bedroom

2, when the WWR was reduced, the illuminance level systematically reduced, and the average daylight factor results approximately met the required level.

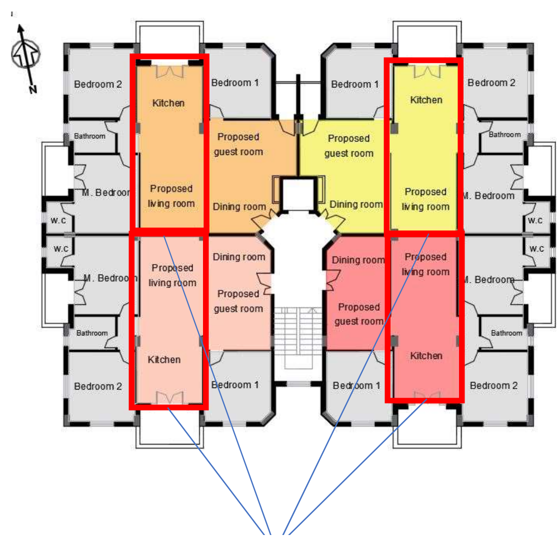
(7) It is observed that less reflective wall finishes reduced the reflectivity making the space more dull and dark

Few modifications in the existing building can improve considerable indoor daylighting. The results prove that applying the retrofit strategies enhances daylight performance by 71% for apartment #1, 66% for apartment #2, 68% for apartment #3, and 64% for apartment #4 on the first floor. While on the seventh floor, daylight performance enhanced by about 65% for apartment #1, 51% for apartment #2, 67% for apartment #3 and 69% for apartment #4 .

Excess glare and heat should be avoided. This can be achieved by controlling solar radiation using a shading device strategy. Therefore, this thesis concluded that a combination of strategies (such as shading device, light shelf, and blinds) can have an important role in creating a desirable environment based on daylight quality as well as thermal comfort. Furthermore, most people prefer daylight due to contact with the outside world which is provided by windows.

- Deep Plan

The kitchen and proposed living room are considered a deep plan. This room with a depth of more than 6 m.Thus it is difficult to obtain sufficient daylighting by windows. By applying retrofit strategies (adjusting WWR) and open spaces, the illuminance level enhanced but did not meet the requirements of the code. As shown, this room with a depth of more than 6 m. Therefore, in this case, it might not be very feasible to rely only on passive strategies. The balcony also reduction the daylight in the adjacent space.



Deep plan

7.7. Thermal comfort check

All simulation trials were conducted while the HVAC system is turned on - Electricity from the grid was used for cooling and natural gas for heating, natural ventilation was deactivated. Table 7.37 shows the constant input parameters used.

Table 7.37: Simulation constant parameters

Natural ventilation	Inactive
Mechanical ventilation	Active
Domestic hot water DHW	Inactive
Heating system Heating set point	natural gas 22 C
cooling system cooling set point	Electricity from grid 24 C
Air infiltration	0.7 ac/h

Table 7.38 shows an example of energy consumption for heating and cooling before and after applying retrofit strategies. The simulation results show that the annual heating and cooling loads decreased for the bedrooms and kitchen after enhancing the natural daylight when the average daylight factor decrease. In contrast, the simulation results show that the annual heating and cooling loads for the living room and guest room increased after enhancing the natural daylight when the average daylight factor increased, but the results are relatively closed.

Table 7.38: simulation results of the heating and cooling loads and average daylight factor before and after applying retrofit strategies

	Total cooling and heating loads (kWh) before retrofit strategies	Total cooling and heating loads (kWh) after retrofit strategies	Average daylight factor Before retrofit strategies	Average daylight factor after retrofit strategies
		Case 2		
Master bedroom	1418.09	1247.47	4.2%	1.2%
Bedroom 1	1035.84	1019.277	2.5%	0.8%
Bedroom 2	1086.36	913.82	0.68%	0.91%
Kitchen	1110.04	966.07	2.79%	1.90%
Living room	1396.5	1511.5	2.30%	1.87%
Guest room	994.39	997.19	0.48%	0.96%

7.8. Economic study (Cost estimation)

The retrofitting process was conducted by accumulative and successive steps, such that, the result of each step of retrofitting strategies was used as a simulation input for steps next to it. In this way, the final result would be the total of all proposed retrofit strategies.

In contrast, this section examines the effect of each retrofitting strategy isolated from other strategy taking into account the economic feasibility. The balance between the cost of the retrofit and the expected benefits may determine whether a specific retrofit plan is carried out.

Table 7.39 shows the detailed costs for case 2 - apartment 1 on the first floor. A comparison between the proposed cumulative retrofit strategies and each proposed retrofit strategy isolated from other strategies was conducted to investigate the best way to enhance natural daylight in the existing residential building considering economic feasibility.

Table 7.39: The detailed costs for proposed retrofit strategies (case 2 - apartment 1 on the first floor)

Room	**Proposed retrofit strategies**	**Cost unit with installation**	**Accumulative Daylight factor (DF%) result**		**Daylight factor result for each strategy**	
			Average daylight factor	**Total cost**	**Average daylight factor**	**Total cost**
Master bedroom	Base model		3.759%		3.759%	
	Level 1 – Using Blinds	125 NIS/ m	3.467%	1000NIS	3.467%	1000 NIS
	Level 2- adding shading device + replacing glass type	240 NIS/ m2 + 400 NIS/ m2	1.363%	1760NIS	1.360%	1760NIS
	Level 3 – adjusting WWR	1500 NIS Without installation window	1.088%	4040 NIS	1.147%	4040NIS
Final result for master bedroom			1.088%	6800 NIS	1.14%	4040 NIS
Bedroom 1	Base model		1.815%		1.815%	
	Level 1 – Using Blinds	125 NIS/ m	1.556%	500NIS	1.556%	500NIS
	Level 2- adding shading device + replacing glass type	240 NIS/ m2 + 400 NIS/ m2	1.139%	1120NIS	1.15%	1120NIS
	Level 3 – adjusting WWR	1500 NIS Without installation window	-		1.02%	2020 NIS
Final result for bedroom 1			1.139%	1620NIS	1.15% or 1.02%	1120 NIS 2020 NIS
Bedroom 2	Base model		0.892%		0.892%	
	Level 1*- Changing material reflectance	Painting 20 NIS/m2 Tilling 100 NIS/m2	1.166%	800 NIS 2000 NIS	-	0 NIS

Final result for bedroom 2			1.166%	2800 NIS	0.892%	0 NIS
Kitchen	Base model		1.651%		1.651%	
	Changing material reflectance	Tilling 100 NIS/m2	1.904%	1700 NIS for wall	-	
	Level 2* – adjusting WWR	1500 NIS Without installation window	-		1.928%	2500 NIS
Final result for kitchen			1.904%	1700 NIS	1.928%	2500 NIS
Living room	Base model		1.354%		1.354%	
	Changing material reflectance + room arrangement	Painting 20 NIS/m2 Tilling 100 NIS/m2 Room arrangement 2000 NIS	1.673%	660 NIS 1900 NIS 2000 NIS	1.673%	660NIS 1900 NIS 2000 NIS
	Adding light shelf	240 NIS/ m2	1.818%	1700 NIS	1.57%	3700 NIS With room arrangement
	adding shading device	240 NIS/ m2	1.622%	480 NIS		
Final result for living room			1.622%	6740 NIS	1.57%	3700 NIS
Guest room	Base model		0.005%		0.005%	
	Changing material reflectance+ room arrangement	Painting 20 NIS/m2 Tilling 100 NIS/m2 Room	0.087%	660 NIS 1600 NIS	0.087%	660 NIS 1600 NIS
	The effect of using a light shelf		0.097%		0.006%	
	The effect of adding a shading device		0.096%			
Final result for guest room			0.096%	2260 NIS	0.006%	0 NIS

When comparing the cumulative daylight factor (DF) strategies to the results of the daylight factor (DF) for each strategy. DF for each strategy seems to be cost-effective and achieves the daylight factor requirement for each room. Table 7.39 shows that the cost of applying the proposed retrofit strategies for each strategy for all rooms is less than the cumulative strategies, excluding the kitchen. Changing the reflection of the tiles in the kitchen depends on the desire of its occupants.

Recommendations and Conclusion
Introduction

This study was conducted to enhance natural daylighting in the existing multi-story residential buildings, taking into account thermal comfort to create high-quality spaces. This chapter, as the last chapter, indicates the overall thesis findings achieved through the previous chapters. Therefore, firstly, the implications and contributions of the proposed strategies are discussed to enhance daylighting performance. The developed retrofit framework is also discussed, especially the proposed visual comfort chart. Secondly, general guidelines and recommendations were presented for enhancing the natural daylight in existing multi-story residential buildings. Finally, challenges that are facing architects and some future studies are presented related to this research.

8.1 Findings

This thesis is divided into four parts, which discussed issues related to enhancing the performance of natural daylight in existing multi-story residential buildings, especially in the Mediterranean climate zone (Hebron city - Palestine) .

The four parts build on each other; **the first part** was the introduction, which included developing the research proposal, explaining the problem statements, formulating a research question, explaining the research goals and aims, and developing the research methodology. (Chapter 1)

The second part of the thesis focused on the following:

Firstly, it covered literature relevant to an understanding of the building retrofit method. It also presented background information on indoor environmental quality improvement, focusing on enhancing the performance of natural daylight in existing multi-story residential buildings. (Chapter 2)

Many passive retrofitting actions have been systematically organized into the framework to achieve the required illumination level inside the rooms. A different level of the passive strategies was proposed. The actions are provided into two contexts of facade retrofitting and spatial retrofitting. Decision-makers, by following the visual comfort chart 1 to improve the performance of natural daylight in relation to the problem, can determine the required actions. (For visual comfort chart 1, see page 45). (Chapter 3)

Secondly, depending on the literature reviews, a local residential retrofit framework for multi-story buildings was proposed to identify, implement, and apply the most efficient retrofit scenarios that help decision-makers in the retrofit process. (For the visual comfort retrofit roadmap process, see chapter

4- p54). Thirdly, a general study was conducted for the city of Hebron to create a database for building information. It includes four main activities: 1- site surveys, 2- interviews, 3- case studies selection and analysis, 4- questionnaires. (Chapter 5,6)

In the **third part** of this thesis, four typical multi-story residential buildings were studied and analyzed regarding daylighting and discomfort problems. The purpose is to compare the performance of multi-story residential buildings built at different times in terms of the performance of natural daylight. Also, to exam the effectiveness of different combinations of natural daylight and energy efficiency retrofit strategies and technologies. (Chapter 7)

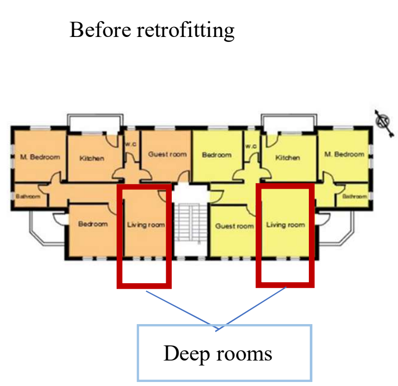
The **fourth and last part** was conclusions, findings, and recommendations. This thesis enhanced the natural daylight in multi-story residential buildings were built after 1993 in Hebron city by providing a local residential retrofit framework that helped support designers in early design phases. It also provided detailed guidance and retrofit strategies to improve the performance of natural daylight, taking into account thermal comfort.

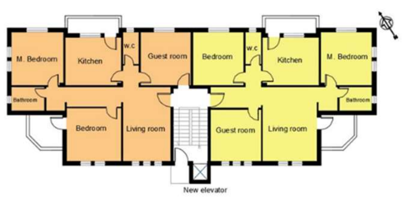
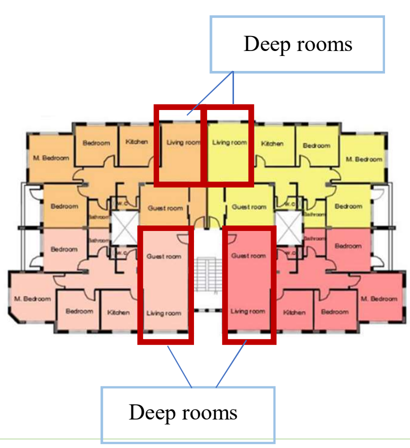
8.2 Conclusion and Discussion

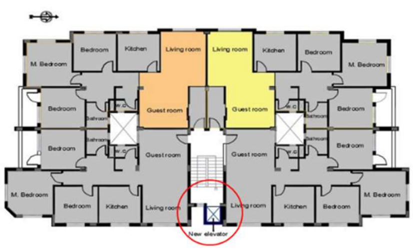
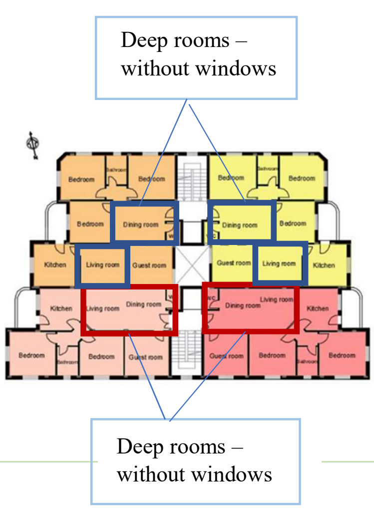
This thesis enhanced the natural daylight in multi-story buildings by developed and discussed a local residential retrofit framework for the visual comfort process to aid the architects in taking steps towards achieving the goals and objectives of comfort housing provision.

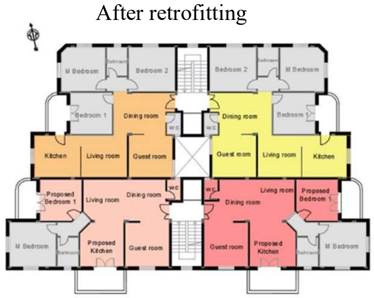
Four typical multi-story residential buildings had been studied and analyzed with relation to daylighting and discomfort problems. Table 8.1 below represents case studies problems and solutions.

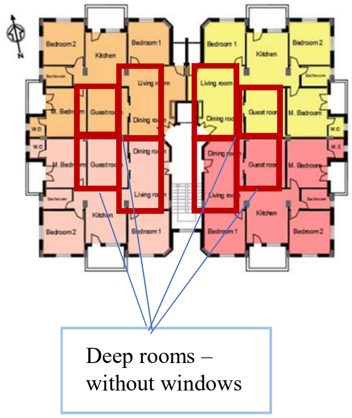
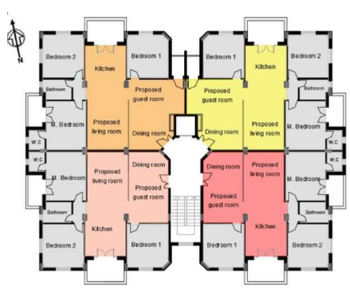
Table 8.1 presents case studies problems and solutions.

Main typical types of the selected buildings sample	Description	Problems	Solutions
Case study 1 "Type 1" **Two apartments on each floor "Extended family residential building"**		**General problems** There were no elevators in the buildings that built between 1993-1999 **Visual comfort problems** - Some rooms show a low level of natural light - Other rooms show a high level of natural light **Deep room problem** If the room depth exceeds 2.5 times the window height, the daylight illuminance levels drop. Thus, according	**Building scale** The unverified requirements should be detected. It could be by fulfilling existing laws and regulations. The optimal spatial retrofit strategies should be defined to optimizing the quality of internal spaces and distribution. It could be by joining rooms together to create new common areas (Resident needs) and /or by adding

	After retrofitting 	to the height of windows in multi-story residential buildings in Hebron city the daylight illuminance levels drop after depth 4.375 - 5.125 m **Some Problems from the residents' point of view** The lighting level was better before the surrounding buildings were constructed Residents were satisfied with the apartment layout, but some users need extra space to feel more comfortable Residents expressed their desire to install an elevator	spaces to apartments; such as (adding new balconies, etc.) (Resident needs). "Rooms that showed a high average daylight factor." **Façade scale** - Use blinds that provide glare-free while still allowing partial visibility - Use a shading device to control glare - Replacing window glass type - Adjusting WWR Rooms that showed a " low average daylight "factor **Room-scale** - Joining rooms together to create new common areas - Bright, matt finishing, and top reflective surface materials should be used **Facade-scale** - Use light shelves - Adjusting WWR
Case study 2 "Type 3" **Four apartments o n each floor "Investment resid ential buildings"**	Before retrofitting 	**General problems** In this case, the area of the light well was less than 10m2. If the room has one window open on light well. the light well area should be more than 10m2, to provide appropriate natural daylight. There was no elevator in this building **Visual comfort problems** - Some rooms show a low level of natural light - Other rooms show a high level of natural light	**Building scale** The unverified requirements should be detected. It could be by fulfilling existing laws and regulations. The optimal spatial retrofit strategies should be defined to optimizing the quality of internal spaces and distribution. It could be by joining rooms together to create new common areas (Resident needs) and /or by adding spaces to apartments; such as (adding new

	After retrofitting 	**Deep room problem** If the room depth exceeds 2.5 times the window height, the daylight illuminance levels drop. Thus, according to the height of windows in multi-story residential buildings in Hebron city the daylight illuminance levels drop after depth 4.375 - 5.125 m **Some Problems from the residents' point of view** The residents who lived on the first and second floors reported that the guest room was partially dark . The lighting level was better before the surrounding buildings were constructed. Residents were satisfied with the apartment layout, some users need to combine rooms in an open plan design	balconies, etc.) (Resident needs). "Rooms that showed a high average daylight factor." **Façade scale** - Use blinds that provide glare-free while still allowing partial visibility - Use a shading device to control glare - Replacing window glass type - Adjusting WWR Rooms that showed a " low average daylight "factor **Room-scale** - Joining rooms together to create new common areas - Bright, matt finishing, and top reflective surface materials should be used **Facade-scale** - Use light shelves - Adjusting WWR
Case study 3 "Type 4" **Four apartments o n each floor "Investment residential buildin gs"**	Before retrofitting 	**General problems** In this case, the area of the light well was less than 10m2. If the room has one window open on light well. the light well area should be more than 10m2, to provide appropriate natural daylight. According to the Jordanian code, WWR should not be less than 15% in living areas, and 10% in the service areas. Thus, in this case the existing WWR in the living area did not meet the requirements. **Visual comfort problems**	**Building scale** The unverified requirements should be detected. It could be by fulfilling existing laws and regulations. The optimal spatial retrofit strategies should be defined to optimizing the quality of internal spaces and distribution. It could be by joining rooms together to create new common areas (Resident needs) and /or by adding spaces to apartments; such as (adding new

	After retrofitting 	- Some rooms show a low level of natural light - Other rooms show a high level of natural light **Deep room problem** If the room depth exceeds 2.5 times the window height, the daylight illuminance levels drop. Thus, according to the height of windows in multi-story residential buildings in Hebron city the daylight illuminance levels drop after depth 4.375 - 5.125 m **Some Problems from the residents' point of view** The living room was dark and the level of light for the guest room in was ranging from dark to partially dark. Residents were dissatisfied with the apartment layout, therefore some users need extra spaces to feel more comfortable with room arrangement and natural light. Some residents need to combine the living room and kitchen in an open plan design in order to bring natural lighting to the living room	balconies, etc.) (Resident needs). "Rooms that showed a high average daylight factor." **Façade scale** - Use blinds that provide glare-free while still allowing partial visibility - Use a shading device to control glare - Replacing window glass type - Adjusting WWR Rooms that showed a " low average daylight "factor **Room-scale** - Joining rooms together to create new common areas - Bright, matt finishing, and top reflective surface materials should be used **Facade-scale** - Use light shelves - Adjusting WWR
Case study 4 "Type 2" **Four apartments on each floor "Investment residential buildings"**		**General problems** According to the Jordanian code, WWR should not be less than 15% in living areas, and 10% in the service areas. Thus, in this case the existing WWR in the living area did not meet the requirements. **Visual comfort problems** - Some rooms show a low level of natural light - Other rooms show a high level of natural light **Deep room problem**	**Building scale** The unverified requirements should be detected. It could be by fulfilling existing laws and regulations. The optimal spatial retrofit strategies should be defined to optimizing the quality of internal spaces and distribution. It could be by joining rooms together to create new common areas (Resident needs) and /or by adding spaces to apartments;

	Before retrofitting  After retrofitting 	If the room depth exceeds 2.5 times the window height, the daylight illuminance levels drop. Thus, according to the height of windows in multi-story residential buildings in Hebron city the daylight illuminance levels drop after depth 4.375 - 5.125 m **Some Problems from the residents' point of view** The living room and the guest room was dark . Some users need to combine the living room and kitchen in an open plan design in order to bring natural lighting to the kitchen.	such as (adding new balconies, etc.) (Resident needs). "Rooms that showed a high average daylight factor." **Façade scale** - Use blinds that provide glare-free while still allowing partial visibility - Use a shading device to control glare - Replacing window glass type - Adjusting WWR Rooms that showed a " low average daylight "factor **Room-scale** - Joining rooms together to create new common areas - Bright, matt finishing, and top reflective surface materials should be used **Facade-scale** - Use light shelves - Adjusting WWR

The outcome results show that the level of natural daylight was enhanced in all case studies when implementing the proposed retrofit strategies. The result of enhancement ranges between 84.5% - 97.68% for case 1, 79.9%- 97.6% for case 2, 53.14%- 84.4% for case 3 and 50.76% - 70.8% for case 4. The case studies' results were obtained after following a local residential retrofit framework. This framework helped support initial decisions and provided detailed guidance that considers how the decision-maker uses this framework. Many passive retrofitting actions have been systematically organized into the framework. See figure 8.1 bellow

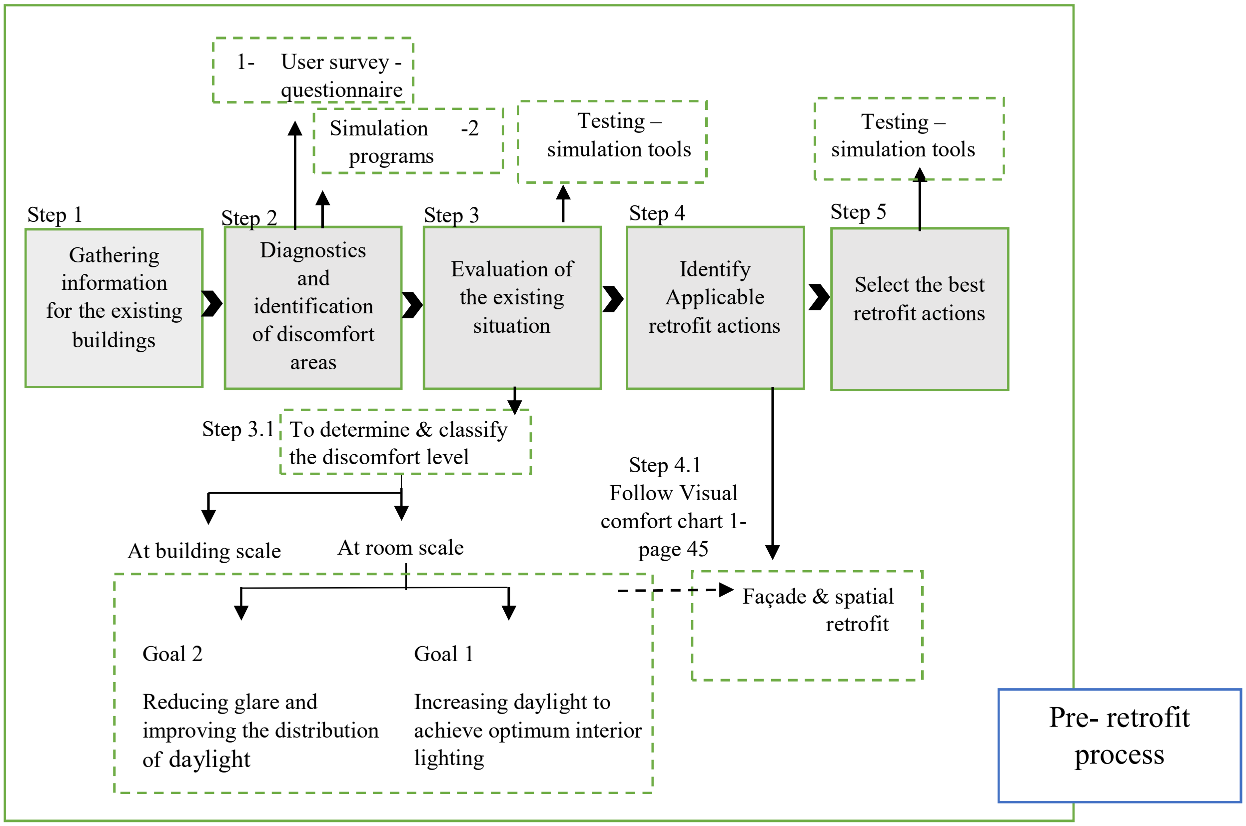


Figure 8.1 Diagram of visual comfort retrofit roadmap process (source- researcher).

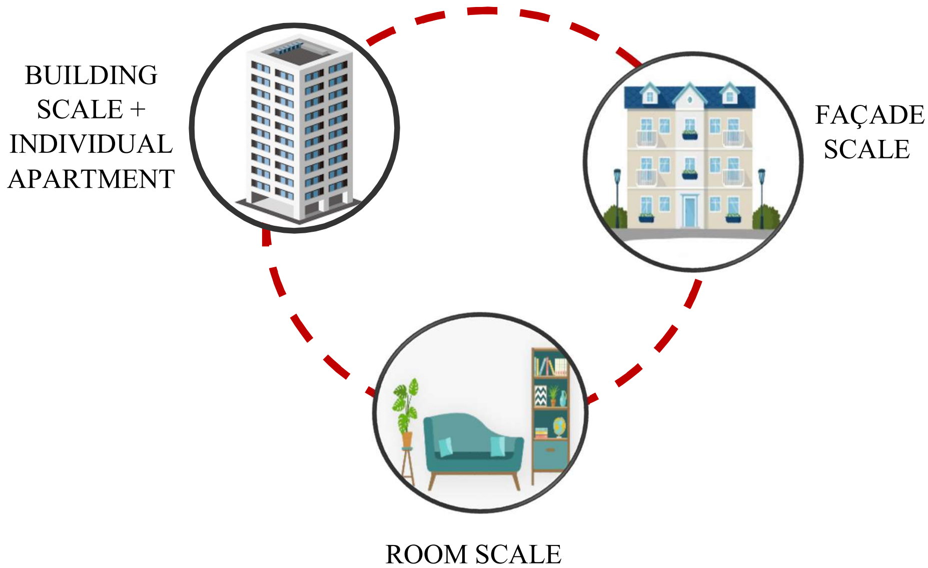
The retrofit process includes three main phases :the first phase is a pre-retrofit process, the second phase is a retrofit process, and the third phase is a post-retrofit process.

Regarding diagram 8.1, the first phases include 5 steps:

- Step 1: It begins with collecting information about the characteristics of the existing building and its performance
- Step 2: Diagnostics the building and identifying the main problems and discomfort sources, by user surveys .
- Step 3: Evaluation of the existing situation using design builder software to determine & classify the discomfort level at building-scale, room-scale, and facade scale
- Step 4: This phase requires a list of retrofit actions, the user comfort requirements determined based on the surveyed data. The conducted visual comfort chart 1 page 82 in this thesis can be used.

- Step 5: Select the best retrofit actions for each case using design builder software.

As mentioned, the retrofitting interventions were classified into two categories: 1) spatial retrofitting, and 2) facade retrofitting. Three process are taken into consideration to create the retrofit framework; 1) Building Scale: to define the characteristics of the existing building to improve energy performance, 2) Room Scale: to develop a spatial comfort framework due to every room in the residential building have special requirements, and 3) Facade Scale: organizing passive retrofitting actions.



Building scale and Individual apartment

It can be concluded that retrofit strategies affect human comfort and enhanced natural daylight, which is vital and needs to be considered through several guidelines and special measures. **The guidelines to be considered in the building retrofit process at building scale and individual apartment are below**:

1. The characteristics of the existing building and the unverified requirements should be detected. For example, it could be by fulfilling existing laws and regulations.
2. The optimal spatial retrofit strategies should be defined for improving energy performance and optimizing the quality of internal spaces and distribution.
    - It could be by joining rooms together to create new common areas (Resident needs).

- It could also be by adding spaces to apartments, such as facade addition through the extension of indoor space and adding a new space (adding new balconies, etc.) (Resident needs).

At building scale and individual apartments, the characteristics of the existing building and the unverified requirements should be detected. Then the optimal spatial retrofit strategies should be defined for optimizing the quality of internal spaces and distribution.

It could be by fulfilling existing laws and regulations, such as adding an elevator. As shown in case studies 1 and 2, in these cases, four floors were allowed to be built without an elevator according to the building code in that period. Therefore, a new elevator has been added to improve the quality and accessibility of the interior spaces. The residential elevator also increases the level of safety and increases the value of the property.

Another building law that could be taken into consideration is WWR. According to the Jordanian code, WWR should not be less than 15% in living areas and 10% in service areas. Thus, the existing WWR also was investigated in all cases.

The stage of spatial retrofit of the interior spaces was complex and depended on the needs of the residents and the architect's vision to solve the problems of discomfort. Therefore, several alternative distribution proposals have been evaluated to determine which are most effective and capable of responding to the goals.

Room scale

In the beginning, the main objectives of the existing problems must be identified. This thesis proposed two main goals for visual discomfort problems:

1. Increasing daylight to achieve optimum interior lighting in the rooms that showed a low average daylight factor
2. Reducing glare and improving the distribution of daylight in the rooms that showed a high average daylight factor

The main problem in the room could be identified by calculating the daylight factor for each roo. **The guidelines to be considered in the building retrofit process at room-scale are below:**

1. Joining rooms together to create new common areas which optimizing the quality of internal spaces and distribution (Architect vision) - spatial retrofit strategies
2. Bright, matt finishing and top reflective surface materials should be used to improve the amount of light reflected in inner spaces.- spatial retrofit strategies

Items 1 and 2 used to increase daylight to achieve optimum interior lighting in rooms that showed a low average daylight factor.

As shown in the last chapter, most rooms in previous cases only have one window, which caused the distribution of daylight throughout the spaces to be not uniform. As shown, a few modifications to the existing building improve considerable indoor daylighting. Such as, it is observed that material with low reflectance wall finishes reduced the reflectivity making the space more dull and dark. Thus, by changing the material reflectance: 85% for walls, 40% for the floor, and 90% for the ceiling, the illumination level increased systematically. See p. No 38.

The rooms with great depth and small windows caused an unequal distribution of the sunlight. As shown in case 3 and case 4, there are rooms with great depth without windows; by applying the retrofitting strategies - optimizing the living spaces and create new common areas- the quality of use of the apartments was improved.

Façade scale

As mentioned, this thesis proposed two main goals for visual discomfort problems. **The guidelines to be considered in the building retrofit process at facade scale to achieve goal 1: increasing daylight to achieve optimum interior lighting is below:**

- LEVEL 1*: Use light shelves, especially on the southern facade, to increase daylight in the deep zone and to improve the quality distribution of daylight
- LEVEL 2*: Install larger windows, where increasing the window-to-wall ratio causes an increase in illuminance level. The aesthetic of the external facade should be taken into account when modifying the windows.

While the guidelines to be considered in the building retrofit process at facade scale to achieve goal 2: Reducing glare and improving the distribution of daylight are below:

- LEVEL 1: Use blinds (curtains) that provide glare-free while still allowing partial visibility
- LEVEL 2: Use a shading device to control glare to ensure comfortable interior spaces. It also uses to control intense direct sunlight. Replacing window glass type, use double glazed windows (with 13mm spacer), Low-E layer clear or gray as needed.
- LEVEL 3: install smaller windows. Where reducing the window-to-wall ratio causes a reduction in illuminance level. The aesthetic of the external facade should be taken into account when modifying the windows.

Levels that were used according to the retrofit application levels. The retrofitting strategies can be applied within three possible levels: Firstly, minor retrofit. Secondly, intermediate retrofit. Thirdly, major retrofit. Thus level 1 is a minor retrofit, while level 3 is a major retrofit.

If changing the reflection of the material is not sufficient to achieve optimal daylight. The LEVEL 1 – façade retrofit can be applied to increase the illumination (using a light shelf).

- LEVEL 1* – Adding a light shelves
- As shown in the cases, the light shelf has effective results in improving the quality distribution of light. At the same time, it can provide light penetration deeper into space and provide good shading from the sun. Light shelves performed best when installed in southern facades. But when installed on the western or eastern facade, the performance is almost negligible. As shown in case 2
- LEVEL 2* – Adjusting Window- to -wall ratio (WWR)
  Modification in the window wall ratio considers the significant level for problem 1. As shown in the cases, increasing the window-to-wall ratio caused an increase in illuminance levels. The aesthetic of the external facade should be taken into account when modifying the windows.

For problem 2, three levels can be applied to reducing glare and improving the distribution of daylight

- LEVEL 1 -Using blinds
  Some modifications to the existing building can reduce glare and improve the distribution of daylight in the rooms showing a high average daylight factor—for example, the use of blinds that provide glare-free light while still allowing partial visibility. As shown in the cases, the average DF was reduced, and daylight distribution improved.

- LEVEL 2 - Adding shading devices or/ and replacing glass type

If LEVEL 1 is insufficient to achieve the optimal daylight, the windows have been replaced with double glazed windows (with 13mm spacer), Low-E layer clear or grey as required. This type is recommended in the literature (see p No.34 & 42) when retrofitting the building's glass surfaces in regions with the same climate (Hebron climate) to provide an ideal balance between sufficient daylight in the building and minimal heat transfer through the envelope .

This level also uses the shading device to control intense direct sunlight by allowing it to enter the building when it is needed for heating in winter and preventing sunlight from entering in summer. It is also used to control glare to ensure comfortable interior spaces.

- LEVEL 3 – Adjusting Window- to -wall ratio (WWR)

Modification in the window wall ratio considers the final level for problem 2. As shown in the cases, when reducing the window-to-wall ratio caused a reduction in illuminance levels. The aesthetic of the external facade should be taken into account when modifying the windows.

General conclusions are presented below:

1. The periods for constructing the multi-story buildings in this context (Hebron City) have no significant influence on the proposed retrofit strategies.
2. It is essential to be aware of the surrounding buildings. Thus, the closeness of adjacent buildings can cause shadow effects and minimize the chances of lighting from reaching the building facade.
3. In most multi-story residential buildings, it might not be very feasible to rely only on passive strategies. Consequently, to achieve optimal daylight, a combination of passive and active retrofit strategies needed. In general, the results show that following the proposed retrofit strategies of the building creates spaces that meet the requirements of the code. But in the rooms with a great depth of more than 6m (deep plan rooms) did not meet the code's requirements.
4. This thesis concluded that a combination of strategies (such as shading devices, light shelves, and blinds) could have an essential role in creating a desirable environment based on daylight quality and thermal comfort.

5. In last section, the retrofit strategies are briefly presented in terms of the level of modifications that have been made and the cost-effectiveness of each has been verified. As shown, when comparing the cumulative daylight factor (DF) strategies to the results of the daylight factor (DF) for each strategy. DF for each strategy seems to be cost-effective and achieves the daylight factor requirement for each room.

The retrofitting of existing housing at the building scale can improve the house's energy efficiency and enhance indoor comfort. Thus, large-scale retrofitting has many additional benefits for the local area to create a green, healthy environment for the whole community

General recommendation are presented below:

For architect

1. Before the retrofitting process, collaborative relationships should be established during the design process between designers and residents to understand the current building. Consequently, involved residents in a retrofit project's decision-making process helped develop existing residential buildings and build a bridge between occupant needs and residents' needs and the proposed retrofit strategies.
2. It is recommended to integrate the simulation modeling before and after applying the retrofit strategies to give the designer a full image of the advantages and disadvantages of the proposed strategies.
3. It is recommended to make a detailed survey of the apartments to obtain accurate data.
4. It is recommended to do surveys before retrofitting to learn the opinions from the residents.
5. It is recommended to arranged interior construction work appropriately to minimize the impact on residents' daily life.
6. For new multi-story buildings, a shallow plan is more recommended than the deep plan for a better daylight illuminant, with the important reason due to interior space configuration and the window to wall ratio.
7. It is recommended to avoid the cubic Building designs for multi-story buildings with four apartments.

For municipalities

1. Regulations by the municipalities and architects should consider the performance of daylight not only in residential buildings under construction but also in existing buildings. Therefore,

enforcing the value of retrofits through legislation laws (if legislation laws are difficult, the incentives can encourage the process). Retrofitting measures can target visual comfort or other human comfort issues

2. It is recommended to put and develop relevant evaluation and supervision standards for retrofitting into practice

8.3 Challenges every architect faces when retrofitting buildings

There are three challenges facing architects when retrofit existing residential buildings

1. The aesthetic of the external facade.
   The architects should be taken into account the aesthetic of the external facade when modifying the windows or adding elements to the facade .
2. Joining rooms together to create new common areas should take into account the functional aspect- for example, it is not logical to merge a living room with a bedroom; it could improve the quality of the room but affect the function of the room .
3. Joining rooms together to create new common areas should take into account privacy- for example, when merging a guest room with a living room for enhancing the quality of the room, movable partitions or decorative partitions that provide privacy can be used.

8.4 Recommendations for future studies

1. The developed proposed framework and proposed visual comfort chart do not include active strategies and technologies. The proposed passive building strategies and technologies can only offset a portion of the lighting and thermal comfort requirements. Therefore, making a combination of passive and active measures can support using active systems with lower energy technologies. So the combined strategies need to be considered in future studies.

References

ABOAMIR, S. (2014). *Towards energy security in Gaza Strip. Exploring passive design strategies in residential buildings.* Sweden: CHALMERS UNIVERSITY OF TECHNOLOGY.

Abu-Hafeetha, M. F. (2009). Planning for Solar Energy as an Energy Option for Palestine.

Alazza, N., & al-Orzza, A. (2017). *Forced Population Transfer: The Case of Palestine - Denial of Access to Natural Resources and Services.* Bethlehem, Palestine: BADIL Resource Center for Palestinian Residency and Refugee Rights.

Alhrub, K. (2020, January 9). Most common type of residential building .

Applied Research Institute . (1995). *Environmental Profile for The West Bank Volume 3: Hebron District.* Jersalem : Applied Research Institute.

Itma, M. (2014). High-density housing in Palestine: learning from traditional typologies. *WIT Transactions on Ecology and The Environment, 191*, 1743-3541.

Juaidi, A., Montoya, F. G., Ibrik, I. H., & Manzano-Agugliaro, F. (2016). An overview of renewable energy potential in Palestine. *Renewable and Sustainable Energy Reviews, 65* , 943–960.

Kawasmi, A. (2020, January 9). Most common type of residential apartment .

Kittanah, O., Hilow, M., & Hamouda, A. (2012). *Renewable Energy in the Palestinian Territory: Opportunities and Challenges.* Palestine: Palestine Economic Policy Research Institute.

Lazzeroni, P., Olivero, S., Stirano, F., Micono, C., Montaldo, P., Zanzottera, G., . . . Repetto, M. (2017). Energy efficiency measures for buildings in Hebron city and their expected impacts in the distribution grid. Chania, Crete, Greece: 9th International Conference on Sustainability in Energy and Buildings.

Maraqa, S. (2020, January 12). Most common type of residential apartment .

Ministry of Local Government. (2004). *Energy Efficient Building Code.* Palestine: Ministry of Local Government.

Njore, & Mark, M. (2016). *WEST BANK & GAZA ENERGY EFFICIENCY ACTION PLAN 2020-2030.* Washington.

PASSIA . (2019). *Infrastructure.* Palestine : PASSIA Factshee.

PCBS. (2017). *Palestinian Central Bureau of Statistics*. Retrieved from http://www.pcbs.gov.ps/Portals/_Rainbow/Documents/HebronE.html

PNA. (2010). *Building Palestine - Achievements and Challenges.* Madrid: Ad Hoc Liaison Committee (AHLC).

Qawasmeh, s. (2020, June 18). Changing in building pattern after 1993.

Salameh, W. (2012). *Towards Sustainable Construction Systems Of External Walls Of Buildings In The West Bank Of Palestine.* Nablus, Palestine: An-Najah National University.

Santamouris, M., Papanikolaou, N., Livada, I., Koronakis, I., Georgakis, C., Argiriou, A., & Assimakopoulos, D. N. (2001). On the impact of urban climate on the energy consumption of buildings. *Solar Energy, 70*(3), 201-216.

Sharawi, R. (2020, January 19). Changing in building pattern after 1993.

PA- Palestinian Authority, 2010. Building Palestine Achievements and Challenges. Ramallah.

Abdelhamid, A., 2006. Urban development and planning in the occupied Palestinian territories: impacts on urban form, in: Conference on Nordic and International Urban Morphology: Distinctive and Common Themes. pp. 1–17.

Aboamir, S., 2013. Towards energy security in Gaza Strip-Exploring passive design stregies in residential buildings (Master's Thesis).

Acred, A., 2014. Natural ventilation in multi-storey buildings: a preliminary design approach (PhD Thesis). Imperial College London.

Aflaki, A., Mahyuddin, N., Mahmoud, Z.A.-C., Baharum, M.R., 2015. A review on natural ventilation applications through building façade components and ventilation openings in tropical climates. Energy Build. 101, 153–162.

Ahadi, A.A., Saghafi, M.R., Tahbaz, M., 2019. The study of effective factors in daylight performance of light-wells with dynamic daylight metrics in residential buildings q. Sol. Energy 155, 679–697. https://doi.org/10.1016/j.solener.2017.07.005

Ahmad, T., Thaheem, M.J., 2017. Developing a residential building-related social sustainability assessment framework and its implications for BIM. Sustain. Cities Soc. 28, 1–15.

Ahsan, T., 2009. Passive design features for energy-efficient residential buildings in tropical climates: The context of Dhaka, Bangladesh. KTH Architecture and the Built Environment, Stockholm.

Aksamija, A., 2013. Sustainable facades: Design methods for high-performance building envelopes. John Wiley & Sons, Canada.

Al Qadi, S., Sodagar, B., Elnokaly, A., 2018. Estimating the heating energy consumption of the residential buildings in Hebron, Palestine. J. Clean. Prod. 196, 1292–1305.

Alatawneh, B., Gramana, M.L., Corrao, R., 2015. Near Zero Energy House in Palestine: Identification of the Future Challenges. 5th International Energy Conference–Palestine (IECP), Ramallah. Palestine, pp. 47–50.

Alibaba, H., 2016. Determination of optimum window to external wall ratio for offices in a hot and humid climate. Sustainability 8, 187.

Alkhalidi, A., Jarad, H., Juaidy, M., 2016. Glass properties selection effect on LEED points for core and shell high rise residential building in Jordan. Int J Therm Env. Eng 13, 29–35.

Alsamamra, H., Said, N., 2019. An Overview of Green Buildings Potential in Palestine 8, 22–33.

Al-shurafa, A.Y., 2016. A study of the daylighting performance in the multi-storey residential buildings of Gaza Strip. The Islamic University of Gaza, Gaza– Palestine.

Altaş, N.E., Özsoy, A., 1998. Spatial adaptability and flexibility as parameters of user satisfaction for quality housing. Build. Environ. 33, 315–323.

Andersen, D., Foldbjerg, R., 2012. Daylight, Energy and Indoor Climate–Basic Book. Editor. Team Daylight Energy Indoor Clim. DEIC VELUX AS.

Angeraini, S.J., 2016. Sunspace design solutions based on daylight performance in a multi-storey residential building. (Master thesis in Energy-efficient and Environmental Buildings). Lund University, Scandinavia.

Arup United Kingdom, 2008. Survival Strategies: A Toolbox for Re-Energizing Tired Assets and reducing operating cost.

Asfour, O.S., Al Shurafa, E.A.Y., 2016. A Study of Daylighting Performance in Apartment Buildings with Reference to the Gaza Strip, in: 6th International Engineering Conference on Energy-Efficient Buildings. Islamic University of Gaza, pp. 42–49.

Awbi, H.B., 2011. Energy efficient ventilation for retrofit buildings. Presented at the Proceedings of 48th AiCARR international conference on energy performance of existing buildings, p. e23.

Ayyad, K.M.B.A.-K., 2017. GREEN RETROFITTING OF RESIDENTIAL BUILDINGS IN HOT ARID COUNTRIES AS AN APPROACH TO SUSTAINABLE DEVELOPMENT (PhD Thesis). Faculty of Engineering at Cairo University in Partial Fulfillment of the …, FACULTY OF ENGINEERING, CAIRO UNIVERSITY GIZA, EGYPT.

Badawy, U., 2012. Palestinian Contemporary Architecture, analysis of the current situation in Gaza Strip. Presented at the The 4th International Engineering Conference –Towards engineering of 21st century, p. 13.

Bataineh, K., Alrabee, A., 2018. Improving the energy efficiency of the residential buildings in Jordan. Buildings 8, 85.

BEE (Bureau of Energy Efficiency), 2014. DESIGN GUIDELINES FOR ENERGY-EFFICIENT MULTI-STOREY RESIDENTIAL BUILDINGS. Bureau of Energy Efficiency, India.

Bertone, E., Wilson, J., 2016. Guidelines for Building Energy Efficiency Retrofitting. Presented at the Sustainability in Public Works Conference, Australia, pp. 24–26.

Blog, F., 2020. The 4,5, and 7 Point Likert Scale + [Questionnaire Examples] [WWW Document]. URL https//www.formpl.us/blog/point-likert-scale (accessed 6.22.20).

Bournas, I., Dubois, M.-C., 2019. Daylight regulation compliance of existing multi-family apartment blocks in Sweden. Build. Environ. 150, 254–265.

Cantin, F., Dubois, M.-C., 2011. Daylighting metrics based on illuminance, distribution, glare and directivity. Light. Res. Technol. 43, 291–307.

Carlucci, S., Causone, F., De Rosa, F., Pagliano, L., 2015. A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design. Renew. Sustain. Energy Rev. 47, 1016–1033.

Chen, B., Ji, Y., Xu, P., 2012. Impact of Window Shading Devices on Energy Performance of Prototypical Buildings. EPS 30, 0–042.

Chiu, Y.-H., 2004. Development of unsteady design procedures for natural ventilation stacks (PhD Thesis). Nottingham University, United Kingdom.

CIBSE, G.F., 2004. Energy Efficiency in Buildings, The Chartered Institution of Building Services Engineers,London.

Conroy, R., 2015. Sample size A rough guide. Retreived Httpwww Beaumontethics Iedocsapplicationsamplesizecalculation Pdf.

DECC, 2009. Warm Homes, Greener Homes: A Strategy for Household Energy Management [WWW Document]. URL https://www.decc.gov.uk

DOE, 2009. DOE to Fund up to $454 Million for Retrofit Ramp-Ups in Energy Efficiency [WWW Document]. energy.gov. URL https://www.energy.gov/articles/doe-fund-454-million-retrofit-ramp-ups-energy-efficiency

Du, T., Jansen, S., Turrin, M., van den Dobbelsteen, A., 2020. Effects of architectural space layouts on energy performance: A review. Sustainability 12, 1829.

du, T., Jansen, S.C., Turrin, M., Dobbelsteen, A., 2019. Impact of space layout on energy performance of office buildings coupling daylight with thermal simulation. Presented at the E3S Web of Conferences, Netherlands, p. 8.

Eames, M., Dixon, T., Lannon, S.C., Hunt, M., De Laurentis, C., Marvin, S., Hodson, M., Guthrie, P., Georgiadou, M.C., 2014. Retrofit 2050: critical challenges for urban transitions. Cardiff University, Cardiff University.

Einstein, A., 2013. Four principles for achieving good indoor air quality. Indoor Air 23, 353–356.

El-Darwish, I., Gomaa, M., 2017. Retrofitting strategy for building envelopes to achieve energy efficiency. Alex. Eng. J. 56, 579–589.

Elrayies, G., 2010. Daylight Transportation: A Green Lighting Technology to Save Energy 14, 150–168.

ESMAP, 2011. Improving Energy Efficiency in Buildings. State university of New York, Albany, United state of America.

Fan, Y., Xia, X., 2015. A multi-objective optimization model for building envelope retrofit planning. Energy Procedia 75, 1299–1304.

Foldvary, V., 2016. Assessment of indoor environmental quality in residential buildings before and after renovation. Slovak University of Technology in Bratislava, Bratislava.

Foster, M., Oreszczyn, T., 2001. Occupant control of passive systems: the use of Venetian blinds. Build. Environ. 36, 149–155.

Freewan, A.A., 2015. Developing daylight devices matrix with special integration with building design process. Sustain. Cities Soc. 15, 144–152.

Freewan, A.A., 2011. Modifying courtyard wall geometries to optimize the daylight performance of the courtyard, in: Sustainability in Energy and Buildings. Springer, pp. 57–64.

Freewan, A.A., Gharaibeh, A.A., Jamhawi, M.M., 2014. Improving daylight performance of light wells in residential buildings: Nourishing compact sustainable urban form. Sustain. Cities Soc. 13, 32–40.

Gao, W., Zhang, P., 2011. Sustainable renovation projects of residential buildings. 5 examles in Austria. CHALMERS UNIVERSITY OF TECHNOLOGY, Göteborg, Sweden.

Giebler, G., Fisch, R., Krause, H., 2009. Refurbishment manual. Boston: Birkhauser verlag AG. Translated by Gerd H. Soffker.

Givoni, B., 1998. Climate considerations in building and urban design. John Wiley & Sons, Canada.

Groat, L.N., Wang, D., 2013. Architectural research methods, second edition. ed. John Wiley & Sons, Canada.

Hadi, M.H.A., 2013. Possibility of Developing Eco-Friendly Residential Buildings in the Palestinian Cities-A Case Study From Jenin and Ramallah Cities (PhD Thesis). Doctoral Dissertation in Architecture, An-Najah National University, Nablus, Palestine.

Hadid, M., 2002. Architectural styles survey in Palestinian territories Energy Codes for Building (www. molg. pna. ps).

Hariri, N., 2016. Natural Ventilation Integration in Residential High-Rise Buildings In Hot and Humid Climates: Shafts Influence (PhD Thesis). Cardiff University, The Welsh School of Architecture.

Harris, J., Anderson, J., Shafron, W., 2000. Investment in energy efficiency: a survey of Australian firms. Energy Policy 28, 867–876.

He, Q., Ng, S.T., Hossain, M., Skitmore, M., 2019. Energy-efficient window retrofit for high-rise residential buildings in different climatic zones of China. Sustainability 11, 6473.

Hong, Y., Ezeh, C.I., Deng, W., Hong, S.-H., Peng, Z., 2019. Building Energy Retrofit Measures in Hot-Summer–Cold-Winter Climates: A Case Study in Shanghai. Energies 12, 3393.

Huang, Y., Borong, L., Yao, N., Yingxin, Z., 2015. Functional relationship between lighting energy consumption and the main parameters for double atrium offices. Procedia Eng. 121, 1869–1879.

Huovila, P., Ala-Juusela, M., Melchert, L., Pouffary, S., Cheng, C.-C., Ürge-Vorsatz, D., Koeppel, S., Svenningsen, N., Graham, P., 2009. Buildings and climate change: Summary for Decision-Makers. Initiat. Clim.

Hussein, M., Albarqouni, S., 2010. Developing empirical models for estimating global solar radiation in Gaza Strip, Palestine. Islam. Univ. J. Ser. Nat. Stud. Eng. 18, 73–83.

Iannone, F., Fiorito, F., 2005. Use of the stairwell as a component of natural ventilation systems in residential buildings comparison of technologies for the external envelope, in: AIVC 26th Conference.

Ibrahim, H., 2012. The contemporary Islamic house. University of Arkansas, Fayetteville.

Ibrahim, N.L.N., 2006. DAYLIGHT DESIGN RULES OF THUMB 9.

Itma, M., 2018. High-Rise Apartment Buildings in Palestinian, in Response to Human Needs. J. Eng. 6, 60–66.

Iversen, A., Roy, N., Hvass, M., Jørgensen, M., Christoffersen, J., Osterhaus, W., Johnsen, K., 2013. Daylight calculations in practice: An investigation of the ability of nine daylight simulation programs to calculate the daylight factor in five typical rooms 2013, 54.

Iwaro, J., Mwasha, A., 2013. The impact of sustainable building envelope design on building sustainability using Integrated Performance Model. Int. J. Sustain. Built Environ. 2, 153–171.

Jahed, N., Dino, I.G., 2018. Performance based façades: retrofit strategies for energy efficiency and comfort in existing office buildings (Master's Thesis). MIDDLE EAST TECHNICAL UNIVERSITY.

Jonsson, A., Roos, A., 2010. Visual and energy performance of switchable windows with antireflection coatings. Sol. Energy 84, 1370–1375.

Kamaruzzaman, S.N., Razali, A., Ahmad Zawawi, E.M., Riley, M., 2017. Factors affecting indoor environmental quality and potential health risks of housing residents. E-Proc. Natl. Innov. Invent. Compet. Exhib. ICompex 2017.

Kanwal, H., Noshin, S., Aslam, S., Mushtaq, U., 2018. Evaluation of Daylight Performance on the Selected Design Parameters of Light Shelves. Int. J. Sci. Eng. Res. 9.

Kauser, M.N., 2018. Effect of culture, religious beliefs and traditions on residential built forms–A Study on Islamic countries. J. Emerg. Technol. Innov. Res. JETIR 5.

Khattab, N.M.A., 2017. UPGRADING EXISTING EDUCATIONAL BUILDINGS TO A ZERO-NET ENERGY (PhD Thesis). FACULTY OF ENGINEERING, CAIRO UNIVERSITY, GIZA, EGYPT.

Kibert, C.J., 2016. Sustainable Construction: Green Building Design and Delivery. John Wiley & Sons.

Knoop, M., Stefani, O., Bueno, B., Matusiak, B., Hobday, R., Wirz-Justice, A., Martiny, K., Kantermann, T., Aarts, M.P.J., Zemmouri, N., 2020. Daylight: What makes the difference? Light. Res. Technol. 52, 423–442.

Konstantinou, T., Knaack, U., 2011. Refurbishment of residential buildings: a design approach to energy-efficiency upgrades. Procedia Eng. 21, 666–675.

Kontadakis, A., Tsangrassoulis, A., Doulos, L., Zerefos, S., 2018. A review of light shelf designs for daylit environments. Sustainability 10, 71.

Kranti, K.M., Kranthi, N., 2019. Factors Affecting the Day lighting performance in the Residences. Int. J. Recent Technol. Eng. IJRTE.

Kristl, Ž., Krainer, A., 1999. LIGHT WELLS IN RESIDENTIAL BUILDING AS A COMPLEMENTARY DAYLIGHT SOURCE. Sol. Energy 65, 197–206. https://doi.org/10.1016/S0038-092X(98)00127-3

Kubba, S., 2012. Chapter 7 - Indoor Environmental Quality, in: Kubba, S. (Ed.), Handbook of Green Building Design and Construction. Butterworth-Heinemann, Boston, pp. 313–360. https://doi.org/10.1016/B978-0-12-385128-4.00007-X

Lee, J.-W., Jung, H.-J., Park, J.-Y., Lee, J.B., Yoon, Y., 2013. Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements. Renew. Energy 50, 522–531.

Li, D.H., Wong, S.L., Tsang, C.L., Cheung, G.H., 2006. A study of the daylighting performance and energy use in heavily obstructed residential buildings via computer simulation techniques. Energy Build. 38, 1343–1348.

Li, X., Lannon, S.C., Jones, P.J., 2015. Modelling-based low carbon retrofit house design. Urban Flux 42, 34–50.

Ma, Z., Cooper, P., Daly, D., Ledo, L., 2012. Existing building retrofits: Methodology and state-of-the-art. Energy Build. 55, 889–902.

Mahdavi, A.H., Rao, S.P., Inangda, N., 2013. Parametric studies on window-to-wall ratio for day lighting optimisation in high-rise office buildings in Kuala Lumpur, Malaysia. J. Des. Built Environ. 12.

Maier, A.E., 2016. Daylight as starting point for retrofitting residential buildings and cities. Acta Tech. Napoc. Civ. Eng. Archit. 58.

Maliene, V., Malys, N., 2009. High-quality housing—A key issue in delivering sustainable communities. Build. Environ. 44, 426–430.

Martellotta, F., Simone, A., Della Crociata, S., D'Alba, M., 2016. Global comfort and indoor environment quality attributes for workers of a hypermarket in Southern Italy. Build. Environ. 95, 355–364.

Mauro, G., 2015. MULTI-OBJECTIVE OPTIMIZATION FOR COST-OPTIMAL ENERGY RETROFITTING: FROM THE SINGLE BUILDING TO A STOCK. University of Naples Federico II, Department of Industrial Engineering.

McArthur, J.J., Jofeh, C.G.H., 2015. Strategic retrofit investment from the portfolio to the building scale: a framework for identification and evaluation of potential retrofits. Procedia Eng. 118, 1068–1076.

Meiss, A., Padilla-Marcos, M.A., Feijó-Muñoz, J., 2017. Methodology applied to the evaluation of natural ventilation in residential building retrofits: A case study. Energies 10, 456.

Menassa, C.C., Baer, B., 2014. A framework to assess the role of stakeholders in sustainable building retrofit decisions. Sustain. Cities Soc. 10, 207–221.

Meteoblue weather, 2020. Climate Hebron [WWW Document]. meteoblue. URL https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/hebron_palestine_285066 (accessed 7.13.20).

Moore, F., 1991. Concepts and practice of architectural daylighting. John Wiley & Sons Incorporated.

Muhaisen, A.S., Dabboor, H.R., 2013. Studying the impact of orientation, size, and glass material of windows on heating and cooling energy demand of the Gaza strip buildings. Stud. Impact Orientat. Size Glass Mater. Window Heat. Cool. Energy Demand Gaza Strip Build. 27.

Nazer, H., 2019. DEVELOPING AN ENERGY BENCHMARK FOR RESIDENTIAL APARTMENTS IN AMMAN. Jordan Green Building Council, Amman, Jordan.

Nisreen Mohammad Ardda, 2017. Developing assessment tool for new and retrofit residential building in West Bank, Palestine (PhD Thesis). Universidade do Minho Escola de Engenharia.

Ochoa, C.E., Capeluto, I.G., 2006. Evaluating visual comfort and performance of three natural lighting systems for deep office buildings in highly luminous climates. Build. Environ. 41, 1128–1135.

Omar, O., 2009. Master Thesis " Advanced Daylight Technologies For Sustainable Architectural Design ". Alexandria University, Alexandria. https://doi.org/10.13140/RG.2.1.4852.0729

(PDF) Daylight in Buildings - A source book on daylighting systems and components (Technical Report), 2000. . U.S. Department of Energy Office of Scientific and Technical Information, Denmark.

Pearce, D., 2006. Is the construction sector sustainable?: definitions and reflections. Build. Res. Inf. 34, 201–207.

Pittau, F., Malighetti, L.E., Iannaccone, G., Masera, G., 2017. Prefabrication as large-scale efficient strategy for the energy retrofit of the housing stock: An Italian case study. Procedia Eng. 180, 1160–1169.

Rabani, M., Madessa, H.B., Nord, N., 2017. A state-of-art review of retrofit interventions in buildings towards nearly zero energy level. Energy Procedia 134, 317–326.

Rajapaksha, U., Hyde, R., Groenhout, N., 2013. Design Solution Sets for Bioclimatic Retrofit. Sustain. Retrofit. Commer. Build.-Warm Clim.

Reinhart, C.F., Mardaljevic, J., Rogers, Z., 2006. Dynamic daylight performance metrics for sustainable building design. Leukos 3, 7–31.

Rey, E., 2004. Office building retrofitting strategies: multicriteria approach of an architectural and technical issue. Energy Build. 36, 367–372.

Robinson, A., Selkowitz, S., 2013. Tips for daylighting with windows. Assist. Secr. Energy Effic. Renew. Energy Build. Technol. Program.

Rodriguez-Ubinas, E., Rodriguez, S., Voss, K., Todorovic, M.S., 2014. Energy efficiency evaluation of zero energy houses. Energy Build. 83, 23–35.

Rossi, P.H., Wright, J.D., Anderson, A.B., 2013. Handbook of survey research. Academic Press.

Ruck, N., Aschehoug, Ø., Aydinli, S., Christoffersen, J., Edmonds, I., Jakobiak, R., Kischkoweit-Lopin, M., Klinger, M., Lee, E., Courret, G., Michel, L., Scartezzini, J.-L., Selkowitz, S., 2000. Daylight in Buildings - A source book on daylighting systems and components.

Santin, O.G., 2011. Behavioural patterns and user profiles related to energy consumption for heating. Energy Build. 43, 2662–2672.

Saridar, S., Elkadi, H., 2002. The impact of applying recent façade technology on daylighting performance in buildings in eastern Mediterranean. Build. Environ. 37, 1205–1212.

Selkowitz, S., Navvab, M., Mathews, S., 1983. Design and performance of light shelves. Presented at the Proceedings of the international daylighting conference, Washington, pp. 267–272.

Seo, D., Park, L., Ihm, P., Krarti, M., 2012. Optimal electrical circuiting layout and desk location for daylighting controlled spaces. Energy Build. 51, 122–130.

Shahzad, S., Brennan, J., Theodossopoulos, D., Hughes, B., Calautit, J.K., 2017. A study of the impact of individual thermal control on user comfort in the workplace: Norwegian cellular vs. British open plan offices. Archit. Sci. Rev. 60, 49–61.

Shakhashir, T., 2014. Jordan's Third National Communication on Climate Change. Ministry of Environment (MOENV) and United Nations Development Programme (UNDP), Amman, Jordan.

Shamout, S., 2018. Your Guide to Building Envelope Retrofits for Optimising Energy Efficiency Et Thermal Comfort in Jordan. Jordan GBC, Jordan.

Shen, C., Li, X., 2016. Thermal performance of double skin façade with built-in pipes utilizing evaporative cooling water in cooling season. Sol. Energy 137, 55–65.

Sozer, H., 2010. Improving energy efficiency through the design of the building envelope. Build. Environ. 45, 2581–2593.

Spoelstra, K., van Grunsven, R.H., Donners, M., Gienapp, P., Huigens, M.E., Slaterus, R., Berendse, F., Visser, M.E., Veenendaal, E., 2015. Experimental illumination of natural habitat—an experimental set-up to assess the direct and indirect ecological consequences of artificial light of different spectral composition. Philos. Trans. R. Soc. B Biol. Sci. 370, 20140129.

Straube, J., 2006. The Building Enclosure [WWW Document]. Build. Sci. Corp. URL https://www.buildingscience.com/documents/digests/bsd-018-the-building-enclosure_revised

Suriansyah, Y., 2013. Daylight quality potency at Sarijadi mass public housing in Bandung Indonesia. J. Energy Technol. Policies 3, 14–28.

The energy and resource institute (TERI), 2013. Roadmap for Incorporating Energy Efficiency Retrofits in Existing Buildings. TERI Press.

Turunen, M., Toyinbo, O., Putus, T., Nevalainen, A., Shaughnessy, R., Haverinen-Shaughnessy, U., 2014. Indoor environmental quality in school buildings, and the health and wellbeing of students. Int. J. Hyg. Environ. Health 217, 733–739.

UAE, 2011. The UAE's response to climate change [WWW Document]. URL https://u.ae/en/information-and-services/environment-and-energy/climate-change/theuaesresponsetoclimatechange

UNESC, 2017. Framework Guidelines for Energy Efficiency Standards in Buildings. Presented at the Ministerial Conference & the eigth international forum on energy for sustainable development, United Nations Economic and Social Council, Astana,Kazakhstan.

Vanhoutteghem, L., Skarning, G.C.J., Hviid, C.A., Svendsen, S., 2015. Impact of façade window design on energy, daylighting and thermal comfort in nearly zero-energy houses. Energy Build. 102, 149–156.

Visser, F., Yeretzian, A., 2013. Energy Efficient Building: Guidelines for MENA Region.

Ward, G.L., Mardaljevic, J., 1998. Rendering with Radiance: a practical tool for global illumination. ACM SIGGRAPH'98 Course 33.

Xue, P., Mak, C.M., Cheung, H.D., 2014. The effects of daylighting and human behavior on luminous comfort in residential buildings: A questionnaire survey. Build. Environ. 81, 51–59.

Yang, Q., Liu, M., Shu, C., Mmereki, D., Hossain, U., Zhan, X., 2015. Impact analysis of window-wall ratio on heating and cooling energy consumption of residential buildings in hot summer and cold winter zone in China. J. Eng. 2015.

Zhang, X., 2018. Sustainable retrofitting of existing residential buildings at community scale in China (PhD Thesis). Cardiff University.

الجهاز المركزي للاحصاء الفلسطيني | الإحصاء الفلسطيني يعلن مستويات المعيشة في فلسطين،2017 [WWW Document], n.d. URL http://www.pcbs.gov.ps/postar.aspx?lang=ar&ItemID=3114 (accessed 6.26.20).

Appendix A

1 ما هو النموذج الأكثر شيوعا في تصميم المباني السكنية في مدينة الخليل من ناحية عدد الشقق في كل طابق و الشكل الخارجي ؟

2 ما هي مساحة كل شقة تقريبا ؟

3 ما هو عدد طوابق المباني السكنية التي يتم تصميمها عادة ؟

4 هل كل غرفة من غرف الشقة تصلها اضاءة و تهوية طبيعية عن طريق النوافذ ، اذا لا ما هي هذه الغرفة؟

5 هل هناك اختلاف في أنماط بناء الشقق السكنية بعد 1993 ؟ كيف يمكن تصنيف هذه الانماط ؟

6 ما هي تقنيات البناء المستخدمة في كل فترة من هذه الفترات (سواء تغيرات على غلاف المبنى او الخدمات ...) ؟

- من حيث استخدام العوازل.
- تكوين الجدران – مواد البناء المستخدمة.
- النوافذ (أبعادها ، نوع الزجاج المستخدم و عدد الطبقات)
- هل هناك وحدات تكيف او تدفئة مركزية.
- التوزيع الداخلي.
- هل تتوفر مساحات خاصة مفتوحة (بلكونة او تيراس او حديقة خارجية..)
- هل تتوفر المصاعد.
- هل تتم مراعاة شروط الدفاع المدني للمباني السكنية.

7 هل قام المكتب بتنفييذ تغيرات على مباني قائمة ؟
(التغير في استخدام المبنى – تغيرات في تصميم المنزل او إضافة مساحات ... – تغير في الشكل الخارجي للمبنى)

---

1 ما هي قوانين البناء المتبعة حاليا؟

2 هل هناك تغيرات على قوانين البناء أو قوانين الامن و سلامة العامة للمباني السكنية؟

3 ما مدى الالتزام بقوانين البناء و الامن و السلامة العامة للمباني السكنية؟

Appendix B

استبيان تقيمي لوضع المباني السكنية القائمة "الشقق السكنية" في مدينة الخليل

يهدف الاستبيان الى تقييم المباني السكنية القائمة "الشقق السكنية" في مدينة الخليل بالاضافة الى معرفة آراء السكان ببعض قضايا البيئة الداخلية و الاجتماعية و الوظيفية و مدى رضاهم عنها ، بهدف المساعدة في انجاز بحث علمي خاص بطلبة ماجستير: التصميم المعماري المستدام / جامعة بوليتكنك فلسطين .

- نشكر لكم مشاركتكم في هذا الاستبيان والذي سيكون لأغراض البحث العلمي فقط.
- نلفت اننتباهكم بأن الاجابة على الاستبيان تستغرق مدة اقصاها دقيقتين.

<u>الجزء الأول – معلومات عامة:</u>

1. العمر

25≥	35-26	45-36	55-46	56 ≤

2. الجنس

ذكر	أنثى

3. مستوى التعليم

اعدادي	ثانوي	دبلوم	بكالوريوس	التعليم العالي

4. مستوى الدخل الشهري (بالشيكل)

أقل من 1000	2000-1000	3000-2000	أكثر من 3000	غير محدد

5. هل الزوج يعمل

نعم	لا

اذا كانت الإجابة نعم، ما طبيعة العمل

6. هل الزوجة تعمل

نعم	لا

اذا كانت الإجابة نعم ، ما طبيعة العمل

7. ملكية المنزل

ملك	اجار

<u>الجزء الثاني – مواصفات المبنى :</u>

1. بأي طابق تقع شقتك

الطابق الارضي	الطابق الاول	الطابق الثاني	الطابق الثالث	الطابق الرابع	الطابق الخامس

الطابق السادس	الطابق السابع	الطابق الثامن فما فوق

2. ما هو اتجاه شقتك؟ (أكثر من خيار واحد ممكن)

شرق	غرب	شمال	جنوب

3. ما هو عدد الشقق في كل طابق ؟

1	2	3	4	أكثر من ذلك

4. تاريخ بناء المنزل

قبل 1979	1989-1980	1999-1990	2010-2000	بعد 2010	لا أعلم

5. ما هي المساحة الاجمالية للشقة بالمتر المربع؟

أقل من 120	140-120	160-150	180-170	أكثر من 180

6. كم شخص يعيش بالمنزل ؟

7. كم سنة تسكن المنزل ؟

8. كم ساعة تقضيها في المنزل يوميا ؟

9. هل بناء المنزل يتضمن مواد عازلة لانتقال الحرارة او البرودة ؟

نعم ، بشكل كلي	نعم ، بشكل جزئي	ابدا

10. عدد طبقات الزجاج في شبابيك المنزل

طبقة	طبقتين	ثلاث طبقات

11. هل يوجد في البيئة المحيطة لمنزلك أي مصدر للضجيج أو تلوث بيئي (شارع رئيسي، مصانع،... الخ)

نعم بشكل كلي	نعم بشكل جزئي	ابدا

الجزء الثالث – قضايا بيئية – اجتماعية – وظيفية :

12. ما مدى رضاك عن ما يلي : (حدد مقياس من 1 الى 5 : 1 اذا كنت غير راضي و 5 اذا كنت راضي بشده)

12.1	تصميم المنزل (توزيع الغرف ...)	1	2	3	4	5
12.2	اذا كانت الإجابة على بند 12.1 غير راضي، اذكر السبب :					
12.3	مساحة غرفة الجلوس	1	2	3	4	5
12.4	موقع غرفة الجلوس	1	2	3	4	5
12.5	اذا كانت الإجابة على بند 12.3+12.4 غير راضي، اذكر السبب :					
12.6	مساحة المطبخ	1	2	3	4	5
12.7	موقع المطبخ	1	2	3	4	5
12.8	اذا كانت الإجابة على بند 12.6+12.7 غير راضي، اذكر السبب :					
12.9	مساحة غرفة الضيوف	1	2	3	4	5
12.10	موقع غرفة الضيوف	1	2	3	4	5

12.11	اذا كانت الإجابة على بند 12.9+12.10 غير راضي، اذكر السبب :					
12.12	مساحة البرنده	1	2	3	4	5
12.13	موقع البرنده	1	2	3	4	5
12.14	اذا كانت الإجابة على بند 12.12+12.13 غير راضي، اذكر السبب :					

13. ما مدى أهمية المواضيع التالية: (حدد مقياس 1 الى 5 : 1 اذا كان غير مهم و 5 اذا مهم للغاية)

13.1	إمكانية تعديل بناء المنزل (مثل الامتداد الافقي، تغيرات في تصميم المنزل من الداخل ... الخ)	1	2	3	4	5

14. من شارك في تصميم منزلك : (اكثر من خيار واحد ممكن)

عائلتك	المالك	المهندس المصمم	لا أعلم

15. بعد السكن في المنزل هل تم تنفيذ أي من التغيرات التالية في منزلك :

تغير في المساحات المستخدمة (مثل غرفة المعيشة أصبحت غرفة نوم ...)	إضافات مادية (مثل إضافة غرفة ..)	تغير في ديكور المنزل

16. اذا كان هناك تغيرات أخرى اذكرها:

17. ما هو السبب الرئيسي لهذا التغير:

قضايا ثقافية (مثل الخصوصية...)	تغير في حجم الاسرة (زيادة عدد افراد العائلة..)	تحسين جودة البيئة الداخلية	الرفاهية

18. ما أهمية القضايا الاجتماعية التالية: (حدد مقياس من 1 الى 5 : 1 اذا كان غير مهم و 5 مهم للغاية)

18.1	توفر اطلالة مناسبة	1	2	3	4	5
18.2	توفر مساحات خاصة مفتوحة (بلكونة او تيراس او حديقة خارجية..)	1	2	3	4	5
18.3	مراعاة المعاقين " ذوي الاحتياجات الخاصة"	1	2	3	4	5

19. حول القضايا الاجتماعية - خاص بمنزلك ، يرجى الإجابة عن الأسئلة التالية :

19.1	هل يصل ضوء الشمس المباشر الى غرفة المعيشة الخاصة بك	نعم	لا	لا أعلم
19.2	هل تتوفر الخصوصية بمنزلك	نعم	لا	لا أعلم
19.3	هل لديك اطلالة مناسبة	نعم	لا	لا أعلم
19.4	هل لديك إمكانية الوصول الى مساحة خاصة مفتوحة بمنزلك مثل (البلكونه او التيراس او حديقة ....)	نعم	لا	لا أعلم
19.5	هل يوجد مدخل سهل للمعاقين	نعم	لا	لا أعلم

20. في الطقس الحار، أي مما يلي تستخدم لضبط درجة الحرارة في منزلك؟ (أكثر من خيار واحد ممكن)

النوافذ	المروحة	فتح الباب على المساحات الداخلية	المكيف

21. في الطقس البارد، أي مما يلي تستخدم لضبط درجة الحرارة في منزلك؟ (أكثر من خيار واحد ممكن)

النوافذ	مدفأة (غاز – كهرباء...)	تدفئة مركزية

22. ما مدى رضاك عن قضايا جودة البيئة الداخلية التالية - خاص بمنزلك: (حدد مقياس من 1 الى 5 : 1 اذا كان غير راضي و 5 راضي)

22.1	درجة حرارة الهواء و الرطوبة النسبية	1	2	3	4	5
22.2	الإضاءة الاصطناعية	1	2	3	4	5
22.3	جودة الهواء الداخلي و التهوية الطبيعية	1	2	3	4	5

23. كم عدد ساعات التي تقضيها بالمنزل دون استخدام الإضاءة الاصطناعية؟

1>	3-1	5-3	7-5	7<

24. هل لديك أي من المشاكل التالية في منزلك؟

مشاكل رطوبة - عفن	تشققات
هل هناك مشاكل أخرى اذكرها:	

25. حول قضايا الصحة و الرفاهية في منزلك اجب عما يلي:

25.1	هل لديك تهوية ميكانيكية في المطبخ / الحمامات	نعم	لا	لا أعلم
25.2	هل تتعرض لتلوث الهواء (الغبار، انبعاثات المصانع، السيارات ...)	نعم	لا	لا أعلم
25.3	هل تسمح بالتدخين في منزلك	نعم	لا	لا أعلم

26. هل تعتقد أن وسائل الاعلام و البلديات لها دور فاعل في نشر ثقافة تقليل استهلاك الطاقة و تحسين جودة البيئة الداخلية لانشاء منزل بيئي :

دائما	احيانا	ابدا

27. هل سبق و أن سمعت عن مصطلح المباني المستدامة او المباني البيئية ؟

نعم	لا

28. لو اتيح لك فرصة اجراء تعديلات على المنزل ماذا سوف تفعل

Appendix c

List of interviewees

Group	No.	Interviewee	Position	Site	Date
Engineering office	1	Ayda Kawasmi	Projects Director	Ra'ed engineering office	9-1-2020 15-6-2020
	2	Khalil Alhrub	Architect	Al-Areen engineering office	9-1-2020 15-6-2020
	3	Sharif Maraqa	Managing Director	Majal architects & consultants	12-1-2020
	4	Saad Qawasmeh	Projects Director	New vision consulting office	18-6-2020
	5	Mousa Atawneh	Managing Director	Atawneh engineering office	12-1-2020
	6	Hijazi Shaheen	Managing Director	Andalous engineering office	17-6-2020
Hebron Engineering association	7	Razan Sharawi	Architecture Auditor	Hebron Engineering association	19-1-2020
Hebron Municipality	8	Rawan Abu Eisheh	GIS Manager	Department of information systems and technology IT	19-1-2020 17-6-2020
	9	Amjad Ebedo	Building Manager	Department of building	19-1-2020
	10	Mahdi Karaki	Survey engineer - An employee in the Department of Survey Engineering	Department of survey engineering	15-6-2020 17-6-2020
Civil defense	11	Ahmad Abu Kraifeh	An employee in Palestine civil defense	Palestine civil defense	23-1-2020

Appendix D

The main types of glass are:

1. Clear glass – source researcher

2. Tinted Glass – source researcher

2. Coated Glass – source: researcher

Several properties could be combined to have greater solar control when improving the performance of existing windows or replacing them, such as:

1) spectrally selective characteristics

2) reflective surface (mirror like effect)- source: researcher

3) Low-E coated surface.

Appendix E

The Organizing Committee of the 8th Jordan International Civil Engineering Conference (JICEC8), has been accepted the submitted paper from this research.

The paper entitled:

"RETROFITTING STRATEGY TO ENHANCE THE ENERGY PERFORMANCE OF EXISTING RESIDENTIAL BUILDINGS IN PALESTINE"

8th Jordan International Civil Engineering Conference on
Smart Civil Engineering
24-26 March 2020, Amman-Jordan

RETROFITTING STRATEGY TO ENHANCE THE ENERGY PERFORMANCE OF EXISTING RESIDENTIAL BUILDINGS IN PALESTINE

Abdelrahman Halawani

[*] Assistant Professor, Palestine Polytechnic University
Palestine, halawani.abed@gmail.com

Lana Abu Munshar[†]

Keywords: building envelopes, daylight strategies, green buildings, retrofit strategy, and residential buildings.

Abstract. The concepts of sustainability or green building rarely have been taken into account in Palestine. Thus, environmental problems increased as well as the cost of operation and maintenance of buildings. Recently, some of public buildings were constructed following the guidelines and principles of green concepts. Such as the Palestinian Museums which is the first green building with a silver-rated LEED certification. However, no attention was given to the existing residential buildings which form more than 80% of building sector. Therefore, this paper argues that retrofitting of existing buildings provides an excellent choice for reducing energy consumption and greenhouse gas emissions. It focuses on exploration of retrofit strategy in which building spaces and envelope are modified to reduce energy consumption and increase the quality of living spaces.