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Green Rooftops: Enhancing Buildings' Sustainable Performance in Egypt

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***Abstract*—With the increasing importance given to the concept of sustainability, countries have desperately been trying to develop new concepts and ideas to help improve their buildings' sustainability. Roofs, being a main part in the design of every building, are a very powerful element that can greatly affect the buildings' performance if utilized correctly. The aim of this research is to negotiate the topic of how rooftops in Egypt can be utilized to enhance the buildings' performance resulting in a more sustainable architecture, and help designers and architects decide whether green roofs should be integrated into their buildings' designs and later determine the most suitable type of green roof to be used according to the buildings' conditions. In order to achieve this, the review study will start with some of the environmental issues that Egypt faces nowadays, and how these issues affect the users' lives as well as the city's overall sustainable performance. The general features of green roofs are discussed, focusing on how these features can affect the environmental issues that face Egypt, and whether green roofs would be suitable in a climate like that of Egypt. Moreover, this study is aiming to take it in more detailed level, where it will illustrate how to apply green roofs by emphasizing on the three different phases normally takes place to apply a green roof, which are the design, construction and maintenance, which will help the user to decide the most suitable type of green roof.**

Keywords—Energy Consumption, Green Roofs, Rooftops, Sustainability

I. INTRODUCTION

HIGH population growth and fast sprawling urbanization are growing to become one of the most pressing concerns for urban planners, specifically in countries like Egypt, where the population grows at an average of 2% every year. Climate change and the increased demand for natural resources, particularly energy and water, are threatening the natural environment in most countries. Due to unrestricted urban expansion, water has been generally mishandled in the agricultural and construction processes, that in addition to its scarcity in most Arab countries has started to negatively affect the people. Furthermore, energy usage in Arab cities is extremely inefficient .Directly affecting the private and governmental budgets, energy and water conservation have started to attract the public's interest. As a result, many cities face food scarcity; have trouble managing storm water, and lack public green spaces, which serve as the city's breathing room and crucial locations for relaxation and recreation for its residents.

With the rapidly growing population, and with it the increase in housing demand, has led to the gradual increase in the building and construction industry. The economic and environmental performance of the cities and social wellbeing of their users are affected by the building and construction sector. However, they face several challenges in order to try and avoid and negative impacts on the city. Building sector in countries such as Egypt is responsible to almost 40% of energy consumption and around 35% of Carbon Dioxide emission.

Faced with a changing climate and an increasing number of limitations arising from economic growth and constant human urbanization, the requirement for more efficient environmentally friendly constructions and green infrastructure is becoming more widely recognized, and implementation rates have begun to increase around the world. One strategy that is starting to be acknowledged is green roofs. Green roofs are a sustainable and greener alternative to the conventional flat roofs we see on top of most buildings. Roofs are crucial architectural and structural features of every construction. They define architectural style, shape the city's skyline, and shield the higher floors from rain fall and the sun's heat. They also withstand wind forces and carry a variety of weights for users' activities as well as building servicing equipment. Roofs play an important part in controlling how much energy flows into and out of buildings. They also help in the management of rainfall in urban areas; they can either collect the rain water for future use, direct them to be used in a different context, or waste any precipitation that falls on the buildings' tops.

Rooftops have been found to be closely tied to the concept of sustainable design of buildings and therefore the whole built environment. The materials used during the construction process of the roofs can help control heat loss and gain, thus helping in managing of energy consumption. Green roofs provide ecosystem services in urban environments, such as enhanced storm-water management, building temperature regulation and mitigation of the urban heat island effect. The initial construction cost of green roofs is higher than conventional roofs. Due to energy saved and the longer lifespan of roof membranes, green roofs tend to be a more economical option over the life cycle of the building. Several international green building guidelines have started to include green rooftops as a concept in order to encourage the future use of this

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technology. And it is time for green roofs to be implemented into new constructions in Egypt.

II. OBJECTIVE

This research aims to highlight the benefits of green roofs and how they can positively affect the various ecological problems that are faced in Egypt. It shows how green roofs directly affect the buildings' performance as well as the daily lives of the users. This research also aims at showing the different types of green roofs and their design and construction process, as well as their maintenance, in order for designers to understand the most suitable type of green roof to be used in every situation.

III. METHODOLOGY

This research is based on a literature review of several research papers related to the topic of sustainable roofing in general, and green roofs in Egypt more specifically. The first part of the article is a general theoretical overview of green roofs and why they are important for cities. It discusses the different environmental problems that face cities, and specifically Egypt and how these problems affect the users. It then discusses how green roofs can help eliminate these problems and the various advantages they have along with quantitative data to support these findings. The second part discusses the application of green roofs. Starting from the design phase, where it highlights the most crucial factors to take into consideration when selecting a suitable type of green roof to apply into the building. The next step would be the construction phase, where the different methods of construction according to the type of roof are demonstrated along with the features and advantages of each. The construction part also includes the layers needed for the construction and the purpose of each layer. The last part in the application section is the maintenance where methods on how to maintain existing green roofs for best performance are highlighted.

IV. GREEN ROOFS- A THEORETICAL APPROACH

A. Problems in Egypt

With the rapid development of new and innovative construction solutions, great importance had started to be given towards a more sustainable future. People have started noticing the negative impacts the human population has had on the environment and with that, realized the importance of conserving the natural environment to allow for development of future generations. One of the most impactful aspects is the energy consumption throughout the architectural cycle, starting from the construction process to the daily energy consumption of the users. The constant population growth and increasing urbanization has led to increased energy consumption over the years. And with that, the need for alternative passive climate solution to help control the energy consumption has grown. Thermal comfort within architectural spaces is achieved through several passive solutions. In Egypt, this rapidly increasing urbanization has led to the quick deterioration of the country's environmental state and a rise of a number of problems that negatively affect the citizens over time. These problems include but are not limited to; inefficient food production and distribution, gradual decrease of green spaces and limit of open spaces, increased levels of air and noise pollution.

Air pollution in Egypt is a major cause of concern, with some of the world's worst air pollution, according to international standards Egypt's air pollution can reach up to 20 times worse than the average acceptable range. [4] This increased air pollution not only affects the population's health, but also costs the country's economy a huge amount of money accounting to almost 5 billion Egyptian pounds per year.[12] Another problem that Egypt faces is the electricity consumption. Almost 40% of the total Egyptian's energy reserve is accounted to building and construction, less than which 2% is extracted from renewable energy resources (as shown in Fig.1) [2]. This, along with the hot climate increasing the need for cooling, responsible for over 15% of a building's energy consumption, has led to an increase in the gap between energy production and consumption. This rapidly increasing gap, if not treated, would affect the availability of energy sources over the years. Moreover, Egypt has been reported to have a very low green-space to population percentage which is as low as 0.33 square meters per person, one of the lowest ratios in the world as shown in Fig.2. [3]

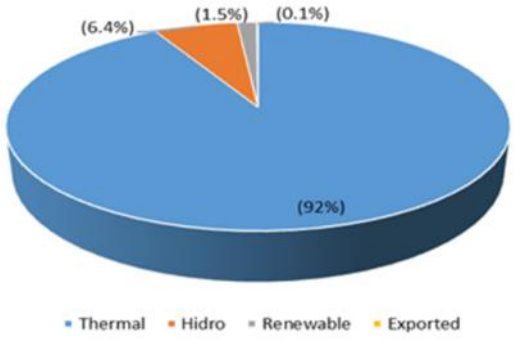

Fig. 1 Egypt's generated energy sources [2]

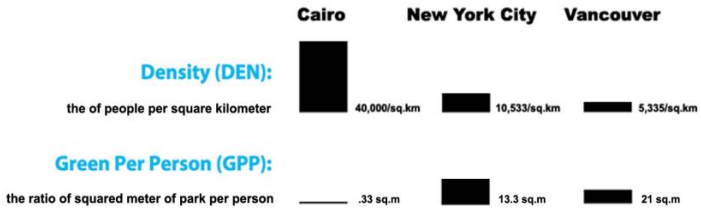

Fig. 2 Density and Green per person ratios in Egypt [3]

Many countries have started to integrate sustainable roofing systems into their design and construction process to try and eliminate many of the environmental issues mentioned above. Roofs are considered one of the envelope's main elements since it protects the building from transmission of rain and solar radiation. With a large surface area that is exposed to the sun all day, roofs present a chance to gain and lose a huge amount of solar radiation;

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they are responsible for 50-70% of building heat gain in a single-story building [2]. Rooftops, and especially in Egypt, have always been used as an unused storage space, where families throw their old furniture and construction remains on flat roofs. This creates a disturbing city image, creates a hazard for building users, wastes potential space and also causes a threat of diseases spread by rodents and other creatures that tend to inhabit unused roof spaces. These roofs that receive a total yearly radiation of over 2409 bankable kWh/m2 per year, with around 3300 hours of full sunshine and hold a great sustainable potential are being greatly misused. Currently, satellite dishes cover almost every rooftop in Egypt, unnecessarily occupying this potential space, a space where solar water heaters can be installed for a price equivalent to that of a satellite dish used by a family. [3]

One roofing method that is widely used in several developed countries is Green Roofs. Germany is known to have the largest version of the green-roof technology, where the industry reaches $77 million in 2008.The area of green roofs in Germany was found to be greatly increasing every year, with an average increase of 8 million square meters annually. With 80% of green roofs maintenance free and able to survive in arid climates, thus being of great cost and energy effectiveness, cities have started integrating green roofs in all new constructions. The city of Hamburg leads a major role among European cities with a decision to transform more than 70% into green roofs topped with vegetation. This decision was implemented in 2015 with 3 million Euros allocated by the city to help construct and renovate building rooftops into green roofs. This decision, as well as other ecological construction measures, was implemented as a way to control the negative environmental effect due to rapid population growth and climatic changes. [9] A green roof is a roof of a building that is covered with vegetation or a growing medium. To enable safe vegetation, it is planted over a damp-proofing membrane. It is usually a self-sustaining system that includes a drainage and irrigation systems. These layers help mitigate the excess solar radiations and prevent buildings from overheating, while providing a green, social space on top of buildings.

B. Effects of green roofs

Implementing green roofs over the huge roof tops spaces that already exist in Egypt can help tackle several problems that people face daily in the city, as well as long term problems that will continue to emerge over time.

1. Improved Air Quality

In a country like Egypt, with air pollution that is increasing daily, the act of breathing clean air has started to become an unimaginable luxury for millions of people. Vegetation on green roofs helps by working as an air pollution filter. There are several ways that implementing a green roof can help lead to an improved air quality. Plants on green roofs trap pollutants from air as it passes through them. Studies have shown that a 100m2 of green roof area can filter and remove almost 20 kg of Particulate Matter; particle pollution that is harmful to human health, from the air annually. This amount of Particulate Matter is roughly the amount emitted by 15 passenger cars during a typical driving year. [3] Another way green roofs improve air quality is by helping decrease emission of green-house gases. The use of fossil fuels to produce electricity, which is used in buildings for cooling, produces harmful air pollutants. By helping decreasing temperature and energy used for cooling, green roofs thus decrease the amount of pollutants produced into the air. Plants are also known to decrease the Carbon Dioxide concentration in the air and increase the Oxygen concentration through the process of Photosynthesis, this helps keep the air cleaner. A study done in Chicago in 2007 using a dry deposition model showed that a total of 1675 kg of air pollutants was filtered by almost 200,000 m2 of green roofs in one year. Fig.3 shows percentages of each pollutant removed monthly.

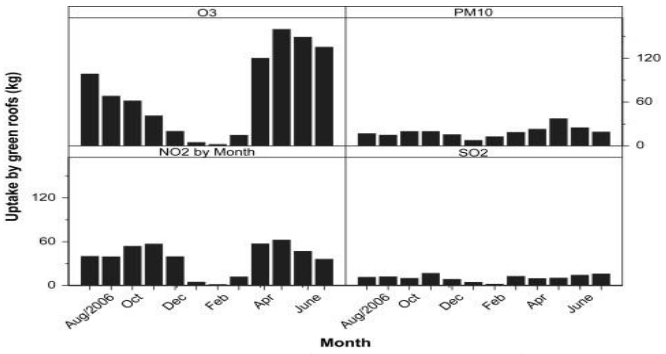

Fig. 3 Monthly removal of pollutants by green roofs [3]

2. Moderation of Energy Consumption

With the climate getting hotter with time, the energy consumed for cooling of building increases. Green roofs help decrease the need for cooling by maintaining a naturally cooler building interior. They help cool buildings by acting as an insulation layer on the buildings' roof, protecting it from excess sun rays and preventing direct heat absorption into upper most floors. A study conducted showed that the addition of green roofs helped reducing the annual energy consumption by 41% compared to that of a traditional roof, while introducing an additional irrigation system into the green roof helped reduce the energy consumption by as additional 20%.[2] . The difference between the energy consumption in a traditional flat roof, a green roof, and a green roof with irrigation system is shown in Fig.4.

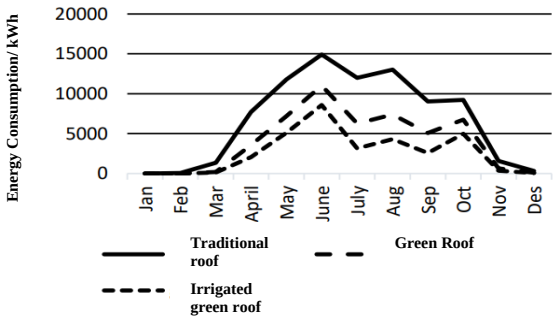

Fig. 4 Energy consumption according to roof type [2]

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3. Green Open Space & Improved Aesthetics

Green roofs can help in playing an important role in the scarcity of green space in many urban areas. Urban green roofs create open areas in the city, which helps to minimize the urban heat island effect and offers the users a connection to the outdoor environment. It provides an additional green outdoor recreational area without the need for addition of any new construction or additional building footprint. They also have the advantage on improving the building's exterior rooftop appearance when viewed from neighboring buildings.

V. APPLICATION OF GREEN ROOFS

Applying a green roof usually is classified in 3 steps, the design, construction and maintenance of green roofs.

A. Designing

Firstly, green roofs are classified into two types according to the substrate depth, which are the extensive green roofs and the intensive green roofs, where the intensive has a deeper substrate, where there could be a real garden as a decorative or farming garden that requires high maintenance, while the extensive green roofs has a shallower substrate layer, with lower maintenance requirement. Starting with the phase of designing a green roof, the first step is to consider the factors affecting green roofs, and help in deciding what plants should be grown and where, which are Wind, Structure and the Use. [7]

1. Wind

Designing according to the wind is a crucial factor to be considered in order to protect green roofs from wind forces to improve its life cycle. There are different systems applied to protect green roofs from the stress of strong wind, which are summarized in the following table:

TABLE I
GREEN ROOF WIND PROTECTION SYSTEMS [17]

Anchoring Systems	Wind Bracing System	Anti-erosion Layer	Use Of Ballasts	Climatic context in the design of vegetation
This system specifies certain plant characteristics to be applied either, as a temporary or a permanent system with specific wind conditions like the foliage, height of the vegetation, anchoring capacity of the root system, the stem and the branches' elasticity.	The angle between bracing and the ground must not be greater than 60 deg. The design of anchorages is carried out considering the action of the wind, with an amplifying factor of at least 1.5, must be countered, by gravity, from the element or from all these, each for their own share.	Some areas are subjected to wind erosion, where the wind, where in this process, the upper continuously eroding layer of soil becomes structure less, then converted into a blowing sand layer. However, by using ant erosion layer, these soil will not be subjected to blowing.	Ballasts are used on the perimeter zones, which are particularly exposed to the wind, with a minimum width of at least 50 cm, which should be used above the drainage layer not the crop layer. One of the examples of ballast material is gravel.	The substrate requires a choice of plant species with higher resistance to drought, in order to consider the wind effect on the water retention capacity of the substrate, the reflected radiation sensitivity and heat accumulation. Moreover, the composition of the plant and their distribution should aim to reduce the wind effect.

2. Structure

Designing a green roof adds an additional load on the building. Therefore, the viability and the cost of installation are two main factors to be determined.

Designing a green roof is normally seen in two cases, whether it takes place in the initial design of a building, where the additional load can be accommodated easily, but if the installation is taking place on an already existing building, then the design of the green roof will depend on the weight capacity of the existing roof, unless it is viable for the owner to upgrade the structure considering that there are two types of green roofs with different weights, the Extensive green roof (60 - 150 kg/msq.) and the Intensive green roof (200 - 500 kg/msq.).

3. Use

The function of the roof will clearly affect the green roof design, as a roof that is designed to retain storm water will be different from the one designed for aesthetic purposes, and these differences will reflect on the required depth of the growing medium, the maintenance and the overall costs.

It is exceedingly vital to use the proper materials and install green roof layers in the correct order to ensure efficiency. The inclusion of technical information for green roof systems as a whole and for each individual component and layer will be found here in the construction phase, where the features, the use and the types of planting will be defined for both types of green roofs, the extensive and intensive green roofs. Moreover, the green roof layers will be precisely described for each type

B. Construction

As green roofs are divided into two types, which are the intensive and extensive green roofs, both have different features, are used for different purposes and not all planting types could be used for both [17]. Therefore, the below diagram will compare both types of green roofs along with the specifications and appropriate use of each:

1. Extensive green roofs

The different features and uses of extensive green roofs is summarized in the following table:

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TABLE II
SPECIFICATIONS OF EXTENSIVE GREEN ROOFS [17]

Features	Used for	Planting
Build up height 50-150mm	Lightweight roof decks	Moss and Sedum
Suitable for large areas	Inaccessible roofs	Moss and Sedum and Herbs
Lightweight	Flat or sloping roofs	Sedum and Grass and Herbs
Easy to install	Reducing water run-off	Grasses and Herbs
Simple to design		
Self-Sustaining plant community		
No irrigation		
No/Low maintenance		

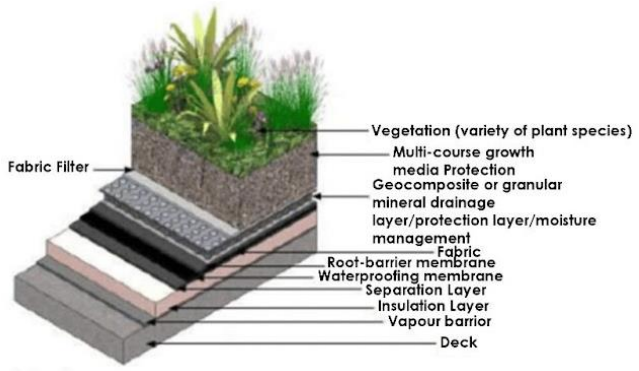

Fig. 5 Layers of Extensive Green Roofs [6]

2. Intensive green roofs

The different features and uses of intensive green roofs is summarized in the following table:

TABLE III
SPECIFICATIONS OF INTENSIVE GREEN ROOFS [17]

Features	Used For	Planting
Build up height 150-1500mm	Natural Gardens	Lawn
Wide range of plants and trees	Recreation and sport	Shrubs
Regular Irrigation	Growing food	Edible Plants
Regular maintenance		Generalist Perennials and grasses
Often indistinguishable from natural gardens		Small deciduous trees and conifers
Usually a mixture of hard and soft scape		
Good insulation properties		

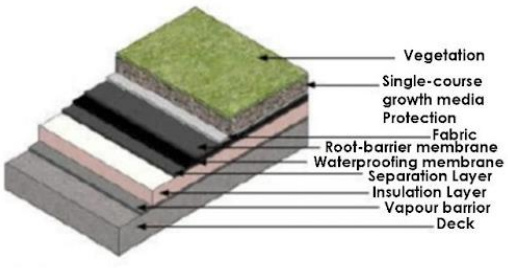

Fig. 6 Layers of Intensive Green Roofs [6]

3) Clay Soil is the main cultivated soil in Egypt. It has good water retaining properties as well as the advantage of

C. Green Roof Typical Layers

Layer 1: Waterproofing membrane

The most important roof layer, which protects the whole building and the green roof itself from leakage. This layer comes in so many formats, where it could be torched down or hot mopped and also so many installations, where it can be used as sheets or fluid applied.

Layer 2: Root Barrier

This layer acts as a barrier on top of the waterproofing membrane, in order to protect the roots digging into the roof, as the roots could result in serious structural damage, and also to protect the waterproofing membrane.

Layer 3: Drainage layer

This layer is mainly used to move excess water to a drain or scupper, then eventually off the roof. In order to determine the best drainage layer, there are some factors that must be taken in consideration first, including:

-The slope of the roof
-Drain quantity and location
-Load capacity
-Desired storm water retention

The drainage layer is responsible for fulfilling the green roofs task to retain and detain storm water, where they hang onto it or slow it down on its way to sewers or natural waterways.

Layer 4: Filter Fabric

The filtering process is quite essential before the water reaches the plants, soil or any growing media, and this process takes place due to the filter fabric, which is basically a cloth that is designed to reduce silts, organics and other particles leaving the system, letting only clean water through.

Layer 5: Growing media

This layer is almost the only layer from all the layers of the green roof that helps in growing healthy plants. This growing media consists of either real soil or any other growing median than can replace soil with the same characteristics, which depends on the plant profile and the designer. Moreover, this layer can also help to lighten storm water load, as it can serve as extra water- retaining material. The most common types of growing Medias that can be implemented in Egypt are: rice husk, pumice and clay soil.

1) Rice husk is abundantly found in Egypt, and is one of the major causes of air pollution due to farmers burning it. It is an organic growing media and its use in green roofs would help minimize this pollution as well as provide a lightweight growing media that allows for ventilation of plants' roots.

2) Pumice is a naturally occurring volcanic rock that contains several elements. It is usually used for its good ventilation properties as well as being easy to disinfect. Sand is usually added to the pumice to provide better drainage. allowing various types of plants to thrive in.

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Layer 6: Plants:

This layer provides space for unlimited creativity; it requires a designing process through the organization of plants with endless possibilities when it comes to the design, aesthetics and function of green roofs. There are factors affecting the decision of choosing the plants type, which is the green roof type whether it is an Extensive or Intensive green roof, the building function, the shade or sun and moisture content.[6]

D. Maintenance

There are maintenance requirements and responsibilities for the vegetative green roof system installer or system manufacturer. For example, the procedures taken for leak detection and repair, due to its importance for the waterproofing membrane, and also the minimum requirements needed for foliage cover after owner acceptance. Moreover, there should be remedies specified In case the cover requirements are not specified by the end of the established period, and also requirements that will achieve a continued performance should be specified, which should include effective drainage, horticultural viability, soil thickness, etc., required longevity for constituent components, while plant maintenance is different for each type of green roof.

1. The Intensive green roof plant maintenance

Its' maintenance is similar to the requirements of ground-level landscaping, which is more frequent and requires more consistent care than the 'Intensive' green roof, where a horticulturist or landscape professional can assist by providing recommendations for the installation of specific garden-roof according to the desired type as shown in figure 6.

2. The 'Extensive' green roof plant maintenance

The best type of maintenance for the Extensive green roof is the proactive maintenance, which involves basic green roof maintenance, such as Watering, Weeding and Plant care. The type of maintenance activities required depends on the planting and regional climate. The three basic planting maintenance activities are applied for 'Extensive green roofs as shown in figure 5..

a. Watering

In many regions, a built in irrigation system is not needed for the extensive green roof. However, there is a general rule, where it shows that if natural precipitation is <0.5 inch in a 10-15 day period during the growing season, water may be needed or plants will fail. Temperatures above 85 degrees or very windy locations will need to be watered sooner. For all green roof systems a permanent irrigation system is needed for ,where supplemental irrigation should be apply with an application of 1 inch of water once per week until there is a reveal more moderate precipitation patterns.

b. Weeding

Every 2-4 weeks during the growing season the green roof should be visually inspected and spot-weeded. In most climates, for green roofs <5,000 sf, from 10-20 man-hours per year will be needed for weeding. Weeding is a great method in order to inspect roof drains and also ensures that the water that the wasted water which is not used by green roofs can drain freely off the roof.

c. Plant Care

Fertilizing and trimming are the two primary components for the green roof plant care. The process of fertilization should be applied at least one time a year specifically in spring for the first 3-5 years directly after the installation of the green roof, after that the schedule of fertilization can be reduced depending on the soil testing and the performance of the plants.

VI. DISCUSSIONS

It is mentioned that green roofs are not applicable in Egypt due to its climate. However, through this research, it is stated through several references that green roofs are applicable in various climates, where each continent is classified into zones and each zone requires different planting types that could survive in certain climates. This classification started in USA, which is called the USDA hardiness zones, this method classifies planting types according to the temperature in each zone, and the same zoning division is applied in Africa. Fig. 7 shows the plant hardiness levels in Africa, showing that Egypt has a climate that is suitable for planting. This study states that the failure of previous green roofs in Egypt was due to the failure of choosing the right system suitable for the growing plant zone, in addition to the failure of the system maintenance, however it was not because of the unsuitable climate of Egypt.

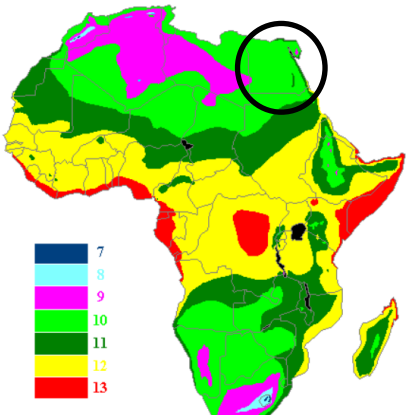

Fig. 7 Plant Hardiness Levels in African Countries [8]

VII. RESULTS

Through literature searches on previous articles, it was clear that Egypt is lacking an adequate green space per inhabitant, equivalent to 0.33 m2 per person, which is one of the lowest proportions in the world. Not only the lack of green space was found to be the only problem that will be solved by applying green roofs, but also previous researches stated that Egypt rooftops have high contribution in the Energy consumption and environmental hazards, as they are poorly insulated, leading to a higher need for energy and also inappropriate usage of rooftops is contributing to Egypt's air pollution. Therefore, increasing the application of green roofs in Egypt was stated to be a solution to several problems, so according

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to the aim of the article which was focusing on the problems of roofs in Egypt that green roofs can solve, there are several specifications for a green roof that is most suitable for applying it specifically in Egypt , which was according to the study of different roof types through the application of green roofs that was previously mentioned in the article. As the steps of applying a green roof was illustrated in the article on 3 phases:

1- Design (Extensive - Intensive)
2- Construction (Different layers of green roofs)
3- Maintenance (Steps for continued efficient performance)

The results of this research showed that the best performance achieved by applying the extensive green roof type using the Rice husk as a growing media moisture, which showed in the results on the below graph the best results in reducing energy consumption in the climate of Egypt, the Rice husk is one of the layers mentioned in the construction section. In the maintenance part, both types of green roofs were mentioned with a comparison between the maintenance procedures taken for each type, where the typical three steps were:

1-Watering
2-Weeding
3-Plant care

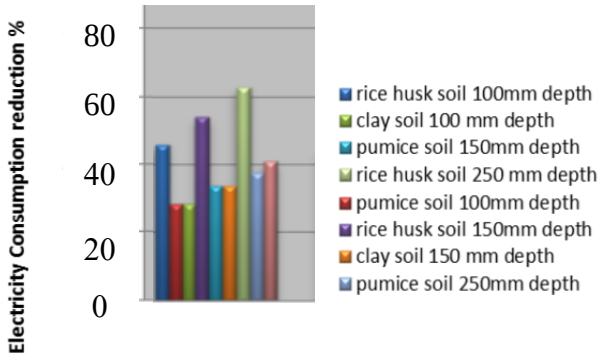

Fig. 8 Percentage of Reduction of Electricity Consumption According to Growing Media [10]

VIII. CONCLUSION

To conclude, the constantly increasing population and urbanization has led to the increased energy and resources consumption. Therefore new sustainable methods are being introduced to help save these resources and help ensure a better future for coming generations. Roofs being the cover for every building hold a very important role in the energy exchange of a building. Planting different types of veggies and fruits, or simply any type of green plant, on our roof can change a lot of things. Roof gardening has many valuable advantages that directly affect the lives of users in the city. The vegetation in green roofs helps to filter and remove harmful pollutants from air leading to a better air quality free of pollution. Green roofs also help reduce energy consumption for cooling by preventing conduction of sun heat directly from the sun into the interior spaces of the top floors, thus helping keep the space cooler and reduce the need for artificial cooling. Green roofs also act as an aesthetically pleasing green area for users to enjoy the outdoors without the need for new construction. To many architects, Roof gardens seem like the perfect solution for a better sustainable performance. However, they cannot be constructed unless the factors influencing their design and construction are studied carefully through understanding the different types of green roofs, where the study showed clearly the different green roof layers to be applied for different types of buildings in Egypt according to the building function, the difference between both types was clearly illustrated in terms of features, use and planting, and finally coming to the maintenance, explaining clearly the basic maintenance activities for any green roof, in order to ensure a good life cycle for green roofs in Egypt.

LIST OF FIGURES

LIST OF TABLES

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