**An-Najah National University**

**Faculty of Graduate Studies**

# Towards Green Palestinian Cities the Feasibility of Using Roof Gardens in Nablus as a Case Study

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# Dedication

To my parents, my brothers and sister.

# Acknowledgment

*I wish to express my gratitude to my supervisors Dr. Mouhammad Ata Yousef and Dr. Haithem Ratrout. Appreciation for Dr. Muhannad Haj Hussein for his help. Dr. Erik Henry, Dr. Hafida Boulekbache ,and Dr. Patrizia Laudati from Université de Valenciennes for their hospitality and support. Mr. Rick I am much obliged.*

*My family both at home and in the department of architecture thank you all, teachers ,and colleagues.*

# الإقرار

أنا الموقع أدناه، مقدم الرسالة التي تحمل العنوان:

***Towards Green Palestinian Cities the Feasibility of Using Roof Gardens in Nablus as a Case Study***

أقر بأن ما شملته هذه الرسالة إنّما هو نتاج جهدي الخاص، باستثناء ما تمّت الإشارة إليه حيثما ورد، وأنّ هذه الرسالة ككل، أو أيّ جزء منها لم يقدّم من قبل لنيل أيّ درجة أو لقب علميّ لدى أيّ مؤسسة تعليمية أو بحثية أخرى.

## Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

**Student's Name:** **اسم الطالب:**

**Signature:** **التوقيع:**

**Date:** **التاريخ**

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## Abstract

Urban greening is considered to be a very important issue in many cities, just like the city of Nablus where the topography and the political situation restrict the establishment of new green spaces.

In this study, the feasibility of green roofs in the city of Nablus was tested, after displaying the background of green roofs and the benefits could be provided by green roofs, and how cities encourage the application of green roofs to take advantage of these benefits. Then the physical and environmental profile of the city was clarified, to determine if the city's buildings could accommodate green roofs, after studying the common construction method in the city and the building structure it is clear that the city existing buildings can sustain extra load added by the lighter types of green roof without structural reinforcement. Also the added cost of the green roof was calculated to be 37.5%.

After exploring the city's buildings ability to sustain green roofs and the availability of construction materials, the citizens knowledge regarding green roofs and their willingness to apply green roofs to their building was measured by qualitative and quantitative approach, questionnaire results shows that the participants were willing to add green roofs to their

buildings but have concerns over the cost of green roofs, further more the participants linked the benefits of green roofs with the benefits provided by plants and green areas in general, but not to the reduction of energy used in heating and cooling, or reducing urban heat. So in the last part of this research calculation of the actual reduction of direct solar radiation on the roof was conducted using Ecotect, About 50% reduction on the total all year direct solar radiation in the villa and 62% reduction is achieved in the multi storey building, also reduction in the energy used for cooling and heating was also calculated. The Ecotect results indicate that insulated green roof have the lowest energy consumption rate, reducing approximately 10% for the villa total year consumption and 18% for multi storey building. Where green roof provide about 9% and 17% reduction for the villa and multi storey building. Thermal computation resulting from different U-value, calculations showed total saving up to 26% of total energy consumption by green roof, and 37% by adding insulation to the green roof layers.

These results show that green roofs can be cost effective on the long term as the increase of building construction cost is to be returned in the reduction of energy loads.

# Chapter One

# Introduction

## 1.1. Introduction

Like other cultures worldwide, plants and gardens are considered important in Islamic culture and religion. This is due to their benefits to humans' physical and psychological health. These aspects have sparked the interest of many people who have established gardens in their houses, both inside and outside. This concept can easily be applied with the help of some architectural elements, such as balconies, window ledges and some roofs. In the Arab and Islamic traditional cities, gardens were widely used. The Courtyard garden is the main example where it became the living core of buildings. However, in the contemporary new, crowded high-rise building style, there is, unfortunately, little space left for gardens.

People generally enjoy being surrounded by greenery," *the belief that contact with nature is good or beneficial for people, is an old and widespread notion"* (Kellert & Wilson, 1993). Historically, this was highly considered by planners and designers. Wilson (1984) stated that there is a genetic basis for humans' positive response to nature, which is called Biophilia (Kellert & Wilson, 1993). This is *"an innate and genetically determined affinity of human beings with the natural world"*. (oxford dictionaries, 2014)

Regrettably, the lack of gardens in Palestine in general and the city of Nablus in particular, may be due to its topography as it slopes steeply and severely. This generates problems in developing new city gardens due to the difficult nature of the city of Nablus, especially, with the current urban sprawl.

This research explores and develops ways of creating more green areas and spaces in the city of Nablus by implementing the concept of roof gardens. The reason behind suggesting the concept of green roofs is due to the fact that it will improve greatly the air quality, outdoor environment and eventually the health of the city's residents as a whole.

## 1.2. Problem Statement:

In the Palestinian cities; especially the city of Nablus, there is not enough landscape or in some areas no green spaces at all. This is due to the increasing population and existing land use, therefore, it is hard to create new green spaces; however, there is a possibility to provide new green areas without confiscation of land or even demolishing buildings. This can be achieved by providing green roofs or roof gardens on the unused roofs of city buildings.

Like other Palestinian cities, the steep slope of the mountains demarcates the city of Nablus. This topographical characteristic presents an excellent panoramic city view, regrettably, green space and landscape are very meager, and so to improve the urban appearance of the city and human comfort, there is a need to establish roof gardens. This would be in contrast to what can be viewed at present Nablus city roofs; i.e. water tanks and solar water-heating panels. By implementing the green roof concept, the citizens of the city of Nablus will have garden view and private garden on their roof. Indeed, instead of going to the gardens they all would live in gardens.

Recently the weather in Palestinian cities have changed, one can notice the hotter summer and colder winter temperature, this climate change can be reduced by increasing the green surfaces in the city. The use of green roofs will also increase the area of the city covered with plants and at the same time, the roof will not be directly exposed to the different weather conditions, which will reduce the heat gain and loss of the building.

## 1.3. Aims and Objectives

This research presents the concept of green roofs for the city of Nablus. This will improve the physical environment of Palestinians and provide outdoor human comfort, in addition to escape from the summer heat and to make gardens accessible to everyone.

It may be the best way to increase green areas in the city of Nablus by making roof gardens on the city of Nablus roofs. This study clarifies the feasibility and benefits of roof gardens in the city.

Green roofs are considered a multidisciplinary field of study. This study will not investigate all aspects regarding green roofs application in the city of Nablus. The environmental and economical aspects, along with the residents opinion regarding green roofs will be studied.

## 1.4. The importance of the study:

Roof gardens are a growing research field, which is multidisciplinary and new research area. According to a bibliometric study on the directions in green roof research, *"the number of publications in this field increased in the last two decades. Papers on green roofs were classified into 32* *research areas. The percentages of plant sciences, forestry, marine and freshwater biology and biodiversity conservation of the total research areas classifications used each year increased significantly with time, while architecture decreased significantly with time signifying an increased interest in environmental issues and less focus on architectural issues*." (Lior, et al., 2013)

Statistics of publications throughout the world indicated that the USA and the EU conducting 66% of the research, However, there has been a sharp increase in the number of countries that conduct green roof research. (Lior, et al., 2013)

Yet, this area of research has not received much attention in Palestine. This research draws attention to the benefits of roof gardens. Starting with this research on the city of Nablus it is hoped to encourage Palestinian universities, cities, and neighboring countries to develop gardens on the roofs of their buildings.

## 1.5. Literature review

In the last decade of the twentieth century, green roofs in European countries received increasing amount of attention. Germany considered to be one of the leading countries in the number of publications and application of green roofs.

The German FLL (FOERSCHUNGSGELLSCHAFT LANDSCHAFTSENTWICKLUNG LANDSCHAFTSBAU, Landscaping and Landscape Research Society), issued roof greening guidelines (guidelines for planning execution and upkeep of green-roof sites) (FLL, 2002). This publication was widely accepted not only in Germany but also in other countries. These guidelines *"set out the basic principles and requirements which apply in the general terms to the planning, execution and maintenance of such green schemes, taking into account the present scientific knowledge and the most advanced technology. "* (FLL, 2002). FLL intended for the guidelines to be used by professionals and craftsmen working in relevant green sectors and trades. FLL and other researchers, such as *GREEN ROOF SYSTEM* (Weiler & Scholz-Barth, 2009), and *GREEN ROOF CONSTRUCTION AND MAINTENANCE* (LUCKETT, 2009), focus only on the technical aspects of constructing green roofs such as drainage and materials for constructing green roofs. Although such aspects are extremely important for green roofs research, other aspects have to be tackled, such as the effect of roof gardens on the urban appearance of the city physically and environmentally.

The USA and EU are leading countries in the contribution to the publications regarding green roofs. For example, the available publications on the topic are 34% for the USA, and the EU about 33% (Lior, et al., 2013). The results of this concentration of research are having almost no reliable data on green roofs environmental effect in the Mediterranean climate including Palestine.

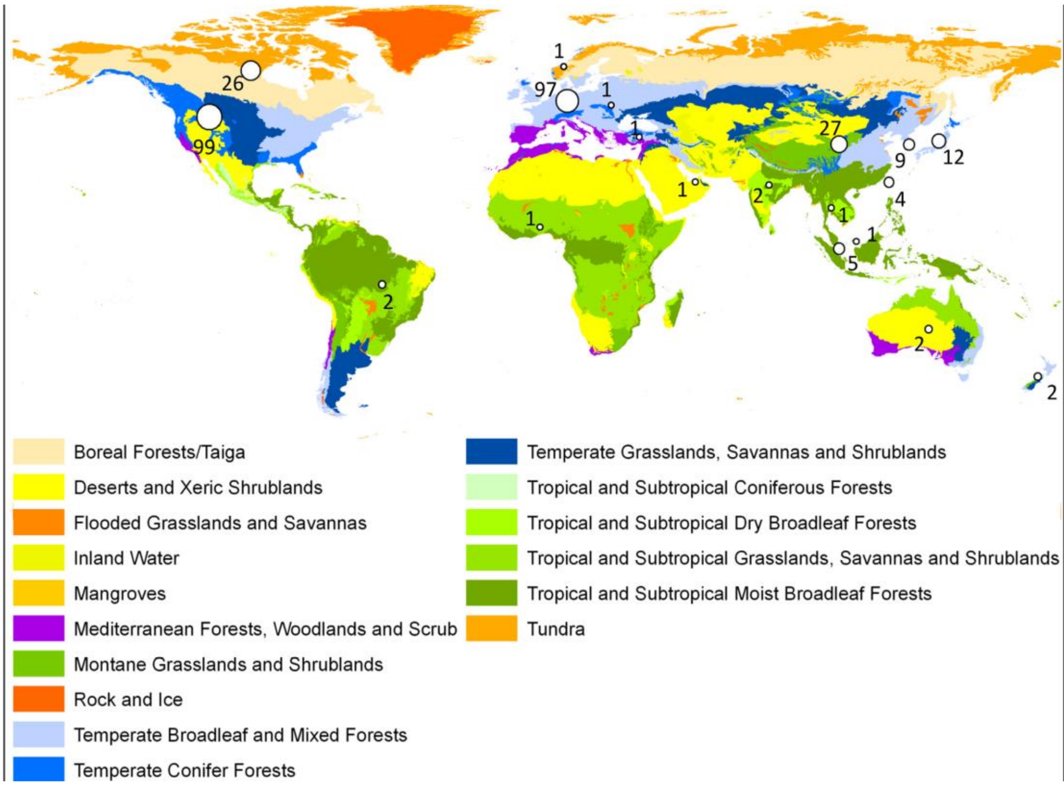



**Fig.1** Number of publications per country (between 2001 and 2012) overlaid on terrestrial ecoregions map.
Source: (Lior, et al., 2013)

As shown in the previous figure, the largest number of publications was in temperate countries. It is focusing on information regarding green roof environmental benefits including improved storm-water management, better regulation of the buildings' temperature, a reduced urban heat-island effect, and increased urban wildlife habitat.

Growing interest in researching green roof effects in tropical, semi-tropical, and tropical island climates. However, green roof research is to be encouraged particularly with reference to Mediterranean climate and in Middle Eastern countries. This research may well be the starting point for filling the gap in information on green roof behaviors in Palestine, taking the city of Nablus as a case study. (OBERNDORFER, et al., 2007)*) (* (Bau-Show Lin, 2013)

Green roof technology is attractive, but still untested in the high-rise buildings of Palestine. Due to the lightweight nature of some green roofs, it can potentially be used to green up many existing roofs. These could be made without structural alteration to accommodate extra load on the roofs. Indeed, there is room and large potential for this technology in Palestinian cities.

## 1.6. Methodology

This research is based on interdisciplinary and multidisciplinary approaches. It is divided into three stages; **the first stage** is theoretical. It involves data collection relevant to Green Roofs and Roof Gardens from different sources. Examples of technology and construction roof gardens worldwide have been studied. This section will demonstrate the benefits of roof gardens.

**The second stage** includes an analysis of the current structure of the city's roofs and Green roof. It elaborates on studying the current use of roofs and to what extent that will be affected and need restructuring when the green roofs are constructed. It also determines to what extent people will be satisfied and comfortable. This part of the research will employ qualitative and quantitative approaches for a set of numbers and indicators resulting from questionnaires.

**The third stage is** a practical one, using an experimental approach to explore the effect of green roof on the city of Nablus by comparing two main building types using computer simulation to clarify the difference in thermal behavior between regular roof and green roof. This will generate answers to the question of; to what extent green roof will improve human comfort and environmental conditions.

## 1.7. Research Outline:

The research is divided into six chapters; **Chapter one** presents research introduction and Methodology. **Chapter two** involves a theoretical background to the study. **Chapter three** investigates green areas in the city of Nablus and the Current roofs of the city of Nablus, their construction technology, maintenance and cost. **Chapter four** contains the questionnaire analysis. **Chapter five** is the computer simulation. The conclusions and recommendations are presented in **chapter six**.

# Chapter Two

# Green Roofs Conceptual and Theoretical Background

This chapter demonstrates the wide use of green roofs through history, up to the present use of green roofs in modern societies, shows peoples' interest and knowledge regarding green roofs.

## 2.1. Introduction:

Roof gardens existed in human culture and architecture ever since the hanging gardens of Babylon, and it is not hard to imagine that these gardens were considered paradise on earth for those people living in the desert where the day is very hot and the night is cold. The first known example is the ziggurats of ancient Mesopotamia, built in the fourth millennium (about 600 BC) roof gardens evolved through the centuries and in different civilizations and they were an essential element in vernacular architecture such as the Scandinavian sod roofs, the sod stripped from grassy meadows covers the heavy timber structure. *"The combination of ground and plants rooted on the roofs prepared it potential to take out roofs insulate comparatively healthy, tight to the air and water, challenging to the wind and fire."* (Almusaed, 2011)

In modern time, people use green roofs developed from the sod roofs, which are lighter, more effective and mass-marketed industry.

As the green roofing technology developed, the reasons for its use and benefits evolved. For example, they were used to escape summer heat, as an extension of living rooms, protection from weather changes, planting food, a way of flood control and in some cultures to show wealth and status in the community, on the other hand modern green roofs are being used to deal with almost the same problems in addition of recent problems created by the urbanism such as the heat island effect, water runoff, bad air quality, and a need for increasing green spaces.

## 2.2. Green roof definition

The vast majority of researchers and authorities identified the green roofs, as "*Green roofs are vegetated layers that sit on top of the conventional waterproofed roof surfaces of a building. Whilst green roofs come in many different forms and types, usually a distinction is made between extensive, intensive and biodiverse or wildlife roofs."* (the green roof centre, 2014). Another definition was presented by the Green Roof Guide to be *"A green or living roof is a roof or deck onto which vegetation is intentionally grown or habitats for wildlife are established."* (green roof guide, 2014)

Karen Liu, who researches in National Research Council, defines the green roofs in her research *"the engineering performance of rooftop gardens through field evaluation"*. According to her, *"Green roofs or rooftop gardens are roofs planted with vegetation"*. (Liu, 2003)

In 2009, the Indianapolis city published a manual for Storm-water design and Specification. It identified roof gardens to be *"A green roof (vegetated roof/eco roof/roof garden)"*. It was also defined as *"a system consisting of waterproofing material, growing medium, and vegetation. A green roof can be used in place of a traditional roof as a way to limit impervious site area and manage storm-water runoff "*. (City of Indianapolis, 2009)

## 2.3. Historical Development of Green Roofs:

Green roofs have evolved throughout the years since ancient Mesopotamia to present day green roofs.

### 2.3.1. Ancient Green Roofs

#### 2.3.1.1. The ziggurats of ancient Mesopotamia

The earliest record shows that these massive pyramids were built between 4000-600 BC. And were considered to be one of the seven wonders of the ancient world. The ziggurats were huge stepped structure of stone, the landings of these steps were planted with trees and shrubs that softened the climb and offered refuge from the Babylon heat (Magill, Midden, Grouninger, & Therrell, 2011). The planted terraces are accessed by stairs, as these ziggurats had no interior rooms the plants offers shading and cool place for visitors to rest. (Shimmin, Heather Shimmin Photography, 2012) (OBERNDORFER, et al., 2007)

The great ziggurat of Ur is one of the best-preserved ziggurats; its base area is about 2000$m^2$, constructed with watertight foundation, asphalt panels, bricks, and mortar. Historians believe that the gardens were constructed for aesthetic purposes because of the choice of trees, blooming bushes, climbing plants, and spice gardens. (Pearen, Dinsdale, & Wilson, 2006)

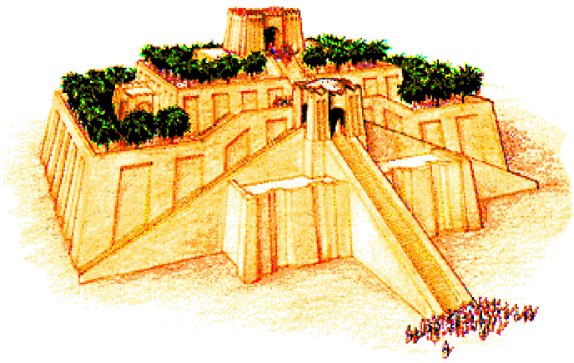


**Fig. 2** Sketch of the ziggurat of Ur.
Source : (Shimmin, Heather Shimmin Photography, 2012)

**Fig. 3** Sketch for the Hanging Gardens of Babylon.
Source : (Christopher Klein, 2013)

It may be that the best-known roof gardens in the world were the hanging garden of Babylon, built by the king Nebuchadnezzar. "The hanging garden" phrase came from the vegetation which hung over the walls to the lower level terrace. The engineering of the building was spectacular; the weight was supported by arcades with about 5 meters thickness and a square base of 120m x120m. (Shimmin, Heather Shimmin Photography, 2012) (Pearen, Dinsdale, & Wilson, 2006) (Magill, Midden, Grouninger, & Therrell, 2011)

### 2.3.1.2 Roman roof garden

Romans planted trees on the top of their buildings especially in many municipal buildings. Historical evidence indicates that roof gardens existed on the mausoleums of Augustus and Hadrian (Magill, Midden, Grouninger, & Therrell, 2011). The discovery of Pompeii in 1749 under the ashes of the volcano eruption which preserved almost the entire roman lifestyle, which revealed many roof garden, the roof garden was an important element of roman lifestyle, as a place for social activities and dine, external living room, and to escape summer heat.

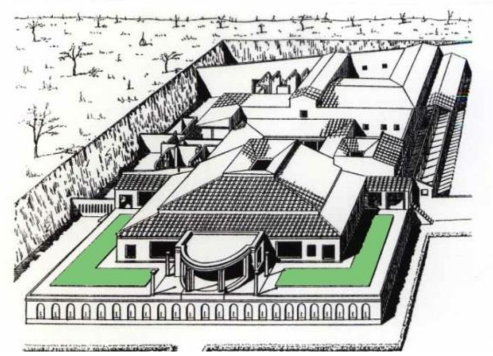


**Fig.4** Reconstruction of Villa of Mysteries, near Pompeii, Italy.
Source: (Shimmin, Heather Shimmin Photography, 2012)

**Fig.5** Image of Villa of Mysteries roof garden.
Source: (Shimmin, Heather Shimmin Photography, 2012)

An example of roman roof gardens is the Villa of Mysteries, located on the road to Herculaneum, close to the northwest gate of the city. Vegetation was grown on the U-shaped terrace arcade. (Shimmin, Heather Shimmin Photography, 2012)

### 2.3.2. Islamic roof garden

Little is known about the use of roof gardens in the Islamic period but the traveler "Nasir Khusraw" in his book *"Safarnama"* described Cairo in the 10th century *"in the city orchards and trees between castles irrigated by well water. And in the sultan castle an orchard's no other orchard resembles it, water mill used to irrigate it. Trees are planted above roofs and became parks"*. (Khusraw, Safar Namah, 1993)

Also, describing the buildings in Egypt *"in Egypt houses of 14 floors, and houses of seven floors. And heard from a trusted person that a man planted a garden on the top of seven floor house, and planted on this roof trees orange and banana and planted roses and other type of flowers"*. (Khusraw, Safar Namah, 1993)

### 2.3.3. Renaissance green roofs

Roof gardens at that time were owned by the rich and Benedictine monks. Although the steeply terraced gardens were widespread in Genoa, but the first known roof garden or controlled landscape (manmade landscape) on top of a structure was in Pienza where Pope Pius II, in 1463, asked Bernardo Rossellino to design his private summer residence "The Palazzo Piccolomini" on top of the palazzo a roof garden designed with trees in a formal organization. (Shimmin, Heather Shimmin Photography, 2012)


**Fig.6** Garden loggia atop the Palazzo in Poccolomini, Pienza overlooking the Val D'Oria.
Source: ("Gardens in Tuscany," n.d.)

### 2.3.4. Sod (turf) roofs

Some researchers believe that turf roofs are first known green roofs dated back to the Bronze Age (3000 years) (STATER, 2008). The sod or turf roofs were used in cold Scandinavian countries, especially in Norwegian vernacular architecture (1600-1800). These roofs were not designed to impress or for esthetical value but mainly for their benefits in insulation, water proofing, and increasing roof life (protect the roof from rain and prevent it from rooting, while the root system gave the roof structure more strength) figure (7). The roof was built using local materials and covered with birch bark for waterproofing and a layer of twigs was added for drainage. This roofing technique arrived to the United States and Canada by the immigrants that continued to use sod (turf) to cover the new houses they built in late 1800. (Shimmin, Heather Shimmin Photography, 2012) (Donnell -Kilmer, 2013)

**Fig. 7** Norwegian sod roof
Source : (Kamta, 2012)

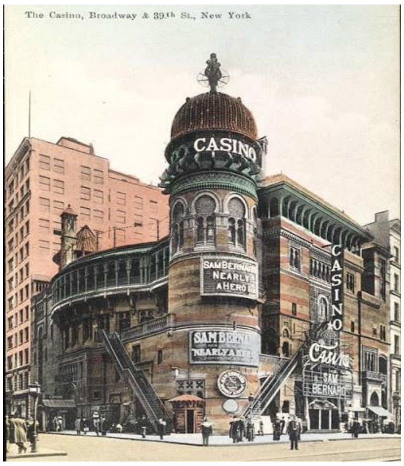



**Fig.8** The Casino Theatre, 1909.
Source: (Miller, 2013)

### 2.3.5. Modern green roofs.

The roof gardens developed as the building materials improved, to support more weight and with better waterproofing. 1890s roof top gardens were popular in New York, in 1882 the first roof garden was constructed, Rudolph Aronson a musician and artist visited Paris in the summer and he was charmed by the theater gardens, but the land prices in New York city made it impossible to duplicate the Parisian summer theater gardens on the ground level, to solve this problem he proposed to elevate the theater garden to the roof (with the stage surrounded by plants) of the casino theater at 39th and Broadway, figure (8). This summer theater became very successful in New York, which encouraged other theaters to add gardens to their roofs. The most famous summer theater, Madison Square Garden's and Winter Gardens got their names from the roof gardens.

Modern architecture changed the entire architectural principles in early 20th century. Architects like Frank Lloyd Wright and Le Corbusier started a new way of thinking about architecture, presenting new theories for architectural design.

Le Corburiser’s Cinq Points de l’Architecture Moderne became principles of design and theory. The five points are freestanding support pillars, Open floor plan independent from the supports, Vertical facade free from supports, long horizontal sliding windows, and Roof gardens.

These five points of architecture were demonstrated in the design of houses in the Weissenhof settlement, Stuttgart, 1927, but the best-known example to clarify the five points of architecture is Villa Savoye1929–31 designed by Le Corburiser. (le-corbusier, 1931)

Le Corburiser has been credited for bringing the roof gardens back to life after being almost forgotten. Le Corbusier explained the benefits of using a roof garden to restore the area occupied by the building, in general, roof gardens mean to a city the recovery of all the built-up area (le-corbusier, 1931),according to him; *"it became the most favored place in the building"*.

**Fig.9** Images of Villa Savoy
Source: (Glynn, 2001)

Today Germany is the leading country in present green roof research materials regarding green roof benefits starting in 1960s, new building materials is still been developed to create green roofs ever since. In 1970s, two parallel groups worked on the development of roof gardens researchers for technical evaluating the ecological benefits of green roofs, and citizen concerned for the environment.

Accidental plants growing (late 70s) on the “rental barracks” in Berlin (working class housing roof constructed with tar, gravel, and sand). Lead the researchers to study the roof ecological value. The FLL (the Research Society for Landscape Development and Construction) was launched in 1975 and started to write down guidelines and standards for the construction of green roofs with high quality.

**Fig. 10** image of Stuttgart, Germany, since 1989, municipal regulations require green cover for all new flat-roof buildings.
Source: (“design you trust.com,” n.d.)

(Bürgerinitiativen) citizen movement shed the light on urban areas environmental concerns such as growing urbanization and scarce green spaces. This movement led to the creation of political party the Greens (Die Grünen). In 1980s, many municipalities and stats started programs to greening the cities. The programs engorged many greening methods such as green roofs, green walls, and courtyard, by funding 50 to 100 per cent of the expenses. By 1983 more than 24 cities granted subsidies for urban greening. In addition to federal building codes and regulations, which was submitted to support greening the city that encouraged the use of green roofs systems. Today Germany possesses the largest number of green roofs. Other European and western countries are adopting green roof technology to help mitigate the effects of urbanization. (Lawlor, Currie, Doshi, & Wieditz, 2006) (STATER, 2008)

## 2.4. Green Roofs building types, Technologies, and components.

Modern green roofs concepts are basically divided into two main types; intensive and extensive. Between these two types, there are a number of green roof technologies derived from these two main types, including semi-intensive and semi-extensive. All of these types present various benefits to the urban environment, as well as, having various methods of construction. This part will explain these technologies and their components.

Dividing green roofs to intensive and extensive is a general way or the most common way for spotting the differences between green roofs types, manufacturers usually list the green roof technology after construction method, mat based systems or substrate based systems, pre-vegetated or vegetated after application, also different drainage technologies used in the drainage layer; drainage plates, granular media or drainage mats, many other factors play a role in defining the green roof type; flat roof or sloped roof, built in layered-style or modular vegetative grid.

All green roofs must contain the following layers: plant layer, growing media (soil), filter layer, drainage layer, root barrier, waterproofing, vapor control and in some thermal insulation.

### 2.4.1. Green roof types: Structural Load

Plant type and design controls substrate depth, which affects the weight of the green roof components, different types of roofing have different substrate depth, therefore different added weight to the structure.

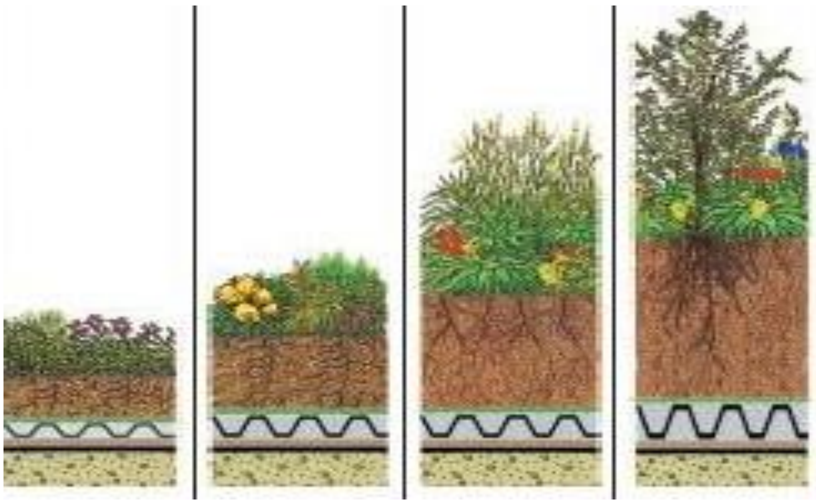


**Fig. 11** Section in green roof types from Extensive (left) to Intensive (right)
Source: (“Green Roof Systems | Green Roofing Solutions | Products, Materials,” 2006)

#### 2.4.1.1 Extensive Green Roof (Climatic Skin Roof)

This type of green roofs have shallow growing media, range between 5 to 15 cm substrate, hence the growing media is shallow small plants only used in this type of green roofs such as grass, sedums (low laying ground covers), and herbs plant, their height doesn't exceed 25 cm, therefore, extensive green roofs requires little or no maintenance and irrigation, the plants are watered and fertilized in the first year, after that the roof is to be inspected three times a year. (Townshend, 2007)

As these roofs are not designed to be accessed by the public or the users of the buildings only basic access is needed for maintenance (weeding or mowing). The extra load added by extensive green roofs range between 60 to 150 kg/m2 and the added cost range from 100$ to 200$ / m2. (Lawlor, Currie, Doshi, & Wieditz, 2006)

This type of roofing is purely functional as for storm-water management, thermal insulation, fire proofing and other environmental aspects of a green roof, but it offer limited benefits for living space or a garden. (OBERNDORFER, et al., 2007)

This type of roofing is less likely to provide amenity space, but it is more appropriate for high levels and retrofitting.

Extensive Green Roof have two ways of constructing 1st **mat based system** which are pre-grown with mostly sedum species, and a very shallow growing media 20-40 mm, this mat system retain less rainfall and have lower thermal mass. The 2nd is **substrate based systems** this system have more depth 75-150mm, a wider variety of species could be planted, higher thermal mass and could retain more rainfall, although it have more advantages than mat based system but it takes more time to have full vegetation cover and higher weight. (Gedge, et al., 2008)

**Fig. 12** Mat based system
Source: (Dorsey, 2013)

**Fig. 13** Substrate based system
Source: ("Green Roof Report | ZinCo," 2012)

### 2.4.1.2 Semi-Intensive.

Is a way of bridging the gap between intensive and extensive roofing system (hybrid of the two systems) with substrate depth ranging between 12 to 25 cm, and 120-200 kg/m2 weight. This system can sustain grass, herbs and shrubs figure (15). Therefore, seasonal maintenance is needed. The cost of this system is medium (more than the extensive and less than the intensive). (International Green Roof Association (IGRA), 2008)

### 2.4.1.3 Intensive green roof. (Garden roof, sky garden)

Garden roofs are very similar to the landscape on earth. Consequently requires more substrate depth than extensive roofs, the substrate depth varies according to the type of plants used, but the depth growing media depth more than 20 cm, or 30 cm, up to 200 cm for tree planting, therefore the added weight to this type of green roofs is higher, between 180 to 900 kg/m2 added cost more than 200$ /m2. (OBERNDORFER, et al., 2007)

**Fig. 14** Intensive green roof, Namba Parks, Japan.
Source: (Yuka Yoneda, 2014)

Although the intensive roof considered expensive, needs more maintenances and a complicated irrigation system, but it will be used and accessed as a garden in the same way as a garden at ground level, so it will provide more than just functional environmental value for the building and users, as an escape, outdoor living room and adds aesthetic value as an amenity or recreational space to the building and the city. (Townshend, 2007) (Lawlor, Currie, Doshi, & Wieditz, 2006)

### 2.4.1.4 Mixed green roof

Using different roofing type on different locations on the roof, the design of this roof combines intensive and extensive areas, figure (16), the substrate depth can range from five to 200 cm, growing vast diversity of plants, grass, shrubs, and trees. So mixed green roofs needs a mixed maintenance and irrigation as the roof garden type differ, as well as, uneven weight distribution from 30 to 500 kg/m2. (Velazquez, 2005) (Almusaed, 2011)


**Fig. 15** Semi-Extensive green roof
Source: ("Roof Systems Consultants," n.d.)

**Fig. 16** Mixed green roof.
Source: ("Highlighting Baltimore Green Roofs!," 2013)

### 2.4.1.5 Rooftop gardens

*"Rooftop gardens consist of movable growers strategically placed on existing rooftops that do not always require structural reinforcement".* (Ayalon, 2006)

This system is simpler than the extensive and intensive roofing systems where the garden can be a group of planted pots or containers distributed on the accessible roofs.

**Fig.17** roof top garden
Source: (" InteriorHolic.com," 2012)

**Fig.18** Terrace garden in New York
*Source:* ("Garden, Gardens Apartments," n.d.)

Table (1) demonstrates a comparison between different characteristics of green roof types, obtained after reviewing green roofs guidelines, manufacturers' details, and published research. As the preceding part of this chapter explained these characteristic in detail; table (1) surmise the green roof type's information, to extract the needed information easily, for example, one can see that extensive green roofs are lighter but intensive green roof can support wider range of plants.

**Table (1): green roof types comparison**

| characteristic | **Extensive Green Roof** | **semi-intensive Green Roof** | **Intensive Green Roof** | **mix green roof** | **Rooftop Garden** |
|---|---|---|---|---|---|
| Substrate depth | 5 to 15 cm | 12 to 25 cm | 20 to 200 cm | vary | vary according to the planting container |
| weight | light (30 to 150kglm2) | medium 120-200kg/m2 | high 180-970 kg/m2 | 30-500 kg/m2 | vary according to the planting container |
| cost | low ($100 to 200/m²) | medium | high(more than $200-2000/m²) | high | low |
| Plants utilized | sedum-herbs and grass | grass-herbs and shrubs | shrubs and trees | grass-herbs shrubs and trees | grass and shrubs |
| plant diversity | low | medium | high | high | medium |
| accessibility | often | may be partially accessible | usually accessible | partial accessible | accessible |
| energy efficiency | low | middle | high | over middle | low |
| thermal insulation | middle | middle | high | high | low(no thermal insulation ) |
| Maintenance | low | periodically | high | special | special |
| Irrigation | low | periodically | frequently | periodically | frequently |

Source (Almusaed, 2011) (Townshend, 2007) (ZinCo, 2014) (OBERNDORFER, et al., 2007) (Gedge, et al., 2008) (Weiler & Scholz-Barth, 2009) (FLL, 2002) (Lawlor, Currie, Doshi, & Wieditz, 2006)

### 2.4.2. Other green roof constructing technology, Modular Green Roof Systems (Green grid)

As the green roof technology is developing every day, there is new, easier, less expensive and improved way of constructing green roofs,
such as (Green grid) in this method pre-planted grid of plastic trays, boxes, like flowerpots, installed directly on the insulated roof. These boxes or grid comes in all sizes and with wild variety of plants. It is easier to replace and repair than the non-modular green roofs.(Dineen & Woodward, 2013)

**Fig. 19** Green Grid

Source: (“Greenroofs.com Projects” 2015)

### 2.4.3. Green roof components.

Green roofs usually constructed with layers, which may differ between the types of green roof listed in the previous part of this chapter, the following images, demonstrate the layers used to construct a green roof. The most important layers of green roofs are waterproofing and soil (growing media).

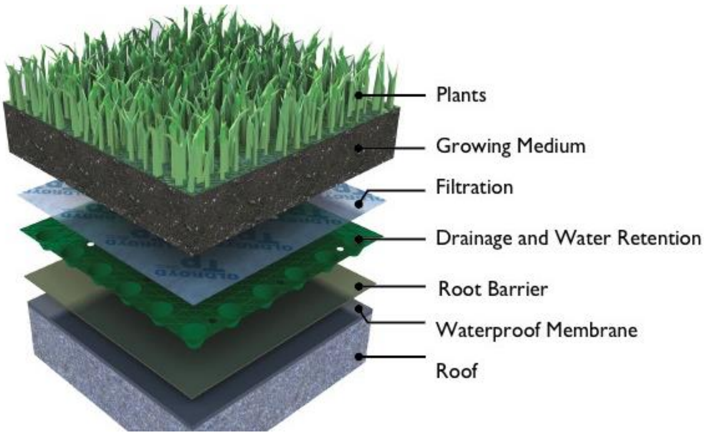



**Fig. 20** Green roof layers (1).

Source: ("Hardscaping 101: Green Roofs: Gardenista" 2015)

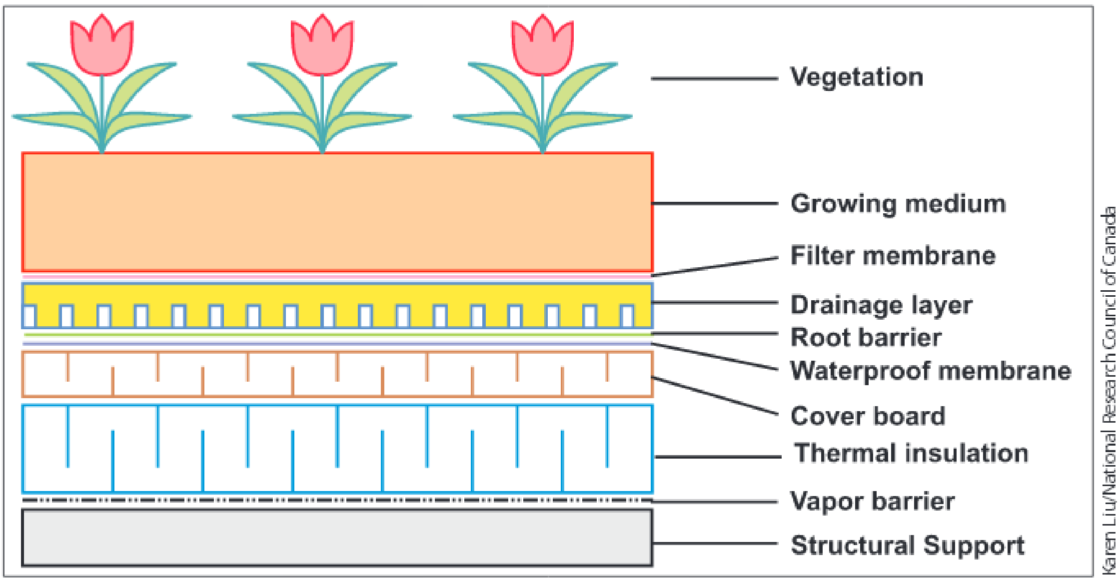



**Fig. 21** Green roof layers(2).
Source: (Dineen and Woodward 2014)

As noted in figure (21), some roof need structural support to sustain a green roof, but if the roof structure could sustain a green roof without the addition of support this layer is no longer needed. Also the thermal insulation layer as its not considered essential component for green roofs but it is usually added to improve the thermal fluctuation of the roof. This layer could be added bellow the roof structure (inside the building), or above roof structure. It is preferred to place this layer above roof structure and above waterproofing membrane. When applying thermal insulation under waterproofing it is needed to add vapor barrier to avoid having water or vapor reaching the roof structure, and also a protection, cover board may be added to protect the thermal insulation layer from cracking or deforming causing the waterproofing layer to rupture.

#### 2.4.3.1. Membrane, waterproofing membrane, Waterproofing Layer (A Seal)

The waterproof membrane is applied to the roof directly; it is one of the most important layers in green roof construction for it prevents moisture from leaking through the roof. Concern over the roof leakage is one of the main reasons drive people to hesitate about applying green roofs. And as this membrane the bottom layer of the green roof system, it's not easily maintained.

The waterproof layer should have been used to cover the roofs of existing buildings, never the less not all roofs in the city are covered with such layer. Commonly Bitumen sheets is used as a water proofing material in Palestine, but in the case of green roofs bituminous roofing material is not the best choice of material for green roofs, other water proofing materials are more efficient such as rubberized asphalt, polyolefin (cartouche ethylene propylene  polypropylene), PVC, or compounded thermoplastic composition. In Europe, mainly use PVC-covered polyester fabric and polyolefin-covered fiberglass fabric. (Almusaed, 2011) (Donnell -Kilmer, 2013) (Pearen, Dinsdale, & Wilson, 2006)

The application of this membrane depends on the type of waterproofing used according to the book (green roofs systems, a guide to the planning, design, and construction of landscape over structure) there are three main types:

- Built-up membrane
- Single-ply membrane (includes hybrid or combined membrane types)
- Fluid-applied membrane

**Built-up membrane:** This type of membrane is assembled on the roof a sequent of layers "felts" and a kind of molten bitumen. The felts made of fibers such as fiberglass ,providing strength , and the molten bitumen is the water resistant(coal tar or asphalt).In this type of membrane the molten bitumen is hot-applied or in some cases can be cold-applied, in either ways the bitumen is mopped or brushed and harden when dries. The final membrane is composed of three or four layers, and needs protection from damage and ultraviolet radiation.

**Single-ply Membrane:** One layer of this type provide the required water proofing, that is by using of thermosetting (elastomeric) or thermoplastic sheets.

**Fluid-Applied Membrane:** This type of roofing membrane is used when the form is complex or for vertical elements, compounds like asphalt emulsions, silicones and neoprene is used and applied with rollers or sprayers. (Weiler & Scholz-Barth, 2009)

### 2.4.3.2. Root-protection layer, root barrier

The root barrier layer or root-protection layer is used to keep the membrane intact from the plants roots, the material used in this layer can be copper sheeting or thick polyester coating. Although it may not be needed if the membrane is single-play membrane (synthetic roof materials) because the roots cannot easily penetrate this type of membrane, it is necessary to be used in all asphalt-based membrane plants can easily damage the layer and use the asphalt organic materials as food. However, it is still advised to use the protection layer to avoid future problems.

The root protection layer is very important to cover the membrane at seams and along perimeters and wall connection where it is most likely to crack and leak.

Simple polyethylene (plastic) sheets is considered one of the most efficient primary root barriers, it's applied over the water proofing membrane, a separation layer can be added to ensure the absence of chemical reaction . Polypropylene geotextile fabrics can be applied as a secondary root barrier over the drainage board to keep plants root from blocking the drainage core. Root barriers usually made as rolls whether it is incorporated with waterproofing or lose-laid, the seams must overlap for minimum 30 cm. The placement of root barrier depends on the type used whether it is directly applied over the membrane or over a protection layer. (Weiler & Scholz-Barth, 2009) (Donnell -Kilmer, 2013)

### 2.4.3.3. Protection Board

After installation of the waterproofing layer, it is important to protect it from damage caused by construction activity and maintenance after construction is complete. In order to protect water proofing layer the protection board supposed to be durable and do not deteriorate in water, such as Semi-rigid sheets of cement board, pressure-laminated fiberglass or mineral-reinforced asphaltic core that is part of the waterproofing system. Typically, protection boards are 1/8 inch (0.3175cm) to 1/4 inch (0.635cm) thick.

For reducing the cost temporary protection layer can be installed but it is not recommended, or rely on the drainage layer or insulation board. These material increase protection but will not provide the required protection under if heavy construction is needed. (Weiler & Scholz-Barth, 2009)

### 2.4.3.4. Drainage layer

This layer remove excess water after filtration, using channels, Drainage plat or Drainage mat, with angle of 1.5 degree if the slope of the roof is greater drainage layer may not be necessary, but still highly recommended in order of removing water quickly. (Donnell -Kilmer, 2013)

It is preferred to use natural material for drainage layer, but using rubber, polyethylene and expanded polystyrene is suitable for the production of drainage elements. (Almusaed, 2011)

#### 2.4.3.4.1. Drainage layer types

When classifying green roofs after the drainage technology used to construct it, there are three main types of green roof drainage technology.1st granular drainage 2nd drainage plates 3rd drainage mats.

Drainage plates are waffled plastic sheets (characteristically of an egg carton style configuration) their work mechanism is to store water above and drain water below. Drainage plates have the advantages of lightweight, easy to installation, and availability of sizes.

Granular drainage system is also lightweight but can sustain a heavier media, but this system of drainage, needs more work to install the slotted plastic triangular drainage conduit covered with inorganic granular media. This can be a layer of 4–8 cm of expanded clay or similar aggregate of 4–8 mm diameter.

Drainage mat is a multi-layer fabric mat that combines soil separation, drainage, and protection functions. The fastest system to install and the thinnest and lightest green roof assembly. Nevertheless, it has limited water storage and drainage capacity, therefore it is mainly used for sloped roofs.

(Conservation Technology, Inc.)

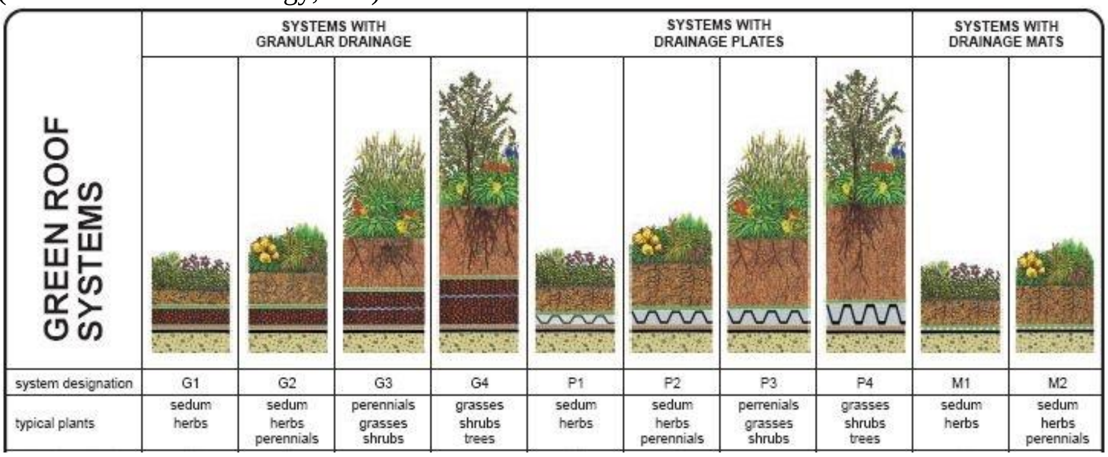



**Fig.22** Comparing types of drainage systems

Source: (Conservation Technology, Inc.)

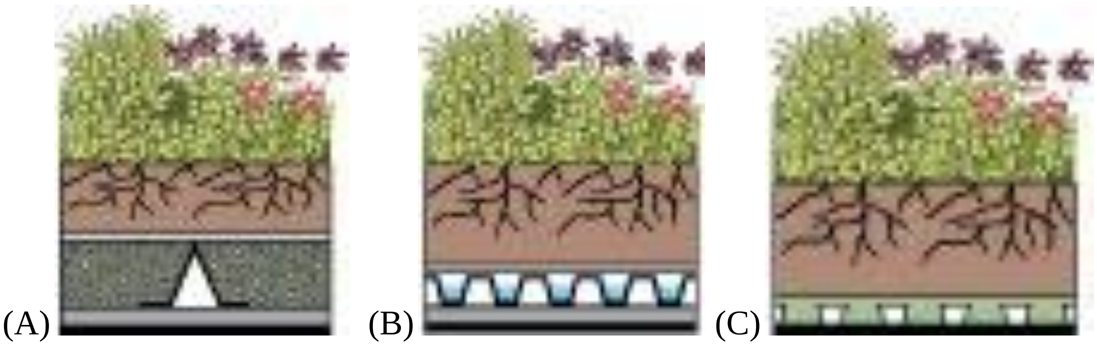



**Fig.23** (A) Granular drainage (B) Drainage plat (C) Drainage mat Comparing

Source: (Conservation Technology, Inc.)

### 2.4.3.5. Filter layer

This layer retain soil media, while allowing only water through to the drain layer, the importance of this layer is retaining the soil and maintaining the drain unclogged.

The filter layer is a special fabric made of strong materials, made from a lightweight polyester geo textile. Non-woven, non-biodegradable, and non-fabric, engineered to retain a specific grain size from passing through, but still passes water easily.

The entire area planted or the plant bed must be lined with filter layer and covering up to 8 inches (20.32cm) the plant container to stop soil from slipping through. (Donnell -Kilmer, 2013) (Pearen, Dinsdale, & Wilson, 2006) (Almusaed, 2011)

### 2.4.3.6. Planting Media

Substrate, Growing Medium or Soil Medium are other names for the soil used in green roofs, soil is considered the most important part of any garden. Yet green roof soil must have particular characteristics ranging from, heavy clay and light sandy soil, clay soil are very heavy due to its water retaining capacity, while, sand soil are very light do not retain water it is very poor for growing plants and reducing storm water runoff. Engineered soil (slightly sandy loam) is used in green roof, where a balance is needed between weight and nutritious. (Donnell -Kilmer, 2013)

The green roof soil is have to be mixed with lightweight aggregates, slag, expanded slate, or expanded clay; sand and gravel can also be used. Synthetic soil mixes are commonly used. The soil mix is preferred to be just about 75–80% inorganic to 20–25% organic. It is not recommended to use highly organic substrate as it will decompose and cause substrate to shrink (Almusaed, 2011). *"It is important that the soil medium meet the demanding physical, chemical, and biological design requirements associated with storm water drainage. This includes moisture retention, porosity, hydraulic conductivity and maximum water capacities properties."* (Pearen, Dinsdale, & Wilson, 2006)

The type of plants, climate, and area of planting and green roof type determines thickness of the substrate layer.

### 2.5. Green roof benefits

This section of the research explores the benefits of green roofs, although the amount of research conducted on green roof technology and benefits in the Mediterranean region is increasing, but when compared with the research have been done, and being conducted in other climatic regions, the number of green roof research in Mediterranean region seems to be limited. Mainly because of the little knowledge on the green roofs characteristics and benefits. (Fernandez-Cañero, Emilsson, Fernandez-Barba, & Herrera Machuca, 2013)

Not only, green roofs can be beneficial for both macro-city and micro-building level, but also, worldwide benefits can be achieved, as the total area of urban roofs estimated to be $3.8*10^{11}$ $m^2$. Nevertheless, the urban area as assumed by Jacobson in 2007 to be 2.26 times above the estimated area calculated by analyzing satellite data (White & Gatersleben, 2011), about 25% of urban areas are roofs (Akbari, Menon, & Rosenfeld, 2009). By adding greenery to the roofs of urban areas global environmental improvement can be achieved.

The application of green roofs to the urban roofs considered less expensive than constructing a garden on available ground level area, as well as, providing additional benefits (Kolokotsa, Santamouris, & Zerefos, 2013). On the macro-city level, reducing storm-water runoff, reducing the heat island effect, reduction of pollution particulate, the potential for urban food ecology, improving city appearance and citizens' health, and the return of wildlife to the city, and on a micro-building level, reducing heating and cooling costs, extending roof surface life, and having easy access to gardens. (Donnell -Kilmer, 2013)

### 2.5. 1. Storm water management. (Reduce water runoff)

The roof garden concept have been used worldwide to mitigate water runoff, cities like New York, Vancouver, Toronto, Waterloo, Portland and several cities in Germany.

As the majority of the cities surfaces are impervious, man-made hard surfaces, (buildings roofs and walls, sidewalks, streets, paved parking lots). Consequently, about 75% of rain in urban area is lost directly to run-off, when compared with 5% in a forest where 95% of rainwater infiltrates into the ground or captured by vegetation. (Lawlor, Currie, Doshi, & Wieditz, 2006) (Townshend, 2007)

In the urban areas (cities) rainwater is directed to sewer systems. These systems may be different from a country to another. There are two main types of storm water and sewage system, the first system contains separated lines of channels (storm water line and sewage line), the other have combined infrastructure, which is the case in the city of Nablus, in this system the sewers reach maximum capacity rapidly and discharge a mix of rain water and untreated sewage to the city streets.

Many problems occur from water run-off in urban areas such as flooding which make significant disruption and financial damage to private and public property, contamination of storm-water, combined sewage overflows, and increased water temperatures. Run-off from paved areas has higher temperatures than in the surrounding natural areas. This will lead to drop in local water tables, heavy investment in artificial drainage systems and destruction of natural habitat. (Lawlor, Currie, Doshi, & Wieditz, 2006) (Townshend, 2007)

Adding green roofs to the conventional roofs of the city will reduce the impervious surfaces area, as the buildings are usually about 50% of city area, in Nablus buildings are about 67% of city area (Nablus Municipality , 2011), the green roof store rainwater in the growing medium and plants, then evaporate the water to the atmosphere. The storing or evaporating of water depends on the plants types and growing medium depth. Studies have shown that green roof retains 70-90% of rain in summer and 25-40% of rain in winter. (Banting, et al., 2005)

Many cities developed green roof policies and legal recruitments as a consequence of water run-off problem. For example, in Germany between 2000 and 2001, installation 25 million m2 green roofs were recorded mainly as a result of water run-off reduction polices. ("Green Roofs - Enviromental Advantages," n.d.)

The green roofs have two main effects regarding water run-off treatment, on one hand reduce the total run-off, absorb water, and return it to the air, on the other hand spread the run-off water over a longer time, the water is held in the roofing layers for a period before it runs-off. Therefore, reduce the likely hood of local flooding. (Townshend, 2007) (Livingroofs.org ,ecologyconsultancy, 2004) (Banting, et al., 2005)

A study to measure the effect of a green roof in comparison to a regular roof in Canada, the rain incidents and the storm water run-off for the two roof sections were monitored over time in fall 2001. Two rain events occurred the first on October 6, 2001 the following figure shows the difference in rain/run-off, (Rain: purple), run-off from the Reference Roof (Runoff-R: blue) and runoff from the Green Roof (Runoff-G: green), and the orange shows the difference in run-off between the two roofs. While the run-off from the reference roof was equal to the rainfall, the green roof retained 8mm of the 34mm rain.

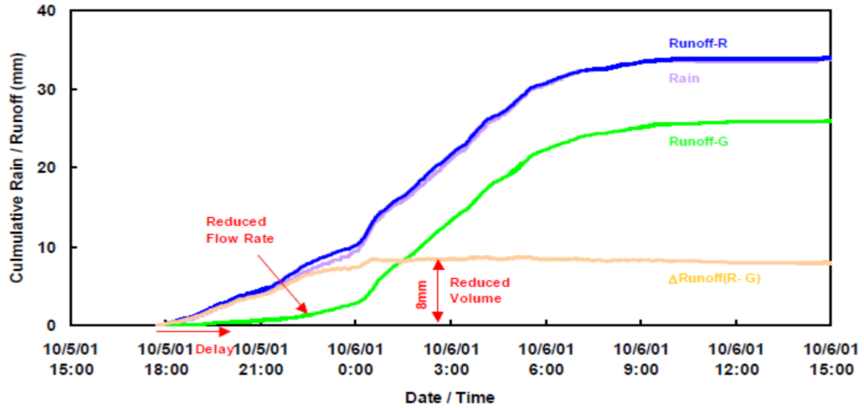



**Fig.24** Rain event on October 5-6, 2011, green roof runoff (in green) and regular roof runoff in blue.

Source: (Bass & Baskaran, Evaluating Rooftop and Vertical Gardens as an Adaptation Strategy for Urban Areas, 2001)

On the second event the results showed a run-off delay for 45minutes from the start of the first rain event and a lower run-off rate the reference roof rate is about 2mm/h while the green roof rate is 0.4mm/h, the green roof retained 2 mm before the run-off start and retained 4.5 mm of the 10 mm rain that fell, although the growing medium was not dry because of light rain the day before. The figure shows the difference between regular roof and green roof run-off.

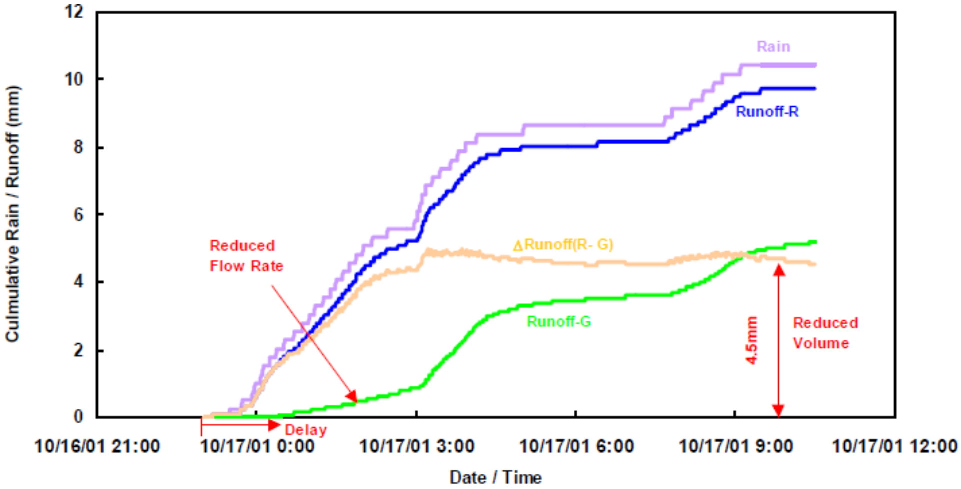



**Fig.25** Rain event on 61-17 October, 2011, green roof runoff (in green) and regular roof runoff in blue.

Source: (Bass & Baskaran, Evaluating Rooftop and Vertical Gardens as an Adaptation Strategy for Urban Areas, 2001)

Another study to determine the engineering performance of rooftop gardens through field evaluation by Liu in Ottawa, showed the difference in green roof run off (in green) and regular roof run off (in blue) in two different rain intensity.

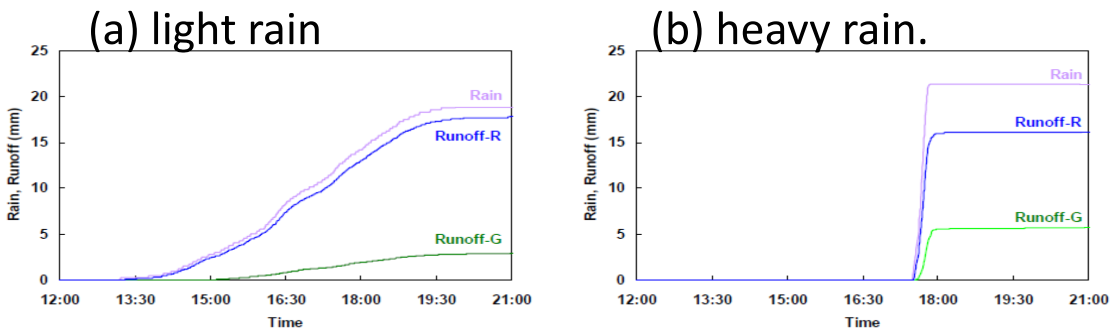



**Fig.26** Runoff of two rain events (a) light rain (b) heavy rain. Showing the difference between green roof runoff (in green) and regular roof runoff in blue.

Source: (Liu, 2003)

In Genoa 2007 a green roof experiment in Mediterranean climate was conducted the results shows that green roofs are excellent device to control storm water " *with an average percent retained volume of 85% and a* *percent peak reduction of 95%. However, in the framework of the assessment of the environmental benefits (prevention of flooding phenomena and reduction of the impact on waste water treatment plants), it is necessary to extend the investigation horizon from the spatial scale of the single rooftop to the one of the entire watershed"*. (Palla, Lanza, & La Barbera, 2008)

### 2.5. 2. Mitigate city heat island effect

The urban heat island effect is one of the most recognized negative effects of urbanization, resulting the air and surface temperature in urban areas to be higher than rural surrounding areas, from 5 to 10°C. The difference in temperature caused by the density of asphalt concrete roofs, glass facades, combined with air pollution caused by motor vehicles and lake of natural elements such as trees. These surfaces absorb sun heat and radiate it to the surrounding air causing the temperature in the urbanized area to rise above cooler surrounding with an isotherm island like pattern. Where the surrounding areas with more vegetation such as rural areas, city park and suburban residence, have cooler air temperature due to the cooling effect of plants, evaporation and transpiration through the leaves. (Lawlor, Currie, Doshi, & Wieditz, 2006) (Banting, et al., 2005)

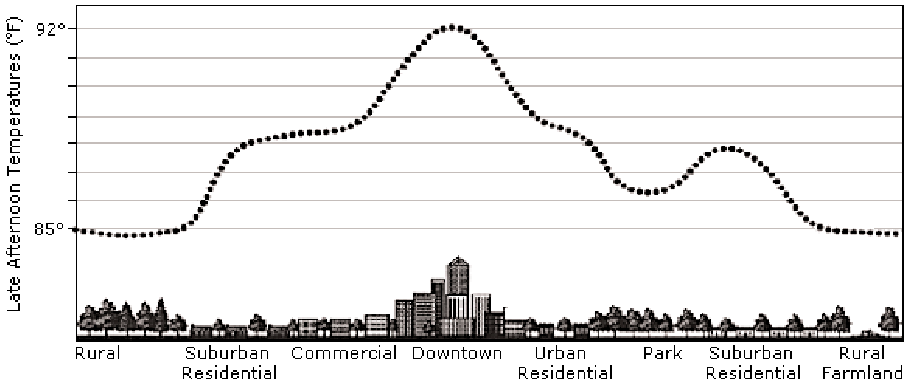



**Fig.27** Sketch of an Urban Heat Island profile

Source: (Paul R. Baumann, 2001)

Different factors effects the intensity of the urban heat island other than density of the urban area, city size and energy consumption, geography of the city and its location, weather, the parentage of green spaces, and time related factors such as season, month, time of the day. The concern over urban heat island effects drive many municipalities and cities to lunch programs to reduce it, various strategies was introduced to increase urban green spaces and trim down the surfaces with direct sun exposure, these strategies includes cool roofs, streets and public spaces greening and green roofs. (Banting, et al., 2005)

Adding vegetation to the cities proved to be a functional way to lower urban heat island also improving aesthetics image of the city, but the demand of ground level areas in cities makes adding new green spaces more difficult, therefore green roofs considered being a great way to reduce the city urban heat island as they add greenery to the existing impermeable surfaces. (Banting, et al., 2005)

The adoption of green roofs on a large scale has the potential for reducing urban heat island (Liu, 2003). Green roofs cover the roof surface preventing the sun from accessing and increasing the roof structure temperature and as green roof constructed with materials that do not radiate heat the air temperature above the roof is lowered. Also with evapotranspiration, where plants release water through their leaves contributes to the cooling factor of green roofs, plants provide wide array of benefits including lowering $CO_2$ percentage. (Donnell -Kilmer, 2013)

The reduction of urban heat island provided by adding green roofs cannot be easily computed (Banting, et al., 2005). A simulation of green roofs added to 1km in the city of Toronto to calculate the effect of green roof on the urban heat island, for 48 hours in June, a Mesoscale Community Compressible (MC2) model with conjunction of the ISBA SVAT scheme and an urban canyon, with green roof covering 5% of total land area, reduction of temperature about 1C$^o$ across the city. While the difference between irrigated green roof and dry green roof in this simulation showed that irrigated green roof reduced the temperature 2C$^o$ and maintained the 1$^o$C reduction for a longer time. (Bass, Krayenhoff, Martilli, & Stull, 2002)

A field study of Ottawa campus in 2000 comparing 72m2 roof divided in half with 1 meter divider. On one installed extensive green roof with 150mm growing medium, and the other is a conventional roof assembly covered with modified bituminous. And on both roofs instruments monitored temperature profile, heat flow, solar reflectance, relative humidity, soil moisture content and storm water run-off. The results showed a reduction in roof surface temperature from over 70°C of the conventional roof to about 30°C under the green roof in summer. And the daily temperature fluctuation of the Conventional Roof in spring and summer ranged from 42 to 47°C, but the temperature fluctuation was reduced to 5-7°C by using green roofs. (Liu, 2003)

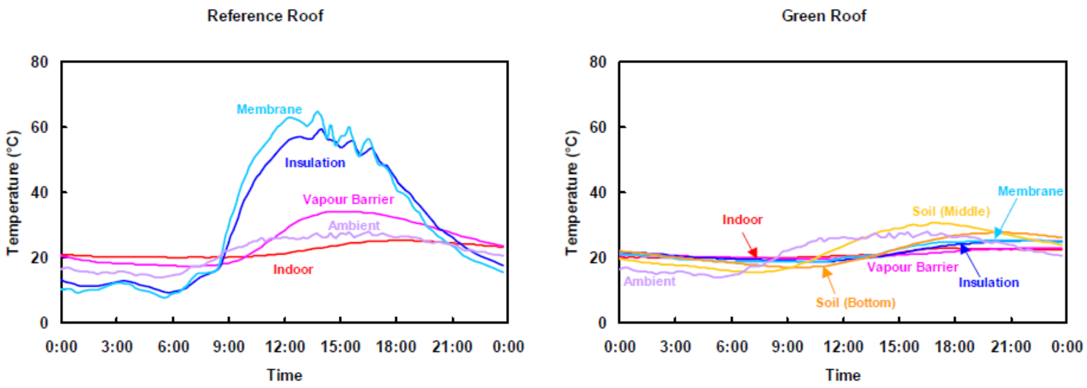



**Fig.28** Temperature profile of the roofing systems on (July 16, 2001) indicating the green roof reduction on temperature fluctuation within the roofing system.

Source: (Liu, 2003)

An advanced weather Research and Forecasting Model (ARW) combined with an urban canopy model was conducted to determine the green roof mitigation effect in Chicago, Illinois. The research concludes that *"Vegetative rooftops, or green roofs, offer a potentially attractive mitigation strategy by increasing equivalent albedo and thereby reducing temperatures in the urban environment"*, and green roofs have the potential of reducing the urban environment temperature up to 3°C. (SMITH & ROEBBER, 2011)

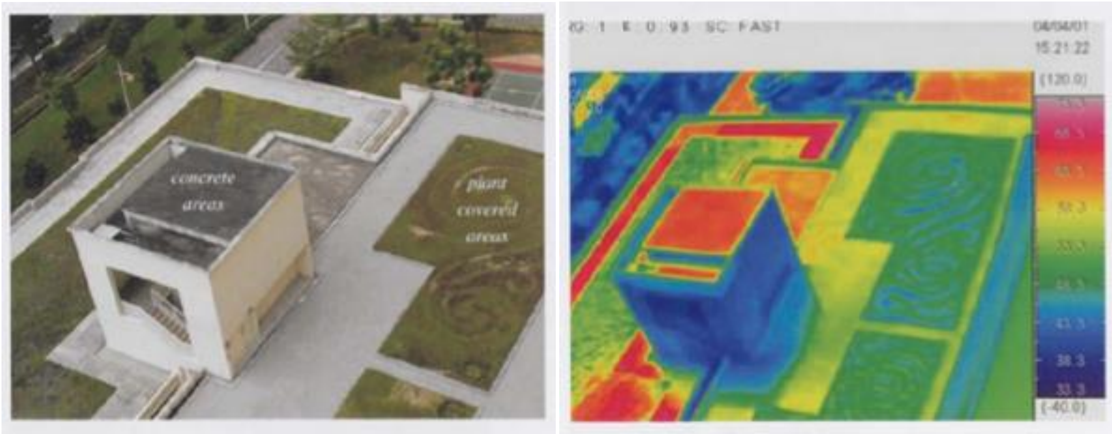



**Fig. 29** Infrared image of a roof in Singapore.

Source: (Townshend, 2007)

Yok & Sia in their book *"Selection of Plants for Green Roofs in Singapore"*, demonstrated infrared images to show the difference in temperature between the concrete roof and roof covered with plants in Singapore (Townshend, 2007). As shown in figure (29) the vegetated area has lower temperature than the concrete roof.

A new low in Tokyo, Japan was initiated in order to install green roofs on new buildings with roof area more than 1000 m$^2$, to reduce the urban heat island effect. (Liu, 2003)

### 2.5. 3. Reduce energy budget for building

By adding an extra layer to the roof the thermal insulation of the roof is increased, as well as, decrease the direct exposure of the roof structure to the sun. This, on one hand, will reduce heat gain in summer, and on the other hand reduce the heat lose in winter.

The type of green roof applied can affect the added thermal insulation, but in general green roofs provides lower U-value than all other roofs. (D'Orazio, Di Perna, & Di Giuseppe, 2012)

A research shows that the cooling load in the warmer months was reduced by green roof to 1.5(5,100 BTU/day) when compared with the load of the reference roof 6.0-7.5 KWh/day 20,500-25,600 BTU/day) (Liu, 2003). In Germany Zinco International (German green roof company) estimates, that the green roof saves about 2 liters of fuel oil/m2/year, and Possman Cider Cooling and Storage Facility in Frankfurt declared the recovering of the green roof installation cost after 2-3 years as the heating and cooling costs was reduced to save about £4,300 per year. (Livingroofs.org ,ecologyconsultancy, 2004)

The monitoring of an extensive green roof during the summer of 2010, 2011 and 2012, with a different density of vegetation each year, results 60% reduction of heating gain when the roof is covered with dense vegetation when compared with non-vegetated roof. The green roof with dense vegetation acts like a passive cooling system, this study demonstrates the importance of vegetation density in the cooling effect of the green roof. (Olivieri, Di Perna, D'Orazioc, Olivieri, & Neilaa, 2013)

A study of the effect of green roof technology on energy saving and thermal benefits through computer simulation was conducted on an apartment building in Amman, Jordan. The analysis of the simulation data showed that green roof decrease heat loss by 41% through the roof, and a reduction of 17% of total energy consumption was calculated. (Goussous, Siam, & Alzoubi, 2014)

Although green roofs have the greatest effect on the roof directly implemented on, but also reduction of cooling loads in the lower floor levels can be achieved, when implementing the green roof technology on a city level, the urban heat island effect is lowered, the overall temperature of the city is reduced and therefore the need to use air conditioning or other cooling devises. This eventually will reduce energy consumption and budget.

### 2.5. 4. Aesthetic value (for both the building and the city)

Although the green roof research area is more focused on the environmental benefits of green roofs, the visual improvement of green roofs recently have the attention of many architects and researchers, as in cities with high building density dominated by the gray concrete and modern building materials, the green roofs add new colors and bring life back to city (Fernandez-Cañero, Emilsson, Fernandez-Barba, & Herrera Machuca, 2013), the city skyline aesthetic appearance can also be enhanced with green roof design (Abdul Rahman, Ahmad, Mohammad, & Rosley, 2015). By reducing the artificial appearance of urban area, and improving the architectural design. (Abdul Rahman & Ahmad, Green Roofs As Urban Antidote, 2012)

A study in Seville, Spain carried out to examine public preconception and preferences for green roof design used computerized images (containing different types of green roof and one without green roof on the same roof structure). Questioned 450 respondents to choose the most aesthetic visually in their opinion. The results showed that respondents favored the roof garden that has variety of plants and colors and good maintenance, when the image with no green roof got the lowest rating. Figure (30). (Fernandez-Cañero, Emilsson, Fernandez-Barba, & Herrera Machuca, 2013)

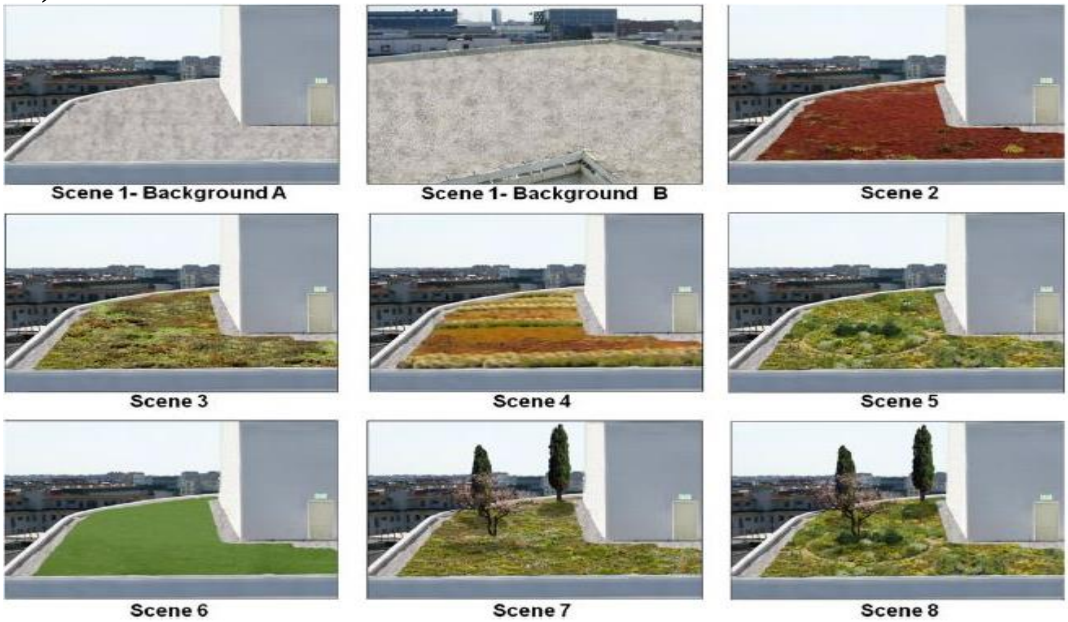



**Fig.30** Scenes shown to participants
Source: (Fernandez-Cañero, Emilsson, Fernandez-Barba, & Herrera Machuca, 2013)

The study indicates *"On a daily basis many participants found themselves attracted to the green roof almost unconsciously. They would be chatting on the phone, or looking out over the cityscape, and would find their eyes drawn to the roof"*. (Loder, 2014)

Moreover, in a study conducted in the Northeastern United States, seven roof gardens was included in questionnaire, to measure the visitor's reaction towards green roofs, overall reactions to green roofs were positive. (Jungels, Rakow, Broussard Allred, & Skelly, 2013)

More research were carried out on the same issue such as, a test of the visual improvement theory in the UK by adding five different type of greenery to four sample houses and introduced to the participants of the experiment with six different computerized images of the four houses (the sixth image of the original houses without any green elements) figure (31). This study concludes, *"Houses with integrated vegetation are more liked, aesthetically pleasing, and restorative than houses without vegetation"*. (White & Gatersleben, 2011)


**Fig. 31** Houses in different vegetation conditions shown to participants
Source: (White & Gatersleben, 2011)

Another study in Chicago and Toronto, to explore the relationship between aesthetic and green roof among office workers viewing roof gardens in both cities. Find that all the participants preferred looking at green roof than to look at black tar or gravel roof. (Loder, 2014)

In the Arab world, an initiative in 2012 arises to greening the city of Beirut. It was started by architect Wassim Melki due to the lack of green spaces, only 3% of Beirut land area is gardens.

Computerized images were created to show the difference between the city image with and without the vegetation to encourage people to add and maintain plants on their roofs and balconies, figure (32). To describe the project Melki said, *"Aside from the major environmental and social benefits, it would also be incredibly iconic," he says. "Just imagine: The world's first rooftop garden city".*(Webster, 2012)

(a)  (b) 

**Fig. 32** Images of Beirut (a) with green roofs and (b) the current image of the city.
Source: (Webster, 2012)

Different studies have almost the same results, visitors, or respondents agreed on preferring well-designed roof garden with different types and colors of vegetation.

All the studies documented a relationship between childhood memories (environmental background, growing up in urban or rural environment) and socio-demographic factors effected the preference of green roof or vegetation layout options. Still all the studies proven that greenery or vegetation visually improve the overall appearance of the building and were preferred by the population when compared with no green roof alternative.

### 2.5. 5. Social benefits: Green amenity space and improving citizens' health.

All over the world, the city development and urban sprawl especially in cities with improper planning which could be the case in the city of Nablus, ends up with the destruction and loss of open spaces and green areas.

Highly urbanized cities in the world tend to combine the urban structure with green elements to replace the lost green areas. (Abdul Rahman, Ahmad, Mohammad, & Rosley, 2015)

Usually citizens benefiting from urbanization do not mind the loss of green spaces and do not recognize their need to green spaces until the green spaces are very limited. As the urban life have many stressors like traffic, noise and jam, pollution, crimes and crowding, but greenery and open natural spaces offer opportunity to reduce stress and mental fatigue (van den Berg, Hartig, & Staats, 2007). Many researchers suggested that visitors go on foot to urban green areas, to places approximately three to five minutes from their living place, which is about the time needed for residents to reach the roof of their building, green roofs offer a great replacement of ground level amenity gardens. (Abdul Rahman & Ahmad, Green Roofs As Urban Antidote, 2012)

Earlier studies demonstrate the human preference of viewing green natural spaces rather than built urban environment. And that residents and workers with access or view of a green roof have better health and greatly value it, a study on the tenants at 401 Richmond Ltd, Toronto, revealed that tenants consider their green roof as *"an oasis in the city"* (Banting, et al., 2005). Likewise, in a report for the city of Toronto, discuss a study by Bass et al. (2004) on graduate students living in Charles Street, Toronto, described the viewing of a green roof as *it "provides sanity and relief".* (Banting, et al., 2005)

Many other studies suggests that human interaction with nature or viewing green spaces provide calmness, reduce stress, increase the ability to focus (Banting, et al., 2005), and employees who view natural elements were less stressed, their blood pressure was lower and reported less sick days (Abdul Rahman & Ahmad, Green Roofs As Urban Antidote, 2012), as the natural view holds their attention, and drive their awareness to a meditation-like state away from their worries and thoughts (Townshend, 2007). Study suggests that the increase of green spaces improve the mental health (Vries et al., 2003). While physical access to green space provides benefits such as cleaner air, reduction in heart rate and blood pressure and can improve overall well-being (Livingroofs.org ,ecologyconsultancy, 2004). For instance, people living in high urban density having a garden on their balcony or terrace, known to be less subjected to illness, as plants provides air filtration, additional oxygen, control of humidity and other not measurable benefits such as the movement, sounds, smells and colors. (Townshend, 2007)

Providing spaces for recreation and social interaction in the community is another benefit could be achieved by adopting green roofs, the building tenant can use it for relaxing, dining and meditation (Banting, et al., 2005). Green roofs also endorse sense ownership, and bring occupants closer to greenery. 80% of Singapore citizens participating in survey voted to increase the number of green roofs in the city (Abdul Rahman & Ahmad, Green Roofs As Urban Antidote, 2012). Another survey in Malaysia indicates that 95% of respondents agreed with the increase of green roofs in Malaysia, and 92% were interested in adding green roof to their building. This is because they think that green roofs add new dimension to the private gardens and they do not find space on the ground to have green area (Abdul Rahman, Ahmad, Mohammad, & Rosley, 2015). In Hong Kong green roofs are created on podium decks and used as public or private gardens, and described as essential for well-being of the population and enriching of the urban experience and quality of life. (Townshend, 2007)

In the report "Green Roofs Benefits and Cost Implications" number of studies supporting the positive effect of green roofs on human health was presented, such as, study was performed in Texan hospital on post-surgery recovery showed that patients with green space view recovered faster and had lower relapse rates. As result of this study many hospitals had planned to redesign their views to allow the patients to profit from the benefits provided by greenery. (Livingroofs.org ,ecologyconsultancy, 2004)

**2.5. 6. Air Quality**

Plants and trees are known to improve air quality; in fact, some people think that improving air quality is the only benefit provided by trees. The trees and greenery contribution to increase the levels of $O_2$ and filter the particles in the air have been documented by many researchers.

The green roof contribution to the air quality improvement have and still been studied by researchers, they believe that intensive green roofs might have more effect on air quality than extensive green roofs.

A study Hong Kong conducted by using filed measurements and computer simulation to compare green roof CO2 levels absorption in day and CO2 levels emission in the night. Concludes that on extensive green roof CO2 concentration could be lowered up to 2%on areas near the green roof.(Li et al., 2010)

Investigation on six scenarios of green roof vegetation and their effect on improving air quality. The results point that although grass roofs (extensive) contribution to air pollution mitigation could be similar to trees and shrubs but planting shrubs on roof (extensive) would have more impact in mitigating air pollution (Currie & Bass, 2008). And adding 109ha of green roofs would remove 7.87 tons of air pollutant per year. (Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014).

The effect of roof greening on air quality in street canyons was calculated using computational fluid dynamics; the results shows that the cooling effect of the green roof could reduce the concentration of pollutant and improve air quality near roads. (Baik et al., 2012)

In Chicago, a study revealed that 19.8 ha of green roof removed 1675 kg of air pollutants. And one hectare of green roof annually removes 85 kg ha-1 yr-1.(Yang et al., 2008)

Likewise, investigation of the effect of green roof on particular particles such as sulphur dioxide, fund that adding green roof reduced its levels by 37%.(Tan & Sia, 2005)

Other studies discuss that green roofs contributes to the air pollution reduction by reducing urban heat resulting in less use of air conditioning and this reduction in consumed energy would decrease the air pollution (Berardi et al., 2014).

### 2.5.7. Improve property value

Apartments and office building overlooking greenery such as New York central park tends to having higher property value. Researcher's documented rented offices with landscape scene have 7% increase in their rental rate. (Clements, St Juliana, & Levine, 2013)

The green roof will improve the value of the building constructed on and the building surrounding it, as the owner of the building ask for higher rent because of the extra amenity space provided for the residence, and surrounding buildings overlooking the green roof can charge higher rent (Tomalty, Komorowski, & Doiron, 2010). In a study in Washington, DC, buildings with green roofs have 15% higher rental value per square foot when compared with similar buildings (Abbott & Lewis, 2013). Similarly, in New York, rental rates for buildings with green roofs were 16% higher. (Ichihara & Cohen, 2011)

### 2.5.8. Extend roof structure life

The roof structure not exposed to UV light and other weather conditions, temperature change during day and night, and this leads to longer life span for the roofing material. Green roofs are known to have the potential of doubling the roof material life. (Livingroofs.org ,ecologyconsultancy, 2004)

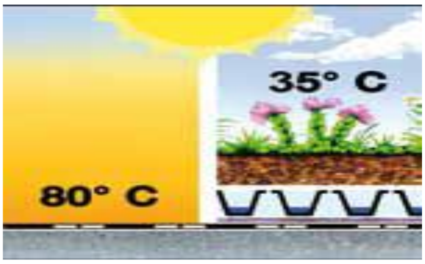



**Fig.33** Sketch of the difference in roof temperature.
Source : (ZinCo, 2014)

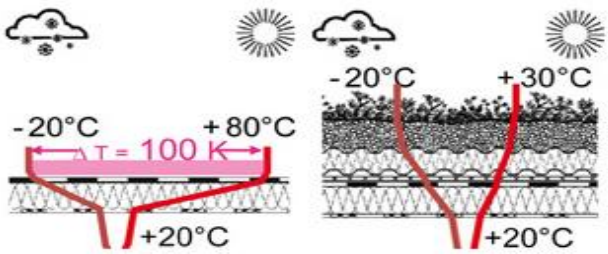



**Fig. 34** Reduction heat fluctuation
Source: (Ecovegetal, 2015)

Green roofs have the potential of providing wild range of benefits such as noise and sound insulation, the soil and plants absorb, reflect, or deflect sound (Livingroofs.org ,ecologyconsultancy, 2004). Urban farming is another way to benefit from green roof where edible plants grown for the building consumption or for larger market, and green roofs could be beneficial for biodiversity and Wildlife restoration.

## 2.6. Worldwide cities experience

Many cities around the world have policies encourage or enforce the application of green roofs to solve environmental problems caused by urbanization, every city have a different approach regarding green roof polices some cities have building regulations, mandatory requirements, planning policies, building bylaws to enforce the use of green roofs, while other cities use motivation such as financial incentive, subsides, tax reduction and increased building area,  several cities use both polices to insure the use of green roofs.

The policies each city enforce or implement were derived from the main environmental problem the city is seeking to solve, for example, if the city main problem is rainwater runoff, it is more likely to implement tax reduction on storm water management charges.

This part reviews polices and regulation from different cities, including the policies for these cities:

- Berlin: financial incentives and mandatory policy requirements.
- Münster: financial incentives.
- Cologne: financial incentives.
- Stuttgart: financial incentives and mandatory policy requirements.
- Basel: building regulations.
- Tokyo: planning policy and financial incentives.
- Osaka: planning policy and financial incentives.
- Chicago: building regulations and financial incentives.
- Portland, Oregon: financial incentives.
- Seattle: mandatory policy requirements.
- New York: tax reduction.

- Toronto: financial incentives.
- Vancouver: planning policy and building bylaws.
- Linz: planning policy and financial incentives.
- Paris: mandatory policy requirements.

The following table shows the policies of each city, which explains policies type and implementation technique.

**Table (2): Policies of cities worldwide regarding the application of green roofs**

| Location | | Policy type | Details |
|---|---|---|---|
| Germany | **Berlin** | Requirement | The city has pioneered the "biotope area factor" (BAF), which expresses the ratio between "ecologically effective surfaces" (e.g. gardens, green roofs, etc) and the total area of a site. BAF target values are set for different forms of development, with new housing attracting a BAF of 0.6 and commercial development 0.3. |
| | | Financial incentives | reduction of drainage charges of 50% |
| | **Münster** | Financial incentives | The city imposed a storm water fee based on the amount of storm water that runs off a property. 80% or more reduction to the fee when a green roof is installed. |
| | **Cologne** | Financial incentives | offers developers reductions in storm water drainage connection charges if their buildings incorporate green roofs meeting specified performance standards |
| | **Stuttgart** | Requirement | Require the installation of green roofs as a condition of development where technically feasible. In most cases, that means roof with a gabled roof angle of less than 20 degrees. |
| Germany | **Stuttgart** | Financial incentives | Direct financial subsidies by government in the form of start-up grants can amount to 10-20 Euros per square meter of green roof. Reduced storm water fees are provided to those who install a green roof. |

| | | | |
|---|---|---|---|
| Switzerland | **Basel** | Requirement | In 2002, the City of Basel's' Building and Construction Law was modified. All new and renovated flat roofs must be greened also stipulates associated design guidelines. |
| | **Tokyo** | Requirement | A policy that compels developers of new private buildings with a footprint larger than 1,000m2, and new public buildings with a footprint greater than 250m2, to green 20 per cent of their roof areas or face an annual fine. |
| | | Financial incentives | The public foundation of the Tokyo metropolitan prefecture provides funding for green roofs on public buildings to cover up to 50% of installation costs, or 2,000 Euro |
| Japan | | Density bonus | The urban planning office allows the approved floor space ratio of a building to be exceeded if green roofs are included. |
| | **Osaka** | Requirement | A policy that compels developers of new private buildings with a footprint larger than 1,000m2, and new public buildings with a footprint greater than 250m2, to green 20 per cent of their roof areas or face an annual fine. |
| | | Financial incentives | Provides funding for green roofs on public buildings to cover up to1/2 of installation costs, members only or limited use 1/4 of the cost, none 1/6 of the cost |
| | | Density bonus | Bonus is allowed only if trees is installed or high quality greening |
| USA | **Chicago** | Requirement | Energy conservation code that requires roofs to achieve a minimum solar reflection or ‘albedo’ of 25%. Although the city’s policy does not state as such, it is accepted that green roofs are a practical means of meeting this requirement. |
| | **Chicago** | Financial incentives | Grants scheme 50% grant of the cost if green roof is added to building in central district maximum amount $100,000. Residential and small commercial projects granted $5,000 by the green roof grant project. Storm water retention credits |

| | | | |
|---|---|---|---|
| USA | | Density bonus | Allow to developing a higher density than policy would otherwise allow if at least 50% or more than 160m$^2$ of a roof surface area – whichever is greater – is covered by vegetation. |
| | **Portland** | Requirement | City-owned buildings are required to have a green roof covering at least 70% of the roof. |
| | | Financial incentives | Property tax and a 35% reduction in storm water management charges. |
| | | Density bonus | Bonus area based on the covering percentage.<br>10-30% Green Roof = 1 extra square foot of floor area.<br>30-60% Green Roof = 2 extra square feet of floor area.<br>60% + Green Roof = 3 extra square feet of floor area. |
| | **Seattle** | Requirement | Requires the equivalent of 30% of a site to be vegetated |
| | **New York** | Financial incentives | One year tax abatement of $4.5 for square foot of green roof up to maximum $100,000 |
| Canada | **Toronto** | Requirement | Green roofs are required on public buildings. And on all new commercial, institutional, multi unit residential developments |
| | | Financial incentives | financial incentives to encourage green roofs in private development bylaw. Incentives of $7 per square foot. |
| | | Awareness raising programmes. | Focus group workshops, round table meetings |
| | **Vancouver** | Requirement | A development plan that requires all buildings to have at least 50% green roof coverage |
| Austria | **Linz** | Requirement | New and proposed buildings with an area of over 100m2 and a slope of up to 20 degrees are to be greened. at least 80%. is covered with living plant material. |
| Austria | **Linz** | Financial incentives | Up to 30% of construction costs subsidies |

| | | | |
|---|---|---|---|
| France | **Paris** | Requirement | Green Roofs and Green Walls should be built on municipal buildings. Requires that all new buildings constructed in commercial areas to be partially covered by either solar panels or green roofs. |
| | | encourage the participation of the citizens | The city wants to encourage private owners and real estate companies to be part of the programme. the city is developing a series of measures: changing the town planning rules, giving a free technical support, create an internet participating platform on greening buildings, create "a green permit" for people to be allowed to rent public space for free for their green projects |

Source: (Charley Cameron, 2015); ("European Climate Adaptation platform," 2015; Green Roofs for Healthy Cities, n.d.; IGRA, 2015, n.d.; Tatiana White, n.d.; Wolfgang Ansel, 2009) (International Green Roof Congress, Appl, Ansel, & International Green Roof Association, 2009) (Graduate School of Horticulture, Chiba University, Kim, Ikebe, Koshimizu, & Lee, 2013) (Gedge, et al., 2008); (Shimmin, LONDON THE VERTICAL GARDEN CITY AND THE TRANSFORMATIVE POWER OF ROOF GARDENS, 2012)

## 2.7. Summary

Having discussed the historical development of green roofs and their benefits including contemporary worldwide experience, it is clear that this treatment in our buildings and cities will have a distinctive impact towards developing the architecture and urban form in the city of Nablus. If this is not the case, at least this will solve many problems that occurred as a result of the city of Nablus present urban sprawl. Consequently, the use of green roofs in the city of Nablus will be very useful to address the problem of green landscape and other environmental problems, which will be discussed in the next chapter.

# Chapter Three

# City of Nablus

In this chapter, two main points will be discussed, starting with the city of Nablus physical profile. The second part of the chapter discusses building technology used in the city of Nablus and how it could be affected by the addition of green roofs to the building.

### 3.1. City of Nablus Physical Profile

In this part the location, expansion, land use and weather condition in the city of Nablus is discussed.

#### 3.1.1. City location

Nablus is one of the northern cities of the west bank, about 65 kilometers north of Jerusalem. Nablus city is 28.57 square kilometers and it lays in the narrow valley between two mountains chains. The mountain chains are about 65 km length from north to south and about 55 km width from west to east. The northern mountain, Ebal, is 940 m high, while, the southern mountain, Gerizim, is 881 m high. (Nablus Municipality, 2012)

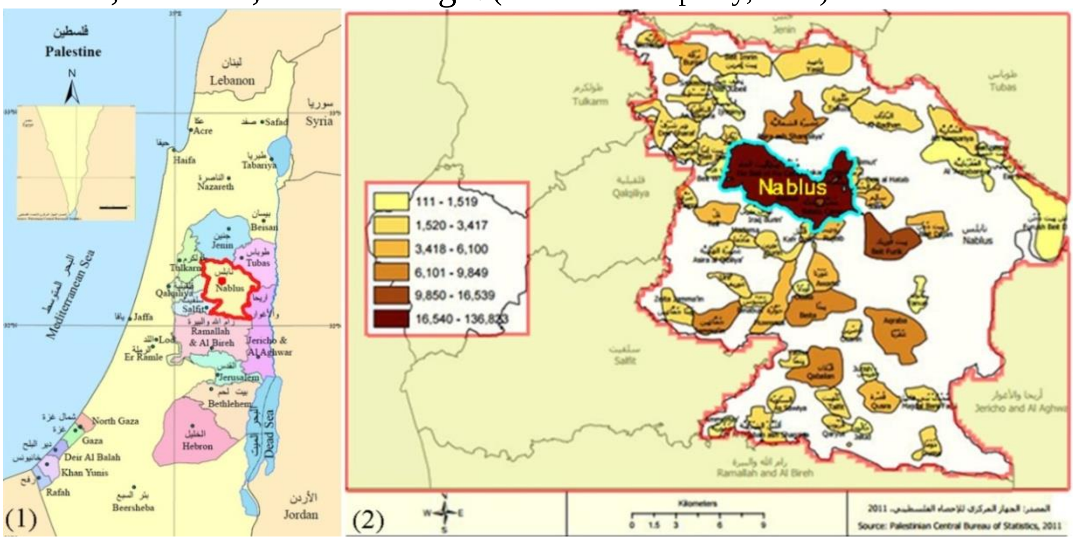



**Fig.35** (1) Governorates of West bank and Gaza showing Nablus Governorate in red

(2) Population in Nablus Governorate at Mid Year by Locality 2011 , City of Nablus is shown in cyan.

Source: (1)(2) (Palestinian Central Bureau of Statistics (pcbs), 2011)

**Fig. 36** Satellite image of Nablus showing in red the city boarders.
Source: ("Google Maps," 2015)

### 3.1.2. City expansion and urban development:

The historical expansion of the city, demonstrated in figure (37), started in the valley between the two mountains, from a Canaanite city circa 1400B.C. to the current city borders. Through the age's linear expansion of the city occurred along the mountain chains, as the urban sprawl of the city is restricted by its geographical nature.

The political situation in the city of Nablus is one of the factors restricting urban development as the current political situation limits the horizontal expansion. As shown in figure (38), the city is surrounded by area (C), military base, and settlements, where Palestinians are not allowed to access or build on.

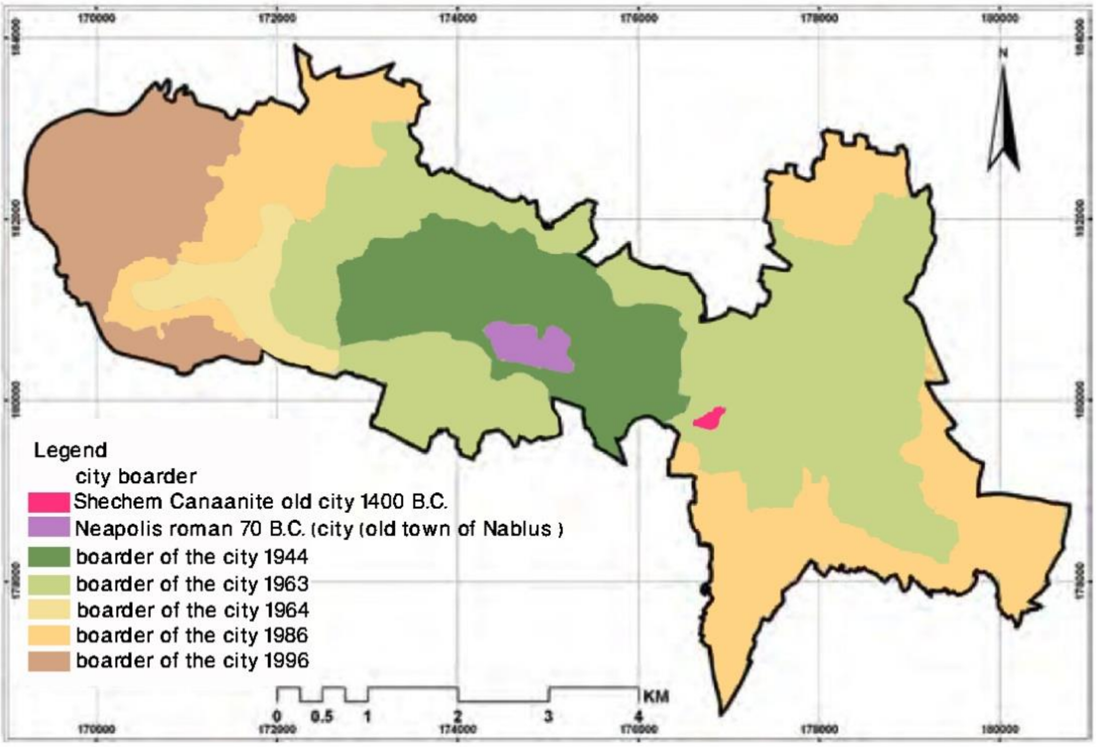



**Fig. 37** Historical expansion of the city
Source: (Welfare-Association, 2011)

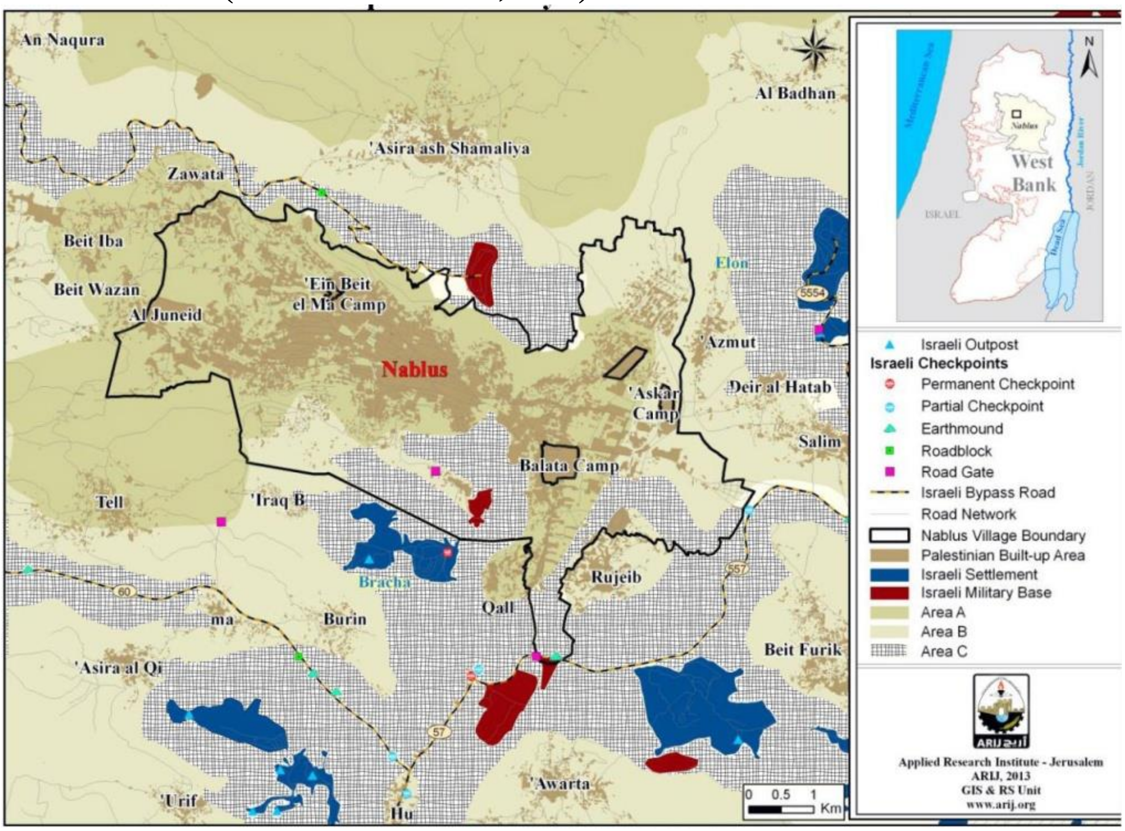



**Fig. 38** Nablus political areas
Source: (ARIJ, 2015)

| Area | Area in dunums | Percentage of Total village area % |
|---|---|---|
| Area A | 20,373 | 62 |
| Area B | 6,949 | 21 |
| Area C | 5,625 | 17 |
| Nature Reserve | 0 | 0 |
| **Total** | **32,404** | **100** |

**Fig. 39** The geopolitical divisions of Nablus city according to Oslo agreement 1995
Source : (ARIJ, 2015)

### 3.1.3. Topography and morphology

Comparing the city of Nablus with other cities in the west bank, Nablus contains one of the highest populated urban gatherings. Moreover, the density of population has been increasing massively, due to the increasing population and to the limitation on horizontal urban expansion. Not only because of the political situation, but also because of the topography of the city of Nablus as it is located between two steep sided mountains.

**Fig. 40** Photo of the city between the two mountains.
Source: (Palden Jenkins, 2011)

Results of a study projected that density of built-up area in the city of Nablus will continue to increase, for example, in 1989, the density of built-up areas was 150 $m^2$/capita and it reached 78 m2/capita in 2000. (Hudhud, 2007)

Figure (41) demonstrates that the city population may continue to increase and the limits to expansion will lead to higher density of urban areas.

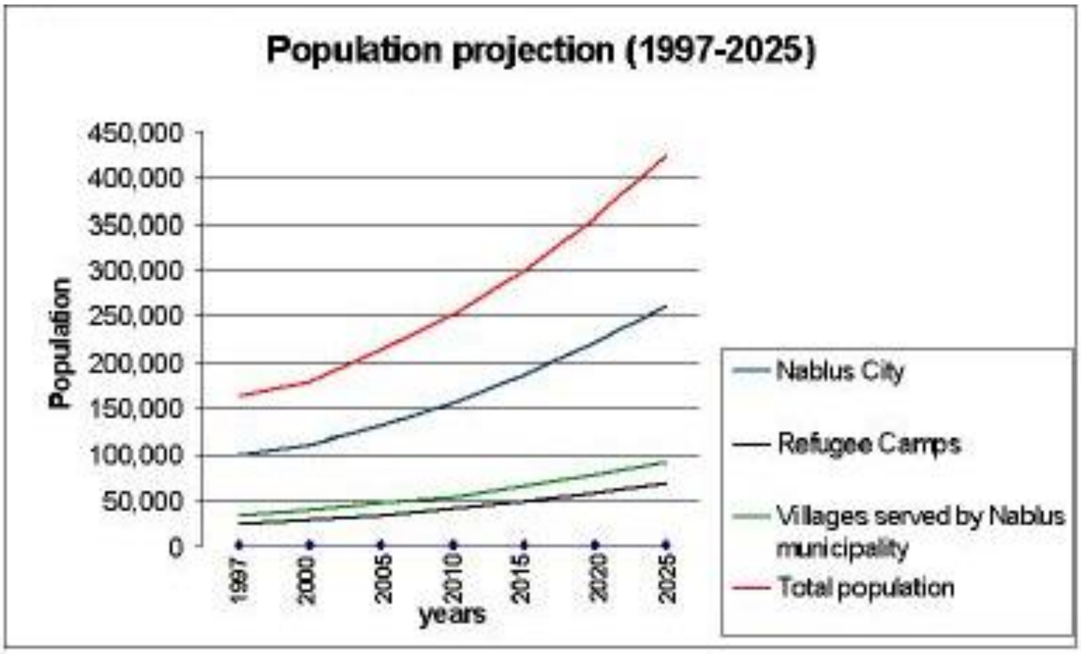



**Fig. 41** Population projection (1997-2025)
Source: (Hudhud, 2007)

### 3.1.4. Land use

The city of Nablus total area is calculated to be 28.57km2, the land use distributed according to the municipality: 5.5 km² (20%) streets (existed and proposed ones), 16 km² (56%) housing (total area of housing including the building and land around the house), 1.5 km² (5.15%) industrial area, 0.8 km² (2.75%) commercial area, 0.3 km² (1.1%) the area of the old city, 0.5 km² (1.7%) refugee camps area, 0.1 km² (0.35%) agriculture housing, 0.3 km² (1%) cemeteries, 0.1 km² (0.35%) quarries, 0.2 km² (0.7%) parks, 1.5 km² (5.215%) green landscapes, 0.4 km² (1%) agriculture area and, 1.37 km² (4.75%) other uses (car parking, public buildings, etc). thus, agriculture area, parks and open spaces forms only 2.1 km² (6.85%) out of the total city area. (Nablus municipality 2007)

Figure (42) shows that street and housing occupy the highest percentage of land use whilst gardens in the city are one of the lowest percentages 0.70%.

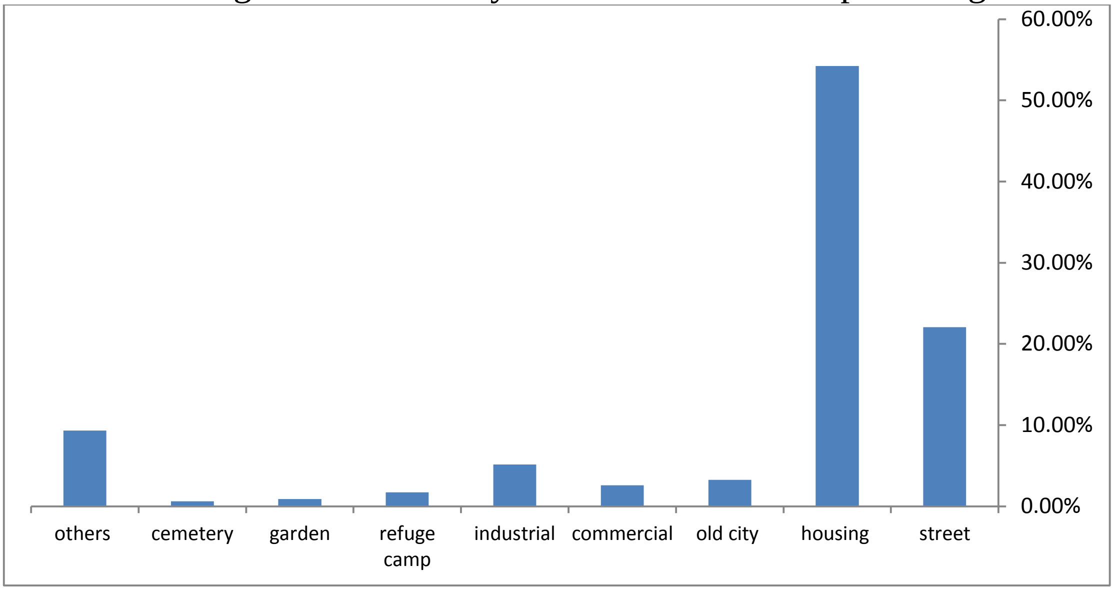



Fig. 42 Land use percentage
Source: (Nablus municipality, 2007)

According to the Nablus municipality, the built-up area of the city is 8700 km2 about 30% of the total area of the city.

### 3.1.5. Green areas in the city

The open green areas in Nablus are decreasing dramatically and the existing public parks (already not enough by public opinion) are being urbanized due to the rapid urban development.

This limitation on urban sprawl combined with the steep slope of the city's mountains makes the establishment of new green areas not only difficult but also very expensive.


Fig.43 Map of the city of Nablus showing the contour lines of the mountains with the building density and distribution.
Source: Edited by the researcher

Table (3) representing green areas and public parks in the city of Nablus, should be taken in consideration that green areas are decreasing, for instance, Jamal Abed El Nasser Park, was reduced to build schools, then a street cut through the park. Also Sama Nablus was converted to an almost completely built-up area, with restaurants and asphalt street connecting them.

## Table (3): Green area in the city

| Green area name | Area m2 | Type of visitors |
|---|---|---|
| **families Park** | 7074.58 | families only |
| **Jamal Abd El Nasser Park** | 70704.8 | public |
| **Children Happiness Center** | 13307.7 | children and families |
| **Sama Nablus** | 44464 | public |
| **Al-Horsh Park** | 20813 | public |
| **Danish Garden** | 5979 | public |
| **Al-Fayniq Park** | 4331 | public |
| **Yasser Arafat Park** | 4121 | public |
| **Al-Makhfia Park** | 971 | public |
| **Total** | **171766.08** | |

Source: (Nablus Municipality 2014)

In Palestinian cities like the city of Nablus, with a dense urban environment and very limited open spaces on level ground the flat roofs present a usable space, a new amenity and a refuge area for citizens to renew themselves mentally and spiritually.

### 3.1.6. Weather data

The climate of the city of Nablus is commonly known as Mediterranean, which is hot and dry summer with moderate, rainy winter. The maximum average temperature in the coldest month of the year (January) is 13.1 degrees Celsius, declining to 6.2 degrees Celsius. In August, the rate of maximum temperatures is up to 29.4 degrees Celsius, while declining to 19.5 ° C. the prevailing winds are Northwest in the Nablus area, with an average speed of 10 km/h, while the humidity rate is up to 61%. (Nablus Municipality, 2012)

The following schedule shows the weather data for the city of Nablus in the year 2014.

#### 3.1.6.1. Average Mean Monthly Temperature

**Table (4) The mean monthly temperature in Nablus in the year 2014**

| Station | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | Av. | Max. | Min. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nablus | 11.5 | 12.1 | 14.9 | 18.9 | 21.0 | 23.6 | 25.1 | 25.5 | 23.5 | 20.1 | 15.2 | 13.3 | 18.7 | 25.5 | 11.5 |

Source: (Meteorological Authority, 2014)

#### 3.1.6.2. Average Wind speed

Mean Monthly Wind Speed (Knots)

**Table (5) The mean monthly wind speed in Nablus in the year 2014**

| Station | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | Av. | Max. | Min. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nablus | 2.8 | 2.8 | 2.6 | 2.9 | 3.1 | 3.3 | 4.0 | 3.4 | 3.1 | 2.6 | 2.4 | 2.3 | 2.9 | 4.0 | 2.3 |

Source: (Meteorological Authority, 2014)

### 3.1.6.3. Average Mean Monthly Relative Humidity

**Table (6) The mean monthly Relative Humidity (percentage) in Nablus in the year 2014**

| Station | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | Av. | Max. | Min. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nablus | 73.2 | 68.2 | 69.6 | 59.8 | 64.8 | 66.6 | 75.6 | 76.6 | 79.5 | 78.5 | 78.4 | 82.8 | 72.8 | 82.8 | 59.8 |

Source: (Meteorological Authority, 2014)

### 3.1.6.4. Mean Monthly Evaporation (mm)

**Table (7) The mean monthly Evaporation (mm) in Nablus in the year 2014**

| Station | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | Av. | Max. | Min. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nablus | 2.8 | 3.0 | 4.4 | 6.0 | 6.5 | 7.8 | 8.0 | 7.5 | 6.1 | 3.9 | 3.2 | 1.9 | 5.1 | 8.0 | 1.9 |

Source: (Meteorological Authority, 2014)

### 3.1.6.5. Total Monthly Rainfall (mm)

**Table (8) The of the mean monthly rainfall in Nablus in the year 2014**

| Station | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nablus | 3.4 | 9.2 | 91.8 | 0 | 26.9 | 0 | 0 | 0 | 0 | 32.5 | 174.1 | 22.9 | 360.8 |

Source: (Meteorological Authority, 2014)

### 3.1.7. Problems in the City of Nablus that could be addressed by using green roofs.

#### 3.1.7.1. Climatic change in the city and mean temperature

Although, global warming and the change in air temperature is a worldwide problem, it has also affected the climate in the city of Nablus.

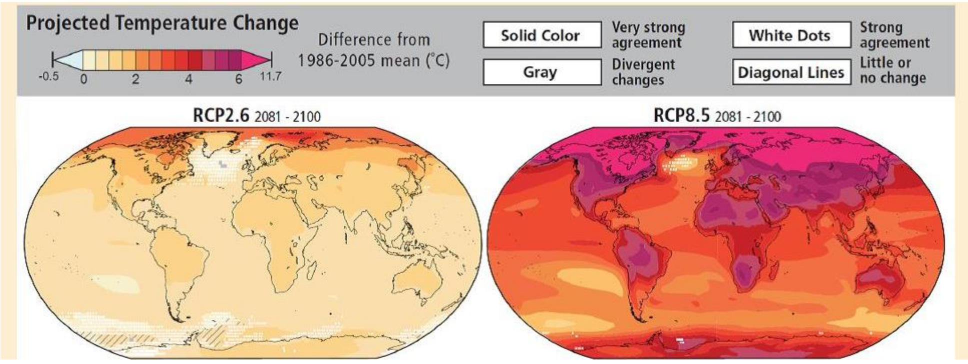



**Fig. 44** Difference in world means temperature 1986-2005
Source: (sense and sustainability, 2014)

Over the past 10 years, temperatures in the city of Nablus have been increasing, and the citizens of Nablus notice that the city center is usually warmer than other areas. The following diagrams show the difference between the average maximum and minimum temperatures from 1997 to 2010.

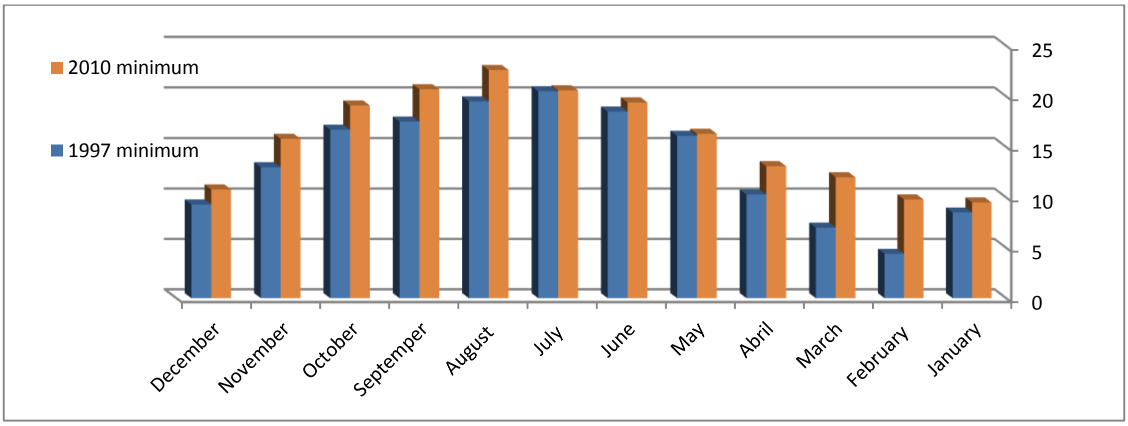



**Fig. 45** Minimum temperature from 1997 to 2010 in Nablus
Source: (Palestinian Central Bureau of Statistics (pcbs), 2011)

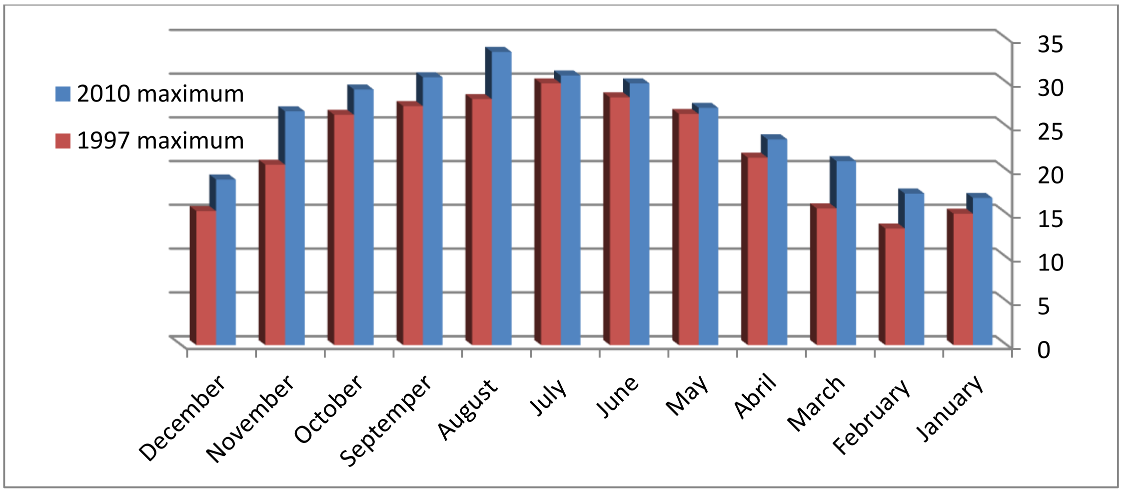



**Fig. 46** Maximum temperature from 1997 to 2010 in Nablus
Source: (Palestinian Central Bureau of Statistics (pcbs), 2011).

From the previous diagram, it can be noticed that the maximum average temperature has increased from 21° in 1997 to 23.7 ° in 2008 and to 25.4° in 2010. The average minimum temperature from 13.4 ° in 1997 to 14.4 ° in 2008 to 15.8 ° in 2010, although the average minimum temperature has increased, the ultimate minimum temperature in January has decreased from 4.2 ° in 2004 to, 2.5 ° in 2005, to -1 in 2008.

### 3.1.7.2. Sewage systems flooding in winter

In wintertime, when the most amount of rainfalls in the city of Nablus, and as Nablus has combined sewers, for rainwater or buildings discharge; this causes many problems every winter, such as, houses of the old town, streets, and shops swamped.


**Fig. 47** Images of the city streets flooding with water in winter.
Source: Local photographer.

### 3.1.8. Obstacles restraining the application of green roofs in the City of Nablus.

Generally, many problems face the application of green roofs such as, lack of common standards, lack of polices, engineering problems, structural issues, leakage and damage to the water proofing layer, maintenance and cost, etc…

In the city of Nablus one can spot more problems withholds the development and application of green roofs. The roofs are usually shared property of the multi storey buildings. The shared properties are considered to be areas of conflict between the investor of the building and the owners and tenants of apartments. Also the roofs are being used to store the water tanks, water solar heating panels, and satellite dishes which is another constrain faces the application of green roofs.

The city of Nablus has no regulations force or encourage the use of green roofs. This is one of the obstacles that faces the application of green roofs in many cities worldwide. Recently the municipality stopped the permission for roof* on the top of multi storey buildings this will give extra space for the application of green roofs.

## 3.2. Building technology

In this section, the general way of building and constructing in the city of Nablus is discussed. Roof structure and the extra load capacity on the roof is examined, which type of green roofs could be added to the existing roofs, and the current use of the roof and how it could be redesigned when applying green roof to the building.

As housing represents the major use of buildings in the city representing (56%) of land use in the city of Nablus, this study focuses on applying green roof to residential buildings in the city. In Nablus governorate, there are two main types of households distributed as the following figure (48) shows about 71% apartment or multi-storey building or independent house or villa, which occupies about 30% of housing types in the year 2010.

* Roof is an extra floor on the top of multi-storey buildings, that was permitted by the city of nablus municipality, with conditions of regression from the lower floor.


**Fig. 48** Percentage distribution of households in Nablus Governorate by type of housing unit
Source: (Palestinian Central Bureau of Statistics (pcbs), 2011)

Most of the city buildings constructed with concrete and the elevations are covered with stone (exterior).

**Fig. 49** Images of the city building taken from different locations.
Source: Taken by researcher.

The previous images demonstrate that the majority of buildings in the city are built by using concrete.

### 3.2.1. Structural design

The most common type of roof structure in the West Bank is concrete flat roofs(Salameh, 2012), as the city of Nablus is a part of the West Bank the common way of constructing roofs in the city of Nablus is concrete structure.

Reinforced slabs have various types of design, every type have a different strength-to-weight ratio, such as:

- **Solid slab:** concrete slabs used usually to cover small areas as its weight is higher than other types, one way (for rectangular areas, enforcement parallel to the short span) or two way solid slab (for square areas).
- **A ribbed slab:** Consisting of equally spaced ribs are usually supported directly by columns. They are either one-way spanning systems known as ribbed slab or a two-way ribbed system.
- **A waffle slab:** This slab has equally spaced ribs parallel to the sides, and from below the slab has the appearance of a waffle.(“Civil Engineering

Projects," 2010, "Ribbed or Waffle Slab System - Advantages & Disadvantages |," 2014, "dictionary of construction.com," 2016)

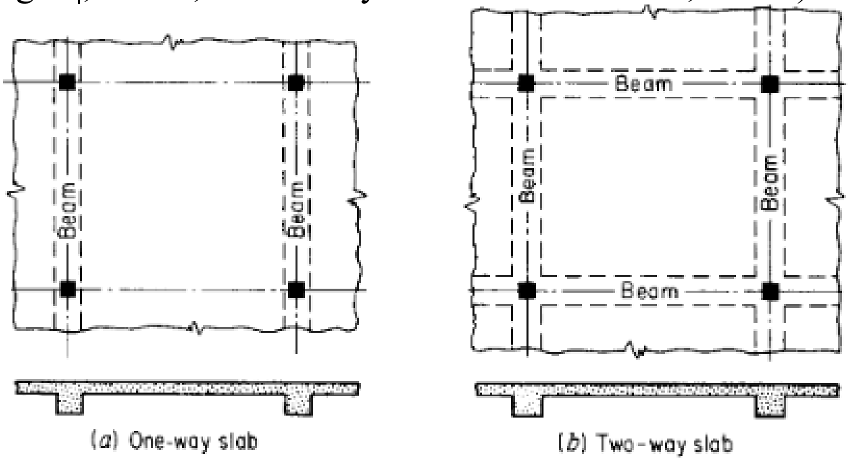



**Fig. 50** The difference in support between one-way slab and two-way slab
Source: (Park & Gamble, 2000)

The common structural method to construct roofs in residential buildings in the city of Nablus is ribbed slabs, usually one-way.

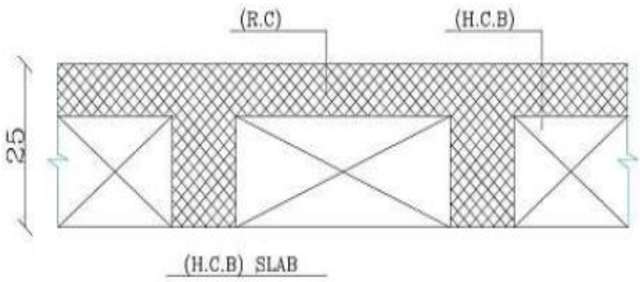



**Fig. 51** Section of a conventional ribbed roof structure
Source: (Salameh, 2012)

**Fig. 52** Image of a conventional ribbed roof structure
Source: taken by the researcher

### 3.2.2. Extra weight

In the city of Nablus roofs are usually designed to sustain extra weight up to 400kg/m$^2$ dead load and 300 to 500 kg/m$^2$ for live load (Dwaikat, 2015). By applying this information to the data from the chapter two, the following diagram was created, showing the intersection between the extra weight the roof can sustain and the extra weight added by the green roof, Extra loads added by the different types of green roofs (darker shade horizontal lines), the standard extra weight the roofs in the city designed to sustain (rectangular lighter shade area) and the intersection representing the type and weight could be used for building green roofs in the city. Figure (53).

From a structural point of view, retrofitting green roofs to existing roofs with concrete structural systems requires the least amount of intervention *(Dineen & Woodward, 2014)*. Therefore, adding green roofs to the city of Nablus could be done without redesigning the structural loads, or reinforcing the current structures.

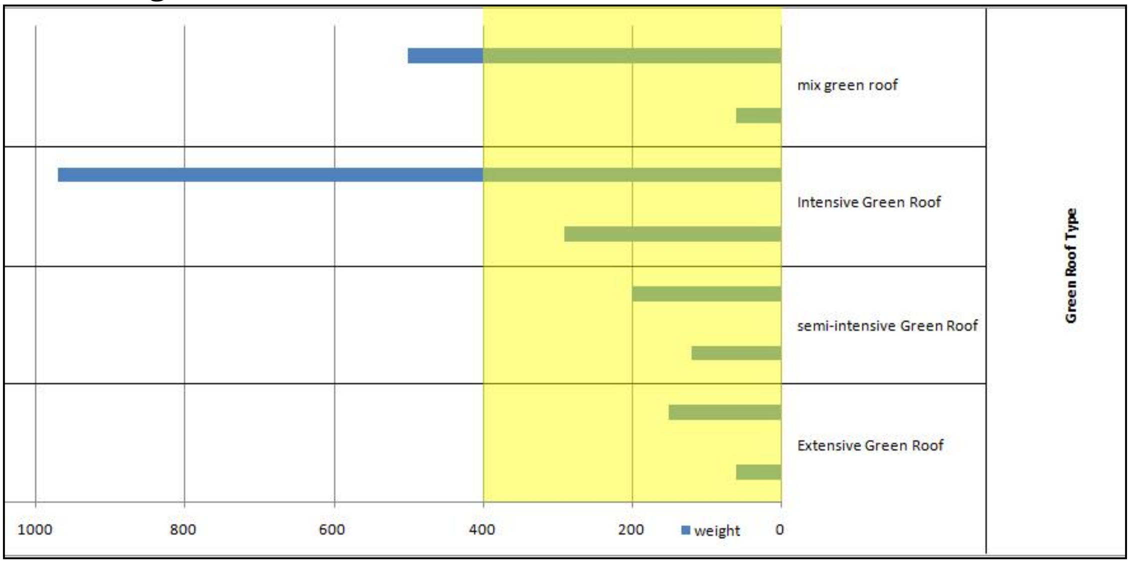



**Fig. 53** Extra loads added by the different types of green roofs in blue, yellow is the standard extra weight the roofs in the city designed to sustain and green representing the intersection.

### 3.2.3. Current use of the roof.

The roofs of the buildings in the city of Nablus are usually occupied with water tanks, water solar heating panels, and satellite dishes as shown in the following images.

**Fig. 54** Images of the city roofs showing the current use for roofs
Source: Taken by the researcher

Although the roofs of the city seems to be crowded and have no place for green roofs, by simply redesigning the roof area as the following images illustrate a green area can easily be created.

Figure (55) demonstrate how water tanks could be camouflaged by surrounding the tanks with a box or grid and using climbing plants to cover the box.

**Fig. 55** Images of the city roofs showing the current use for roof to the left, and the same building with green roof to the right.
Source: Taken and edited by the researcher.

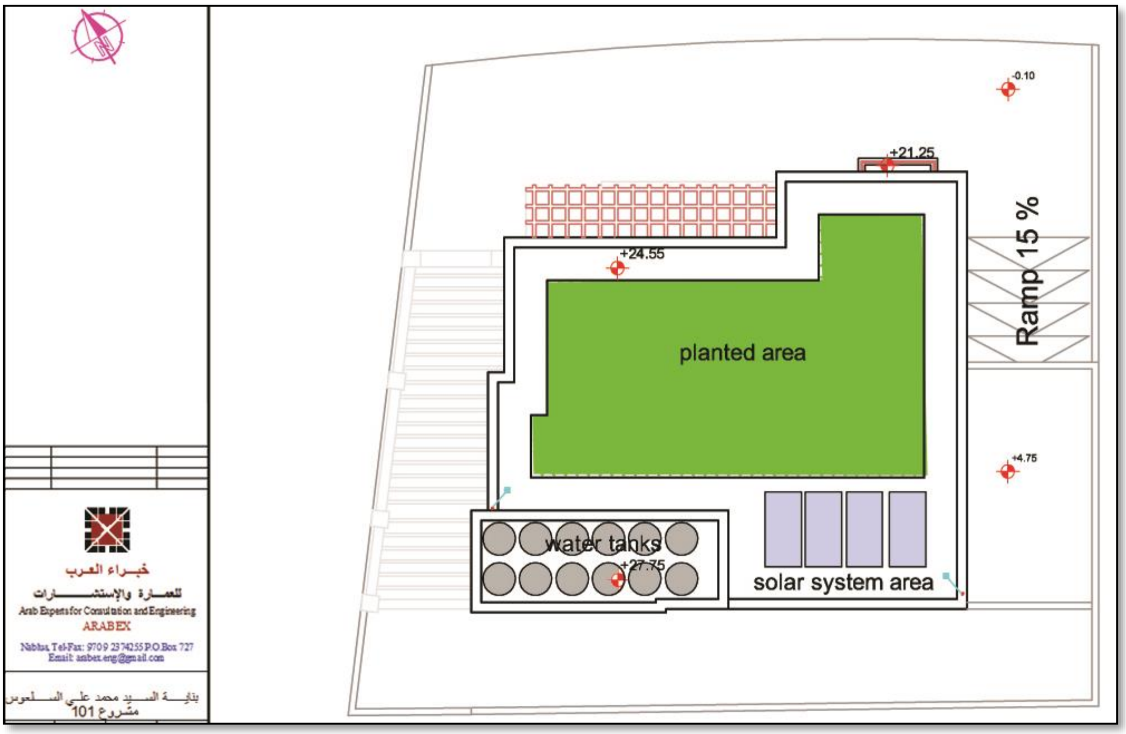



**Fig. 56** site plan of building used in the simulation multi-storey building
Source: Arab Experts for Consultation and Engineering ARABEX

The site plan in figure (56) shows how the roof of a local building could be organized to sustain the current use and the addition of green area (planted area), by putting the water tanks on the roof of the staircase and assigning an area for solar water heating system.

### 3.2.4. Cost of green roof

Green roof costs could range widely depending on many factors, such as components (type of plants, amount of plants, growing medium, type of drainage system) and the green roof industry in the country, for example in Germany where green roofs are more common, the costs of a green roof range from $8 to $15 per square foot($80 to $150 per squar meter). On the other hand, in the United States it's estimated to cost $15 to $20 per square foot ($150 to $120 pes squar meter). It's more likely for the cost to decreases when there is an increase in market demand for green roofs and contractor experience (Dineen & Woodward, 2014). In a study conducted that the addition of extensive green roofs will cause an increase of 30% for the original cost. (William D. Cox, 2007)

To estimate the green roof cost in the city of Nablus, the following design have been created (for the same buildings used in simulation in chapter five). In this design materials usually available from local suppliers will be used.

**Table (9): Estimated green roof cost**

| | | | |
|---|---|---|---|
| Material | Type | Weight | Price JD |
| Thermal insulation | 1 | ------ | 12.5 |
| Humidity insulation | Izoflex | ------ | 9 |
| Soil (1*1*0.25) | peat moss | 57.5 kg | 22 |
| Flower bed | Concrete (300) | 168(1*1*0.07m) | 11 |
| Drainage | Drainage ducts | ----- | 11 |
| | Gravel(1*1*0.17m) | 99 kg | 4.5 |
| Plants | | 20% of soil weight 19.8 kg | |

70 JD is the cost of applying green roof to a building, the application of green roof will increase the cost of construction in final floor 20% of the original cost. (cost and weight obtained from local suppliers and contractores)

The added weight is estemated to be 345kg/m$^2$, the cost of structural reinforcement for 100kg/m$^2$ is 3-5% of the orignal cost as the regular roof ugualy cost abou 350jd/m$^2$ (Dwaikat, 2015), this added weight was calculated to add 61.25JD, structural reinforcement will increase the over all cost of the building 17.5% of the original cost.

**Table (10): Structural reinforcement**

| Regular roof cost ($m^2$) | green roof cost ($m^2$) |
|---|---|
| 350 JD | 481.25 |

Percentage of the overall additional cost is 37.5% of the original cost for the entire building.

## 3.3.Summary

To sum up, the city of Nablus has very limited green areas as a result of urban sprawl and it is suffering from many problems. The instillation of green roofs would be an excellent solution to address these problems in addition to its aesthetical function. On the financial side the application of green roofs will to some point increase the overall cost of the building, however, in the long term, this will be economical on the theoretical side, while on the practical side, there is a need to explore how the people of the city of Nablus will react to applying green roofs to their buildings and city. This will be examined in the next chapter.

# Chapter Four

# People of The City of Nablus and The Use of Green Roofs, Questionnaire.

## 4.1. Introduction.

This survey was conducted to establish attitudes towards green space and green roof technology within the sociodemographic environmental of the citizens of the city of Nablus.

A sample of the city's residents was asked a series of questions to measure their preferences regarding the existence of plants in their homes (Attitude towards plants and green roof), the citizens' estimation regarding availability of green spaces in the city (Opinion), knowledge regarding green roof technology and their willingness to add green roofs to their own buildings.

The residents of the city of Nablus were surveyed, the sample size was 1% of the families of the city as the estimated number of families is 23800(calculated by dividing the city population on the average number of family members in the West Bank) (Palestinian Central Bureau of Statistics, 2013)

An online form (was created by using Google documents) of the questionnaire was sent to different people by email or social network. The questionnaire link. (https://goo.gl/forms/M0DgwIG5ucCBa88V2)

## 4.2. General information

In the first part of the questionnaire, participants were asked to give general information: gender, age, academic level, city district and property information.

248 city citizens were covered by this survey.111 male and 137 female. Percentage was almost equal 55% for female and 45% for males. Figure (57)

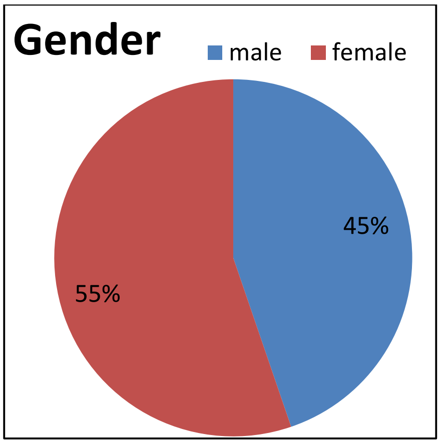


**Fig.57** male and female percentage.

As seen in table (11) and figure (58) the highest number of participants by age group are among young adults between 20and 30 years old; people aged more than 60 had the least participation.

**Table (11): age groups**

| | |
|---|---|
| less than 20 | 39 |
| 21_25 | 78 |
| 26_30 | 45 |
| 31_40 | 36 |
| 41_50 | 34 |
| 50-60 | 13 |
| more than 60 | 3 |

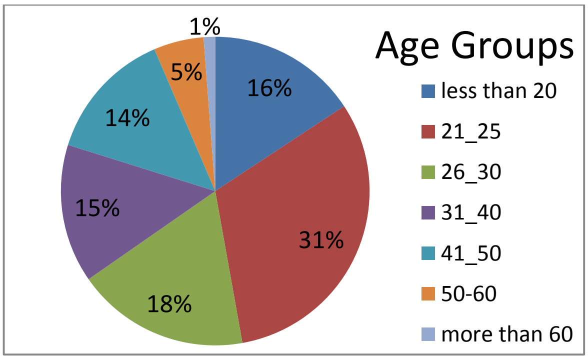


**Fig. 58** age groups percentage.

Residents from different districts of the city of Nablus participated in this questionnaire. Figure (59) and table (12), it was noticeable that the highest percentages of respondents were from the western districts of the city.

**Table (12): districts of the city**

| | |
|---|---|
| Rafidia | 52 |
| Al-makhfia | 27 |
| Al-jabal Al-shamali | 48 |
| Ras al-eayn | 8 |
| Old town | 6 |
| Al-dahia | 9 |
| city center | 2 |
| Al-masakin | 12 |
| Industrial Area | 1 |
| Al-quds Street | 17 |
| Other | 47 |

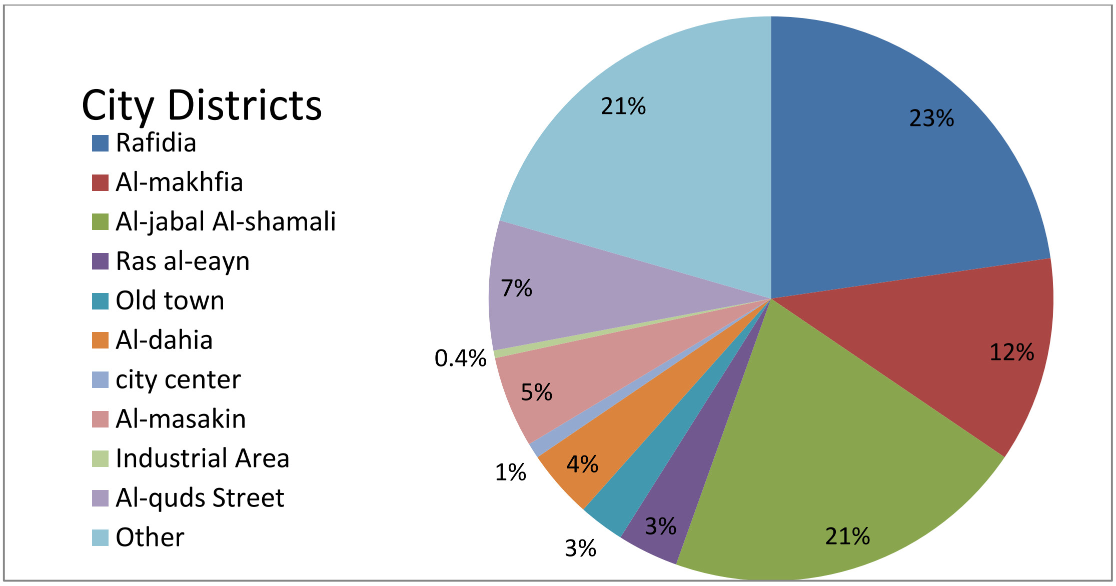



**Fig. 59** city districts percentage.

respondents were also asked to provide their academic level as a part of the general information. Most had a bachelor's degree (171), only 3 had school certificate, as shown in figure (60).

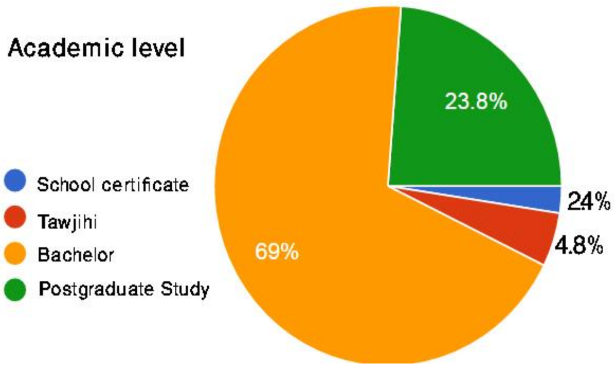



**Fig. 60** Academic levels percentage.

Property information was required to study the effect of ownership and building type on the willingness of respondents to add green roofs to their buildings. Most of the properties were owned and multi storey buildings.

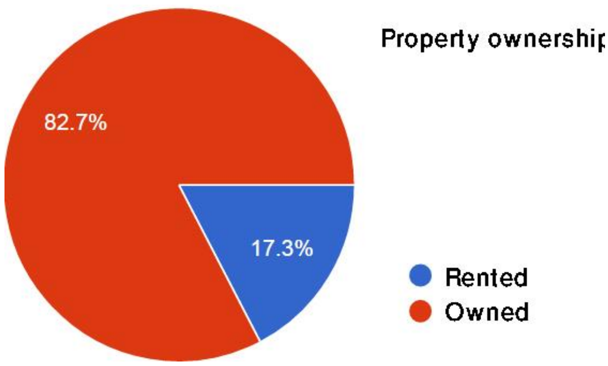



**Fig. 61** Property ownership percentage

157 (70.6%) respondents lived in a multi storey building and 105 of them lived in middle floors about 59% of residents of multi storey building live in middle floors.

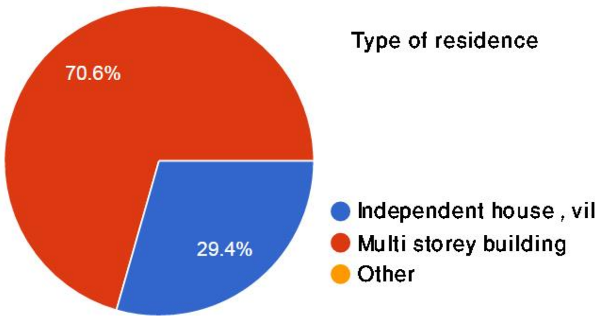



**Fig. 62** Type of residence

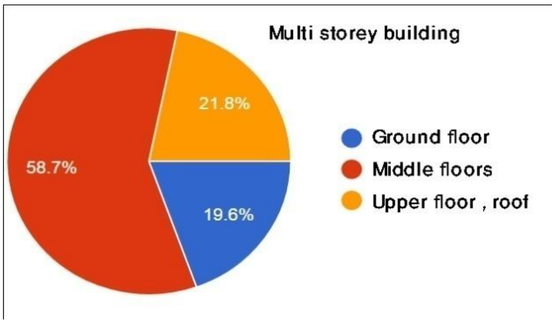



Fig. 63 Floor level for residence of multi storey building

When people were asked about accessibility to a private ground level garden and accessibility to the building roof, the results indicate that more people had access to the building roof than people with access to a private garden did. Figures (64), (65), (66).

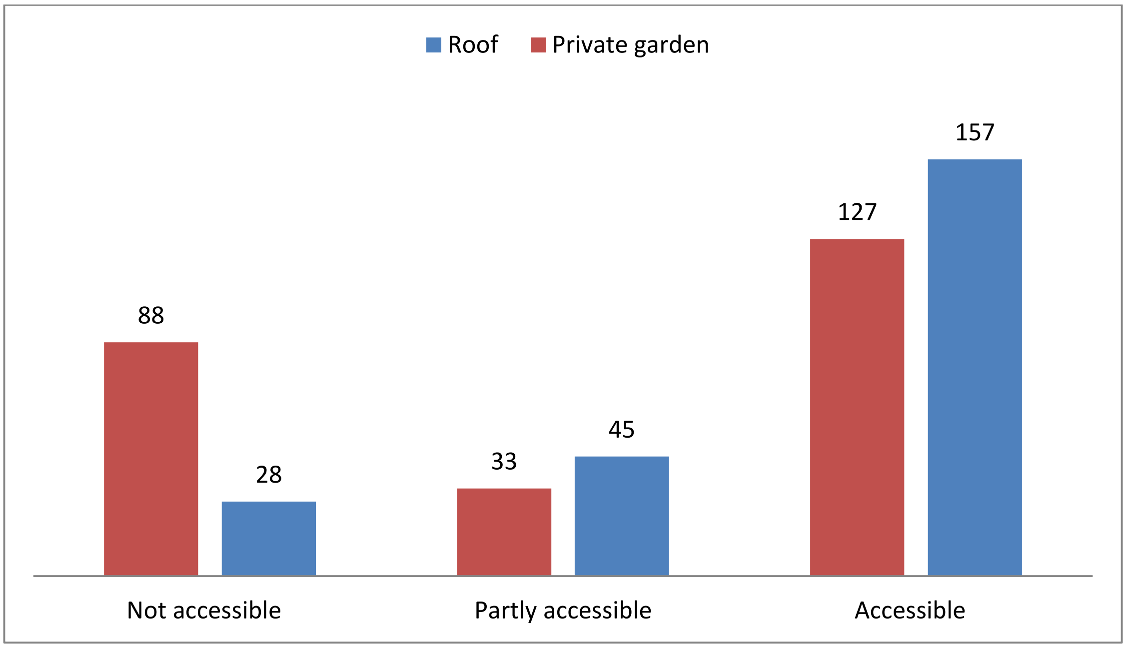



**Fig.64** comparing accessibility to a private ground level garden and accessibility to the building roof

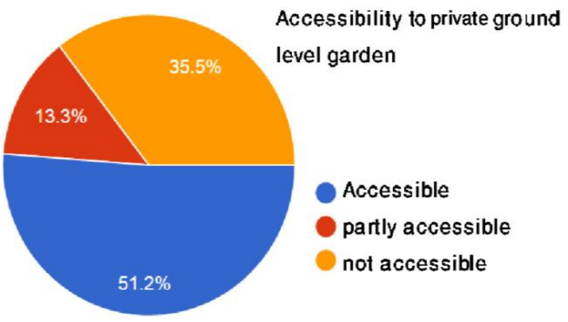



**Fig.65** accessibility to a private ground level garden

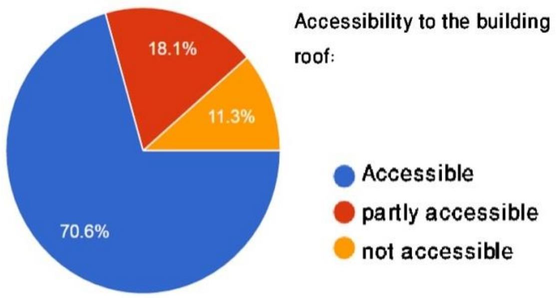
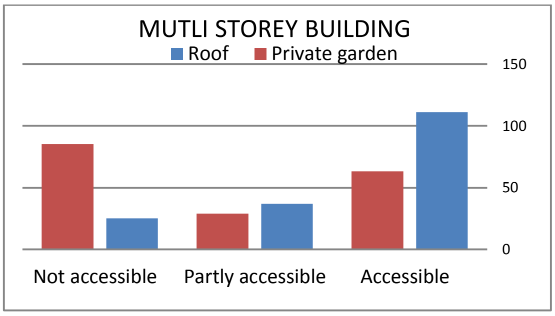



**Fig. 66** accessibility to the building roof

Residents of multi storey buildings are less likely to have access to a private garden, while residents of villas or independent houses mostly have access to both roof and garden. Figure (67)



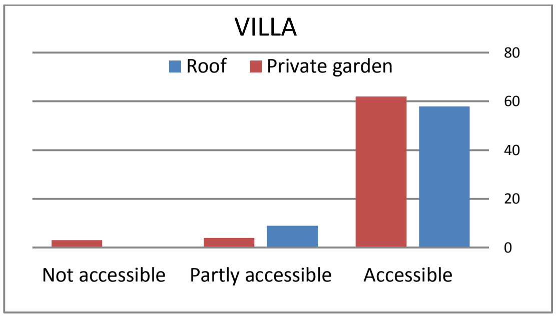




**Fig. 67** comparing accessibility to a private ground level garden and accessibility to the building roof for both building types.

## 4.3. Plant and Garden Preferences

The second part of the questionnaire assessed the participants' preference for vegetation and their views regarding the current green areas of the city of Nablus.

The respondents were asked about the existence of plants in their homes to assess their preference for having vegetation, 66.5% already had plants inside their homes in different locations, window ledges, living room, balcony and some even had plants on their roofs.

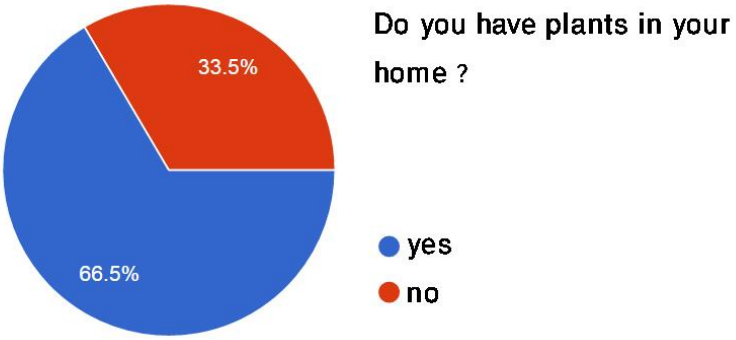



**Fig. 68** the existence of plants in homes.

Next, asked about the availability of public green spaces in their district, about 60% said that there were no public green spaces in their district. Respondent who said yes were asked to state how many times in one month they visited the public green spaces; most of the answers ranged from never to once or twice a month.

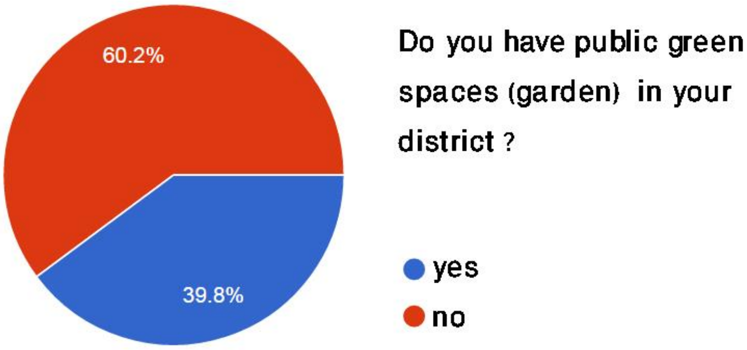



**Fig. 69** the availability of public green spaces on the respondent district

A Likert scale was used to measure the opinion of the respondents to the availability of gardens in the city of Nablus, they had to choose number from 1 to 5 (1 representing availability of gardens and 5 representing the absence of gardens), as shown on figure (70), most of respondents chose 4, meaning that the respondents believed that there are not enough gardens in the city.

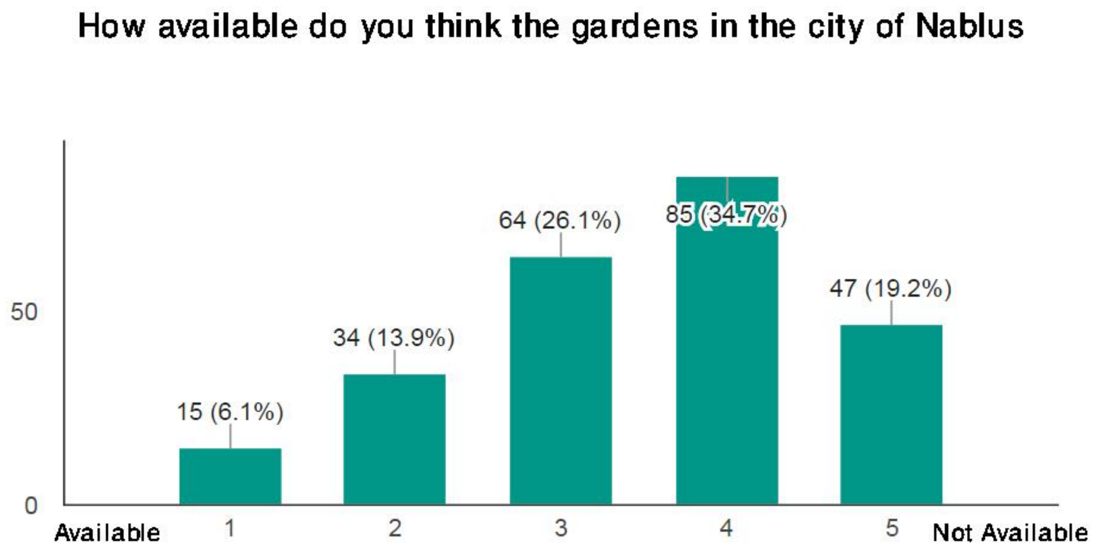



**Fig. 70** the availability of gardens.

## 4.4. Green Roof Knowledge

In this part of questionnaire, the participants were asked to answer questions regarding green roof knowledge.

Figure (71) up to 70% of the total respondents had heard about green roofs, but more than 70% of those did not have technical knowledge regarding green roof types.

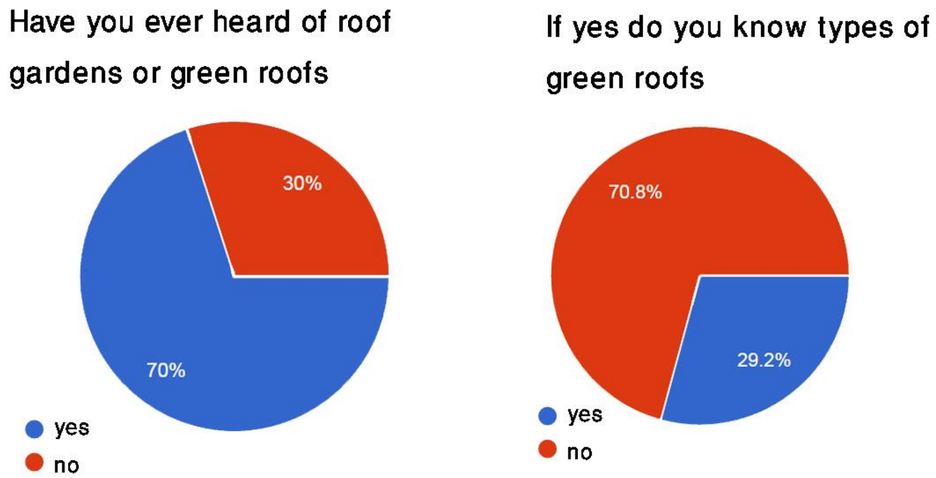



**Fig. 71** green roof knowledge.

The respondents were asked to assess the benefits provided by green roofs (strongly agree, agree, neutral, disagree or strongly disagree with the benefits). As stated in chapter three green roofs are shown to provide all the following benefits. Figure (72)

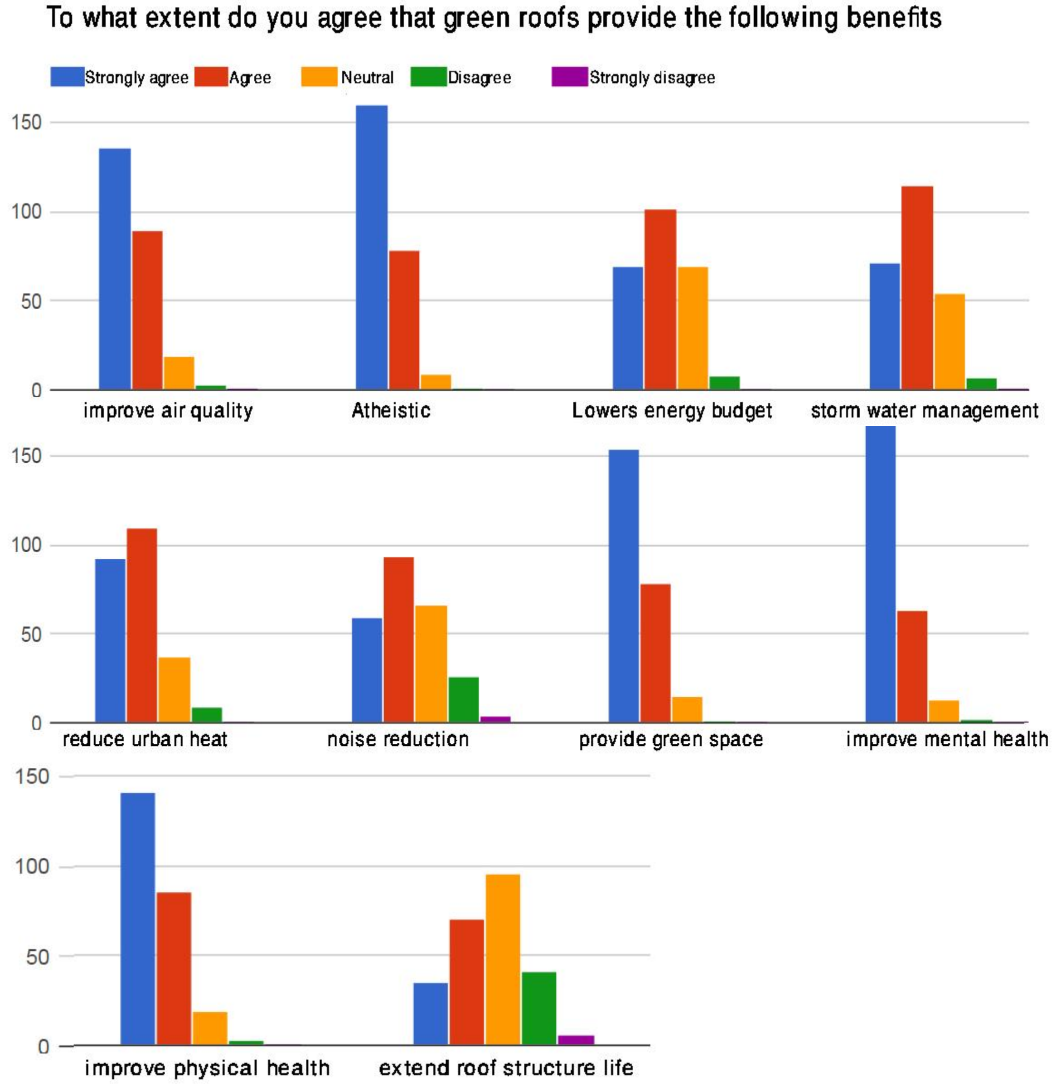



**Fig. 72** green roof benefits.

Respondents believed that green roofs could provide some benefits more than others, as they strongly agreed with improved air quality, atheistic quality, provided green space, and improved mental and physical health. On the other hand, respondents were less likely to agree with: lowers energy budgets, storm water management and reduced urban heat, whilst, noise reduction and extended roof structure life were more likely to be disagreed with.

## 4.5. Green roof preferences

Images of the city of Nablus taken by the researcher and then edited by using computer programs before and after adding green roof, images were shown to the participants and they were asked to choose the image they preferred visually.

The respondents preferred images of the city of Nablus with green roof, as 97.5% choose the image with green roofs from the first example, 96.3% from the second example and 98.3 from the third example.

(a) Before

(b) After

**Fig. 73** First example of before and after adding green roof images(a) Before(b) After

(a) Before

(b) After

**Fig. 74** Second example of before and after adding green roof images(a) Before(b) After

(a) Before

(b) After

**Fig. 75** Third example of before and after adding green roof images. (a) Before(b) After

The final question was, (would you alter your roof to make it green roof ?), 79% of the respondents said yes, while the other 21% had their reasons such as lack of knowledge and working experience regarding green roofs, lack of space or fully occupied roof, shared roof or the roof is a private property for the last floor, fear of additional load and cost and people having a private ground level garden are less likely to add green roof to their building.

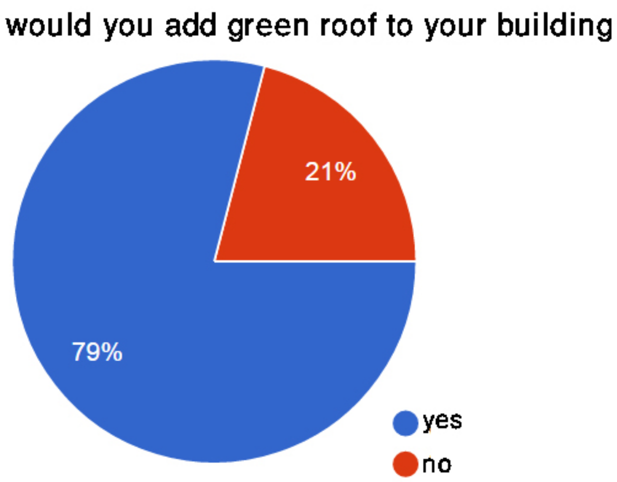



**Fig. 76** Adding green roofs to buildings.

33% of residents of multi storey buildings responded negatively when asked about adding green roofs to their building, because the roofs of multi storey buildings were the property of top- floor residents or shared area used for water tanks and water solar heating systems. On the other hand, 12% of villa residents answered no to adding green roof, as they explained that they have ground level garden around the house and felt no need for another garden in their building. Figure (77)

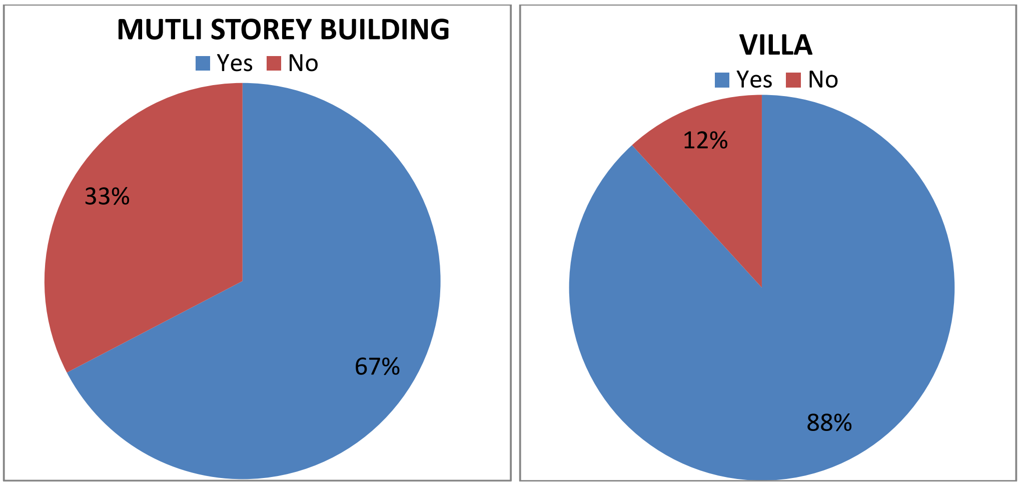



**Fig. 77** Comparing answers to adding green roof to the building for both building types.

When comparing the answers after building ownership (rented or owned) it was concluded that the results are almost the same but it was noticed that residents of rented property were less likely to add green roofs, Figure (78), which would be accounted for as 91% of rented property are in multi storey buildings. Figure (79)

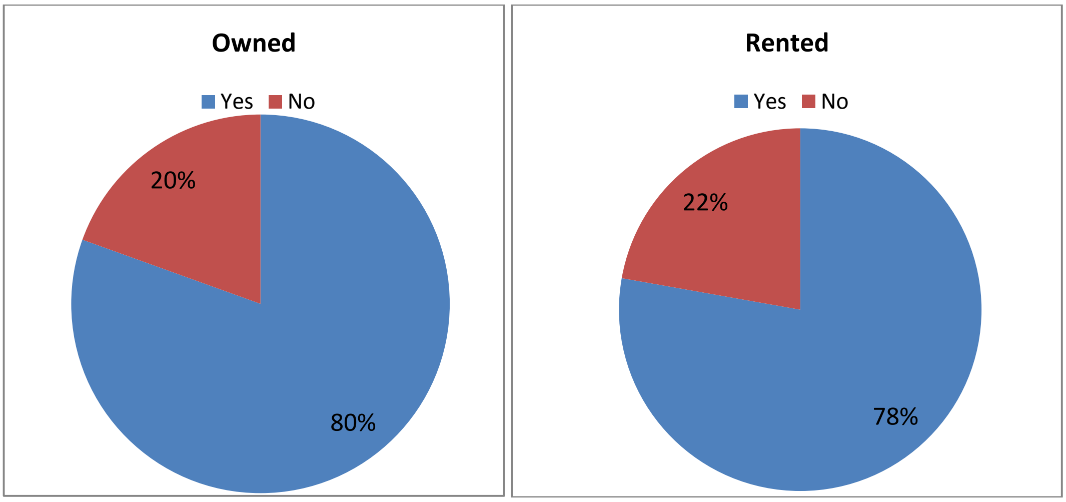



**Fig. 78** comparing answers to adding green roof to the building for owned and rented property.

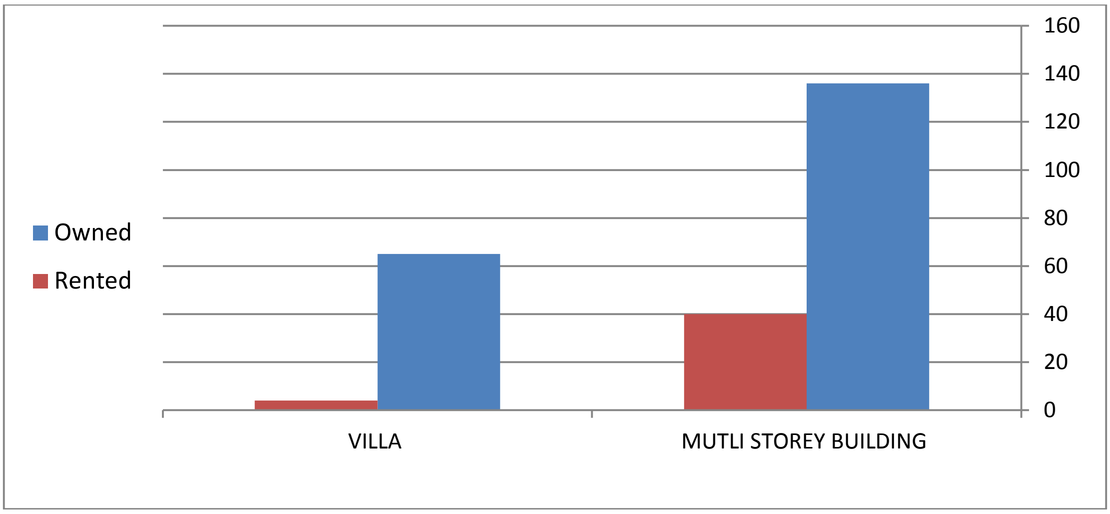



**Fig. 79** comparing answers of the building ownership for the two building types.

## 4.6. Summary

The questionnaire results demonstrated that the majority of residents of the city of Nablus were willing to add green roofs to their buildings, and the residents of the city had basic knowledge of green roofs. If Awareness-raising program were implemented a large number of citizens may add green roofs.

To present solid convincing scientific evidence to citizens of the city of Nablus on the environmental benefits of applying green roofs, a simulation investigation was conducted in chapter five. Examines to what extent green roofs can improve the environmental comfort of buildings and how energy consumption can be effected by adding green roofs.

# Chapter Five

# Green Roof Simulation and Environmental Comfort

A computer simulation investigation was conducted to evaluate the effect of applying green roof to two different buildings. As the residential building is the dominant type of building in the city of Nablus this simulation was conducted on two residential buildings. In the city of Nablus (as stated in chapter 3) the main two types of buildings are independent (villa) or multi-storey. Therefore, representative samples of these two most common building types of the city of Nablus were used in this simulation.

## 5.1. Autodesk Ecotect

Autodesk Ecotect Analysis was used to carry out this study, it is a program used for environmental analyses, simulating buildings' performance, providing analysis functions along with interactive display. Ecotect Analysis also offers integrated analysis tools such as: solar radiation, luminance level, shadows, water usage, heating loads, cooling loads, and energy consumption. *(“Autodesk Ecotect Analysis - Wikipedia,” 2016)* Autodesk network identify Ecotect Analysis as *"is the most comprehensive and innovative building analysis software on the market today. It features a designer-friendly 3D modeling interface fully integrated with a wide range of performance analysis and simulation functions".(“Ecotect Analysis,” 2016)*

## 5.2. Climate

The climate of the city of Nablus has been previously discussed (chapter three), but there is no Ecotect weather data for the city of Nablus, therefore in this simulation Jerusalem weather data have being used, as Jerusalem has the closest climate to Nablus. Both cities have the same longitude and topography, the following climatic information provided by Ecotect for the city of Jerusalem demonstrates the similarities to the city of Nablus in weather.

### 5.2.1. Solar Radiation

By examining the sun chart diagram, the best possible orientation in consideration of solar radiation is displayed. The best orientation is South West-North East at 260˚, where the building short facades face north and south.

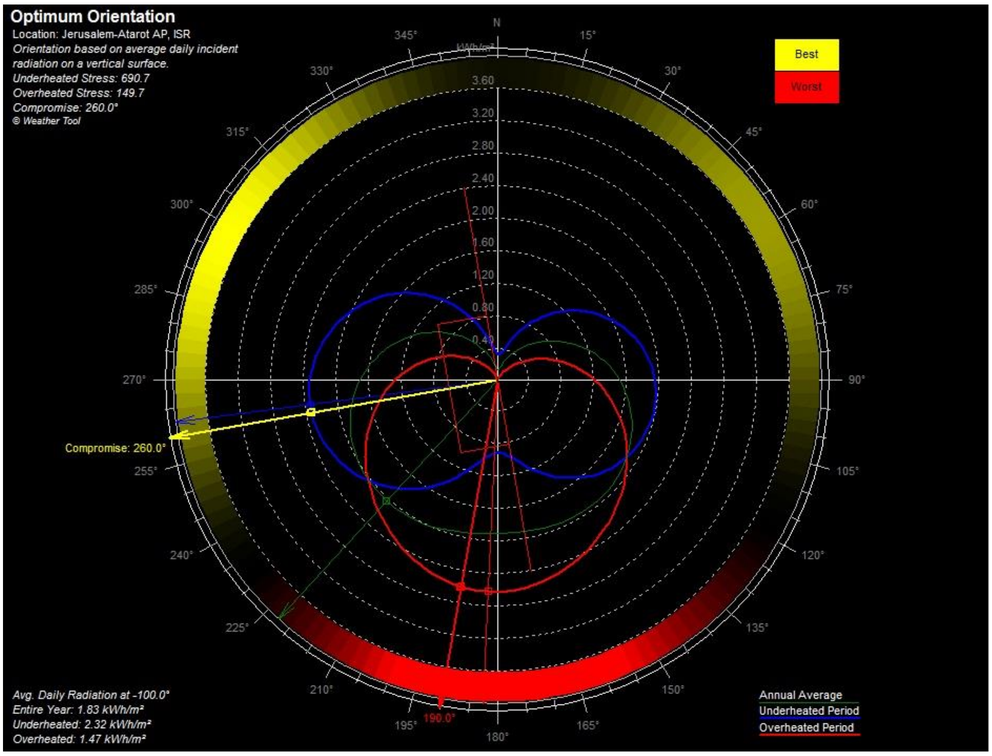



**Fig. 80** the best orientation of the buildings.
Source: Ecotect.

Figure (80) the best orientation, where the solar radiation can be decreased during the warmer months or increased for the colder months.

In figure (81) the red and blue areas represents the hottest (red) and coldest (blue) months in the year, the thick bright yellow line is the average solar radiation through 30 days (monthly average), and the thin yellow line represents the actual recorded value of solar radiation.

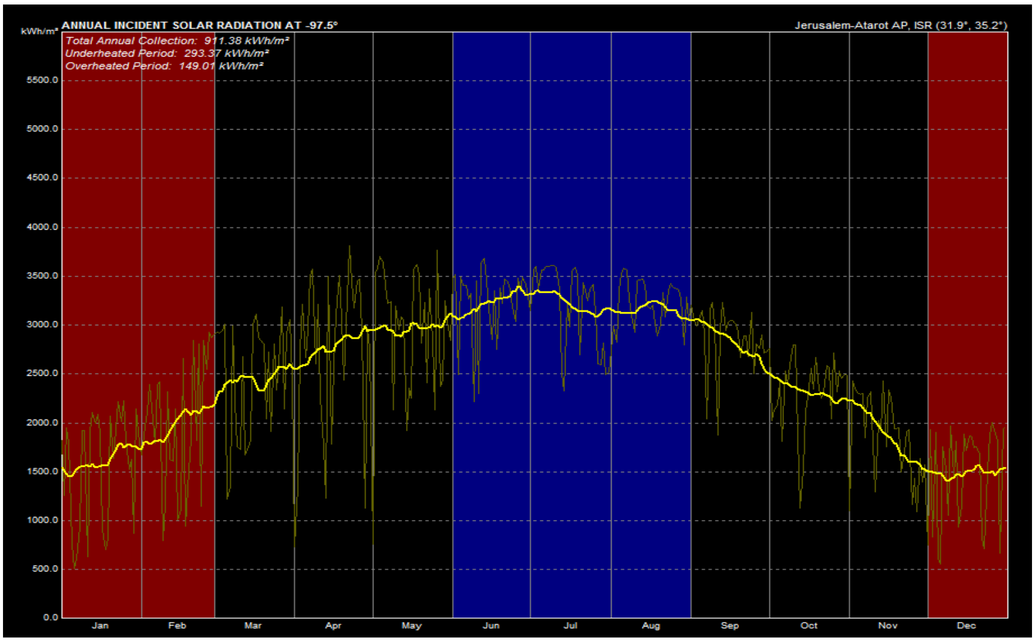
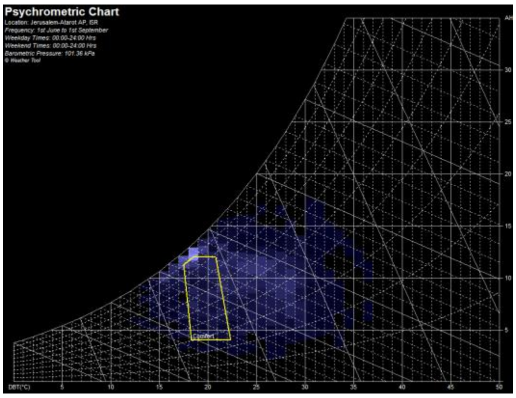



**Fig. 81** Solar radiation.
Source: Ecotect.

### 5.2.2. A psychrometric Chart

*"Psychrometric charts show temperature vs. humidity, and can be used to express human thermal comfort, design strategies, and energy requirements for those strategies". (“Psychrometric Charts | Sustainability Workshop,” 2015)*

The following figure (82) shows the relationship between dry-bulb temperature on the horizontal axis, and relative humidity on the vertical axis. The thermal comfort zone with yellow boundaries is defined according to temperature and relative humidity as well as the occupant's involvements such as clothing and activity level.

(A) 

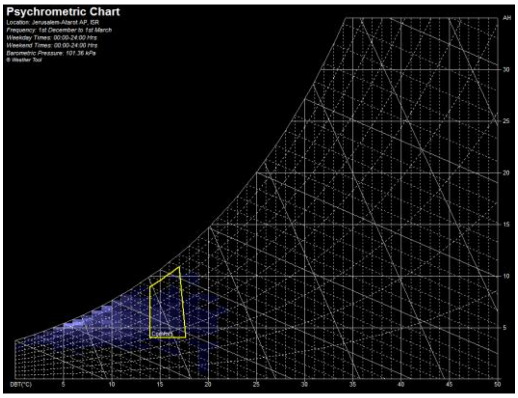
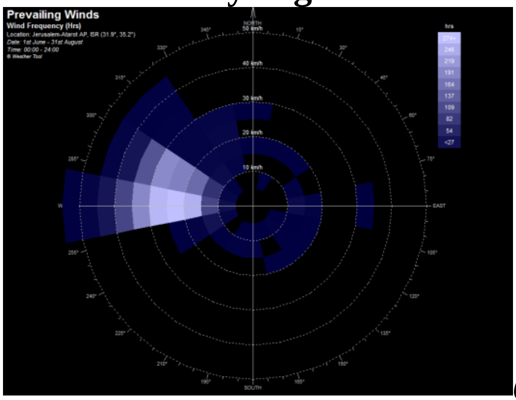

(B) 


**Fig. 82** Psychrometric Chart (A) summer (B) winter
Source: Ecotect.

### 5.2.3. Wind Analyzing

(A) 

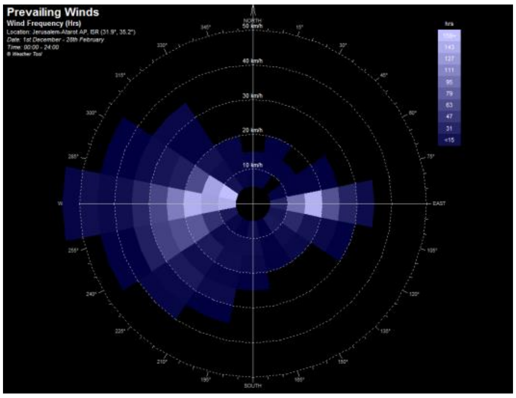

(B) 


**Fig.83** Wind rose (A) summer (B) winter
Source: Ecotect.

### 5.2.4. Conclusion of Climate Analyzing

The following figure (84) shows the most amount of cooling needed in summer months, especially in August where the cooling load reaches to the highest point. During a cold rainy winter, it can be seen from figure (80) that more heating is needed than cooling.

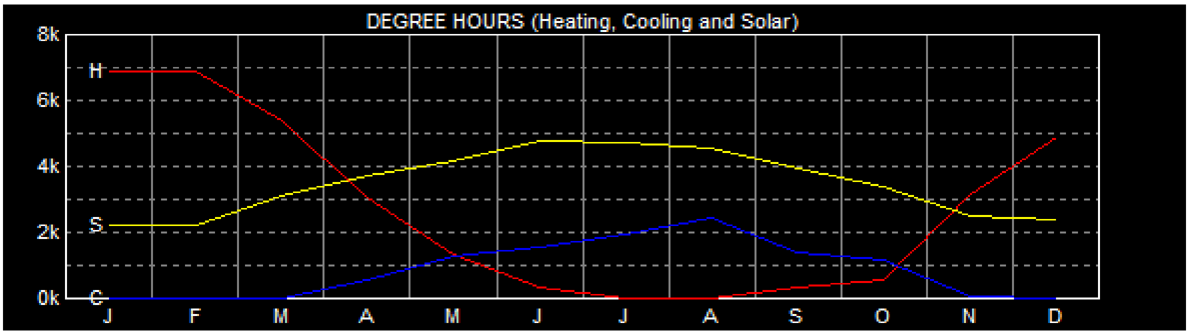
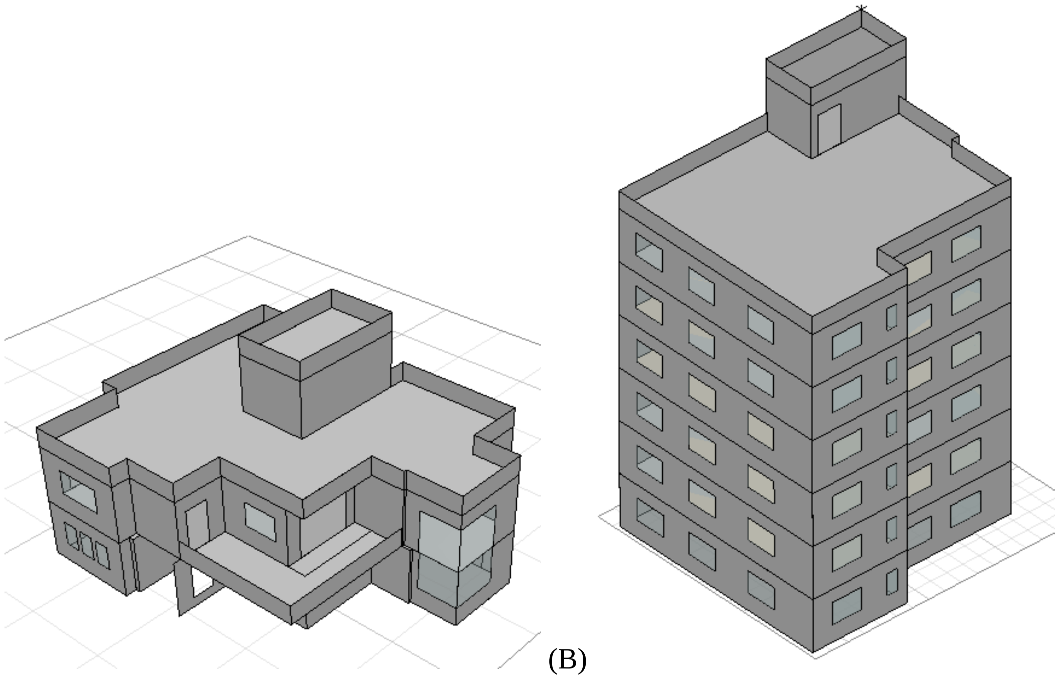



**Fig. 84** Climate analyses
Source: Ecotect.

### 5.3. Building Simulation

The simulated buildings in figure (85) are representative samples for typical residential buildings in the city of Nablus. Ecotect simulation was performed on those two buildings.



(A) (B)

**Fig. 85** Images of building used in the simulation (A) individual house (villa) (B) multi storey building
Source: Modeled in Ecotect by the researcher.

As the thermal behavior of a building can by affected by several factors (the building envelope) such as; walls, roof, and windows. Each element has a certain thermal transmittance value (U-Value) *"is the rate of transfer of heat through a structure (which can be a single material or a composite), divided by the difference in temperature across that structure. The units of measurement are W/m²K. The better-insulated a structure is, the lower the U-value will be. Workmanship and installation standards can strongly affect the thermal transmittance. If insulation is fitted poorly, with gaps and cold bridges, then the thermal transmittance can be considerably higher than desired. Thermal transmittance takes heat loss due to conduction, convection and radiation into account". ("u-value-heat-loss-thermal-mass-and-online-calculators," 2015)*

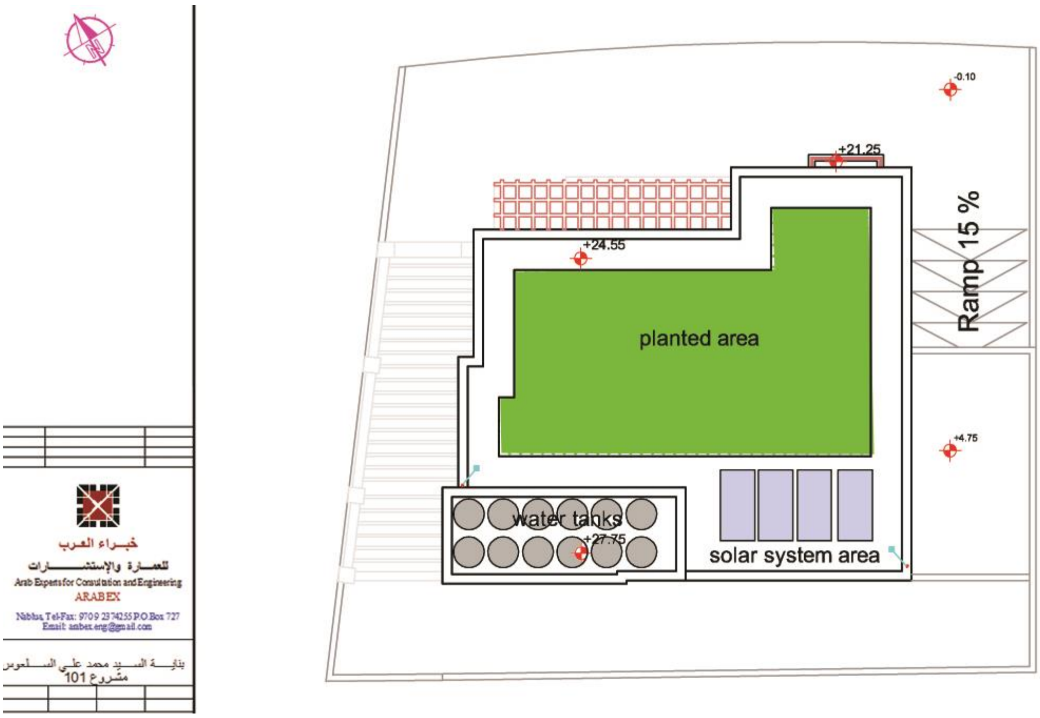



**Fig. 86** site plan of building used in the simulation multi storey building
Source: Arab Experts for Consultation and Engineering ARABEX

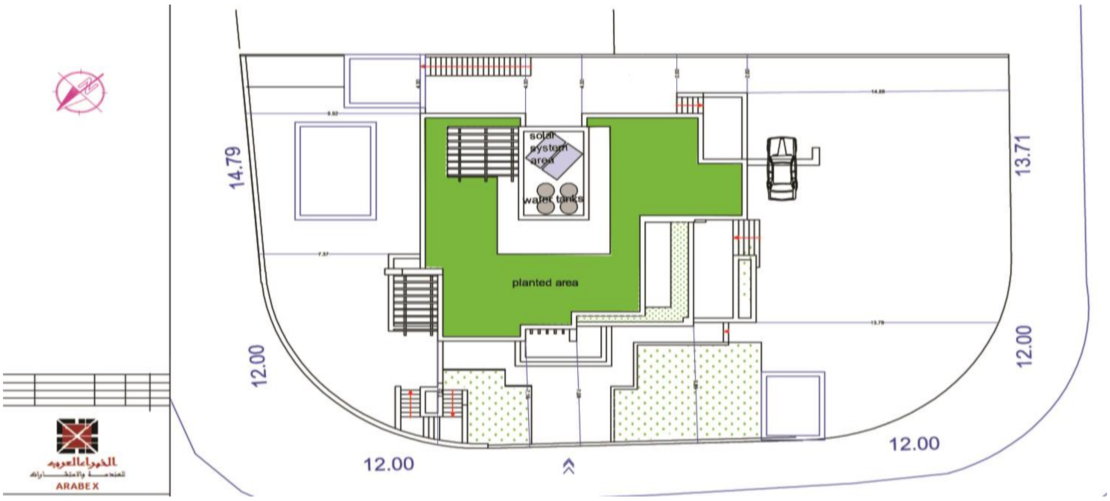
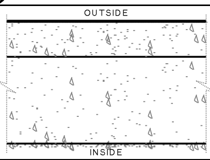
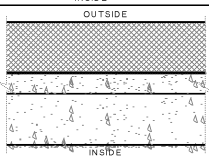
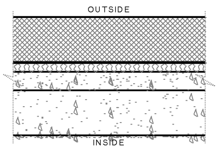



**Fig. 87** site plan of building used in the simulation villa
Source: Arab Experts for Consultation and Engineering ARABEX

In these simulations all elements but the roof are given fixed thermal characteristics. To investigate the difference in thermal behavior of the building three types of roof layers have been simulated 1st regular(conventional) roof, 2nd green roof, 3rd green roof with thermal insulation.

**Table (13) roof materials and types**

| Roof type | Section | | Layer Name | Width | Density | Sp.Heat | Conduct. |
|---|---|---|---|---|---|---|---|
| **Regular roof U-value 0.95** |  | 1. | Bitumen / Felt Layers | 0.003 | 1700.0 | 1000.000 | 0.170 |
| | | 2. | Foam Slag | 0.100 | 500.0 | 960.000 | 0.160 |
| | | 3. | Concrete | 0.250 | 2000.0 | 656.900 | 1.170 |
| | | 4. | Plaster | 0.010 | 1570.0 | 840.000 | 0.530 |
| **Green roof U-value 0.49** |  | 1. | soil media | 0.250 | 1700.0 | 1000.000 | 0.250 |
| | | 2. | Bitumen / Felt Layers | 0.003 | 1700.0 | 1000.000 | 0.170 |
| | | 3. | Foam Slag | 0.100 | 500.0 | 960.000 | 0.160 |
| | | 4. | Concrete | 0.250 | 2000.0 | 656.900 | 1.170 |
| | | 5. | Plaster | 0.010 | 1570.0 | 840.000 | 0.530 |
| **Insulated green roof U-value 0.29** |  | 1. | soil media | 0.250 | 1700.0 | 1000.000 | 0.250 |
| | | 2. | Bitumen / Felt Layers | 0.003 | 1700.0 | 1000.000 | 0.170 |
| | | 3. | Polystyrene | 0.050 | 28.0 | 1130.000 | 0.035 |
| | | 4. | Foam Slag | 0.100 | 500.0 | 960.000 | 0.160 |
| | | 5. | Concrete | 0.250 | 2000.0 | 656.900 | 1.170 |
| | | 6. | Plaster | 0.010 | 1570.0 | 840.000 | 0.530 |

### 5.3.1. Results and analysis:

The simulation was conducted on the two building types investigate out the green roof effect on the thermal performance of the building and to estimate the consequences of applying green roof to the consumption of the energy used for heating and cooling.

### 5.3.2. Direct solar radiation

In the first part of the simulation direct solar radiation was calculated, "Ecotect" was used to simulate data for cumulative incident solar radiation on a horizontal surface, of the testing models, both monthly and yearly. The average value of the solar radiation is given in $Wh/m^{2}$. The following figures show the result of the simulation of the two building models with different orientation and area, during summer, winter, and whole year.

As shown in the site plan of the testing models, 76% of the villa roof was covered with green roof; table (14) and (15) explains the difference on direct solar radiation before and after applying a green roof. 55% of the multi-storey building roof was covered with a green roof. Before and after green roof results shown in table (16) and (17).

About 50% reduction on the total all year direct solar radiation in the villa and 62% reduction is achieved in the multi storey building, Figure (88).

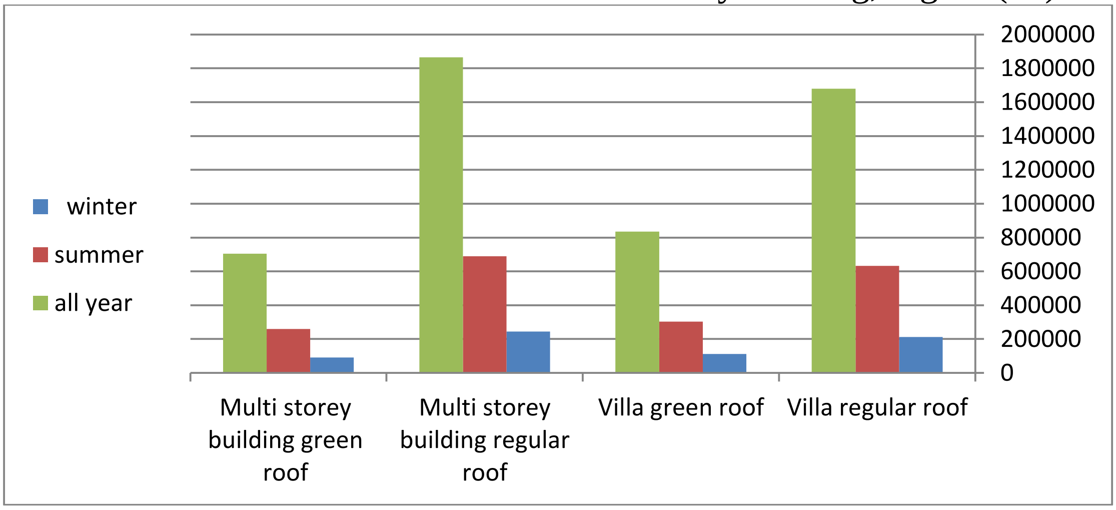



**Fig. 88** Comparison between direct solar radiation for a green roof, a regular roof on the villa and multi storey building.
Source: Result of Ecotect simulation

**Table (14) Villa: Regular roof.**

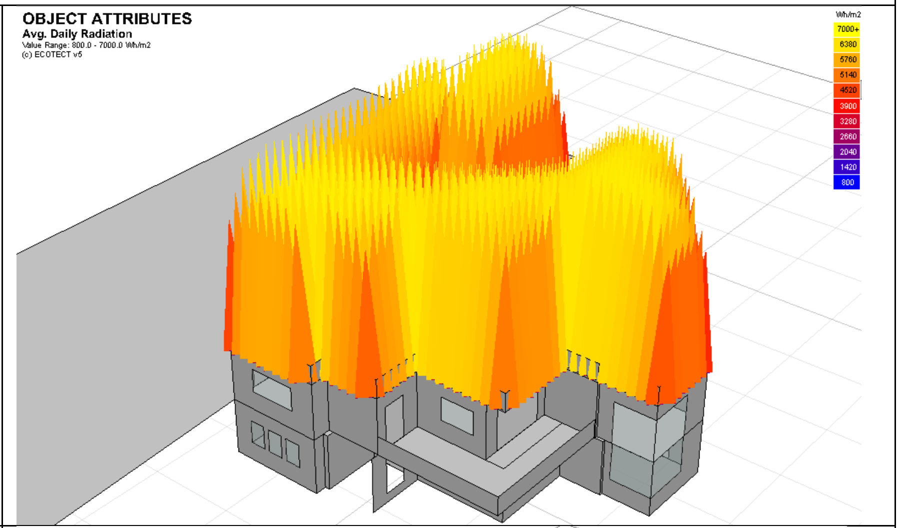
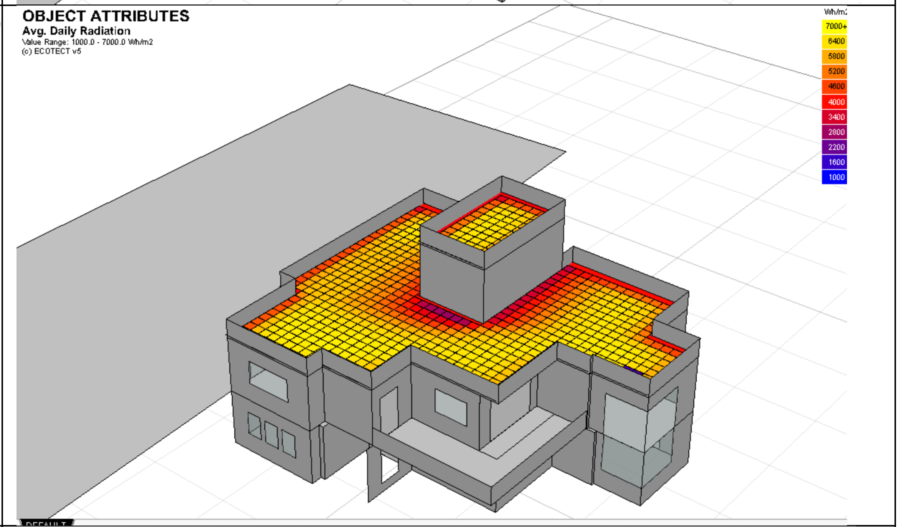
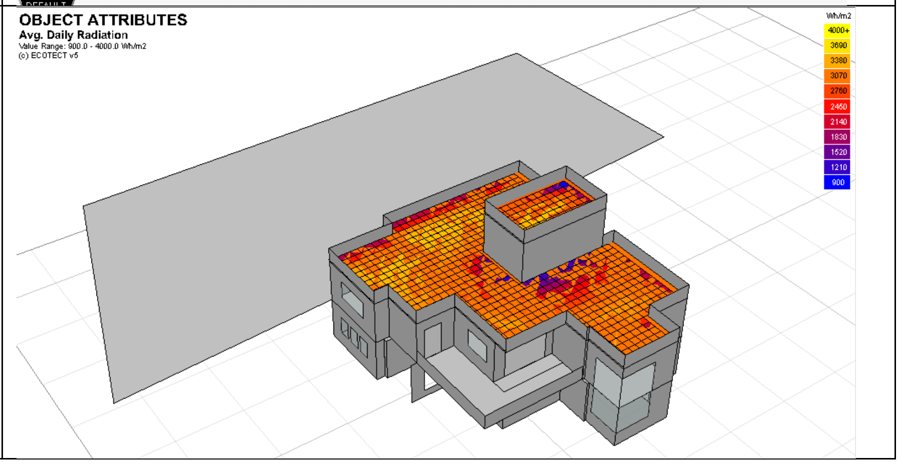
| direct solar radiation | |
|---|---|
| All year |  |
| Summer |  |
| Winter |  |

**Table (15) Villa: Green roof results.**

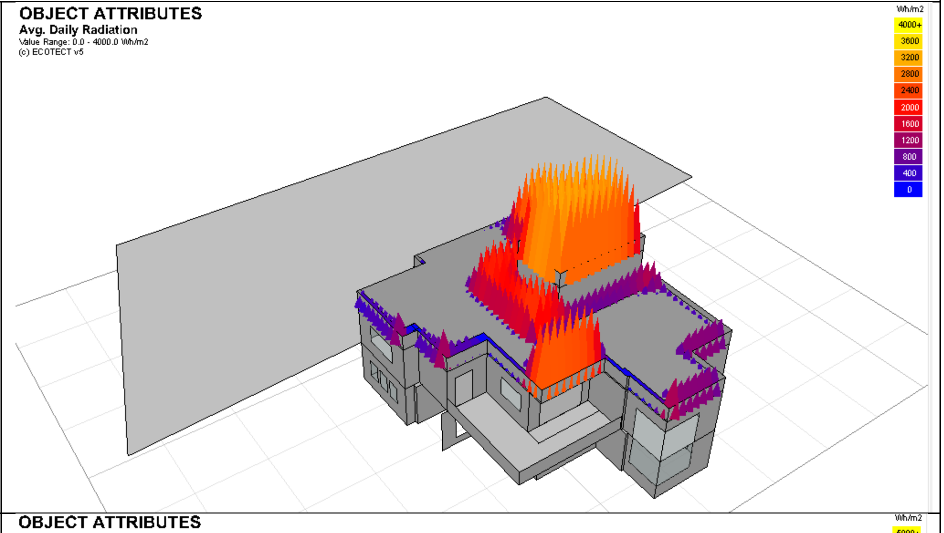
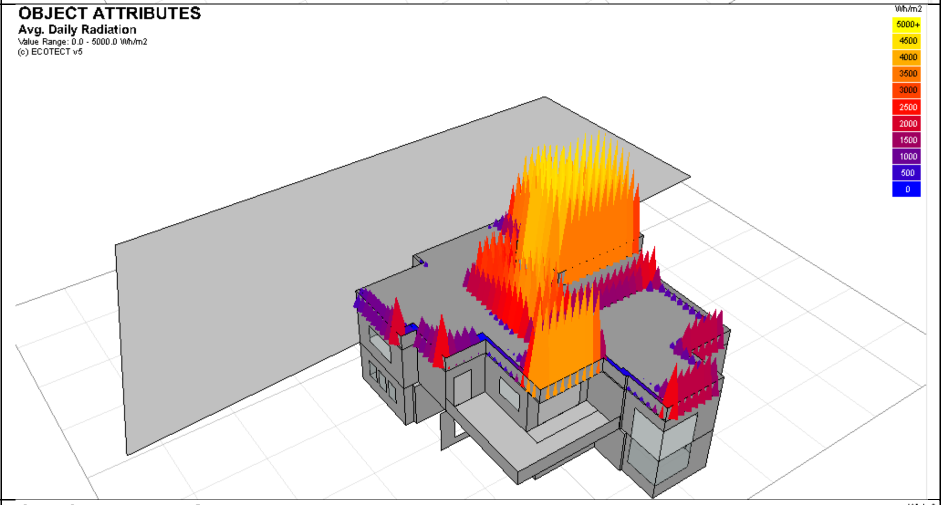
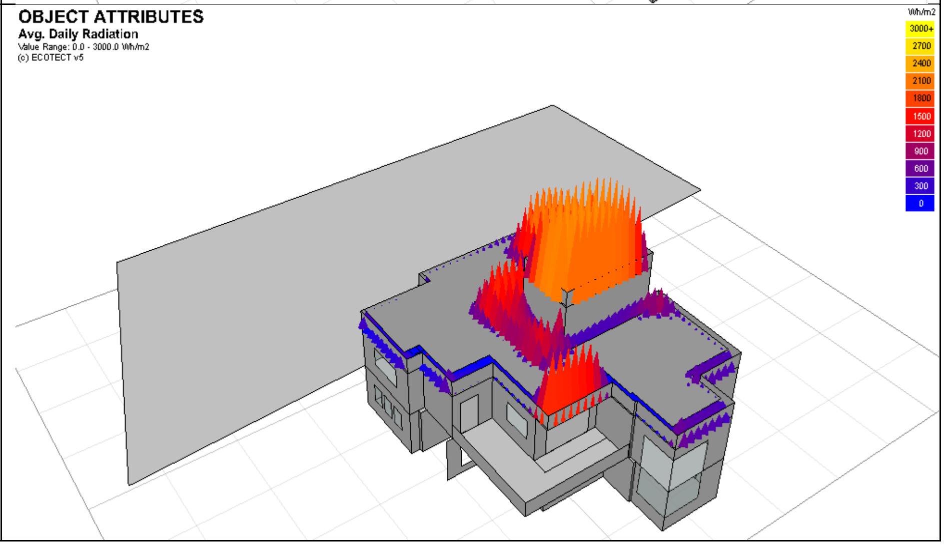
| direct solar radiation | |
|---|---|
| All year |  |
| Summer |  |
| Winter |  |

**Table (16) Multi story building: Regular roof.**

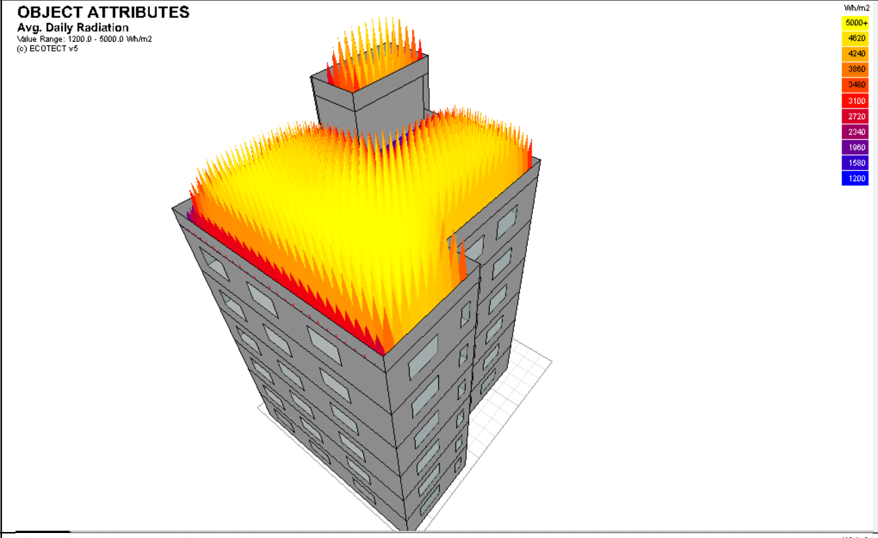
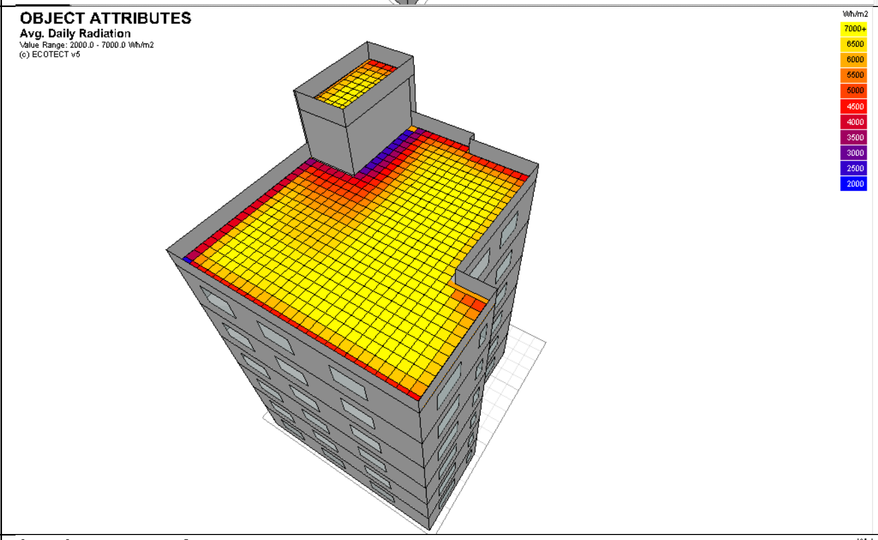
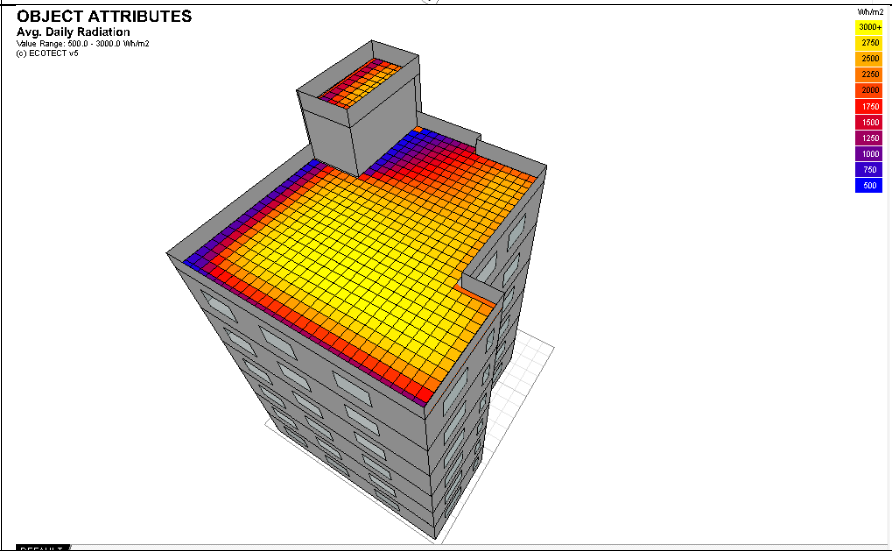
| direct solar radiation | |
|---|---|
| All year |  |
| Summer |  |
| Winter |  |

**Table (17): Multi story building: Green roof.**

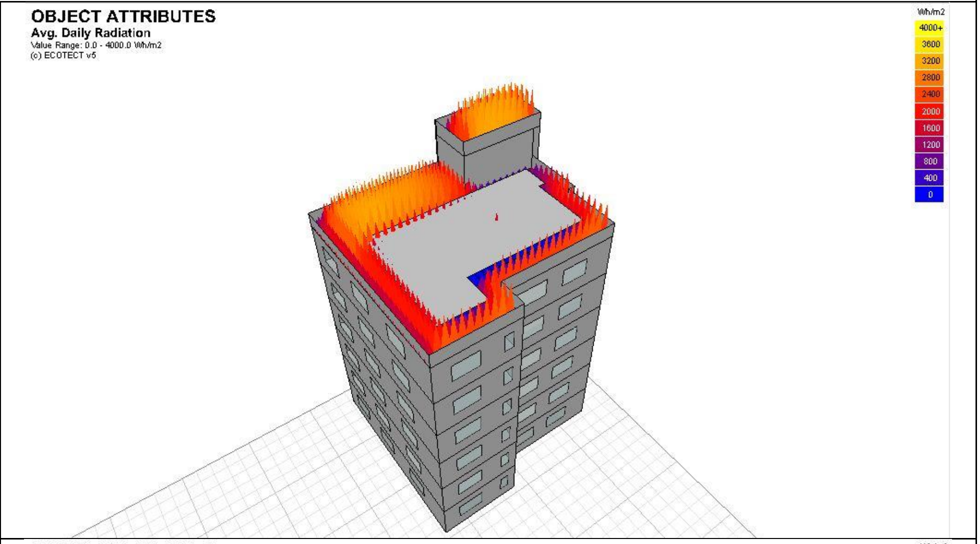
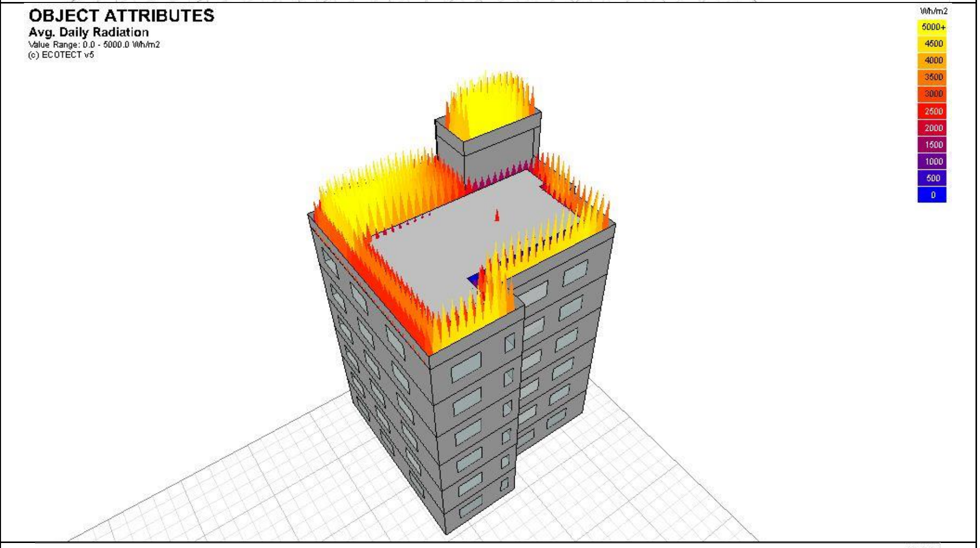
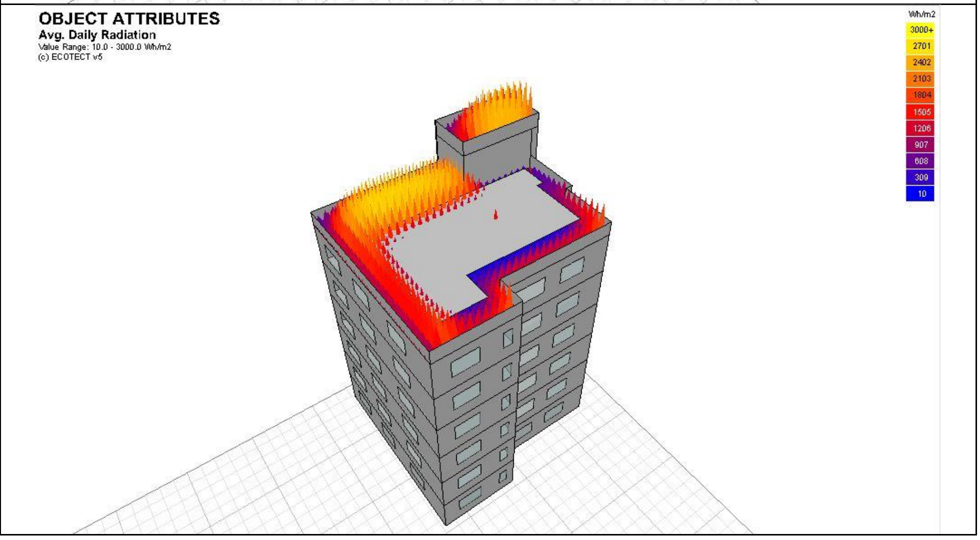
| direct solar radiation | |
|---|---|
| All year |  |
| Summer |  |
| Winter |  |

**Table (18): Results of average direct solar radiation for the regular roof**

| regular roof | Villa | Multi-storey building |
|---|---|---|
| Total solar radiation for the roof summer | 631665.5Wh/$m^2$ | 688873.88 Wh/$m^2$ |
| Total solar radiation winter | 211590.77Wh/$m^2$ | 245009.95Wh/$m^2$ |
| **Total solar radiation all year** | **1680266.62Wh/$m^2$** | **1865268.38 Wh/$m^2$** |

**Table (19): Results of average direct solar radiation for the green roof**

| green roof | Villa | Multi-storey building |
|---|---|---|
| Total solar radiation for the roof summer | 303453.72Wh/$m^2$ | 259506.92Wh/$m^2$ |
| Total solar radiation winter | 112802.72Wh/$m^2$ | 90884.94Wh/$m^2$ |
| **Total solar radiation all year** | **835910.44Wh/$m^2$** | **704078.12Wh/$m^2$** |

Reduction of the direct solar radiation leads to a reduction on the internal gain through the roof that can be calculated by the following rule.

Total Solar Radiation (Wh/m²) * Total Area of the Roof (m²) = Wh

Wh / Total Built up area (m²) = Internal solar gain*(Elmira Jalali Saeid, 2011)*

**Table (20): Internal solar gain Wh/$m^2$**

| | Villa regular roof | Villa green roof | Multi-storey building regular roof | Multi-storey building green roof |
|---|---|---|---|---|
| all year | 659297.4406 | 327991.7646 | 310878.0633 | 117346.3533 |

As shown in table (20) and figure (89) reduction of the internal solar gain by the green roof was up to 50% for the villa and 62% for the multi storey building.

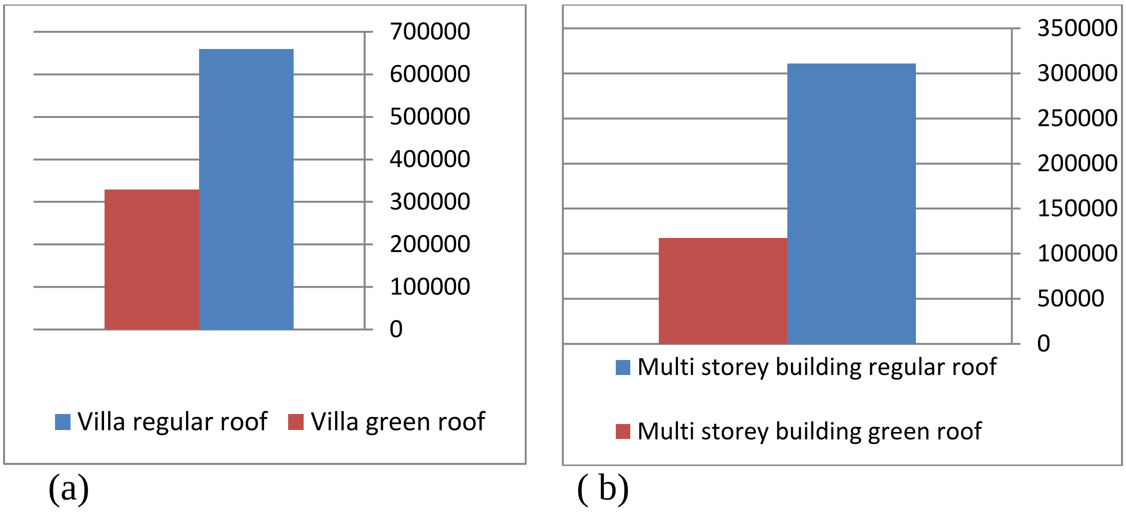



**Fig. 89** Comparison between internal solar gain for a green roof, a regular roof on the (a) villa and (b) multi storey building .
Source: Result of Ecotect simulation

The 2nd part of the simulation analysis was to compute the effect of green roof material on heat gain and loss and the change in the heating and cooling load of the building.

### 5.3.3. Fabric gain

As the materials of the building envelope (walls, roofs, windows) are defined in Ecotect, heat loss and gain through the building fabric can be calculated; materials and thickness affect heat transfer; all elements of the building envelope are fixed except the roof. Results in tables (21), (22), (23) for villa, and tables (24), (25), (26) for the multi-storey building, demonstrate the effect of changing roof material has changed losses and gains through the year. Figure (90) (villa) and Figure (91) (multi storey building) shows that the rate of heat loss and gain through a green roof is lower than the regular roof and the insulated green roof results are slightly lower than the green roof. Therefore, the insulated green roof produces more stable room temperature, which is the result of reduction of heat loss in winter and heat gain in summer.

## Villa

**Table (21): Villa Fabric gain for Regular roof**

| **ANNUAL LOADS TABLE** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fabric Gains - Qc + Qs** | | | | | | | | | | | | |
| **1st - Monthly Averages** | | | | | | | | | | | | |
| **HOUR** | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| **-----** | ------ | ------ | ------ | ------ | ----- | ----- | ----- | ----- | ----- | ----- | ------ | ------ |
| **0** | -2127 | -2374 | -1799 | -1181 | -560 | -191 | -12 | -7 | -185 | -252 | -1130 | -1690 |
| **1** | -2170 | -2433 | -1848 | -1225 | -594 | -229 | -16 | -14 | -224 | -300 | -1183 | -1734 |
| **2** | -2213 | -2471 | -1906 | -1284 | -629 | -268 | -21 | -17 | -262 | -347 | -1239 | -1792 |
| **3** | -2254 | -2490 | -1959 | -1349 | -674 | -309 | -33 | -23 | -296 | -392 | -1289 | -1855 |
| **4** | -2287 | -2518 | -2010 | -1399 | -715 | -358 | -62 | -41 | -329 | -435 | -1333 | -1910 |
| **5** | -2315 | -2563 | -2058 | -1411 | -703 | -320 | -50 | -46 | -359 | -464 | -1363 | -1925 |
| **6** | -2354 | -2605 | -2054 | -1289 | -608 | -215 | -20 | -22 | -296 | -470 | -1392 | -1938 |
| **7** | -2317 | -2509 | -1866 | -1029 | -454 | -90 | 41 | 78 | -144 | -335 | -1248 | -1831 |
| **8** | -2101 | -2256 | -1586 | -839 | -335 | -25 | 77 | 194 | -2 | -165 | -997 | -1578 |
| **9** | -1862 | -2006 | -1435 | -755 | -216 | 42 | 132 | 282 | 59 | -87 | -823 | -1264 |
| **10** | -1746 | -1870 | -1331 | -600 | 3 | 273 | 290 | 429 | 153 | -38 | -757 | -1131 |
| **11** | -1670 | -1731 | -1084 | -232 | 390 | 655 | 653 | 758 | 409 | 142 | -608 | -1024 |
| **12** | -1470 | -1476 | -656 | 177 | 679 | 932 | 864 | 1137 | 821 | 498 | -269 | -746 |
| **13** | -1102 | -1075 | -426 | 387 | 878 | 1083 | 1043 | 1335 | 996 | 695 | -32 | -387 |
| **14** | -945 | -929 | -329 | 489 | 1044 | 1219 | 1149 | 1391 | 1026 | 768 | 86 | -238 |
| **15** | -878 | -906 | -287 | 606 | 1126 | 1254 | 1245 | 1439 | 1100 | 847 | 126 | -201 |
| **16** | -926 | -951 | -231 | 650 | 1118 | 1252 | 1226 | 1440 | 1159 | 897 | 96 | -274 |
| **17** | -1026 | -1078 | -369 | 553 | 1042 | 1241 | 1190 | 1379 | 1117 | 813 | -32 | -387 |
| **18** | -1220 | -1341 | -621 | 355 | 894 | 1171 | 1094 | 1200 | 900 | 575 | -251 | -638 |
| **19** | -1384 | -1554 | -873 | 3 | 581 | 959 | 948 | 888 | 681 | 426 | -421 | -861 |
| **20** | -1564 | -1742 | -1051 | -204 | 339 | 640 | 668 | 727 | 498 | 255 | -578 | -1082 |
| **21** | -1784 | -1984 | -1283 | -472 | 113 | 437 | 490 | 509 | 266 | 27 | -795 | -1301 |
| **22** | -2005 | -2226 | -1537 | -784 | -162 | 207 | 288 | 248 | 15 | -209 | -1031 | -1540 |
| **23** | -2080 | -2293 | -1745 | -1100 | -417 | -12 | 117 | 20 | -141 | -241 | -1109 | -1637 |

# Table (22): Villa Fabric gain for Green roof

| ANNUAL LOADS TABLE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fabric Gains - Qc + Qs | | | | | | | | | | | | |
| 1st - Monthly Averages | | | | | | | | | | | | |
| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| HOUR | ------ | ------ | ------ | ------ | ----- | ----- | ----- | ----- | ----- | ----- | ------ | ------ |
| 0 | -1765 | -1957 | -1493 | -995 | -471 | -171 | -12 | -11 | -168 | -215 | -954 | -1415 |
| 1 | -1797 | -2002 | -1528 | -1024 | -499 | -198 | -16 | -16 | -199 | -257 | -992 | -1445 |
| 2 | -1829 | -2040 | -1575 | -1064 | -526 | -230 | -20 | -18 | -227 | -297 | -1036 | -1488 |
| 3 | -1859 | -2060 | -1624 | -1116 | -565 | -265 | -31 | -23 | -256 | -341 | -1073 | -1536 |
| 4 | -1886 | -2079 | -1667 | -1165 | -601 | -311 | -58 | -37 | -281 | -380 | -1110 | -1583 |
| 5 | -1907 | -2112 | -1711 | -1171 | -585 | -267 | -45 | -39 | -305 | -399 | -1127 | -1590 |
| 6 | -1941 | -2148 | -1696 | -1042 | -483 | -156 | -14 | -16 | -237 | -394 | -1150 | -1596 |
| 7 | -1899 | -2047 | -1497 | -773 | -320 | -23 | 51 | 86 | -79 | -249 | -1000 | -1480 |
| 8 | -1679 | -1789 | -1206 | -572 | -193 | 54 | 96 | 206 | 68 | -68 | -742 | -1218 |
| 9 | -1436 | -1531 | -1044 | -490 | -85 | 98 | 141 | 292 | 134 | 12 | -567 | -907 |
| 10 | -1310 | -1388 | -953 | -416 | 21 | 182 | 205 | 381 | 183 | 54 | -497 | -774 |
| 11 | -1256 | -1307 | -867 | -237 | 252 | 426 | 443 | 559 | 262 | 97 | -451 | -718 |
| 12 | -1215 | -1239 | -608 | 12 | 388 | 539 | 524 | 759 | 514 | 298 | -279 | -617 |
| 13 | -972 | -1001 | -504 | 104 | 449 | 562 | 560 | 816 | 555 | 372 | -159 | -404 |
| 14 | -918 | -975 | -500 | 107 | 494 | 590 | 561 | 752 | 491 | 348 | -123 | -349 |
| 15 | -889 | -983 | -518 | 149 | 535 | 587 | 580 | 728 | 509 | 384 | -103 | -369 |
| 16 | -956 | -1033 | -493 | 159 | 500 | 555 | 545 | 706 | 550 | 436 | -132 | -450 |
| 17 | -1041 | -1133 | -586 | 83 | 444 | 571 | 536 | 672 | 533 | 396 | -243 | -556 |
| 18 | -1185 | -1330 | -748 | -65 | 361 | 572 | 521 | 586 | 412 | 228 | -395 | -705 |
| 19 | -1274 | -1453 | -947 | -313 | 156 | 471 | 462 | 397 | 310 | 182 | -478 | -841 |
| 20 | -1351 | -1544 | -1011 | -372 | 57 | 276 | 327 | 390 | 282 | 139 | -526 | -944 |
| 21 | -1468 | -1635 | -1112 | -486 | -17 | 226 | 303 | 350 | 198 | 35 | -652 | -1074 |
| 22 | -1666 | -1843 | -1264 | -639 | -129 | 140 | 224 | 240 | 18 | -189 | -865 | -1291 |
| 23 | -1727 | -1893 | -1458 | -933 | -351 | -4 | 117 | 17 | -136 | -213 | -932 | -1370 |

## Table (23): Villa Fabric gain for Insulated green roof

| ANNUAL LOADS TABLE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fabric Gains - Qc + Qs | | | | | | | | | | | | |
| 1st - Monthly Averages | | | | | | | | | | | | |
| HOUR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| ----- | ------ | ------ | ------ | ------ | ----- | ----- | ----- | ----- | ----- | ----- | ------ | ------ |
| 0 | -1762 | -1953 | -1490 | -993 | -470 | -171 | -12 | -11 | -168 | -215 | -952 | -1412 |
| 1 | -1794 | -1998 | -1525 | -1022 | -498 | -198 | -16 | -16 | -199 | -256 | -990 | -1442 |
| 2 | -1825 | -2036 | -1572 | -1062 | -525 | -230 | -20 | -18 | -227 | -297 | -1034 | -1485 |
| 3 | -1855 | -2055 | -1621 | -1114 | -564 | -265 | -31 | -23 | -256 | -341 | -1070 | -1533 |
| 4 | -1882 | -2075 | -1664 | -1163 | -600 | -310 | -58 | -37 | -281 | -379 | -1108 | -1580 |
| 5 | -1902 | -2107 | -1707 | -1169 | -584 | -266 | -45 | -39 | -304 | -398 | -1125 | -1587 |
| 6 | -1936 | -2144 | -1692 | -1039 | -482 | -155 | -14 | -16 | -236 | -393 | -1148 | -1592 |
| 7 | -1895 | -2042 | -1493 | -770 | -319 | -22 | 51 | 86 | -79 | -248 | -997 | -1476 |
| 8 | -1674 | -1784 | -1202 | -569 | -192 | 55 | 96 | 207 | 69 | -66 | -739 | -1214 |
| 9 | -1431 | -1526 | -1040 | -487 | -84 | 98 | 141 | 292 | 134 | 13 | -564 | -903 |
| 10 | -1306 | -1383 | -949 | -416 | 19 | 179 | 203 | 379 | 183 | 55 | -494 | -770 |
| 11 | -1252 | -1304 | -867 | -240 | 248 | 422 | 439 | 555 | 258 | 94 | -451 | -716 |
| 12 | -1215 | -1240 | -611 | 8 | 383 | 532 | 519 | 752 | 508 | 294 | -281 | -619 |
| 13 | -972 | -1003 | -507 | 99 | 443 | 555 | 553 | 808 | 548 | 367 | -162 | -407 |
| 14 | -919 | -977 | -503 | 101 | 486 | 582 | 553 | 743 | 485 | 343 | -126 | -352 |
| 15 | -890 | -984 | -521 | 143 | 528 | 580 | 572 | 720 | 502 | 378 | -106 | -371 |
| 16 | -957 | -1034 | -496 | 154 | 493 | 547 | 538 | 698 | 544 | 432 | -135 | -452 |
| 17 | -1041 | -1133 | -588 | 79 | 438 | 565 | 530 | 665 | 528 | 393 | -244 | -557 |
| 18 | -1184 | -1329 | -748 | -68 | 357 | 567 | 516 | 581 | 408 | 226 | -395 | -704 |
| 19 | -1272 | -1451 | -946 | -315 | 153 | 468 | 459 | 394 | 308 | 181 | -477 | -840 |
| 20 | -1347 | -1540 | -1009 | -372 | 56 | 274 | 326 | 389 | 282 | 140 | -523 | -941 |
| 21 | -1463 | -1629 | -1108 | -484 | -16 | 226 | 304 | 351 | 199 | 37 | -649 | -1071 |
| 22 | -1662 | -1838 | -1260 | -635 | -126 | 141 | 225 | 242 | 20 | -189 | -863 | -1288 |
| 23 | -1724 | -1888 | -1455 | -931 | -350 | -3 | 118 | 17 | -136 | -213 | -930 | -1367 |

## Multi-storey building

## Table (24): Multi-storey building Fabric gain for Regular roof

| ANNUAL LOADS TABLE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fabric Gains - Qc + Qs** | | | | | | | | | | | | |
| **Zone 10 - Monthly Averages** | | | | | | | | | | | | |
| **HOUI** | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| **-----** | ----- | ------ | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| **0** | -874 | -970 | -738 | -490 | -231 | -82 | -6 | -5 | -80 | -104 | -470 | -699 |
| **1** | -887 | -987 | -755 | -503 | -244 | -94 | -7 | -6 | -93 | -121 | -483 | -711 |
| **2** | -904 | -1010 | -776 | -522 | -257 | -109 | -9 | -9 | -108 | -141 | -508 | -732 |
| **3** | -919 | -1019 | -800 | -548 | -274 | -126 | -13 | -10 | -123 | -162 | -527 | -756 |
| **4** | -934 | -1028 | -821 | -572 | -293 | -146 | -24 | -15 | -135 | -181 | -546 | -780 |
| **5** | -944 | -1044 | -843 | -581 | -295 | -142 | -26 | -20 | -148 | -194 | -557 | -790 |
| **6** | -959 | -1063 | -846 | -543 | -259 | -97 | -11 | -13 | -132 | -197 | -569 | -792 |
| **7** | -954 | -1039 | -783 | -422 | -151 | 23 | 52 | 45 | -63 | -153 | -528 | -760 |
| **8** | -877 | -927 | -619 | -258 | -30 | 120 | 139 | 163 | 69 | -35 | -404 | -654 |
| **9** | -730 | -762 | -476 | -141 | 98 | 233 | 230 | 297 | 180 | 66 | -270 | -479 |
| **10** | -620 | -627 | -372 | -41 | 218 | 348 | 345 | 414 | 279 | 159 | -174 | -352 |
| **11** | -538 | -527 | -282 | 122 | 445 | 600 | 573 | 612 | 399 | 237 | -113 | -282 |
| **12** | -498 | -438 | -69 | 326 | 571 | 700 | 683 | 782 | 606 | 409 | 28 | -194 |
| **13** | -324 | -302 | 18 | 404 | 628 | 741 | 726 | 836 | 657 | 474 | 125 | -24 |
| **14** | -267 | -253 | 8 | 398 | 623 | 717 | 693 | 799 | 630 | 479 | 157 | 42 |
| **15** | -272 | -270 | -36 | 357 | 563 | 613 | 607 | 692 | 570 | 446 | 136 | -10 |
| **16** | -342 | -360 | -70 | 285 | 464 | 512 | 516 | 594 | 479 | 371 | 54 | -89 |
| **17** | -441 | -470 | -190 | 148 | 334 | 383 | 384 | 452 | 342 | 250 | -70 | -206 |
| **18** | -554 | -621 | -327 | 3 | 210 | 299 | 292 | 320 | 224 | 133 | -171 | -319 |
| **19** | -608 | -688 | -437 | -126 | 83 | 193 | 206 | 203 | 167 | 113 | -211 | -390 |
| **20** | -646 | -740 | -477 | -171 | 28 | 127 | 149 | 184 | 144 | 83 | -244 | -444 |
| **21** | -714 | -798 | -540 | -241 | -22 | 86 | 124 | 149 | 89 | 21 | -311 | -519 |
| **22** | -819 | -911 | -622 | -323 | -81 | 34 | 81 | 97 | 7 | -88 | -419 | -628 |
| **23** | -850 | -937 | -717 | -453 | -174 | -23 | 43 | 8 | -63 | -102 | -454 | -669 |

## Table (25): Multi-storey building Fabric gain for Green roof

**ANNUAL LOADS TABLE**

**Fabric Gains - Qc + Qs**
**Zone 10 - Monthly Averages**

| Hour | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| **0** | -530 | -593 | -443 | -289 | -133 | -41 | -3 | -1 | -40 | -57 | -280 | -419 |
| **1** | -543 | -611 | -460 | -302 | -147 | -53 | -4 | -3 | -52 | -74 | -292 | -431 |
| **2** | -554 | -623 | -478 | -317 | -155 | -64 | -5 | -3 | -61 | -85 | -307 | -445 |
| **3** | -565 | -628 | -493 | -336 | -168 | -76 | -8 | -5 | -72 | -98 | -320 | -462 |
| **4** | -575 | -632 | -504 | -352 | -178 | -89 | -15 | -9 | -79 | -107 | -333 | -479 |
| **5** | -582 | -643 | -517 | -352 | -173 | -74 | -10 | -10 | -87 | -111 | -338 | -481 |
| **6** | -593 | -656 | -511 | -316 | -147 | -48 | -3 | -5 | -68 | -112 | -348 | -486 |
| **7** | -580 | -626 | -458 | -258 | -122 | -35 | -1 | 12 | -35 | -74 | -305 | -454 |
| **8** | -522 | -562 | -416 | -237 | -106 | -29 | 2 | 27 | -30 | -60 | -264 | -391 |
| **9** | -496 | -534 | -396 | -231 | -90 | -27 | 5 | 39 | -24 | -61 | -245 | -351 |
| **10** | -477 | -515 | -383 | -216 | -65 | -1 | 22 | 59 | -15 | -55 | -235 | -333 |
| **11** | -472 | -503 | -362 | -119 | 73 | 172 | 174 | 173 | 37 | -41 | -226 | -322 |
| **12** | -454 | -441 | -198 | 30 | 165 | 245 | 227 | 289 | 206 | 97 | -112 | -280 |
| **13** | -297 | -310 | -127 | 82 | 204 | 266 | 257 | 328 | 243 | 163 | -9 | -117 |
| **14** | -232 | -248 | -112 | 87 | 211 | 262 | 246 | 306 | 231 | 195 | 34 | -44 |
| **15** | -202 | -214 | -92 | 84 | 199 | 206 | 217 | 272 | 233 | 214 | 55 | -30 |
| **16** | -220 | -238 | -88 | 82 | 168 | 175 | 182 | 255 | 224 | 205 | 29 | -43 |
| **17** | -248 | -276 | -123 | 50 | 144 | 146 | 157 | 222 | 198 | 174 | -12 | -79 |
| **18** | -283 | -321 | -169 | 12 | 131 | 157 | 163 | 210 | 176 | 140 | -48 | -125 |
| **19** | -317 | -359 | -203 | -2 | 116 | 146 | 165 | 197 | 170 | 130 | -69 | -177 |
| **20** | -343 | -396 | -231 | -27 | 85 | 134 | 149 | 182 | 148 | 107 | -93 | -214 |
| **21** | -402 | -442 | -277 | -85 | 47 | 104 | 124 | 146 | 104 | 57 | -155 | -281 |
| **22** | -496 | -545 | -347 | -153 | -8 | 60 | 81 | 95 | 29 | -47 | -251 | -379 |
| **23** | -519 | -571 | -433 | -266 | -95 | 10 | 44 | 6 | -33 | -56 | -275 | -405 |

## Table (26): Multi-storey building Fabric gain for Insulated green roof

**ANNUAL LOADS TABLE**

**Fabric Gains - Qc + Qs**

**Zone 10 - Monthly Averages**

| HOUR | JAN (Wh) | FEB (Wh) | MAR (Wh) | APR (Wh) | MAY (Wh) | JUN (Wh) | JUL (Wh) | AUG (Wh) | SEP (Wh) | OCT (Wh) | NOV (Wh) | DEC (Wh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| **0** | -526 | -590 | -440 | -287 | -132 | -41 | -3 | -1 | -39 | -57 | -278 | -416 |
| **1** | -539 | -607 | -457 | -300 | -146 | -53 | -4 | -3 | -52 | -73 | -290 | -428 |
| **2** | -550 | -619 | -475 | -315 | -154 | -64 | -5 | -3 | -61 | -84 | -304 | -442 |
| **3** | -561 | -624 | -490 | -334 | -167 | -75 | -8 | -5 | -71 | -97 | -317 | -459 |
| **4** | -571 | -628 | -501 | -350 | -176 | -88 | -15 | -9 | -79 | -106 | -331 | -476 |
| **5** | -578 | -639 | -513 | -350 | -171 | -73 | -10 | -10 | -87 | -110 | -336 | -478 |
| **6** | -589 | -651 | -508 | -313 | -145 | -48 | -3 | -4 | -68 | -111 | -346 | -483 |
| **7** | -576 | -621 | -455 | -257 | -122 | -35 | -2 | 12 | -35 | -73 | -303 | -451 |
| **8** | -518 | -559 | -414 | -237 | -107 | -31 | 1 | 25 | -31 | -60 | -263 | -389 |
| **9** | -493 | -532 | -395 | -232 | -92 | -29 | 3 | 37 | -26 | -62 | -245 | -350 |
| **10** | -475 | -514 | -383 | -218 | -68 | -5 | 19 | 56 | -18 | -57 | -235 | -333 |
| **11** | -471 | -503 | -362 | -121 | 69 | 168 | 170 | 169 | 33 | -44 | -227 | -322 |
| **12** | -453 | -441 | -199 | 27 | 161 | 240 | 222 | 284 | 202 | 94 | -114 | -281 |
| **13** | -297 | -310 | -128 | 79 | 199 | 261 | 252 | 323 | 239 | 159 | -11 | -118 |
| **14** | -232 | -248 | -114 | 84 | 207 | 257 | 241 | 301 | 227 | 192 | 33 | -45 |
| **15** | -201 | -213 | -92 | 81 | 196 | 202 | 213 | 268 | 230 | 211 | 54 | -30 |
| **16** | -219 | -237 | -88 | 80 | 165 | 172 | 179 | 251 | 222 | 204 | 29 | -42 |
| **17** | -246 | -274 | -122 | 49 | 142 | 144 | 155 | 219 | 197 | 173 | -12 | -78 |
| **18** | -280 | -318 | -167 | 12 | 130 | 155 | 162 | 209 | 175 | 140 | -47 | -123 |
| **19** | -314 | -356 | -200 | -1 | 116 | 146 | 165 | 197 | 170 | 130 | -68 | -175 |
| **20** | -340 | -393 | -228 | -26 | 85 | 134 | 149 | 182 | 148 | 108 | -91 | -212 |
| **21** | -399 | -438 | -274 | -83 | 47 | 104 | 124 | 146 | 104 | 57 | -154 | -278 |
| **22** | -493 | -542 | -344 | -151 | -7 | 60 | 81 | 95 | 29 | -46 | -249 | -377 |
| **23** | -516 | -567 | -430 | -264 | -94 | 10 | 44 | 6 | -33 | -55 | -273 | -402 |

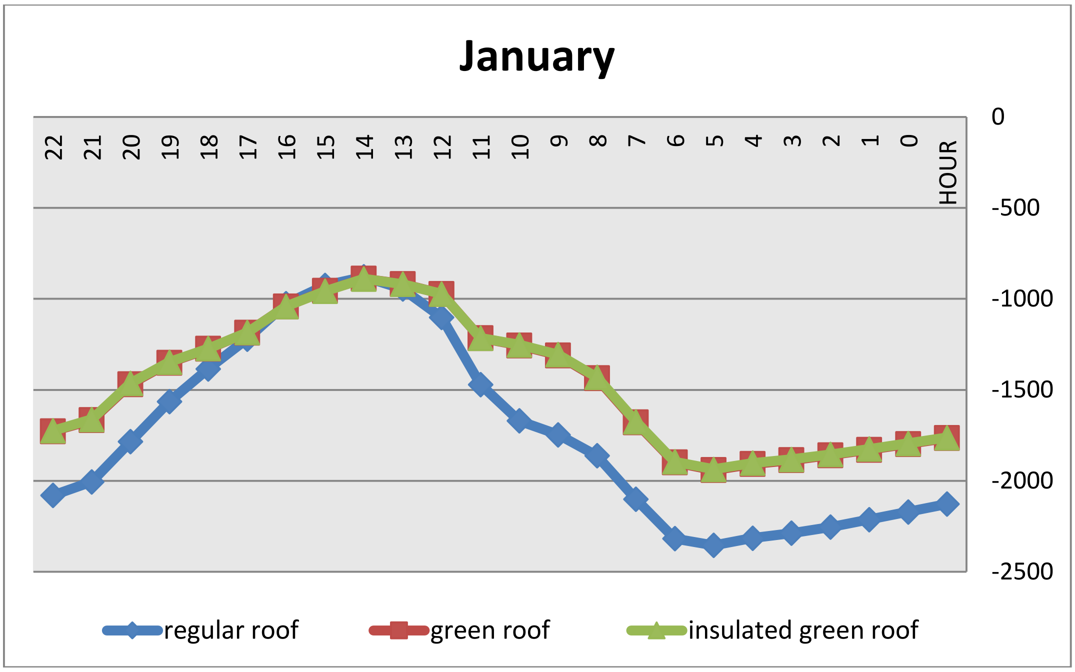



**Fig. 90** Comparison between fabric gains for a green roof, a regular roof and an insulated green roof in January on the villa.
Source: Result of Ecotect simulation.

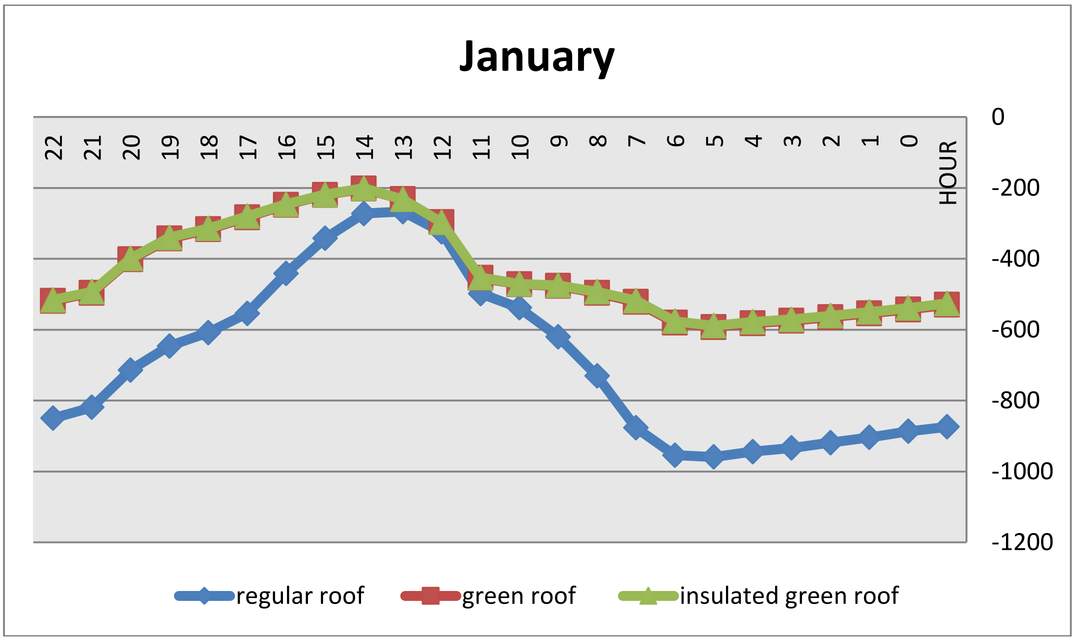



**Fig. 91** Comparison between fabric gains for a green roof, a regular roof, and an insulated green roof in January on the multi-storey building.
Source: Result of Ecotect simulation.

Figures (90) and (91), both demonstrated reduction on heat loss through the fabric of the testing samples; the highest reduction is noticed from 5PM to 10AM in cold months.

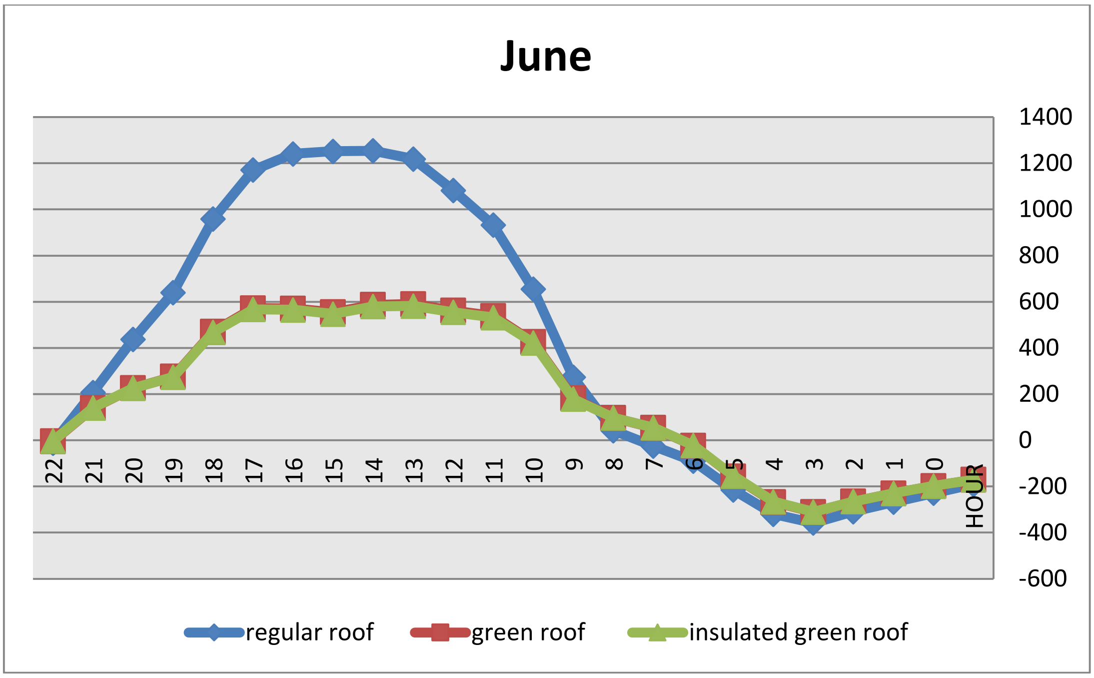



**Fig. 92** Comparison between fabric gains for a green roof, a regular roof, and an insulated green roof in June on the villa.
Source: Result of Ecotect simulation

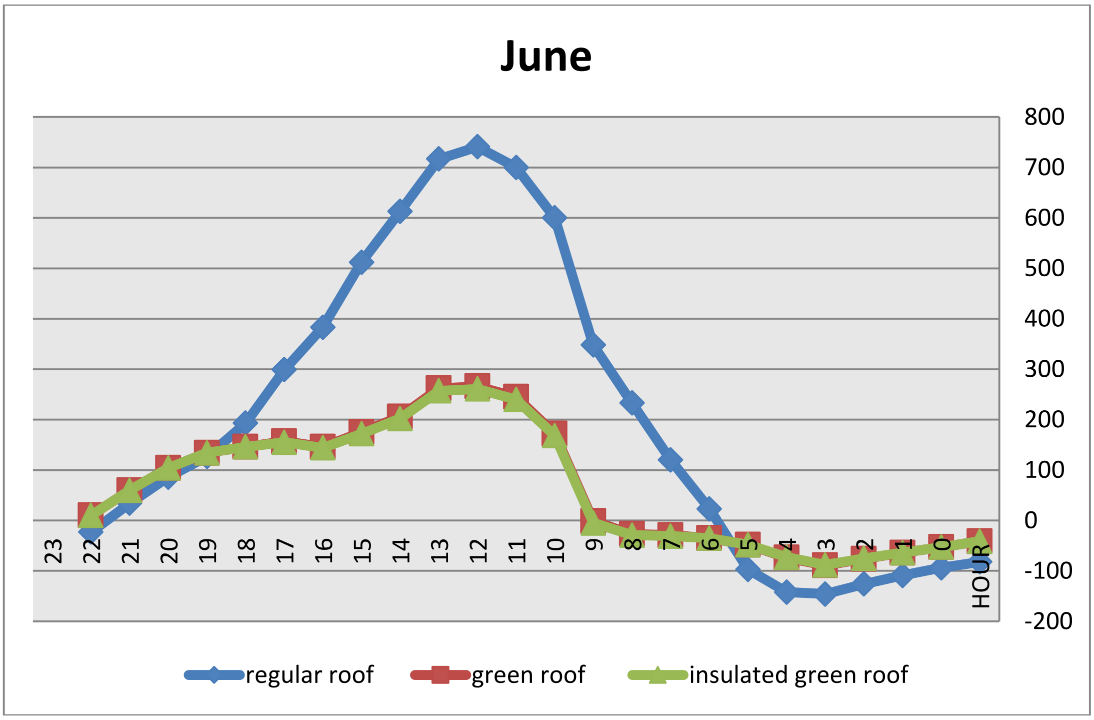



**Fig. 93** Comparison between fabric gains for a green roof, a regular roof, and an insulated green roof in June on the multi storey building.
Source: Result of Ecotect simulation

Figures (92) an (93) demonstrate reduction of heat gain through the fabric of the testing samples, especially from 10AM to 8PM in summer months.

### 5.3.4. Indirect solar heat gain

There are two types of indirect solar heat gain from the sun *"direct solar gain caused by the fall of the sunrays on the building openings leading to increasing the indoor temperature. The other type is indirect solar gain caused by the movement of the air molecules due to the solar radiation building materials used in the constructions. This leads to raising the temperature in the adjacent zones"*. (Goussous et al., 2014)

The following tables show a comparison preformed on the thermal zone, resulting from monthly average indirect solar gain between the roofing types of the two buildings. Indirect solar gain is reduced by the green roof as demonstrated in figures (94), (95), (96), and (97).

## Villa

## Table (27): Villa Indirect Solar Gains for Regular roof

ANNUAL LOADS TABLE
Indirect Solar Gains - Qs
1st - Monthly Averages

| HOUR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| +------+------+------+------+------+------+------+------+------+------+------+------+------+ | | | | | | | | | | | | |
| 00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 07 | 0 | 0 | 0 | 26 | 48 | 56 | 54 | 43 | 16 | 0 | 0 | 0 |
| 08 | 0 | 3 | 78 | 84 | 89 | 97 | 90 | 102 | 108 | 79 | 63 | 1 |
| 09 | 89 | 93 | 116 | 116 | 118 | 117 | 118 | 135 | 150 | 137 | 125 | 99 |
| 10 | 124 | 140 | 132 | 154 | 185 | 209 | 190 | 184 | 172 | 160 | 141 | 134 |
| 11 | 133 | 162 | 192 | 285 | 408 | 456 | 445 | 370 | 281 | 212 | 171 | 138 |
| 12 | 174 | 216 | 411 | 494 | 557 | 620 | 574 | 603 | 559 | 417 | 316 | 197 |
| 13 | 344 | 423 | 506 | 586 | 646 | 693 | 678 | 699 | 656 | 535 | 425 | 359 |
| 14 | 413 | 503 | 538 | 622 | 741 | 802 | 758 | 736 | 657 | 574 | 481 | 440 |
| 15 | 452 | 522 | 551 | 693 | 794 | 838 | 836 | 794 | 721 | 627 | 500 | 482 |
| 16 | 461 | 539 | 632 | 767 | 815 | 849 | 835 | 847 | 808 | 693 | 519 | 506 |
| 17 | 464 | 540 | 622 | 777 | 821 | 878 | 853 | 873 | 806 | 658 | 499 | 509 |
| 18 | 362 | 414 | 532 | 729 | 796 | 875 | 807 | 787 | 658 | 485 | 390 | 390 |
| 19 | 289 | 327 | 378 | 510 | 593 | 745 | 713 | 566 | 505 | 406 | 299 | 291 |
| 20 | 211 | 260 | 324 | 433 | 469 | 524 | 503 | 498 | 423 | 327 | 223 | 200 |
| 21 | 125 | 172 | 239 | 325 | 362 | 430 | 406 | 391 | 298 | 189 | 128 | 124 |
| 22 | 0 | 16 | 128 | 202 | 217 | 299 | 266 | 222 | 122 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 38 | 143 | 122 | 10 | 0 | 0 | 0 | 0 |

**Table (28): Villa Indirect Solar Gains for Green roof**

ANNUAL LOADS TABLE

Indirect Solar Gains - Qs

1st - Monthly Averages

| HOUR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| 00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 07 | 0 | 0 | 0 | 26 | 48 | 56 | 54 | 43 | 16 | 0 | 0 | 0 |
| 08 | 0 | 3 | 78 | 84 | 89 | 97 | 90 | 102 | 108 | 79 | 63 | 1 |
| 09 | 89 | 93 | 116 | 116 | 118 | 117 | 118 | 135 | 150 | 137 | 125 | 99 |
| 10 | 124 | 140 | 132 | 135 | 135 | 135 | 133 | 151 | 163 | 160 | 141 | 134 |
| 11 | 133 | 153 | 137 | 193 | 276 | 303 | 305 | 249 | 185 | 160 | 144 | 138 |
| 12 | 123 | 140 | 284 | 316 | 340 | 364 | 348 | 374 | 360 | 277 | 216 | 138 |
| 13 | 232 | 263 | 315 | 337 | 352 | 357 | 362 | 386 | 373 | 316 | 265 | 239 |
| 14 | 248 | 282 | 300 | 317 | 379 | 400 | 379 | 356 | 318 | 293 | 274 | 269 |
| 15 | 269 | 292 | 284 | 349 | 412 | 418 | 417 | 379 | 348 | 323 | 288 | 282 |
| 16 | 269 | 308 | 345 | 406 | 422 | 414 | 411 | 426 | 427 | 394 | 311 | 308 |
| 17 | 292 | 330 | 367 | 437 | 443 | 464 | 450 | 472 | 446 | 390 | 303 | 316 |
| 18 | 220 | 239 | 332 | 422 | 458 | 500 | 450 | 434 | 355 | 261 | 238 | 255 |
| 19 | 194 | 203 | 208 | 272 | 325 | 439 | 408 | 282 | 277 | 251 | 204 | 204 |
| 20 | 165 | 182 | 217 | 277 | 283 | 292 | 286 | 298 | 289 | 252 | 184 | 164 |
| 21 | 125 | 169 | 195 | 247 | 261 | 294 | 281 | 292 | 255 | 189 | 128 | 124 |
| 22 | 0 | 16 | 128 | 202 | 206 | 253 | 223 | 219 | 122 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 38 | 143 | 122 | 10 | 0 | 0 | 0 | 0 |

## Table (29): Villa Indirect Solar Gains for Insulated green roof

ANNUAL LOADS TABLE
Indirect Solar Gains - Qs
1st - Monthly Averages

| HOUR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| 00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 07 | 0 | 0 | 0 | 26 | 48 | 56 | 54 | 43 | 16 | 0 | 0 | 0 |
| 08 | 0 | 3 | 78 | 84 | 89 | 97 | 90 | 102 | 108 | 79 | 63 | 1 |
| 09 | 89 | 93 | 116 | 116 | 118 | 117 | 118 | 135 | 150 | 137 | 125 | 99 |
| 10 | 124 | 140 | 132 | 134 | 134 | 134 | 132 | 151 | 163 | 160 | 141 | 134 |
| 11 | 133 | 153 | 135 | 191 | 273 | 299 | 301 | 246 | 182 | 158 | 144 | 138 |
| 12 | 122 | 138 | 280 | 312 | 334 | 357 | 343 | 368 | 355 | 273 | 214 | 136 |
| 13 | 229 | 259 | 310 | 331 | 345 | 348 | 355 | 378 | 366 | 310 | 261 | 236 |
| 14 | 244 | 276 | 294 | 310 | 370 | 390 | 370 | 347 | 310 | 286 | 269 | 264 |
| 15 | 264 | 286 | 277 | 341 | 403 | 407 | 407 | 368 | 338 | 316 | 283 | 277 |
| 16 | 264 | 302 | 338 | 397 | 412 | 403 | 401 | 415 | 418 | 386 | 306 | 303 |
| 17 | 288 | 325 | 360 | 428 | 434 | 453 | 440 | 462 | 437 | 383 | 299 | 311 |
| 18 | 216 | 234 | 327 | 414 | 449 | 491 | 441 | 426 | 348 | 256 | 235 | 252 |
| 19 | 191 | 200 | 204 | 266 | 319 | 431 | 401 | 275 | 271 | 247 | 202 | 202 |
| 20 | 163 | 180 | 215 | 273 | 278 | 287 | 280 | 293 | 286 | 250 | 183 | 163 |
| 21 | 125 | 169 | 194 | 246 | 259 | 291 | 278 | 290 | 254 | 189 | 128 | 124 |
| 22 | 0 | 16 | 128 | 202 | 205 | 252 | 222 | 219 | 122 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 38 | 143 | 122 | 10 | 0 | 0 | 0 | 0 |

## Multi-storey building

## Table (30): Multi-storey building Indirect Solar Gains for Regular roof

ANNUAL LOADS TABLE
Indirect Solar Gains - Qs
Zone 10 - Monthly Averages

| HOUR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| 00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 07 | 0 | 0 | 0 | 19 | 52 | 75 | 55 | 34 | 9 | 0 | 0 | 0 |
| 08 | 0 | 10 | 55 | 93 | 128 | 151 | 139 | 122 | 98 | 53 | 29 | 1 |
| 09 | 51 | 73 | 127 | 179 | 220 | 255 | 225 | 231 | 198 | 136 | 96 | 60 |
| 10 | 115 | 159 | 191 | 254 | 296 | 338 | 317 | 316 | 283 | 222 | 160 | 122 |
| 11 | 171 | 224 | 242 | 359 | 472 | 549 | 517 | 475 | 369 | 282 | 202 | 166 |
| 12 | 183 | 265 | 388 | 489 | 560 | 622 | 604 | 604 | 537 | 405 | 287 | 203 |
| 13 | 290 | 338 | 433 | 531 | 590 | 647 | 635 | 633 | 573 | 450 | 342 | 305 |
| 14 | 315 | 370 | 408 | 509 | 570 | 622 | 603 | 598 | 544 | 453 | 358 | 347 |
| 15 | 304 | 360 | 362 | 461 | 505 | 528 | 526 | 513 | 489 | 419 | 332 | 308 |
| 16 | 254 | 293 | 338 | 400 | 418 | 438 | 444 | 442 | 413 | 347 | 264 | 267 |
| 17 | 204 | 235 | 264 | 307 | 321 | 324 | 334 | 337 | 294 | 242 | 184 | 206 |
| 18 | 129 | 138 | 187 | 220 | 241 | 257 | 255 | 234 | 190 | 143 | 129 | 140 |
| 19 | 109 | 119 | 125 | 148 | 156 | 172 | 179 | 142 | 148 | 142 | 117 | 112 |
| 20 | 95 | 103 | 117 | 136 | 128 | 127 | 128 | 135 | 140 | 130 | 99 | 93 |
| 21 | 65 | 85 | 94 | 107 | 108 | 113 | 112 | 118 | 111 | 91 | 64 | 64 |
| 22 | 0 | 7 | 58 | 77 | 76 | 84 | 81 | 85 | 51 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 13 | 44 | 45 | 4 | 0 | 0 | 0 | 0 |

## Table (31): Multi-storey building Indirect Solar Gains for Green roof

ANNUAL LOADS TABLE
Indirect Solar Gains - Qs
Zone 10 - Monthly Averages

| HOUR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| 00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 07 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 1 | 0 | 0 | 0 | 0 |
| 08 | 0 | 0 | 1 | 2 | 3 | 4 | 3 | 3 | 2 | 1 | 1 | 0 |
| 09 | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 6 | 5 | 3 | 2 | 1 |
| 10 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 8 | 7 | 5 | 4 | 3 |
| 11 | 4 | 6 | 6 | 57 | 113 | 150 | 140 | 101 | 36 | 7 | 5 | 4 |
| 12 | 5 | 36 | 117 | 147 | 176 | 204 | 186 | 193 | 169 | 105 | 73 | 6 |
| 13 | 97 | 107 | 148 | 171 | 194 | 215 | 211 | 217 | 198 | 153 | 140 | 111 |
| 14 | 145 | 157 | 148 | 169 | 190 | 214 | 203 | 202 | 187 | 185 | 167 | 159 |
| 15 | 163 | 184 | 161 | 157 | 169 | 158 | 174 | 170 | 187 | 200 | 182 | 174 |
| 16 | 160 | 170 | 168 | 164 | 147 | 131 | 140 | 162 | 187 | 194 | 167 | 186 |
| 17 | 156 | 160 | 161 | 155 | 137 | 106 | 122 | 142 | 165 | 169 | 148 | 169 |
| 18 | 129 | 134 | 143 | 143 | 145 | 122 | 128 | 136 | 147 | 143 | 129 | 140 |
| 19 | 109 | 119 | 125 | 148 | 145 | 125 | 138 | 138 | 148 | 142 | 117 | 112 |
| 20 | 95 | 103 | 117 | 136 | 128 | 127 | 128 | 135 | 140 | 130 | 99 | 93 |
| 21 | 65 | 85 | 94 | 107 | 108 | 113 | 112 | 118 | 111 | 91 | 64 | 64 |
| 22 | 0 | 7 | 58 | 77 | 76 | 84 | 81 | 85 | 51 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 13 | 44 | 45 | 4 | 0 | 0 | 0 | 0 |

## Table (32): Multi-storey building Indirect Solar Gains for Insulated green roof

ANNUAL LOADS TABLE
Indirect Solar Gains - Qs
Zone 10 - Monthly Averages

| HOUR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) | (Wh) |
| 00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 07 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 08 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 0 | 0 |
| 09 | 1 | 1 | 2 | 3 | 3 | 4 | 3 | 3 | 3 | 2 | 1 | 1 |
| 10 | 2 | 2 | 3 | 4 | 4 | 5 | 5 | 5 | 4 | 3 | 2 | 2 |
| 11 | 2 | 3 | 4 | 54 | 109 | 146 | 137 | 97 | 33 | 4 | 3 | 2 |
| 12 | 3 | 33 | 115 | 144 | 172 | 200 | 182 | 189 | 165 | 102 | 71 | 4 |
| 13 | 95 | 105 | 145 | 168 | 190 | 211 | 207 | 213 | 194 | 150 | 138 | 109 |
| 14 | 143 | 155 | 145 | 165 | 187 | 210 | 199 | 198 | 183 | 183 | 165 | 157 |
| 15 | 162 | 182 | 158 | 154 | 165 | 154 | 170 | 167 | 184 | 198 | 180 | 173 |
| 16 | 159 | 169 | 166 | 161 | 144 | 128 | 136 | 159 | 184 | 192 | 166 | 185 |
| 17 | 155 | 159 | 160 | 153 | 135 | 104 | 120 | 140 | 164 | 168 | 147 | 168 |
| 18 | 129 | 134 | 143 | 142 | 144 | 121 | 126 | 135 | 147 | 143 | 129 | 140 |
| 19 | 109 | 119 | 125 | 148 | 145 | 124 | 137 | 138 | 148 | 142 | 117 | 112 |
| 20 | 95 | 103 | 117 | 136 | 128 | 127 | 128 | 135 | 140 | 130 | 99 | 93 |
| 21 | 65 | 85 | 94 | 107 | 108 | 113 | 112 | 118 | 111 | 91 | 64 | 64 |
| 22 | 0 | 7 | 58 | 77 | 76 | 84 | 81 | 85 | 51 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 13 | 44 | 45 | 4 | 0 | 0 | 0 | 0 |

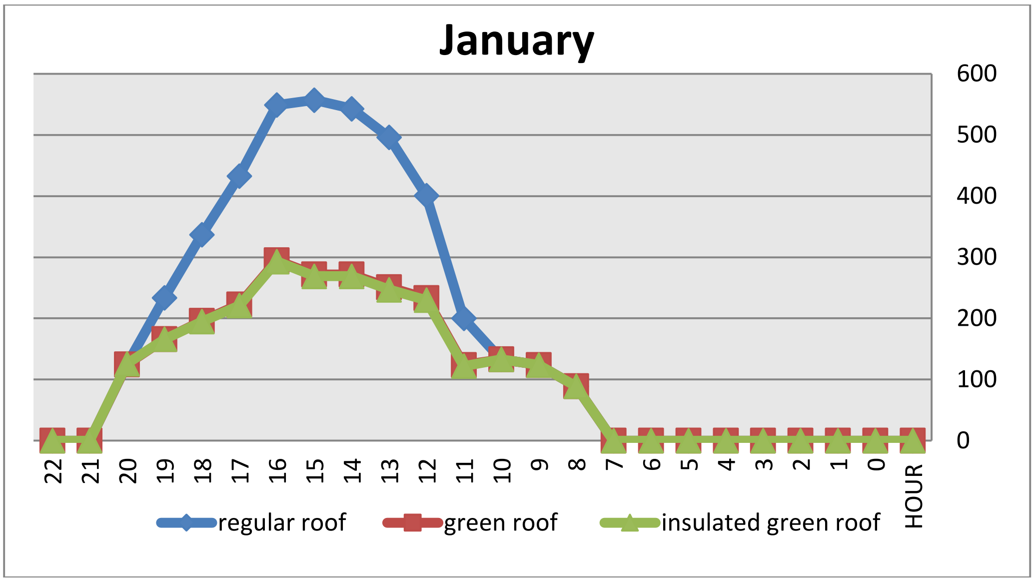



**Fig. 94** Comparison between indirect solar gains for a green roof, a regular roof, and an insulated green roof in June on the villa.
Source: Result of Ecotect simulation

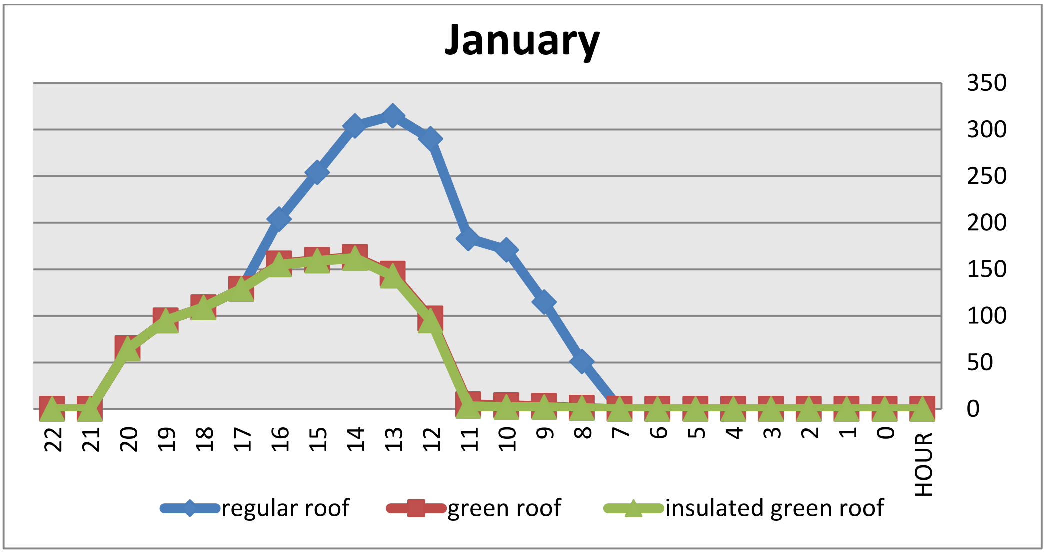



**Fig. 95** Comparison between indirect solar gains for a green roof, a regular roof, and an insulated green roof in June on the multi storey building.
Source: Result of Ecotect simulation

Figures (94) and (95) show the reduction in both building's indirect solar gain by adding a green roof in January. In the villa, starting from 11 A.M. until 8 P.M. Moreover, the reduction begins at 7 A.M. in the multi storey building which maintain no gain until 11 A.M., to 5 P.M.

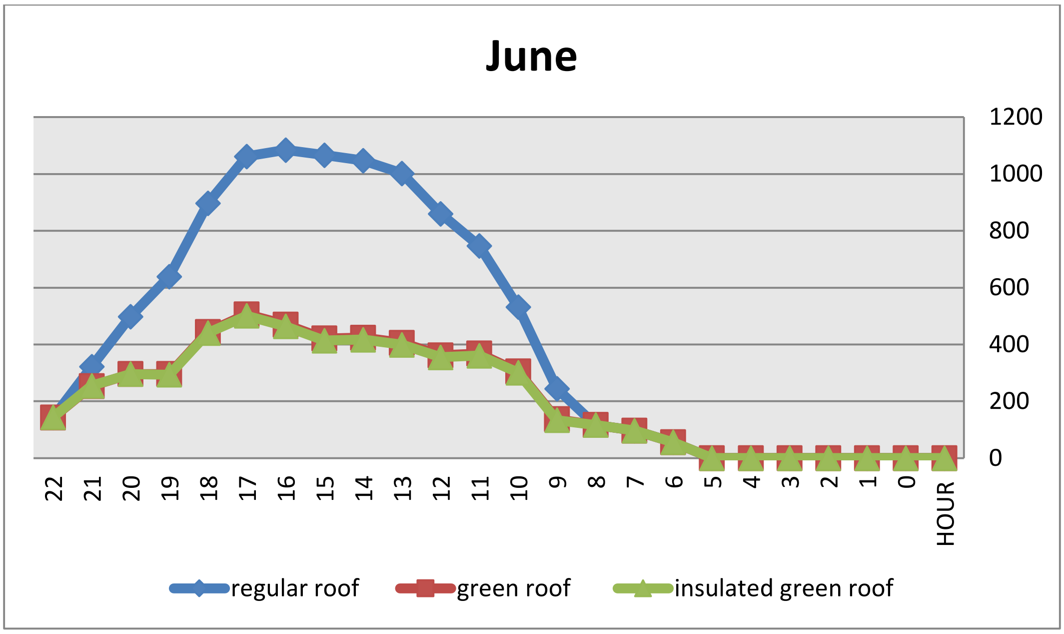



**Fig. 96** Comparison between indirect solar gains for a green roof, a regular roof, and an insulated green roof in June on the villa.
Source: Result of Ecotect simulation

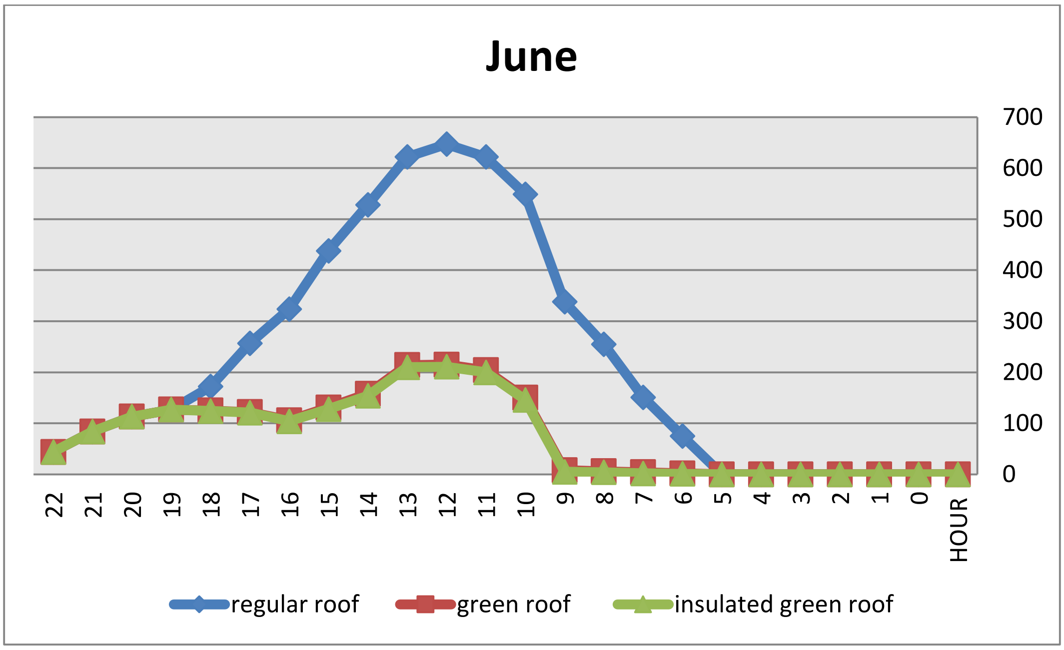



**Fig. 97** Comparison between indirect solar gains for a green roof, a regular roof, and an insulated green roof in June on the multi storey building.
Source: Result of Ecotect simulation

Figures (96) and (97) show that both buildings indirect solar gain was reduced by adding a green roof in June, reduction starts at 9 A.M. for the villa and continues until 10 P.M. then the gain for all roof types returns to normal. And the reduction began at 5 A.M. in the multi storey building which maintained no gain until 9 A.M. At 7 P.M., the gain of all roof types returned to the baseline.

Both buildings' indirect solar gain was reduced by adding a green roof but still reacted differently to the addition. It is clear that, however, this reduction was more effective in summer where it is actually needed as the city of Nablus climate is changing to have hotter summer, and the insulated green roof has almost the same results of the green roof although it provided slightly lower gain.

### 5.3.5. Passive gains breakdown

Passive gain breakdown provides detailed heat losses and gains through the building. As shown in figures (98), (99), (100) and (101), most of the heat gains happen via internal, solar and sol-air or indirect solar gain mechanisms, while the conductivity of the building fabric is the main cause for loss.

**Table (33): Villa gains breakdown**

FROM: 1st January to 31st December

| Regular roof | | | Green roof | | | Insulated green roof | | |
|---|---|---|---|---|---|---|---|---|
| **CATEGORY** | LOSSES | GAINS | **CATEGORY** | LOSSES | GAINS | **CATEGORY** | LOSSES | GAINS |
| **FABRIC** | 39.00% | 1.20% | **FABRIC** | 34.40% | 1.10% | **FABRIC** | 34.30% | 1.10% |
| **SOL-AIR** | 0.00% | 8.60% | SOL-AIR | 0.00% | 4.70% | SOL-AIR | 0.00% | 4.70% |
| **SOLAR** | 0.00% | 16.9% | **SOLAR** | 0.00% | 17.7% | **SOLAR** | 0.00% | 17.8% |
| **VENTILATION** | 60.40% | 2.10% | VENTILATION | 65.00% | 2.20% | VENTILATION | 65.00% | 2.20% |
| **INTERNAL** | 0.00% | 70.7% | **INTERNAL** | 0.00% | 74.1% | **INTERNAL** | 0.00% | 74.1% |
| **INTER-ZONAL** | 0.60% | 0.40% | INTER-ZONAL | 0.60% | 0.20% | INTER-ZONAL | 0.70% | 0.20% |

**Table (34): Multi storey building gains breakdown**

FROM: 1st January to 31st December

| Regular roof | | | Green roof | | | Insulated green roof | | |
|---|---|---|---|---|---|---|---|---|
| CATEGORY | LOSSES | GAINS | CATEGORY | LOSSES | GAINS | CATEGORY | LOSSES | GAINS |
| FABRIC | 23.00 % | 1.60 % | FABRIC | 15.60 % | 1.10 % | FABRIC | 15.60 % | 1.10 % |
| SOL-AIR | 0.00% | 14.2 % | SOL-AIR | 0.00% | 6.30 % | SOL-AIR | 0.00% | 6.20 % |
| SOLAR | 0.00% | 7.50 % | SOLAR | 0.00% | 8.30 % | SOLAR | 0.00% | 8.40 % |
| VENTILATION | 74.90 % | 5.60 % | VENTILATION | 82.00 % | 6.20 % | VENTILATION | 82.10 % | 6.20 % |
| INTERNAL | 0.00% | 67.2 % | INTERNAL | 0.00% | 74.5 % | INTERNAL | 0.00% | 74.8 % |
| INTER-ZONAL | 2.10% | 3.90 % | INTER-ZONAL | 2.30% | 3.60 % | INTER-ZONAL | 2.30% | 3.40 % |

The heat loss through building fabric was reduced by the application of a green roof, as shown in tables (33) and (34), where it dropped about 5% for the villa and 8% for the multi story building. It was also noticed that the green roof and the insulated green roof almost had the same results in the passive gain break down analysis.

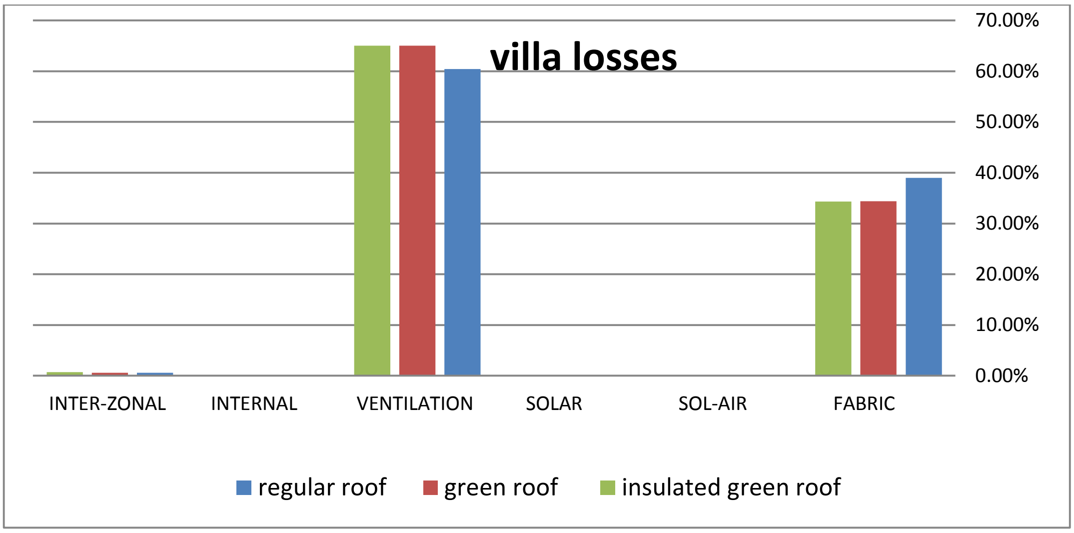



**Fig.98** Comparison between losses of passive gain breakdown for a green roof, a regular roof, and an insulated green roof in June on the villa.
Source: Result of Ecotect simulation

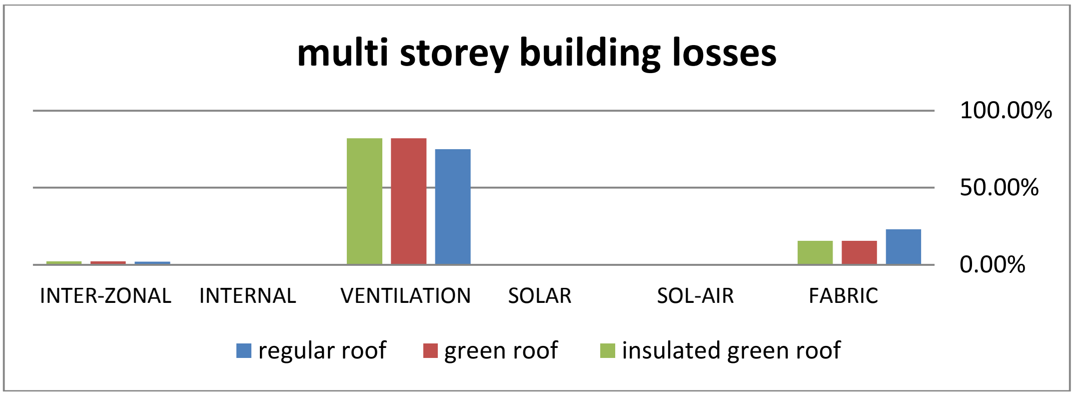



**Fig. 99** Comparison between losses of passive gain breakdown for a green roof, a regular roof, and an insulated green roof in June on the multi storey building.
Source: Result of Ecotect simulation

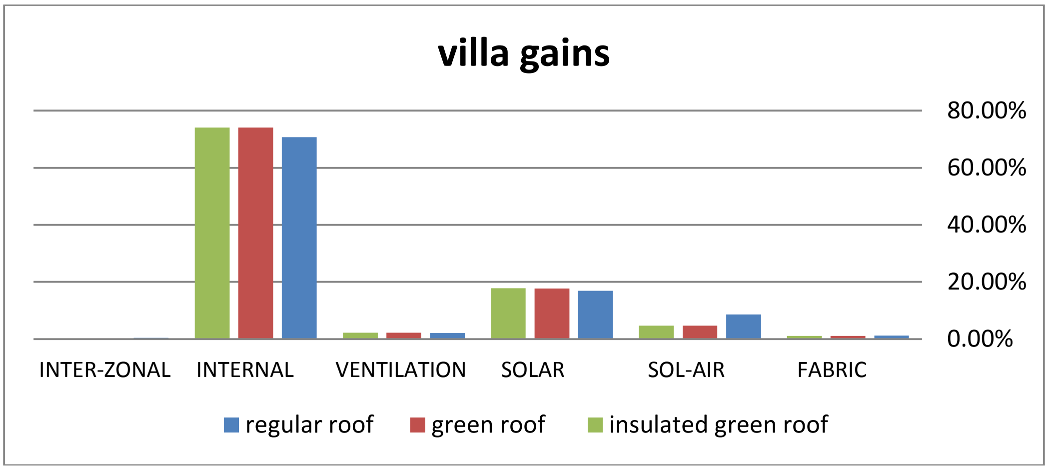



**Fig. 100** Comparison between gains of passive gain breakdown for a green roof, a regular roof, and an insulated green roof in June on the villa.
Source: Result of Ecotect simulation

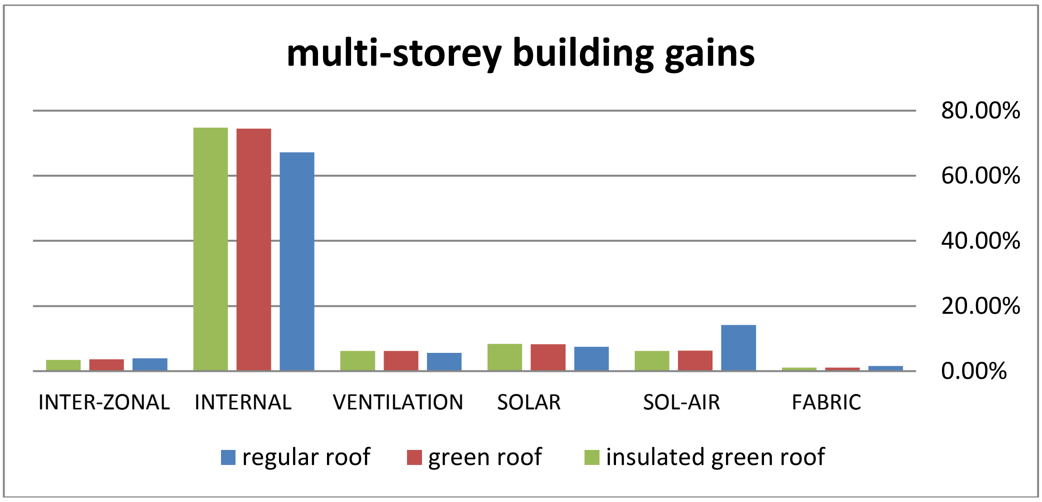



**Fig.101** Comparison between gains of passive gain breakdown for a green roof, a regular roof, and an insulated green roof in June on the multi storey building.
Source: Result of Ecotect simulation

### 5.3.6. Energy consumption

To investigate the effect of green roofs on energy consumption by HVAC (Heating, ventilation, and air conditioning) analysis was conducted to calculate and compare the results of the three roofing types, regular roof, green roof, and insulated green roof. These calculations were also conducted on the two building types (see table (35) and (36) and (37)).

The results indicated that insulated green roof had the lowest energy consumption rate, with a reduction of approximately 10% for the villa total year consumption and 18% for multi storey building, where green roof provide about 9% and 17% reduction for the villa and multi storey building.

**Table (35): Villa energy consumption**

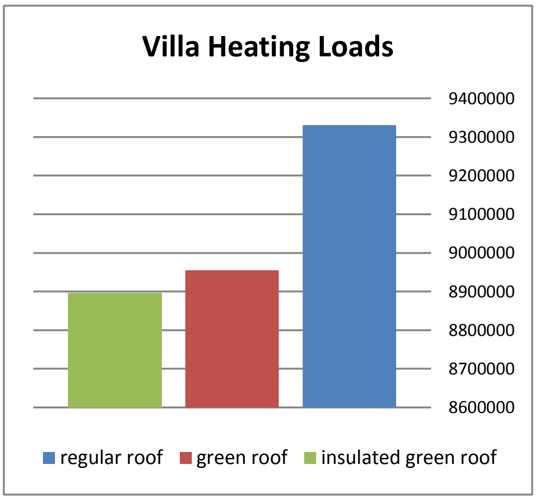
| Regular roof | | | Green roof | | | Insulated green roof | | |
|---|---|---|---|---|---|---|---|---|
| MONTH | HEATING (Wh) | COOLING (Wh) | MONTH | HEATING (Wh) | COOLING (Wh) | MONTH | HEATING (Wh) | COOLING (Wh) |
| **Jan** | 2421114 | 0 | **Jan** | 2310420 | 0 | **Jan** | 2295154 | 0 |
| **Feb** | 4954786 | 0 | **Feb** | 4736478 | 0 | **Feb** | 4705672 | 0 |
| **Mar** | 6534640 | 0 | **Mar** | 6257849 | 0 | **Mar** | 6217759 | 0 |
| **Apr** | 7279880 | 184635 | **Apr** | 6984967 | 154555 | **Apr** | 6941095 | 153540 |
| **May** | 7426098 | 669325 | **May** | 7135395 | 616092 | **May** | 7089830 | 620557 |
| **Jun** | 7428286 | 842685 | **Jun** | 7137903 | 783245 | **Jun** | 7092348 | 786806 |
| **Jul** | 7428286 | 1497166 | **Jul** | 7137903 | 1396655 | **Jul** | 7092348 | 1401658 |
| **Aug** | 7428286 | 2536207 | **Aug** | 7137903 | 2411781 | **Aug** | 7092348 | 2411788 |
| **Sep** | 7436769 | 3169438 | **Sep** | 7147171 | 3007231 | **Sep** | 7101634 | 3005012 |
| **Oct** | 7464426 | 3413582 | **Oct** | 7175818 | 3246276 | **Oct** | 7130306 | 3242974 |
| **Nov** | 8141713 | 3413582 | **Nov** | 7819986 | 3246276 | **Nov** | 7770576 | 3242974 |
| **Dec** | 9330343 | 3413582 | **Dec** | 8953812 | 3246276 | **Dec** | 8897086 | 3242974 |

## Table (36): Multi-storey building Energy consumption

| | Regular roof | | Green roof | | Insulated green roof | |
|---|---|---|---|---|---|---|
| **MONTH** | HEATING (Wh) | COOLING (Wh) | HEATING (Wh) | COOLING (Wh) | HEATING (Wh) | COOLIG (Wh) |
| **Jan** | 5160754 | 0 | 4795668 | 0 | 4795964 | 0 |
| **Feb** | 10596252 | 0 | 9875435 | 0 | 9876721 | 0 |
| **Mar** | 14010439 | 0 | 13057328 | 0 | 13057228 | 0 |
| **Apr** | 15496010 | 470638 | 14441037 | 420180 | 14440285 | 417885 |
| **May** | 15681424 | 1618299 | 14596002 | 1480958 | 14595105 | 1468234 |
| **Jun** | 15681424 | 2152437 | 14596002 | 1960552 | 14595105 | 1935852 |
| **Jul** | 15681424 | 3809823 | 14596002 | 3368298 | 14595105 | 3342259 |
| **Aug** | 15681424 | 6221176 | 14596002 | 5539412 | 14595105 | 5505732 |
| **Sep** | 15681424 | 7496884 | 14596002 | 6721183 | 14595105 | 6681468 |
| **Oct** | 15682995 | 8034813 | 14596002 | 7211900 | 14595105 | 7171262 |
| **Nov** | 16889974 | 8041266 | 15682773 | 7218353 | 15680638 | 7177716 |
| **Dec** | 19227964 | 8041266 | 17785486 | 7218353 | 17780650 | 7177716 |

## Table (37) : Energy consumption reduction

| **Building** | **heating** | **cooling** | **Total** |
|---|---|---|---|
| **Villa** | | | |
| green roof | 4% | 4.9% | 8.9% |
| Insulated green roof | 4.6% | 5% | 9.6% |
| **Multi storey building** | | | |
| green roof | 7.5% | 10.2% | 17.9% |
| Insulated green roof | 7.52% | 10.7% | 18.32% |



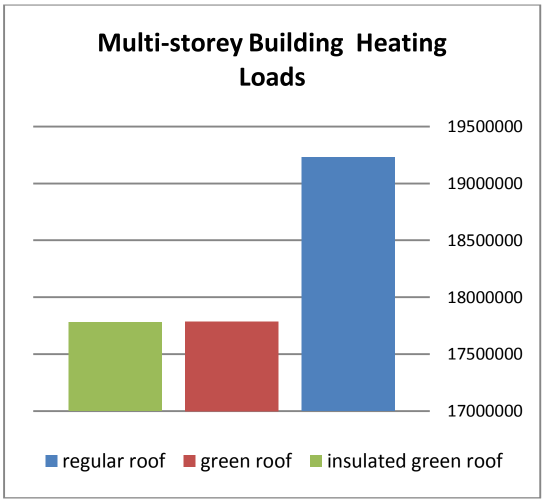
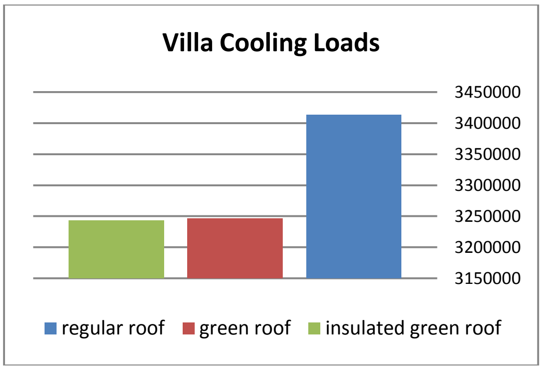




**Fig. 102** Comparison between heating loads for a green roof, a regular roof, and an insulated green roof for villa and multi storey building.
Source: Result of Ecotect simulation



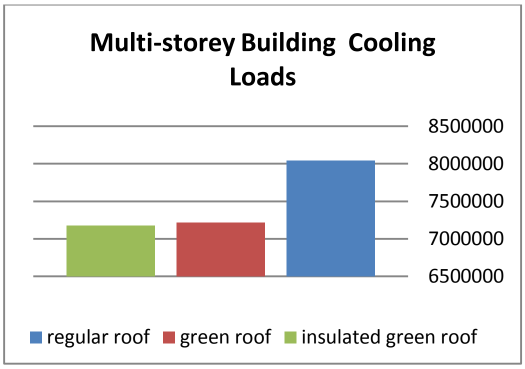




**Fig. 103** Comparison between cooling loads for a green roof, a regular roof, and an insulated green roof for villa and multi storey building.
Source: Result of Ecotect simulation

Analysis of data from the Ecotect model suggests that adding soil media (green roof) to the regular roof has a great effect on the heat transmittance. In addition, this additional layer decreases the U-value of the roof, which will decrease heat loss and improve thermal efficiency of the building.

### 5.3.6. Thermal computation

Thermal calculations were used to compute the entire energy savings for the whole building, formulas were used to calculate heat transfer for both building types and construction components depending on many variables:

U-value of the surface, average temperature differences between outside and inside, and the area of the wall. Then energy consumption for roof, walls, widows, and infiltration from doors and windows cracks. Thermal comfort temperature assumed to be at 21 ◦C to calculate heat transfer and energy consumption. (Goussous et al., 2014)

$$\text{Heat transfer} = \text{Area} * \text{U-value} * \Delta T\ (21^{\circ} - \text{outdoor temp.})$$

$$\text{Energy} = \text{Heat transfer} * \text{Time} * \text{Days}$$

This calculation was conducted on both building types and on the three types of roofing used in simulation.

## Table (38): energy saving in the HVAC through the roof for villa

Heat transfer =area*U-value *ΔT
ΔT= (21˚-temp.)
Energy consumption = heat transfer* time * Days
AC duration (h) time= 10 days /month=30
regular roof U-value 0.95
green roof U-value 0.49
insulated green roof U-value 0.29

| month | Temp aver. | ΔT | regular roof | green roof | insulated green roof | regular roof | green roof | insulated green roof | saving % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ˚C | ˚C | Heat tran.1(w) | Heat tran.2(w) | Heat tran.3(w) | energy con.(w) | energy con.(w) | energy con.(w) | green roof | insulated green roof |
| January | 11.5 | 9.5 | 1425.048 | 735.0245 | 435.0145 | 427514.3 | 220507.35 | 130504.35 | 48 | 69 |
| February | 12.1 | 8.9 | 1335.045 | 688.6019 | 407.5399 | 400513.4 | 206580.57 | 122261.97 | 48 | 69 |
| March | 14.9 | 6.1 | 915.0305 | 471.9631 | 279.3251 | 274509.2 | 141588.93 | 83797.53 | 48 | 69 |
| April | 18.9 | 2.1 | 315.0105 | 162.4791 | 96.1611 | 94503.15 | 48743.73 | 28848.33 | 48 | 69 |
| May | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 48 | 69 |
| June | 23.6 | -3 | -390.013 | -201.165 | -119.057 | -117004 | -60349.38 | -35716.98 | 48 | 69 |
| July | 25.1 | -4 | -615.021 | -317.221 | -187.743 | -184506 | -95166.33 | -56322.93 | 48 | 69 |
| August | 25.5 | -5 | -675.023 | -348.17 | -206.06 | -202507 | -104450.9 | -61817.85 | 48 | 69 |
| September | 23.5 | -3 | -375.013 | -193.428 | -114.478 | -112504 | -58028.25 | -34343.25 | 48 | 69 |
| October | 20.1 | 0.9 | 135.0045 | 69.6339 | 41.2119 | 40501.35 | 20890.17 | 12363.57 | 48 | 69 |
| November | 15.2 | 5.8 | 870.029 | 448.7518 | 265.5878 | 261008.7 | 134625.54 | 79676.34 | 48 | 69 |
| December | 13.3 | 7.7 | 1155.039 | 595.7567 | 352.5907 | 346511.6 | 178727.01 | 105777.21 | 48 | 69 |
| total | | | | | | 1228541 | 633668.49 | 375028.29 | 48 | 69 |

In this table (38) energy saving in the HVAC through the roof for villa, which resulted from the difference in U-value for the roof material. 48% reduction through the roof is achieved by adding a layer of soil (25cm) to the regular roof making the U-value for the green roof 0.49. On the other hand, adding 5cm of thermal insulation will reduce the U-value to 0.29 and energy consumption through the roof is reduced by 69%.

To calculate the contribution of a green roof to an entire building, energy saving it is necessary to calculate energy consumption for the walls, windows and Heat infiltration through the cracks (table (39), (40), and (41)).

**Table (39): energy consumption by the HVAC for the walls (villa)**

walls area=66m* 2.95m=195m$^2$
Heat transfer =area*U-value *ΔT
ΔT= (21˚-temp.)
Energy consumption = heat transfer* time * Days
AC duration (h) time= 10 days /month=30 U-value=0.82

| month | temp aver.(˚C) | U-value | area (m2) | ΔT (˚C) | Heat tran.1(w) | A.C duration | Days/mon. | Energy (W) |
|---|---|---|---|---|---|---|---|---|
| **January** | 11.5 | 0.82 | 195 | 9.5 | 231.5625 | 10 | 30 | 69468.75 |
| **February** | 12.1 | 0.82 | 195 | 8.9 | 216.9375 | 10 | 30 | 65081.25 |
| **March** | 14.9 | 0.82 | 195 | 6.1 | 148.6875 | 10 | 30 | 44606.25 |
| **April** | 18.9 | 0.82 | 195 | 2.1 | 51.1875 | 10 | 30 | 15356.25 |
| **May** | 21 | 0.82 | 195 | 0 | 0 | 10 | 30 | 0 |
| **June** | 23.6 | 0.82 | 195 | -2.6 | -63.375 | 10 | 30 | -19012.5 |
| **July** | 25.1 | 0.82 | 195 | -4.1 | -99.9375 | 10 | 30 | -29981.3 |
| **August** | 25.5 | 0.82 | 195 | -4.5 | -109.688 | 10 | 30 | -32906.3 |
| **September** | 23.5 | 0.82 | 195 | -2.5 | -60.9375 | 10 | 30 | -18281.3 |
| **October** | 20.1 | 0.82 | 195 | 0.9 | 21.9375 | 10 | 30 | 6581.25 |
| **November** | 15.2 | 0.82 | 195 | 5.8 | 141.375 | 10 | 30 | 42412.5 |
| **December** | 13.3 | 0.82 | 195 | 7.7 | 187.6875 | 10 | 30 | 56306.25 |
| **total** | | | | | | | | 199631.3 |

**Table (40): energy consumption by the HVAC for the windows (villa)**

| windows area=35m2<br>Heat transfer =area*U-value *ΔT<br>ΔT= (21˚-temp.)<br>Energy consumption = heat transfer* time * Days<br>AC duration (h) time= 10 days /month=30 U-value=2.7 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **month** | temp aver.(˚C) | U-value | area (m2) | ΔT (˚C) | Heat tran.1(w) | A.C duration | Days/mon. | Energy (W) |
| **January** | 11.5 | 2.7 | 35 | 9.5 | 897.75 | 10 | 30 | 269325 |
| **February** | 12.1 | 2.7 | 35 | 8.9 | 841.05 | 10 | 30 | 252315 |
| **March** | 14.9 | 2.7 | 35 | 6.1 | 576.45 | 10 | 30 | 172935 |
| **April** | 18.9 | 2.7 | 35 | 2.1 | 198.45 | 10 | 30 | 59535 |
| **May** | 21 | 2.7 | 35 | 0 | 0 | 10 | 30 | 0 |
| **June** | 23.6 | 2.7 | 35 | -2.6 | -245.7 | 10 | 30 | -73710 |
| **July** | 25.1 | 2.7 | 35 | -4.1 | -387.45 | 10 | 30 | -116235 |
| **August** | 25.5 | 2.7 | 35 | -4.5 | -425.25 | 10 | 30 | -127575 |
| **September** | 23.5 | 2.7 | 35 | -2.5 | -236.25 | 10 | 30 | -70875 |
| **October** | 20.1 | 2.7 | 35 | 0.9 | 85.05 | 10 | 30 | 25515 |
| **November** | 15.2 | 2.7 | 35 | 5.8 | 548.1 | 10 | 30 | 164430 |
| **December** | 13.3 | 2.7 | 35 | 7.7 | 727.65 | 10 | 30 | 218295 |
| **total** | | | | | | | | 773955 |

**Table (41): Heat infiltration through the cracks. (villa)**

heat loss around windows and doors (cracks area=284ft)
H = 0.018 * Q*ΔT/3.412
H = Heat loss, or heat required to raise the temperature of air leaking into the structure to the level of the indoor temperature (t1) expressed in Btu's per hour.
Q = Volume of air entering the structure expressed is cubic feet per hour
Q = 15 * 284 = 4260("MULTIFAMILY PERFORMANCE PROGRAM Technical Topic – Existing Buildings Using the SG Infiltration-Ventilation and Air-Sealing Worksheets," 2009, "The Crack Method," 2001)
ΔT= (21˚-temp.)
0.018 = The specific heat of air (0.240) times the density of the outdoor air (approximately 0.075)

| Month | temp aver.(˚C) | U-value | area (m2) | ΔT (˚C) | ΔT (˚F) | heat loss | A.C duration | Days/ mon. | Energy (W) |
|---|---|---|---|---|---|---|---|---|---|
| **January** | 11.5 | 2.7 | 35 | 9.5 | 49.10 | 213.4994 | 10 | 30 | 64049.82 |
| **February** | 12.1 | 2.7 | 35 | 8.9 | 48.02 | 200.0152 | 10 | 30 | 60004.57 |
| **March** | 14.9 | 2.7 | 35 | 6.1 | 42.98 | 137.0891 | 10 | 30 | 41126.73 |
| **April** | 18.9 | 2.7 | 35 | 2.1 | 35.78 | 47.19461 | 10 | 30 | 14158.38 |
| **May** | 21 | 2.7 | 35 | 0 | 32.00 | 0 | 10 | 30 | 0 |
| **June** | 23.6 | 2.7 | 35 | -2.6 | 27.32 | -58.4314 | 10 | 30 | -17529.4 |
| **July** | 25.1 | 2.7 | 35 | -4.1 | 24.62 | -92.1419 | 10 | 30 | -27642.6 |
| **August** | 25.5 | 2.7 | 35 | -4.5 | 23.90 | -101.131 | 10 | 30 | -30339.4 |
| **September** | 23.5 | 2.7 | 35 | -2.5 | 27.50 | -56.1841 | 10 | 30 | -16855.2 |
| **October** | 20.1 | 2.7 | 35 | 0.9 | 33.62 | 20.22626 | 10 | 30 | 6067.878 |
| **November** | 15.2 | 2.7 | 35 | 5.8 | 42.44 | 130.347 | 10 | 30 | 39104.1 |
| **December** | 13.3 | 2.7 | 35 | 7.7 | 45.86 | 173.0469 | 10 | 30 | 51914.07 |
| **total** | | | | | | | | | 184059 |

**Table (42): The entire energy savings for the whole building for villa.**

| month | total energy consumption (W) | | | Difference (W) | | saving% | |
|---|---|---|---|---|---|---|---|
| | regular roof | green roof | insulated green roof | green roof | insulated green roof | green roof | insulated green roof |
| **January** | **830357.87** | **623350.92** | **533347.9** | **207007** | **297010** | **25** | **36** |
| **February** | **777914.22** | **583981.39** | **499662.8** | **193932.8** | **278251.4** | **25** | **36** |
| **March** | **533177.18** | **400256.91** | **342465.5** | **132920.3** | **190711.7** | **25** | **36** |
| **April** | **183552.78** | **137793.36** | **117898** | **45759.42** | **65654.82** | **25** | **36** |
| **May** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| **June** | **-227255.9** | **-170601.3** | **-145969** | **-56654.6** | **-81287** | **25** | **36** |
| **July** | **-358364.8** | **-269025.1** | **-230182** | **-89339.7** | **-128183** | **25** | **36** |
| **August** | **-393327.6** | **-295271.5** | **-252638** | **-98056.1** | **-140689** | **25** | **36** |
| **September** | **-218515.5** | **-164039.7** | **-140355** | **-54475.8** | **-78160.8** | **25** | **36** |
| **October** | **78665.478** | **59054.298** | **50527.7** | **19611.18** | **28137.78** | **25** | **36** |
| **November** | **506955.3** | **380572.14** | **325622.9** | **126383.2** | **181332.4** | **25** | **36** |
| **December** | **673026.92** | **505242.33** | **432292.5** | **167784.6** | **240734.4** | **25** | **36** |
| **total** | **2386185.9** | **1791313.7** | **1532674** | **594872.3** | **853512.4** | **25** | **36** |

Table (42) illustrates the effect of a green roof on the entire building energy, saving up to 25% of total energy consumption by applying a green roof, and 36% by adding insulation to the green roof layers.

As this table (43) shows energy saving in the HVAC through the roof for multi storey building, 48% reduction through the roof is achieved by adding a layer of soil (25cm) to the regular roof making the U-value for the green roof is 0.49, on the other hand, adding 5cm of thermal insulation will reduce the U-value to 0.29 and the energy consumption through the roof is reduced by 69%.

**Table (43): energy saving in the HVAC through the roof for multi storey building**

Heat transfer =area*U-value *ΔT
ΔT= (21˚-temp.)
Energy consumption = heat transfer* time * Days
AC duration (h) time= 10 days /mon=30
regular roof U-value 0.95 green roof U-value 0.49 insulated green roof U-value 0.29

| month | temp avr.(˚C) | ΔT(˚C) | regular roof | green roof | insulated green roof | regular roof | green roof | insulated green roof | saving % | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Heat tran. 1(w) | Heat tran. 2(w) | Heat tran. 3(w) | energy con. (w) | energy con. (w) | energy con. (w) | green roof | nsulated green roof |
| January | **11.5** | **9.5** | **1253.121** | **646.3468** | **382.5318** | **375936.4** | **193904.03** | **114759.525** | **48** | **69** |
| February | **12.1** | **8.9** | **1173.977** | **605.5249** | **358.3719** | **352193** | **181657.46** | **107511.555** | **48** | **69** |
| March | **14.9** | **6.1** | **804.6358** | **415.0227** | **245.6257** | **241390.7** | **124506.8** | **73687.695** | **48** | **69** |
| April | **18.9** | **2.1** | **277.0058** | **142.8767** | **84.55965** | **83101.73** | **42862.995** | **25367.895** | **48** | **69** |
| May | **21** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **48** | **69** |
| June | **23.6** | **-3** | **-342.96** | **-176.895** | **-104.693** | **-102888** | **-53068.47** | **-31407.87** | **48** | **69** |
| July | **25.1** | **-4** | **-540.821** | **-278.95** | **-165.093** | **-162246** | **-83684.9** | **-49527.795** | **48** | **69** |
| August | **25.5** | **-5** | **-593.584** | **-306.164** | **-181.199** | **-178075** | **-91849.28** | **-54359.775** | **48** | **69** |
| September | **23.5** | **-3** | **-329.769** | **-170.091** | **-100.666** | **-98930.6** | **-51027.38** | **-30199.875** | **48** | **69** |
| October | **20.1** | **0.9** | **118.7168** | **61.23285** | **36.23985** | **35615.02** | **18369.855** | **10871.955** | **48** | **69** |
| November | **15.2** | **5.8** | **765.0635** | **394.6117** | **233.5457** | **229519.1** | **118383.51** | **70063.71** | **48** | **69** |
| December | **13.3** | **7.7** | **1015.688** | **523.8811** | **310.0521** | **304706.3** | **157164.32** | **93015.615** | **48** | **69** |
| **Total** | | | | | | **1080322** | **557218.94** | **329782.635** | **48** | **69** |

In order to calculate the contribution of a green roof to the entire building energy saving it is necessary to calculate energy consumption for the walls, windows and Heat infiltration through the cracks (table (44), (45) and (46)).

**Table (44): Energy consumption by the HVAC for the walls for multi storey building**

walls area=53m* 3.05m=161.65m2
Heat transfer =area*U-value *ΔT
ΔT= (21˚-temp.)
energy = heat transfer* time * Days
AC duration (h) time= 10 days /mon=30 U-value=0.82

| month | temp avr.(˚C) | U-value | area (m2) | ΔT (˚C) | Heat tran.1(w) | A.C duration | Days/ mon. | Energy (W) |
|---|---|---|---|---|---|---|---|---|
| January | **11.5** | **0.82** | 161.65 | 9.5 | 191.9594 | 10 | 30 | 57587.81 |
| February | **12.1** | **0.82** | 161.65 | 8.9 | 179.8356 | 10 | 30 | 53950.69 |
| March | **14.9** | **0.82** | 161.65 | 6.1 | 123.2581 | 10 | 30 | 36977.44 |
| April | **18.9** | **0.82** | 161.65 | 2.1 | 42.43313 | 10 | 30 | 12729.94 |
| May | **21** | **0.82** | 161.65 | 0 | 0 | 10 | 30 | 0 |
| June | **23.6** | **0.82** | 161.65 | -2.6 | -52.5363 | 10 | 30 | -15760.9 |
| July | **25.1** | **0.82** | 161.65 | -4.1 | -82.8456 | 10 | 30 | -24853.7 |
| August | **25.5** | **0.82** | 161.65 | -4.5 | -90.9281 | 10 | 30 | -27278.4 |
| September | **23.5** | **0.82** | 161.65 | -2.5 | -50.5156 | 10 | 30 | -15154.7 |
| October | **20.1** | **0.82** | 161.65 | 0.9 | 18.18563 | 10 | 30 | 5455.687 |
| November | **15.2** | **0.82** | 161.65 | 5.8 | 117.1963 | 10 | 30 | 35158.88 |
| December | **13.3** | **0.82** | 161.65 | 7.7 | 155.5881 | 10 | 30 | 46676.44 |
| **Total** | | | | | | | | 165489.2 |

**Table (45): Energy consumption by the HVAC for the windows for multi storey building**

windows area=31m2
Heat transfer =area*U-value *ΔT ΔT= (21˚-temp.)
energy = heat transfer* time * Days
AC duration (h) time= 10 days /mon=30 U-value=2.7

| month | temp avr.(˚C) | U-value | area (m2) | ΔT (˚C) | Heat ran.1(w) | A.C duration | Days/mon. | Energy (W) |
|---|---|---|---|---|---|---|---|---|
| January | **11.5** | **2.7** | 31 | 9.5 | 795.15 | 10 | 30 | 238545 |
| February | **12.1** | **2.7** | 31 | 8.9 | 744.93 | 10 | 30 | 223479 |
| March | **14.9** | **2.7** | 31 | 6.1 | 510.57 | 10 | 30 | 153171 |
| April | **18.9** | **2.7** | 31 | 2.1 | 175.77 | 10 | 30 | 52731 |
| May | **21** | **2.7** | 31 | 0 | 0 | 10 | 30 | 0 |
| June | **23.6** | **2.7** | 31 | -2.6 | -217.62 | 10 | 30 | -65286 |
| July | **25.1** | **2.7** | 31 | -4.1 | -343.17 | 10 | 30 | -102951 |
| August | **25.5** | **2.7** | 31 | -4.5 | -376.65 | 10 | 30 | -112995 |
| September | **23.5** | **2.7** | 31 | -2.5 | -209.25 | 10 | 30 | -62775 |
| October | **20.1** | **2.7** | 31 | 0.9 | 75.33 | 10 | 30 | 22599 |
| November | **15.2** | **2.7** | 31 | 5.8 | 485.46 | 10 | 30 | 145638 |
| December | **13.3** | **2.7** | 31 | 7.7 | 644.49 | 10 | 30 | 193347 |
| **Total** | | | | | | | | 685503 |

**Table (46): heat loss around windows and doors cracks area=110ft for multi storey building**

heat loss around windows and doors (cracks area=110ft)
H = 0.018 * Q*ΔT/3.412
H = Heat loss, or heat required to raise the temperature of air leaking into the structure to the level of the indoor temperature (t1) expressed in Btu's per hour.
Q = Volume of air entering the structure expressed is cubic feet per hour
Q = 15 * 110= 1650("Infiltration-Ventilation and Air-Sealing Worksheets," 2009, "The Crack Method," 2001)
0.018 = The specific heat of air (0.240) times the density of the outdoor air (approximately 0.075)
ΔT= (21˚-temp.)

| month | temp avr.(˚C) | U-value | ΔT (˚C) | ΔT (˚F) | heat loss | A.C duration | Days/ mon. | Energy (W) |
|---|---|---|---|---|---|---|---|---|
| January | **11.5** | **2.7** | 9.5 | 49.10 | 82.69343 | 10 | 30 | 24808.03 |
| February | **12.1** | **2.7** | 8.9 | 48.02 | 77.47069 | 10 | 30 | 23241.21 |
| March | **14.9** | **2.7** | 6.1 | 42.98 | 53.09789 | 10 | 30 | 15929.37 |
| April | **18.9** | **2.7** | 2.1 | 35.78 | 18.2796 | 10 | 30 | 5483.88 |
| May | **21** | **2.7** | 0 | 32.00 | 0 | 10 | 30 | 0 |
| June | **23.6** | **2.7** | -2.6 | 27.32 | -22.6319 | 10 | 30 | -6789.57 |
| July | **25.1** | **2.7** | -4.1 | 24.62 | -35.6887 | 10 | 30 | -10706.6 |
| August | **25.5** | **2.7** | -4.5 | 23.90 | -39.1706 | 10 | 30 | -11751.2 |
| September | **23.5** | **2.7** | -2.5 | 27.50 | -21.7614 | 10 | 30 | -6528.43 |
| October | **20.1** | **2.7** | 0.9 | 33.62 | 7.834115 | 10 | 30 | 2350.234 |
| November | **15.2** | **2.7** | 5.8 | 42.44 | 50.48652 | 10 | 30 | 15145.96 |
| December | **13.3** | **2.7** | 7.7 | 45.86 | 67.02521 | 10 | 30 | 20107.56 |
| **Total** | | | | | | | | 71290.45 |

**Table (47): The entire energy savings for the whole building for multi storey building.**

| month | total energy consumption (W) | | | Difference(W) | | saving% | |
|---|---|---|---|---|---|---|---|
| | regular roof | green roof | insulated green roof | green roof | insulated green roof | green roof | insulated green roof |
| January | 696877.22 | 514844.87 | 435700.4 | 182032.4 | 261176.9 | 26 | 37 |
| February | 652863.92 | 482328.35 | 408182.5 | 170535.6 | 244681.5 | 26 | 37 |
| March | 447468.53 | 330584.6 | 279765.5 | 116883.9 | 167703 | 26 | 37 |
| April | 154046.54 | 113807.81 | 96312.71 | 40238.73 | 57733.83 | 26 | 37 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | -190724.3 | -140904.9 | -119244 | -49819.4 | -71480 | 26 | 37 |
| July | -300757.5 | -222196.2 | -188039 | -78561.3 | -112718 | 26 | 37 |
| August | -330099.7 | -243873.9 | -206384 | -86225.9 | -123715 | 26 | 37 |
| September | -183388.7 | -135485.5 | -114658 | -47903.3 | -68730.8 | 26 | 37 |
| October | 66019.947 | 48774.777 | 41276.88 | 17245.17 | 24743.07 | 26 | 37 |
| November | 425461.88 | 314326.34 | 266006.5 | 111135.5 | 159455.3 | 26 | 37 |
| December | 564837.32 | 417295.31 | 353146.6 | 147542 | 211690.7 | 26 | 37 |
| **Total** | 2002605.1 | 1479501.6 | 1252065 | 523103.5 | 750539.8 | 26 | 37 |

The total saving was up to 26% of total energy consumption for a green roof, and 37% by adding insulation to the green roof layers. Table (47)

## 5.4.Summary

To sum up, it is clear that using green roofs has environmental benefits, the simulation results indicated that the addition of green roof layers to the building roof reduced the energy consumed for heating or cooling. It should be considered that these calculations did not include the effect of evapotranspiration and plants in reducing heat transference.

# Chapter six

# Conclusion and Recommendations

## 6.1. Conclusion

One should not undermine the benefits offered by Green roofs towards improving the quality of space and ensuring human psychological comfort.

Results obtained from the experiment and analysis on the possibility of applying Green roofs in the city of Nablus, confirmed that this solution will increase the green areas in the city of Nablus. As it will provide many benefits, such as, improving the physical environment, in addition to making gardens accessible to everyone.

Moreover, many benefits could be achieved on architectural, environmental, and aesthetical levels. The results also revealed that green roofs are feasible from economical point of view.

Taking advantage of these benefits was very crucial for this research. This was addressed by investigating the development of the physical and environmental profile of the city. To determine if the city's buildings could accommodate green roofs, after studying the common construction method in the city and the building structure it is clear that the city existing buildings can sustain extra load added by the lighter types of green roof without structural reinforcement. It is evident that applying Green Roofs to the city of Nablus will have limited effect on the building structural design.

Moreover, the additional cost of the green roof was calculated to be 37.5%, which is very acceptable from financial point of view, when considering the benefits of the Green roofs.

This research not only examined the issue of Green roofs application from structural point of view and the availability of materials, but also from the human perspective. Results confirmed that the citizens are willing to add green roofs to their buildings but have concerns over the cost of green roofs. Furthermore, the participants linked the benefits of green roofs with the benefits provided by plants and green areas in general, but not to specific green roof benefits, such as, the reduction of energy used in heating and cooling, or reducing urban heat.

Calculation demonstrated that applying green roof to building will reduce the energy used for heating or cooling, results of the villa building type demonstrated actual reduction of direct solar radiation of the Green roof using Ecotect program show that about 50% reduction on the total all year. Analysis indicates that insulated green roof has the lowest energy consumption rate, reducing approximately 10% of total year consumption. Moreover, in the multi-story building type 62% reduction of the actual reduction in the direct solar radiation will be achieved. Moreover, 18% reduction in the energy used for cooling and heating when applying insulated green roof.

Regarding thermal computation resulting from different U-value calculation results showed that total saving up to 26% of total energy consumption by green roof, and 37% by adding insulation to the green roof layers.

Indeed calculations and results indicate that green roofs can be cost effective on the long term, as the increase of construction cost can be returned back from the saving through the reduction of energy loads.

## 6.2 Recommendations

Studying and researching green roofs application is not an easy topic to tackle as it is looked. More research needs to be established regarding the green roofs application to the city of Nablus in many areas, such as, social, botanical (plant types), irrigation and green roof policy.

1- In order to make green roof construction practical, there is a need to provide a construction manual or guide lines for the citizens.
2- Green building guideline – state of Palestine, issued by: Palestine Engineers Association, and Palestine Higher Green Building Council, need upgrading and amendments, to contain more clarification regarding green roofs.
3- Increasing public awareness regarding green roofs benefits and construction techniques is another important point to be addressed, on both municipality and citizens' level.
4- There is a need to put a policy for promoting and encouraging green roof in the city of Nablus. If public organizations in the city such as the municipality and the university embraces the application of green roofs and implement green roofs to their buildings, as well as promoting the use of green roofs on schools and others public buildings, this will encourage citizens to apply green roofs to their buildings.
5- Pilot projects is needed to make constructing green roof practical in the city of Nablus, such as, modify water waste in the buildings; separating gray water and use it for irrigating the green roof.

Although applying green roofs in the city of Nablus or in the state of Palestine may be difficult, but by providing municipal support and regulations, increasing citizens awareness to the importance of green roofs and making pioneer projects to lower the cost of sustaining green roofs, will make the greening of the city of Nablus roofs achieved.

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# Appendix

# Appendix 1

جامعة النجاح الوطنية

كلية الدراسات العليا

قسم الهندسة المعمارية

هذا الاستبيان هو جزء من رسالة الماجستير في الهندسة المعمارية حول "إمكانية تطبيق حدائق الأسقف في مدينه نابلس" و يهدف لقياس تفضيل سكان المدينة لوجود النباتات في بيوتهم و كذلك معرفتهم بحدائق الأسقف و فوائدها.

**أولا:معلومات عامه**

1-الجنس: ☐ ذكر ☐ أنثى

2-العمر :............................

3-مكان السكن : ☐نابلس

☐مدينة

أخرى................................

إذا كنت من سكان مدينة نابلس رجاءً حدد المنطقة.................

4-المستوى الأكاديمي:

☐شهادة مدرسيه

☐ توجيهي

☐بكالوريوس

☐دراسات عليا

5-مجال العمل:

☐أكاديمي

☐ تجاري

☐ إداري

☐غير ذلك

6-نوع العقار (السكن):

☐أجار

☐ملك

7-طبيعة السكن

☐بيت مستقل

☐مبنى متعدد الطوابق

○الطابق الأرضي

○الطوابق المتوسطة

○الطابق الأخير

☐غير ذلك..................

8-إمكانية الوصول إلى حديقة خاصة

☐يمكن الوصول إليها

☐يمكن الوصول إليها جزئيا

☐ لا يمكن الوصول إليها

9-إمكانية الوصول لسقف البناية:

☐ يمكن الوصول إليه

☐يمكن الوصول إليه جزئيا

☐ لا يمكن الوصول إليه

**ثانيا:تفضيل وجود النباتات :**

1-هل يوجد لديك نباتات داخل المنزل ؟ ☐نعم ☐لا

إذا كان يوجد لديك هل ممكن أن توضح أماكن وجودهم مثلا على السقف أو الشباك أو في غرفه المعيشة.

..................................................................

2-هل تتوفر حديقة عامه في منطقتك؟ ☐ نعم ☐لا

إذا كان بإمكانك كم مره بالشهر تزورها ...........................

3-ما رأيك بتوفر الحدائق في مدينه نابلس؟

| | | | | |
|---|---|---|---|---|
| متوفرة<br>غير متوفرة | | | | |
| ☐1 | ☐2 | ☐3 | ☐4 | ☐5 |
| | | | | |

**ثالثا : المعرفة في حدائق الأسقف :**

1-هل سمعت عن حدائق الأسقف من قبل؟ ☐ نعم ☐ لا

هل يوجد لديك معرفه بأنواع حدائق الأسقف؟ ☐ نعم ☐ لا

إذا كانت إجابتك نعم هل تعرف هذه الأنواع ؟

| | | |
|---|---|---|
| ☐intensive | ☐extensive | غيرها ............................ |

2-إلي أي حد توافق على أن حدائق الأسقف توفر الفوائد التالية :

| | أوافق بشده | أوافق | محايد | غير موافق | غير موافق بشده |
|---|---|---|---|---|---|
| تحسين جودة الهواء | | | | | |
| تحسن مظهر المدينة | | | | | |
| تقليل تكلفه التدفئة و التبريد | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| إدارة مياه الأمطار | | | | | |
| تقليل درجة الحرارة في المدن | | | | | |
| تقليل الإزعاج | | | | | |
| توفير مناطق خضراء | | | | | |
| تحسين الحالة النفسية | | | | | |
| تحسين الصحة | | | | | |
| زيادة عمر مواد بناء السقف | | | | | |

**رابعا: تفضيل وجود حدائق الأسقف في المدينة:**

1-من الصور المعدلة باستخدام الحاسوب التالية اختر الصورة التي تفضلها من ناحية جمالية :

| المثال | المثال الأول | |
|---|---|---|
| | (أ) | (ب) |

(أ)

(ب)

| المثال الثاني | (ج) | (د) |
| --- | --- | --- |

(ج)

(د)

| المثال الثالث | (هـ) | (و) |
| --- | --- | --- |


(هـ)


(و)

2-هل من ممكن أن تضيف حديقة على سقف منزلك ؟ ☐نعم ☐لا

إذا كان الجواب لا هل يمكن أن توضح

السبب..........................................................................................

.............................

3-ما هو أهم عامل لعدم إنشاء حدائق الأسقف في نابلس من وجهه نظرك ( اختر جواب واحد)؟

☐ناحية إنشائية (الوزن)

☐التكلفة

☐إمكانية حدوث تسريب مياه

☐غير ذلك .....................

ملاحظات أو اقتراحات:

.............................................................................................

.............................................................................................

..................................................................

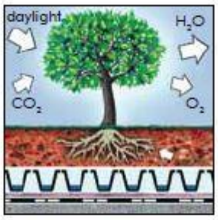
شكرا جزيلا لمساعدتك

# Appendix 2

## Why have a Green Roof?

Beyond their attractive visual nature, Green Roofs offer many undisputable benefits, both ecological and economical, provided they are built with the right system.

### Improve the Microclimate

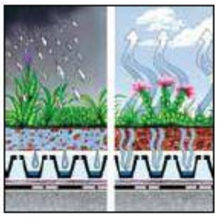



Green Roofs cool and humidify the surrounding air. Thus they contribute to improving the microclimate in urban centres. This cooling effect significantly increases the performance of air-conditioning systems, reducing carbon emissions.

### Bind Dust and Toxic Particles

Green Roof vegetation helps to filter out dust and smog particles. Nitrates and other harmful materials are absorbed by the plants out of the air and rainfall and bound within the substrate.

### Increase Rainwater Retention

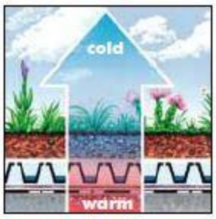


A Green Roof can reduce water run-off by 50-90%; any water flows from the roof with a delay.
Outlets, pipes and drains can be reduced in capacity, thereby saving construction costs. Sewer costs can be reduced in some areas.

### Improve Noise Protection

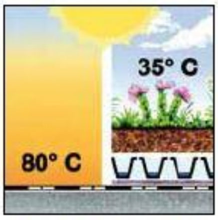
Planted areas are natural sound insulators and absorb more sound than hard surfaces. Green Roofs reduce reflective sound by up to 3 dB and improve sound insulation by up to 8 dB. This is very effective for buildings near airports, noisy nightclubs and factories.

### Reduce of Energy Costs




A Green Roof has the ability to buffer temperature extremes and improve the buildings energy performance.

### Protect the Waterproofing




A Green Roof protects the waterproofing from climate extremes, UV exposure and mechanical damage. This greatly increases the life expectancy of the waterproofing and results in reduced maintenance and replacement costs.

### Offer a Natural Habitat

Landscaped roofs compensate for green spaces, which are lost to building development. They provide natural habitats for wildlife and bring nature back into the cities.

### Provide Additional Space

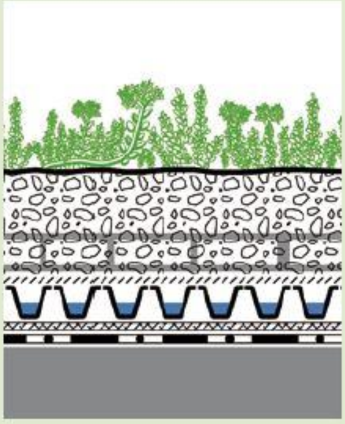
Green Roofs offer additional space for numerous uses. Whether you want a relaxing garden, a playground or a golf course, it all can be achieved as part of the existing footprint.

# Appendix 3

**System Build-up "Sedum Carpet"**

Features:

- Ecological protection layer instead of gravel covering.
- Requires minimum maintenance.
- For roofs without standing water and with a slight slope up to 8°.



Plug Plants FB 50 "Sedum Carpet" 16 pcs/m² or Sedum Cuttings 60 g/m²

System Substrate "Sedum Carpet" ≥ 80 mm*

Fallnet®

Filter Sheet SF

Floradrain® FD 25-E

Protection Mat SSM 45

Root Barrier WSF 40, if waterproofing is not root-resistant

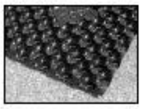
* if there is enough rainfall, maybe less

| | Art.-No. | Unit |
|---|---|---|
| Sedum Cuttings | 8020 | bag of 2 kg |
| Plug Plants FB 50 "Sedum Carpet" | 8110 | tray with 50 pcs. |

| | Unit | Art.-No. | Unit | Art.-No. | Unit | Art.-No. |
|---|---|---|---|---|---|---|
| System Substrate "Sedum Carpet" | big bag | 611101 | bulk | 611201 | silo | 611301 |

This System Build-up allows the integration of the **Fallnet® Fixing Device** for roofs with slopes up to 5° (see page 34-35)

| | Art.-No. | Dimensions | Unit | Pallet |
|---|---|---|---|---|
| Filter Sheet SF | 2100 | ca. 2.00 m x 100.00 m | 200 m²-roll | 4600 m² |
| | 2102 | ca. 1.00 m x 100.00 m | 100 m²-roll | 2500 m² |
| | 2101 | ca. 2.00 m x 10.00 m | 20 m² | |



| | Art.-No. | Dimensions | Unit | Pallet |
|---|---|---|---|---|
| Floradrain® FD 25-E | 3028 | ca. 1.00 m x 2.00 m | 2 m²-board | 200 boards |
| Floradrain® FD 25-R (Roll) | 3023 | ca. 1.00 m x 15.00 m | 15 m²-roll | |
| Floradrain® FD 25-RV (Roll & Filter Sheet) | 3022 | ca. 1.00 m x 15.00 m | 15 m²-roll | |

| | Art.-No. | Dimensions | Unit |
|---|---|---|---|
| Protection Mat SSM 45 | 2045 | ca. 2.00 m x 50.00 m | 100 m²-roll |

| | Art.-No. | Dimensions | Unit | Pallet |
|---|---|---|---|---|
| Root Barrier WSF 40 | 1040 | ca. 8.00 m x 25.00 m | 200 m²-roll | 4600 m² |
| | 1041 | ca. 6.25 m x 20.00 m | 125 m²-roll | 2500 m² |
| | 1043 | ca. 2.00 m x 50.00 m | 100 m²-roll | 2600 m² |
| | 1044 | ca. 3.00 m x 33.50 m | 100.5 m²-roll | 2211 m² |
| | 41040 | ca. 6.25 m x 3.20 m | 20 m² | 600 m² |

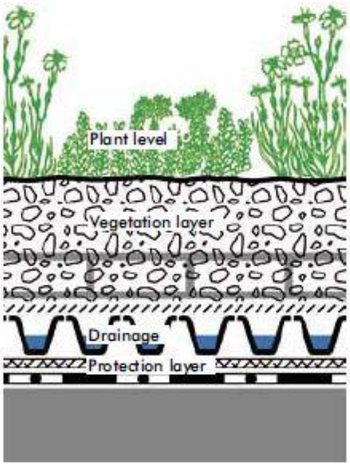
# Appendix 4

## Plant Suggestions "Rockery Type Plants"

| Botanical Name | Common Name | Height (mm) | Blossom | Blossom Period (month) |
|---|---|---|---|---|
| **Accent plants** (groups of 3,5, or 7) | | | | |
| *Dianthus carthusianorum* | Clusterhead | 400 | red | 6-9 |
| *Festuca Cinerea-Hybride* | Blue fescue | 250-300 | brown | 6-7 |
| *Gypsophila repens* e.g. „Rosa Schönheit" | Baby's breath | 100-150 | rose | 5-7 |
| *Helianthemum nummularium* | Sun rose | 50-100 | yellow | 5-7 |
| *Koeleria glauca* | Large blue hair grass | 450-500 | bluish | 6-7 |
| *Petrorhagia saxifraga* | Tunic flower | 100-200 | rose-white | 6-9 |
| *Saponaria ocymoides* | Rock soapwort | 150-200 | rose | 5-7 |
| *Satureja montana ssp. illyrica* | Winter savory | 100-150 | violet | 8-9 |
| *Saxifraga paniculata* | Livelong saxifrage | 200-250 | white | 6-7 |
| *Sempervivum-Hybriden* | Houseleek hybrids | 100-200 | red/rose | 7-8 |
| **Filler Plants** (minimum of four different Sedum varieties) | | | | |
| *Cerastium arvense "Compactum"* | Field chickweed | 50-100 | white | 5-6 |
| *Hieracium pilosella* | Mouseear hawkweed | 150-200 | yellow | 5-7 |
| *Potentilla neumanniana* | Alpine cinquefoil | 100-150 | yellow | 3-4 |
| *Prunella grandiflora* | Large self-heat | 200 | violet | 6-8 |
| *Thymus doerfleri "Bressingham Seedling"* | Bressingham thyme | 60-80 | rose | 5-7 |
| *Thymus serpyllum* | Wild thyme | 50 | violet | 5-9 |

Additional Sedum varieties from the plant community "Sedum Carpet" on page 9.

| Weight kg/m² dry | Weight kg/m² water-saturated | Height mm |
|---|---|---|
| 70 | 98 | 70 |
| 2 | 10 | 30 |
| 72 | 108 | |




Plant level as per plant suggestions "Rockery Type Plants"

System Substrate "Rockery Type Plants"

Safety Device "Fallnet®", if required (attention to load requirements)

Filter Sheet SF

Floradrain® FD 25-E

Protection Mat SSM 45

Root Barrier WSF 40, if waterproofing is not root-resistant

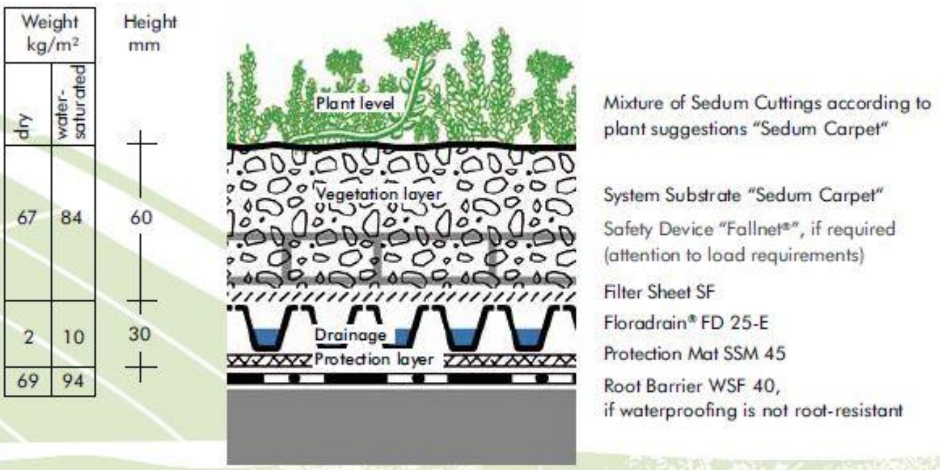
| | |
|---|---|
| Build-up height: | ca. 100 mm |
| Weight, saturated: | ca. 110 kg/m² |
| Water retention capacity: | ca. 36 l/m² |

# Appendix 5

**Plant Suggestions "Sedum Carpet"**
Plants in small groups (groups of 3, 5 or 7)

| Botanical Name | Common Name | Height (mm) | Blossom Colour | Blossom Period (month) |
|---|---|---|---|---|
| *Sedum album varieties* | White stonecrop varieties | 50-100 | white | 6-8 |
| e.g. "Coral Carpet" | | 50-100 | | |
| "Murale" | | 50-100 | white pale-rose | 6-8 6 |
| *Sedum cauticolum* | Nettle-leaved goosefoot | 100-150 | rose | 8-9 |
| *Sedum floriferum* "Weihenstep. Gold" | Gold sedum | 100-150 | yellow | 6-7 |
| *Sedum hybridum* "Immergrünchen" | Hybrid stonecrop | 100-150 | yellow | 7-8 |
| *Sedum reflexum* | Crooked yellow stonecrop | 200-250 | yellow | 6-7 |
| *Sedum sexangulare* | Tasteless yellow stonecrop | 50-100 | yellow | 6-7 |
| *Sedum spurium* in varieties. | Dragon`s blood | | | |
| e.g. "Album Superbum" | | 100-150 | white** | 7-8 |
| "Fuldaglut" | | 100-150 | | 7-8 |
| "Roseum Superbum" | | 100-150 | | 7-8 |
| "Splendens" | | 100-150 | | 7-8 |
| "Variegatum" | | 100-150 | | 7-8 |

** infrequent blooming




| | |
|---|---|
| Build-up height: | ca. 90 mm |
| Weight, saturated: | ca. 95 kg/m² |
| Water retention capacity: | ca. 25 l/m² |

# Appendix 6

## Accessories and Details Programmes

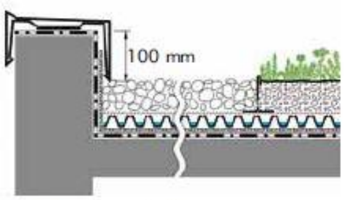
### *Perimeters*

In line with the "German Guidelines for Roofs with Waterproofing", an upstand height of at least 100 mm above the surface covering is required at the roof perimeter. The parapet should have a covering that slopes towards the roof. The protection mat and, where required the root barrier, are drawn upwards and secured.

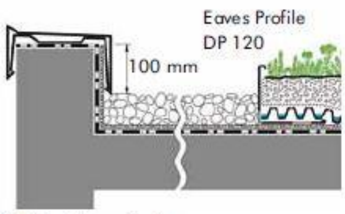
Increased loads must be applied to loosely laid roof waterproofing sheets around the roof perimeter and corner areas where there is high wind suction (high building, exposed location ...). This is very often provided by means of sufficiently wide and heavy edge strips consisting of concrete slabs or grass pavers.

If in projects with high wind loads the perimeter and corner areas of the roof are to be part of the green roof, the vegetation cover must be closed immediately. EcoSedum® is ideal here. These pre-greened grid elements are securely fixed to each other by an interlocking plug connection system. They are sufficiently permeable when greened so that wind suction forces cannot find purchase.

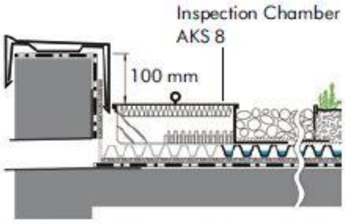
Pre-cultivated EcoSedum® elements can be used both in combination with concrete slabs (loosely laid waterproofing) and on their own (adhered or mechanically fixed waterproofing layer).



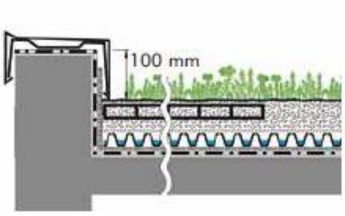

*Standard perimeter solution*



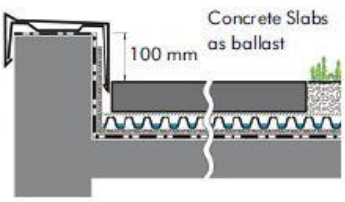

*Solution for low perimeters*



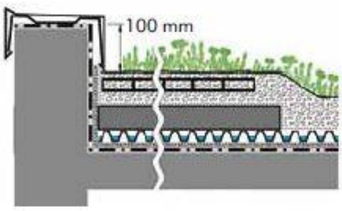

*Draining flat roofs by means of water spouts integrated into the parapet*




*Perimeter solution for high wind loads with EcoSedum® (fixed waterproofing)*



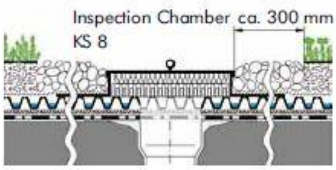

*Perimeter solution for high wind loads (loose waterproofing)*




*Perimeter solution for high wind loads with pavers and EcoSedum® (loose waterproofing)*

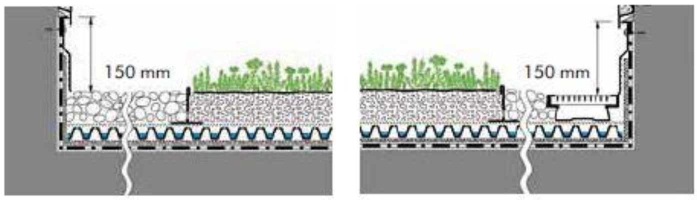
# Appendix 7

### *Roof Drains and Inspection Chambers*




Usually, the drainage of flat roofs is achieved through roof drains. Their quantity as well as their dimensioning is to be determined in accordance with European and German Standard DIN EN 12056-3 and DIN 1986. Inspection chambers make sure the roof drains remain accessible and therefore can be cleaned easily, if necessary.

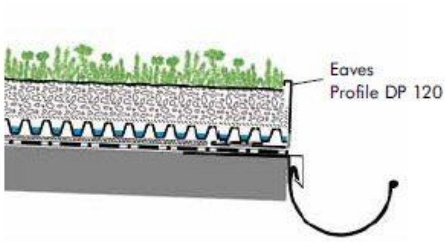
### *Wall Connection*




The connection to walls needs to be waterproof. Therefore the protection mat, the waterproofing and the root barrier are taken up at least 150 mm above the finished surface of the green roof build-up and fixed with a protection profile. In front of facades the installation of additional drainage channels is recommanded in order to lead rainwater directly into the drainage layer. If only little water is expected, a simple gravel strip is sufficient.

### *Drainage Via an External Eaves gutter*

If the drainage of a green roof is to be ensured by an external gutter, the green roof build-up can be bordered by an eaves profile, which is attached to the waterproofing. Eaves profiles border the build-up but allow for unhindered runoff due to their drainage slots.




### *Fall Protection*

National regulations as well as directives brought out by insurance associations prescribe the use of fall protection systems for works at height. The "Fallnet®" which can be integrated into ZinCo Green Roof System Build-ups offer fixing possibilities for safety harnesses without penetrating the waterproofing.

جامعة النجاح الوطنية
كلية الدراسات العليا

# نحو مدن فلسطينية خضراء جدوى تطبيق حدائق الأسقف في مدينة نابلس كحالة دراسية

إعداد
دعاء "محمد رايق" أحمد الملاح

إشراف
د. محمد عطا يوسف
أ.د. هيثم الرطروط

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في الهندسة المعمارية بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.
2017

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**أ.د. هيثم الرطروط**

## الملخص

تعتبر زيادة المساحات الخضراء قضية مهمة جدا في العديد من المدن، كذلك في مدينة نابلس حيث التضاريس والأوضاع السياسية تحد من إنشاء مساحات خضراء جديدة.

في هذه الدراسة تم اختبار إمكانية تطبيق حدائق الأسقف في مدينة نابلس، بعد عرض تطور و فوائد حدائق الأسقف، وكيف تشجع المدن على تطبيقها لاستغلال هذه الفوائد. ثم تم عرض الوضع البيئي و الفيزيائي للمدينة، و لتحديد ما إذا كانت المباني في المدينة يمكنها استيعاب حدائق الأسقف تم دراسة أسلوب البناء السائد في المدينة والتصميم الإنشائي.و وجد ان المباني القائمة في المدينة يمكنها ان تتحمل الحمولات الزائدة التي تضيفها حدائق الاسقف الأخف وزناً دون تعزيز إنشائي. كما تم حساب التكاليف المضافة لحدائق الأسقف لتكون 37.5٪ من التكلفة الاساسية الحالية للبناء.

بعد توضيح قدرة المباني في المدينة على تحمل حدائق الأسقف وتوافر مواد البناء، تم استطلاع معرفة المواطنين حول حدائق الأسقف واستعدادهم لتطبيقها على مبانيهم من خلال نهج نوعي وكمي، اظهرت نتائج الاستبيان أن المشاركين كانوا على استعداد لإضافة حدائق الأسقف على مبانيهم، الا ان التكلفة كانت احد اهم المعوقات امام تطبيقها، كما ربط معظم المشاركين فوائد حدائق الأسقف مع الفوائد التي توفرها النباتات والمساحات الخضراء بشكل عام، ولكن ليس مع الفوائد التي توفرها حدائق الأسقف بشكل خاص مثل: الحد من الطاقة المستخدمة في التدفئة والتبريد، أو تخفيض الحرارة في المدن.

في الجزء الأخير من هذا البحث تم حساب الإشعاع الشمسي المباشر على السقف باستخدام برنامج Ecotect، أوضحت النتائج أن هناك تقليل حوالي 50٪ من الإشعاع الكلي طوال العام في الفيلا و 62٪ في البناء متعدد الطوابق، و تم حساب الطاقة المستخدمة للتبريد والتدفئة ,وتشير النتائج إلى أن حديقة السقف المعزولة حراريا لديها أدنى معدل استهلاك الطاقة مقارنة مع الأسقف المستخدمة حاليا في المباني، وتقلل ما يقرب 10٪ من إجمالي استهلاك العام في الفيلا ,و 18٪ للمبنى متعدد الطوابق. حيث توفر حدائق الأسقف غير المعزولة حراريا حوالي 9٪ في الفيلا و 17٪ للمبنى متعدد الطوابق. و في الحساب الحراري الناتج عن اختلاف U-value، أظهرت نتائج الحسابات أن التوفير الإجمالي يصل إلى 26٪ من إجمالي استهلاك الطاقة بالنسبة لحدائق الأسقف، و 37٪ عن طريق إضافة طبقة عزل لحدائق الأسقف.

وتشير هذه النتائج إلى أن حدائق الأسقف يمكن أن تكون فعالة من حيث التكلفة على المدى الطويل إذ أن الزيادة في تكلفة البناء يتم إسترجاعها عن طريق تخفيض أحمال الطاقة.