Mansoura Engineering Journal

Volume 49 | Issue 2 Article 4

2023

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Recommended Citation

Mohammed, Abdullah Badawy (2023) "Green Roofs to Treat the Local Dwelling Environment Problems Within Egypt's Vision 2030," *Mansoura Engineering Journal*: Vol. 49 : Iss. 2 , Article 4.
Available at: https://doi.org/10.58491/2735-4202.3139

ORIGINAL STUDY

Green Roofs to Treat the Local Dwelling Environment Problems Within Egypt's Vision 2030

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Abstract

The continuous increase in the building ratio to green areas led to disappearing green spaces, and the vertical and horizontal expansion of dwellings as an urgent demand in cities led to various environmental, social, and economic risks. Hence, the research aims to facilitate the application of green roofs for their positive role in treating these risks and improving the performance of dwelling projects and all buildings according to the climate and local conditions. Therefore, the study addressed the history, concept, and significance of green roofs, besides their benefits on architectural and urban levels, according to the three sustainability pillars and the climatic functions of plants. Hence, the execution details of their types and systems were explained. The study conducted a practical experiment to compare the thermal performance of green and traditional roofs, followed by a comparative analysis among international experiences to benefit from them locally at the level of details, concepts, and execution mechanisms. Finally, two executive proposals within a local youth dwelling model were presented as initiatives for activating execution from now, identifying the challenges and opportunities with cultivating roofs and making clear the importance of individuals and governments adopting its application and supporting it financially, technically, and socially.

Keywords: Cultivation, Dwelling, Egypt's vision 2030, Green roofs, Housing, Sustainability

1. Introduction

The need to adopt the concepts and principles of sustainable or green architecture in the construction industry has become one of the priorities that must be worked on in our cities according to Egypt's Vision 2030 to establish environmentally friendly cities, projects, and buildings to mitigate pollution manifestations. Also, the vertical and horizontal expansion of dwellings as an urgent demand in cities led to numerous risks and problems, such as increased concrete structures that deplete energy resources, social isolation, and polluting and destroying the environment and human life (Alim et al., 2022; Carpenter, 2014; Langston, 2015). Besides, the lack or decrease of green spaces, cultivated roofs, and growing carbon emissions cause global warming (Aly and Dimitrijevic, 2022). In contrast, sustainable or green concepts and principles focus on making the most of environmentally conscious techniques for designing buildings to respect the surroundings and reduce the consumption of energy, materials, and resources while decreasing the impacts of construction and activities on the environment and public health while organizing compatibility and harmony with nature (Mohammed, 2021).

Hence, green roofs provide many benefits, including environmental ones, the most important of which is providing thermal insulation for the building, as they warm it during the winter and cool it during the summer. Thus, they reduce energy requirements and consumption as an economic benefit, contribute to the absorption of rainwater, and secure a suitable environment for wildlife. On the other hand, it has social sustainability benefits

List of abbreviations: dB, A decibel is a unit to measure the relative loudness of sounds; m^2, it is the area of a square with sides one meter in length; UHI, urban heat island.

Received 18 August 2023; revised 23 October 2023; accepted 9 November 2023.
Available online 27 December 2023

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https://doi.org/10.58491/2735-4202.3139

since these roofs give a unique character to the city that raises its aesthetic value, improves its general appearance, leaves areas for social interaction, and improves the psychological state and mood (Langston, 2015). Also, benefits on the level of economic sustainability include the exploitation of the roofs of buildings, which represent ~20–25 % of the total urban surface area in general, and sustainably planting them with fruitful plants to relieve pressure on the local economy and improve income for individuals in light of the current economic challenges and the climate change problems negatively affecting the quality of life in Egypt (Goda et al., 2023). Consequently, the cultivation technique of roofs in buildings achieves all the aesthetic, recreational, economic, health, and other benefits people aspire to. It is one of the most important and worthy solutions to achieve the visions and principles of sustainable and green architecture. Accordingly, a lack of green spaces would be addressed and compensated for within cities due to increased building densities.

1.1. Literature review

There are many previous studies on green roofs, each focusing on one of the pillars of sustainability separately or some of these pillars combined (environmental, economic, and social) both on an architectural and urban level. However, most of them are concerned with the first pillar associated with the impact of green roofs on the local or city climate. The possibilities of these new techniques are to reduce the effects of the urban heat island (UHI) and the thermal difference between the city and the countryside. Hence, knowing the thermal discrepancy between the roofs is necessary to estimate the impact of each roof and its impact on the urban climate based on a miniature model for the study and indicating the type of local plants appropriate for each region (Mazzeo et al., 2023; Shao and Kim, 2022). Accordingly, it has been identified as the best technique to eliminate or reduce the UHI phenomenon. This phenomenon causes an increase in the temperature of the external environment due to the emissions and reflections of all devices and surfaces exposed to heat and sun radiation (Cakmakli and Rashed-Ali, 2022).

Also, in many studies, the measurements of temperatures and relative humidity inside and outside buildings using green roofs have been examined and compared using a model with a specific area divided equally into two regions for green and traditional roofs to obtain thermal data on the capability of the green roof to reduce the town temperature and the thermal difference from the city outskirts and increase the percentage of green spaces (Alim et al., 2022; Almaaitah and Joksimovic, 2022; Mahmoud, 2022; Zhang et al., 2022). In other studies, a group of roof models has been studied: the green roof in two cases, with and without plants (soil only), and the concrete roof using miniature models. Temperatures were measured using an electronic thermometer and a thermal camera. The measurements have been compared between the materials of the different roofs and with the outside air temperature to specify the capability amount of the green roof to reduce UHI; besides, this type of roof is a new and meaningful technique that provides environmental, economic, and social benefits (Cakmakli and Rashed-Ali, 2022; Vardhu and Sharma, 2023; Wang et al., 2022). Also, Langston has shown that residential green roofs can be justified separately or together on significant economic, social, and environmental standards when included within a holistic approach. They can be credited with influential contributions to broader sustainable development goals (Langston, 2015).

Despite the diversity of pursued objectives by planners and designers in providing and increasing green spaces in hot, dry, and desert areas, as the local climate dictates, the ultimate purpose is to achieve environmental aims to attain human comfort, with many economic and social benefits. Accordingly, this requires initiatives due to the scarcity and lack of examples and proposals for implementing such technologies as a pillar or starting point towards spreading their application and implementation. Therefore, many countries, such as Hong Kong, Germany, and Singapore, have realized the necessity of cultivating roofs as a top priority within the framework of sustainable development plans that achieve an enormous number of green spaces within dwelling projects (Alim et al., 2022; Mazzeo et al., 2023; Mahmoud, 2022). Consequently, it can increase the percentage of green spaces in existing and emerging cities.

2. Research problem

With the continuous increase in the number of people living in the urban centers of cities, the rising usage of transportation and communications, and the vertical and horizontal expansion of dwelling projects, there has become an urgent need for growth in towns at the expense of green spaces, thus increasing the ratio of built-up areas to green spaces (Goda et al., 2023; Shao and Kim, 2022; Mahmoud, 2022; Wang et al., 2022). The information gathered regarding green areas in Cairo shows that Cairo lost

910 894 m^2 of its already green space between 2017 and 2020. The individual share of the green area fell from 0.87 to 0.74 m^2 as the population increased. Green area loss was most severe in Heliopolis and East Nasr City. Between 2017 and 2020, East Nasr City lost 311 283 m^2, whereas Heliopolis lost 272 274 m^2 (Aly and Dimitrijevic, 2022). Consequently, these led to health, environmental, social, and economic risks (Alim et al., 2022; Carpenter; Langston, 2015). The most important of these risks are the increasing difference in temperature between the countryside and the city (the UHI phenomenon); lack of oxygen; increasing carbon emissions; boosting energy consumption as a global issue; and disappearing social and aesthetic spaces (Al-Kayiem et al., 2020). All this prompts the search for solutions or complementary techniques to establish and increase green areas.

3. The aim and objectives of the research

The study aims to activate the execution of green roofs due to their positive tangible and moral role in addressing environmental, social, and economic problems and risks, promote their application in dwelling projects particularly and all kinds of buildings generally, and improve the performance of these buildings and projects according to the climate and local conditions. This aim is achieved through the following objectives:

(1) To identify the concept, role, and types of green roofs and consider their benefits related to the three pillars of sustainability and the climatic functions of plants;
(2) To compare green roofs with traditional roofs; also, the most significant international experiences according to impact on the environmental, economic, and social aspects; and the most influential details, design and execution concepts, and application mechanisms to locally benefit them; and
(3) To apply the green roof technique to one of the dwelling models as an example of a project type as an initiative through presenting executive proposals, identifying the challenges and opportunities, and assuring the importance of adopting its application and supporting it financially, technically, and socially.

4. Methods

The study followed an inductive approach to study and investigate the concept and importance of green roofs and the benefits achieved through them at the architectural and urban levels, according to the pillars of sustainability and the climatic functions of the plants. Many details related to their types and construction techniques were explained and defined.

Then, the research relied upon an analytical approach while executing the practical experiment for this technique and its most beneficial consequences by comparing the thermal performance of the green roof with the traditional one in the local Egyptian environment. Besides, the study compared the most significant international experiences in rooftop cultivation to benefit from them locally. The most influential concepts, objectives, techniques, benefits, and execution mechanisms for them were clarified, whether for environmental, social, or economic purposes, to make clear the importance of individuals and governments adopting and supporting such a technique financially, technically, and socially.

Eventually, the study utilized the deductive applied approach to benefit from all stages of the research during the application at one of the local dwelling models as an execution mechanism to make two executive proposals as two models for execution on the roof of any residential building to handle the possible challenges and benefit from opportunities for roof cultivation to be green.

5. Definition, and benefits of green roofs

The green roofs of buildings appear to be a modern phenomenon, but their emergence dates back several centuries, starting with the Ziggurats four thousand years ago BC, then the Hanging Babylon Gardens, a giant palace planted on its roof with plants, trees, and flowers of all shapes and types (Mazzeo et al., 2023; Magill et al., 2011; Mohammed, 2023). Likewise, Le Corbusier and other architects began to build buildings with flat roofs, so they arranged gardens on those roofs (Almaaitah and Joksimovic, 2022). A green or living roof is a building's top surface covered wholly or partially with plant medium grown on a waterproofing layer (Langston, 2015). Various kinds of plants and flowers are cultivated on the green roof, depending on the thickness of the substratum (growth medium). Green roofs fall under the category of garden buildings (Alim et al., 2022). Green roofs have higher initial costs than traditional ones, but they have a variety of significant and potential benefits that balance the high cost (Mahmoud, 2022). This technique works to achieve all that a person aspires to in terms of aesthetic, recreational, economic, health, and other benefits according to the three pillars of sustainability, as shown in Table 1. The most common purpose of designers is to preserve the environment, achieve thermal comfort, and reduce heat loads for buildings, daily uses, and activities by preventing high heat from entering buildings and mitigating the UHI effect between the city and the countryside (Shao and Kim, 2022). The solution was to increase green spaces by creating green roofs on the roofs of buildings. Considering Egypt's Vision 2030 and adhering to the goals of the Sustainable Development Agenda, the first goal is quality of life by improving the quality of life of Egyptian citizens and promoting their living standards. Furthermore, the fifth goal is environmental sustainability through an integrated and sustainable ecosystem.

It should be noted that the issue of the proportion of enough green spaces per person in urban areas remains a matter of controversy. In this context, the Los Angeles Forum for Architecture and Urban Design believes that in their study on city parks, one of the crucial metrics was the percentage of residents who walk within 15 min of walking to green spaces as an indicator of the quality of the urban environment (Mahmoud, 2022; Zhang et al., 2022). In effect, this relates to the issue of leaving insufficiently dense and densely populated areas for seemingly adequate city-wide spaces (Alim et al., 2022). Locally, in the existing cities, the perperson share ranged between 0.5 and 1.5 m^2. However, in the new ones, it was between 7 and 13 m^2. Thus, as stipulated by the National Organization for Urban

Table 1. The benefits and importance of green roof technique on the architectural and urban level according to the sustainability pillars (Langston, 2015; Goda et al., 2023; Mazzeo et al., 2023; Shao and Kim, 2022; Cakmakli and Rashed-Ali, 2022; Rollin, 2009).

No.	Sustainability pillars	Benefits
1	Social Pillar	To give a distinctive general character to the city, region, or neighborhood. To promote social interaction and interaction with nature. To provide opportunities for socialization. To achieve physical and psychological comfort. To provide recreational spaces and reduce stress. To provide clean air in urban areas. To fulfill green spaces that reduce heart rate and blood pressure. To minimize particulate matter and particulate matter polluting the air. To add aesthetic value to buildings. To increase the percentage of green spaces per person. To provide easily accessible green areas.
2	Environmental Pillar	To reduce rainwater runoff and purify it from suspended pollutants. To store water and then return it to the atmosphere by evaporation. To minimize pressure on rain drainage networks by storing rest and draining the rest at lower rates than the traditional roof. To reduce heat loss during the winter. The plant surface disperses the sun's rays meaning the heat passing to the roof is as low as possible. To thermally insulate, improve the climate during the summer, and reduce the air temperature inside and outside the space. To absorb solar radiation means that the rays passing to the roof are stored in the plant and soil layer to perform the evaporation process of the existing water. To reduce the thermal difference between urban areas in large cities. To improve air quality by purifying it from harmful substances, particles, and substances, as it reduces greenhouse gases, carbon dioxide, and oxygen production. To isolate the sound in a satisfactory natural way and reduce noise.
3	Economic Pillar	To extend the life of the roof (extending the structure life). To increase the building's value due to its aesthetic appearance. To save needed fuel for heating and cooling buildings. Cost savings using recycled materials. To provide crops needed by homes or restaurants. To consider as an investment project according to the cultivated area as a source of income for families and individuals. To Manage rainwater by controlling it. To achieve good insulation of buildings in terms of sound and reduce noise, especially in areas close to airports and others.

Harmony within the principles and standards for urban coordination of open areas and green spaces of Egyptian Building Law No. 119 of 2008 and its executive regulations, it did not achieve the minimum per-person green area of 7 m^2 in the existing cities or 15 m^2 in the new ones.

6. Climatic functions of plants or green areas

Plants carry out many functions and processes to control the climate, including:

(1) To reduce the temperature (Mazzeo et al., 2023);
(2) To provide shade, disperse direct light, and absorb solar radiation (Shao and Kim, 2022; Almaaitah and Joksimovic, 2022);
(3) To transfer less heat into the building compared with other surfaces or white color (Zhang et al., 2022);
(4) To reduce the rainwater runoff into the streets and filter the rainwater from its suspended pollutants (Vardhu and Sharma, 2023);
(5) To filter the air of harmful substances and polluting particles by reducing greenhouse gas emissions such as carbon dioxide in the atmosphere and releasing oxygen (Al-Kayiem et al., 2020; Dawson et al., 2022); and
(6) To insulate sound and reduce noise in the spaces below them (Langston, 2015).

7. Types and systems to construct green roofs

The two main types of classification of green roofs are according to their construction, installation method, soil thickness, purpose, plant diversity, and building condition. The first type is farming systems with field soil, the most famous of which are intensive and extensive roofs. The second type is urban farming systems that depend on field soil alternatives, the most famous of which are environment farms, hydroponic, and aeroponic farming systems.

7.1. The first type: cultivation in field soil (Intensive or extensive)

The systems constructed on the building roof ensure that their design is suitable for the dead load of the planting layers, the construction quality of the foundation layers, and their compliance with the technical specifications, as shown in Fig. 1, which are arranged from bottom to top (Zhang et al., 2022):

(1) A waterproofing membrane (minimum thickness of 3−4 mm);
(2) Root barrier: a protection layer for two layers of moisture insulation and root penetration (geogrid, geotextiles, polystyrene) with a minimum thickness of 4 mm and a pressure greater than 150 kg/m^2;
(3) The drainage element is granular materials with a thickness of 6 cm and a minimum weight of 150 kg/m^2 for smaller roofs or regular units of polystyrene (2.5−12 cm; the weight of large roofs is 20 kg/m^2);
(4) Filter fabric: a filter layer allows the passage of water only from the planting soil;
(5) Growth substrate: cultivation soil thickness is determined after choosing the cultivation system, according to Table 2. Also, it is possible to combine the three systems in the same place or project according to the target plant diversity and the roof suitability for the system requirements; and
(6) Vegetation layer: its type varies according to the green roof type, the purpose of its use, and the local climate.

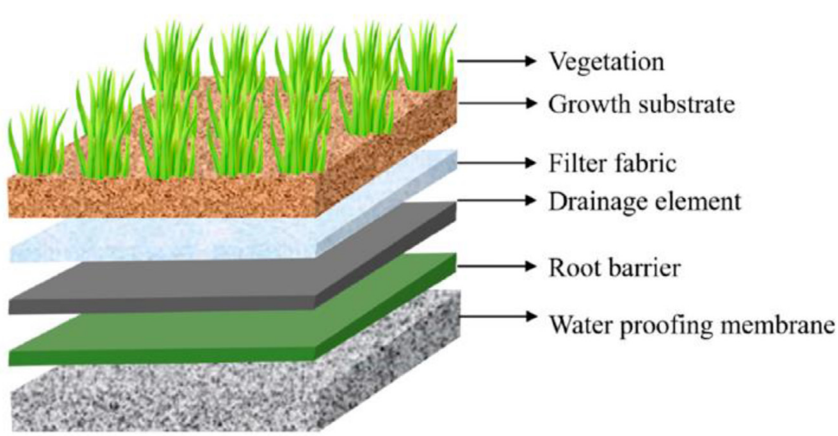

Fig. 1. The field soil cultivation layers (Al-Kayiem et al., 2020).

7.2. The second type: urban farming

It is mainly for use in cities, not the countryside. Its types are systems of farms in different environments, hydroponics, and aeroponics.

7.2.1. Systems of farms in different environments or cultivation in different environments

Systems depend on field soil alternatives and have a similar composition, as previously shown in Fig. 1. The first alternative is organic soil, such as peat moss, rice turf, or coconut fiber, and the second alternative is inorganic soil, such as sand-perlite-glass wool. Otherwise, mix the two types to reach a suitable kind characterized by being lightweight, rich in nutrients, low in water consumption, retaining water, good aeration, good drainage of excess water, easy cleaning, and low maintenance. Furthermore, it takes different forms for cultivating various crops throughout the year, such as systems of beds, bags, packets, hanging sacks, pots, barrels, and containers (Alim et al., 2022).

7.2.2. Hydroponic systems

Systems depend on cultivation in an aqueous medium containing the needed nutrients for the plant, or the so-called 'nutrient solution' (Carpenter). It has a high economic return and is a good option over traditional cultivation for easy control of working conditions and insect infestations, as shown in Fig. 2.

7.2.3. Aeroponics systems

Its idea adopts a multi-story vertical plastic pipe structure. The floors disconnect the rings on which the plants hang, preserving roots in a soilless growing medium. The plants are nourished by spraying roots (Mahrous Ali, 2022). This type has additional advantages over hydroponics; it needs the smallest area, as shown in Fig. 3.

Hence, the urban farming type is superior to the cultivation type in field soil in important points concerning lightweight, less water consumption, fertilizers, and pesticides, and higher productivity/ m^2 of healthy products, which makes it the best and most appropriate option for cultivating the roofs of existing buildings in a country such as Egypt that suffers from the difficulty of achieving self-sufficiency for some crops, a lack of water, and high prices of fertilizers and pesticides. Most buildings are not qualified to bear the field cultivation loads, and the residents are not competent to deal with these roofs.

Fig. 3. Aeroponics systems (Mahrous Ali, 2022).

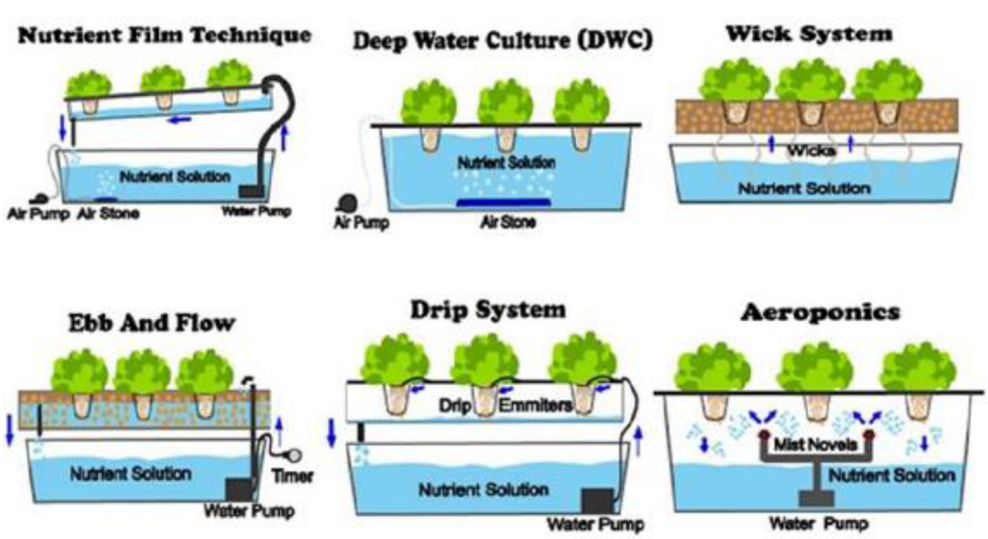

Fig. 2. Hydroponic systems (Mahrous Ali, 2022).

8. Field study as a practical experiment to compare the thermal performance of a green roof with a traditional roof

The study implemented a practical and field experiment with green roofs in the local environment, which has high temperatures in the summer and a lack of vegetation. The concept of the experiment was to compare the thermal performance of the green roof with that of a traditional roof made of concrete with ordinary finishing layers since this type of roof is common in most local buildings. Also, this experiment considers an applied example of the urban cultivation type of the system of farms as the second executive proposal coming later. The stages and conditions of the experiment were:

(1) The experiment location is on the roof of a residential building model for youth dwelling in the semi-desert region, a region with intermediate characteristics between the climatic regions of Egypt and the highest temperature fluctuations.
(2) A cultivation system was chosen that follows the environmental farming systems; the container system, which uses locally made units, as shown in Fig. 4. They are made of galvanized metal sheets with a height of 0.30 m and dimensions of 0.80 * 2.10 m. As four metal boxes were used, the weight of one container reached 60 kg to form an area equal to 6.72 m^2 as a green roof;
(3) The Kochia plant was chosen for cultivation on the green roof due to its rapid growth in hot climates and its tolerance to high temperatures. It is suitable for the local atmosphere in Egypt and has many names, including the paradise broom; the scientific name '*Bassia scoparia* or Kochia scoparia';
(4) Peat moss soil was used in the boxes as a planting medium, with a thickness of 28 cm. Also, peat moss is used when soil drainage is poor. In addition, if the soil contains diseases that can kill young plants, peat moss is highly absorbent. It can hold water better than other types of soil. The peat moss provides a sterile growing medium as it does not include any chemicals or weed seeds. Therefore, an ideal plant culture medium, particularly for plants that are weak or require special care;
(5) Holes were made to drain excess water from the bottom of each box. These holes were protected by a group of small aggregates at the drainage hole top, as shown in Fig. 5, to prevent clogging of the holes with soil or sediment and to collect excess irrigation water and reuse it again;
(6) The metal boxes were isolated from the outside with white foam boards for thermal insulation (50 cm wide × 50 cm long × 5 cm thick) with a density of 8 kg/m^3 to protect and reduce the effect of temperature and direct solar radiation on the conditions and the results of the experiment as much as possible;

(1) Using electronic thermometers that measure temperature and relative humidity and a 1 m long wire with a sensor attached at the end. Records were taken during June, July, and August every 10 days, meaning three readings every month at 12:00 PM and 12:00 AM, respectively; and
(2) Five locations for taking sensor readings were recorded, as shown in Table 3. The first place was above the plant by 20 cm, the second place was on the cultivated soil surface, the third place was in the room under the green roof, the fourth place was on the traditional roof surface, and the fifth place was in the space below the traditional one.

The results of the field study of the two different roofs previously executed and discussed were as follows:

(1) The green roof technique was used during the three study months of June, July, and August; the difference between the highest average

Fig. 4. The container Design (Author).

Fig. 5. The foam boards around containers and small aggregates at the drainage hole top (Author).

Table 2. The requirements for each system are based on field soil (Langston, 2015; Zhang et al., 2022; Magill et al., 2011).

Features	Extensive roof	Intensive roof
Plant diversity	Small plants/ weeds/shrubs	Plants/trees/ shrubbery
Weight	Light 60–150 kg/m^2	Heavy 180–600 kg/m^2
Thickness	5–20 cm	14–40 cm
Cost	Low	High
Irrigation	Low consumption and regular	High consumption and cycle
Maintenance	High	Low

temperature of 29.7 °C and the lowest average temperature of 19.0 °C during most days did not exceed 10.7 °C;

(2) The highest temperature recorded for the green roof was 38.2 °C;
(3) In the traditional ceiling, the average temperature difference between the highest average temperature of 45.9 °C and the lowest average temperature of 29.2 °C on the same day reached more than 16.7 °C on some days of the experiment;
(4) The highest recorded temperature for a traditional ceiling was 47.4 °C;
(5) The temperature difference between the green roof (34.4 °C) and the traditional one (45.9 °C) reached 11.5 °C at the highest temperature recorded for them;
(6) The average temperature difference at noon between the two types of roofs is 10.7 °C;
(7) The average temperature difference between the top and bottom of the traditional one reaches more than 10.2 °C; and
(8) The average temperature difference between the top and bottom of the green roof did not exceed 5.5 °C.

9. Case studies and international experiences

The study followed a comparative analysis of the most significant international experiences in the cultivation of roofs and the most crucial application mechanisms within them to expand green roofs, whether for environmental, social, or economic purposes. The significance of these experiences is due to their role on a large scale within the country, especially legislation and motivating laws, and the importance of governments adopting the application of this technique and supporting it financially, technically, and socially, which was evident in the evaluation of the results of this technique within the projects of those countries, as in Table 4, to apply it locally.

From the analytical comparison of the projects presented in Table 4:

(1) They tried to take advantage of the climate impact of green roofs to reduce the UHI impact.
(2) They also achieved social, aesthetic, psychological, recreational, and economic benefits through saving energy and water and improving the work environment, which increases productivity.
(3) Also, plants and crops that are suitable for the local climate of each region may not be appropriate for another one, such as in Egypt, where it is hot and dry.
(4) However, many concepts, design principles, and initiatives can be extracted from these experiences.

Hence, it turns out that the fields of profiting from these studies are possible and diverse, and they call for combining them and benefiting from the field experiment results locally between the green roof and the traditional one previously dealt with to reach the best results at the local level according to Egypt's 2030 vision.

10. Executive proposals on a local dwelling model as a mechanism for executing green roof technique

Therefore, expanding green roofs, whether for environmental, social, or economic purposes,

Table 3. Average readings every ten days during the three months in the places specified for the thermometer location through the green and traditional roof (Author).

		Average readings over a month (°C)					
		June		July		August	
Roof type	Thermometer locations	AM	PM	AM	PM	AM	PM
Green	Above the plant by 20 cm	25.7	33.9	27.5	34.7	28.2	35.2
	On the soil surface	24.2	32.0	26.2	33.0	27.2	34.4
	The room under the green roof	19.0	26.7	21.9	27.5	23.3	29.7
Traditional	The traditional roof surface	29.2	36.6	32.7	39.7	34.4	45.9
	The space below the traditional one	23.8	31.9	26.9	32.6	28.5	35.7

Table 4. The concepts, objectives, techniques, and benefits of projects that executed green roofs in several countries are international experiences (Rollin, 2009; Dawson et al., 2022; Murodovna, 2022; Peters, 2017).

Project details and design concepts	Project			
	The underground garage roof of a residential complex in Singapore	Green roof of a commercial building in Zaragoza, Spain	Green roof of a finance company in Germany	The green roof of the Humber Hospital building in Canada
Definition, concept, and green roof design	The main design feature is the presence of a large green landscaped ecological deck between the blocks that conceal the parking underneath, as in Fig. 6. The roof garden constitutes 15 460 m^2, or 27.3 %, of the site area, of which 7460 m^2, or 48.6 %, are for green areas and landscaping. It has spaces for seats, open and adult education, fitness centers for the elderly, children's play areas, perimeter paths for walking and picnics, all residential blocks, and a 660-m jogging track.	The buildings are designed with organic shapes with a wide green roof that takes a strip shape with separate small green roofs, as in Fig. 7. It includes different categories of water distribution methods and recreationally shaded spaces. The garden area is 71 000 m^2, of which 11 000 m^2 is covered with wood-covered paths for picnicking, consisting of lawns and some shrubs. Solar cells were integrated into the garden design in a harmonious manner that did not cause any visual distortion.	The project encompassed residential apartments, an office building, and advanced environmentally friendly techniques. It is one of the first buildings to achieve the common objective of working in a green environment with the luxury of living in the middle of a big city, as in Fig. 8. The garden area is 1950 m^2, distributed at different building levels. It is distributed on the garage roof above the ground and on the roofs of offices and residential apartments that enjoy an open view of the apartments to their owners as green lawns and playgrounds for children. It won the country's 2014 Green Roof Prize.	The first fully digital hospital in North America, as in Fig. 9. The green roof can be seen in most patient rooms and treatment areas, covering the different levels of the building.
Objective	This project is one of the most significant public dwelling projects developed by the Dwelling and Development Board to provide a better living environment by creating worthy and sustainable design and considering society's nature in the first place.	Benefit from the advantages of the green roof due to its environmental and economic benefits. Sustainable treatment of rainwater, as the amounts of rain falling in Spain are distributed unevenly, which leads to severe environmental problems, the most important of which is the problem of floods and the problem of rainwater treatment. Therefore, the water problem had to be dealt with responsibly and sustainably by using green roofs to collect water temporarily, as rainstorm management techniques played a prominent role.	Vegetation integration into the city structure is an influential contribution to improving the climate, water balance, and aesthetic appearance given by green roofs to the building users and the residents of the surrounding buildings.	The hospital achieved Gold LEED Certification, considering the efficient use of resources such as energy and water and reducing greenhouse gas emissions.

(*continued on next page*)

Table 4. (continued)

Project details and design concepts	Project			
	The underground garage roof of a residential complex in Singapore	Green roof of a commercial building in Zaragoza, Spain	Green roof of a finance company in Germany	The green roof of the Humber Hospital building in Canada
Green roofing technique	The intensive cultivation system was used, which consisted of a waterproofing layer, a root-blocking layer, and a typical drainage layer, which was placed directly on the isolation layer to create the necessary space between the planting layers, a filter layer, and a 10 cm thick soil layer. Drought-tolerant plants, shrubs, and small trees that require minimal maintenance and care were selected.	Intensive green roof systems were used within a soil layer of 25 cm thickness, a root control layer, a water drainage layer, and a filtering layer. Medium-growing plants, such as shrubs and flowers, requiring minimal maintenance and care, were used.	Advanced green roof systems were used with upper and lower watering systems within the drainage layer. A mechanical system was adopted that prevents water loss even through evaporation by collecting rainwater in tanks under the plant layer. The roof components consist of a protective film, a root inhibitor of 0.8 mm thickness, a drainage layer of 10 cm, and a filter layer to prevent soil erosion. And a soil layer of 30–40 cm and a layer of plants and shrubs. The thickness of all layers is 45 cm, which allows the planting of small trees to grow for about thirty years without replacing or changing them.	The project includes a system of extensive green roofs. It consisted of a root blocker, a drainage layer, and a filter layer to prevent the soil from descending, thus using a light soil layer and a layer of weeds that do not require deep soil.
Benefits	It provides relief from the glaring tropical heat. It creates a better environment for living in this residential complex by allowing the residents to stroll and have fun in the rooftop garden and by ensuring safe play for children without the need to leave the place. The aesthetic value of the project comes from the enjoyment of seeing a beautiful green roof from the windows and balconies instead of the bare concrete roof.	The rainfall discharge rate was reduced by 50–90 %, as a considerable part of it returned to the natural water cycle by absorbing plants and evaporating them into the soil. The cooling effect contribution associated with roof cultivation reduces temperatures at the cultivated area level. Green spaces for project visitors on the roof were provided. There is a big waste of paved areas on the public site at the expense of green spaces.	The project is a first step for urban development, as it achieves many benefits, the most important of which is the intelligent combination of blue and green roofs. Green environments were created for work and living together by providing a distinguishing view from all the building spaces on the green roofs. The use of green spaces by the occupants of the building is in addition to the presence of areas designated for children.	Energy efficiency was achieved since the building uses less than 40 % of the energy stipulated in the National Energy Code of Canada and meets efficient water use and rainwater utilization. Also, it reduces the UHI due to green rooftops in a wide area of buildings and parking lots. Also, it provides psychological comfort to the building's users, including patients, visitors, and workers.

Fig. 6. CASA Clementi dwelling complex and the roof garden's relationship to other buildings and the garage (Murodovna, 2022).

Fig. 7. The Zaragoza 2008 Expo Buildings, Spain, the organic forms, and rooftop garden paths (Rollin, 2009).

Fig. 8. Germany's Allianz Building and the terraced roof garden relationship to the apartments and offices (Dawson et al., 2022).

adopting this technique by governments and individuals, and supporting it financially, technically, and socially were emphasized during the evaluation of the experiences in numerous countries, as shown in Table 4, as a top priority within local sustainable development plans.

Fig. 9. The Humber Hospital, the visibility easiness of roof gardens from the windows of the spaces (Peters, 2017).

Hence, as a newly applicable example of green roofs in one of the models of social dwelling projects for youth, this is a good choice for a model among the Dwelling Ministry projects. It represents the most extensive proportion of previously established dwelling projects in all cities and is regularly used to solve the youth dwelling problem. It is a system of four residential units on a floor with an area of 270 m^2, consisting of a ground floor, as in Fig. 10. The unit area is 65 m^2, as in Fig. 11. In the building's middle, the main staircase does not reach the roof and has a courtyard with an area of 9 m^2, as shown in Fig. 12, five upper floors, and a roof, as in Fig. 13. If applying green roofs is successful in this model, there will be an initiative and great chances for its success in the rest of the other models. Hence, not only are the roofs of other buildings cultivated, but they also transform abandoned, neglected, and unused space into social and functional space that generates income by making good preparations and coordinating it.

The study followed detailed steps to make executive proposals for applying one of the types of green roofs on the model of the residential building roof, as follows:

(1) To study all the architectural plans for a residential building model, namely horizontal plans, facades, and especially the roof and the last fifth floor, as shown in Figs. 10–13;
(2) To decide the type of green roof used and its system;
(3) To define the used soil type and plants with each proposed type;
(4) To determine the green cultivated area of the total roof area and design the distribution of paths;

Fig. 10. The ground floor, the youth dwelling, the four units, and the main entrance to the building.

(5) To specify the materials used in the green roof execution process and arrange the execution layers, if any; and
(6) To provide a complete conception of the irrigation and water drainage processes utilizing a type of irrigation, whether automatic or manual, considering the possibility of recycling gray water in the irrigation process.

After reviewing the drawings, a simple modification must be made to benefit from the roof floor for applying the green roofs on the last floor roof. It is to make the main staircase reach the roof floor. Therefore, the net useable area is 229.0 m^2, as in Fig. 14. There are two proposals, according to the construction status of each building after review:

The first proposal in the building case with a good construction condition is the cultivation type that can be applied with field soil (the system of extensive roofs with an average thickness of 5–20 cm and loads of layers ranging from 60 to 150 kg/m^2), which requires careful attention to the insulation method to protect the lower roof, as in Fig. 1 previously presented. This system is compatible with nature and the local environment because of its great environmental, economic, and social benefits. The available soil type in the surrounding environment is used, the best of which is sandy–clay soil because it is an intermediate between sandy and clay soils. Plants or crops that are suitable for environmental conditions are used. Irrigation and drainage systems are developed by making an integrated system by

Fig. 11. The residential typical floor, youth dwelling, four units, staircase location, and service courtyard.

modifying the rain drainage system on the roof to benefit from it in applying the system to be applied. Instead of the vertical drainage system used in the middle courtyard of the building, a horizontal drainage system is added that works with the vertical one to match the cultivation system that was chosen to end at a tank under the pedestrian corridor, above the roof floor slab, for the extra water from irrigation to be reused again without waste, as in Fig. 15.

The integrated system consists of a water tank containing two parts separated by a water filtration layer. A main pipe comes out of the tank and branches out into thinner ones to cover the entire roof, and sprinklers are installed on them in a typical way, so the distance between each sprinkler is 1.6 m. That ensures that water reaches all the green roof areas. After irrigation, the water is stored in the storage layer through channels that save water for the plant to benefit from again. When the water fills these channels acting according to the direction of their inclination toward the main drainage pipe to return to the water tank, enter the part of the water filtration process, and then move to the second part to rotate it and repeat the watering process in the same way. A movement or pedestrian corridor is made around the roof boundaries from the inside with a width of 60 cm to move around the

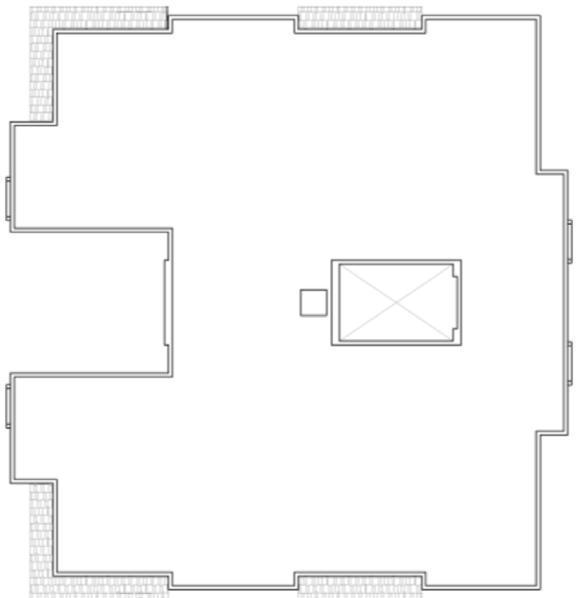

Fig. 12. The roof floor, youth dwelling, and the main staircase didn't have access to it.

cultivated soil. Under it is the horizontal drainage system to facilitate the tank work for additional irrigation water. Thus, the net cultivated area is 170.0 m^2.

The second proposal is for buildings that do not bear loads from the type of farming field soil. The best would be the urban cultivation type, such as the system of farms in different environments based on field soil alternatives or the hydroponics or aeroponics system, as shown in Figs. 2 and 3, because of their previously mentioned advantages. Also, the research encourages using the hydroponics system as a first option for cultivating the specified dwelling model roof. It is a sustainable technique with high productivity and water savings if it is appropriate to the set budget by the responsible authorities, provides trained workers, and benefits from the net useable area of 229.0 m^2. Otherwise, it is preferable to use the system of farms in different environments as a second option for cultivating the roof of the building as a model, which was previously executed when the field study was conducted between the green roof and the traditional roof, as shown in Figs. 4 and 5. That is due to the low operating costs of this system and the ease of cultivation and supervision of the available labor compared with the hydroponic system. Otherwise, integrating the two systems in a balanced manner achieves high production of vegetables at the lowest possible cost; besides, the specialized roof of each building produces a specific crop, with the importance of creating a gray water recycling system and using it for irrigation. Obtaining healthy crops requires an organic farming approach, not using genetically modified seeds, fertilizers, synthetic pesticides, veterinary drugs, or preservatives that cause harm to public health. Also, following the proposed farming method (hydroponic farming or farm systems) helps to provide the population's food needs, invest the surplus, and sell it to meet the needs of other regions, allocating a percentage of the sales revenues to cover the maintenance and development of dwelling and its basic facilities.

11. Results and discussion

Through the results of the field study as a practical experiment to compare the thermal performance of the green roof with the traditional one previously executed and discussed in Table 3, the importance of the green roof is evident in achieving many social, environmental, and economic benefits mentioned in Table 1, which would solve and reduce numerous risks and problems to serve the state's sustainable development plans locally.

One of the most important results of the comparative analysis of many international experiences was that the application of green roofs requires the combination of several factors, the most important and dangerous of which is the consciousness of the importance of these roofs between individuals and countries, besides the existence of legislation, laws, or building regulations that are binding to execute them in all types of buildings and projects. Also, develop action plans at the level of each city. All this is due to the many benefits of this technique at the architectural and urban levels according to the pillars of sustainability (environmental, economic, and social), previously presented in Table 1.

Hence, green roof systems and techniques represent one of the applied principles of green architecture and sustainability. Therefore, the study presented two executive proposals for cultivating roofs within one of the local dwelling models, a residential building in the social young dwelling as a typical model, as in Figs. 14 and 15. Such two proposals relied on what was studied, presented, and analyzed during all stages of the research study.

The most significant results of evaluating the two proposed alternatives to execute the green roof technique locally according to the construction status of any residential building model in the youth social dwelling project were as follows:

(1) The right choice for a model of dwelling projects, which represents the most extensive percentage

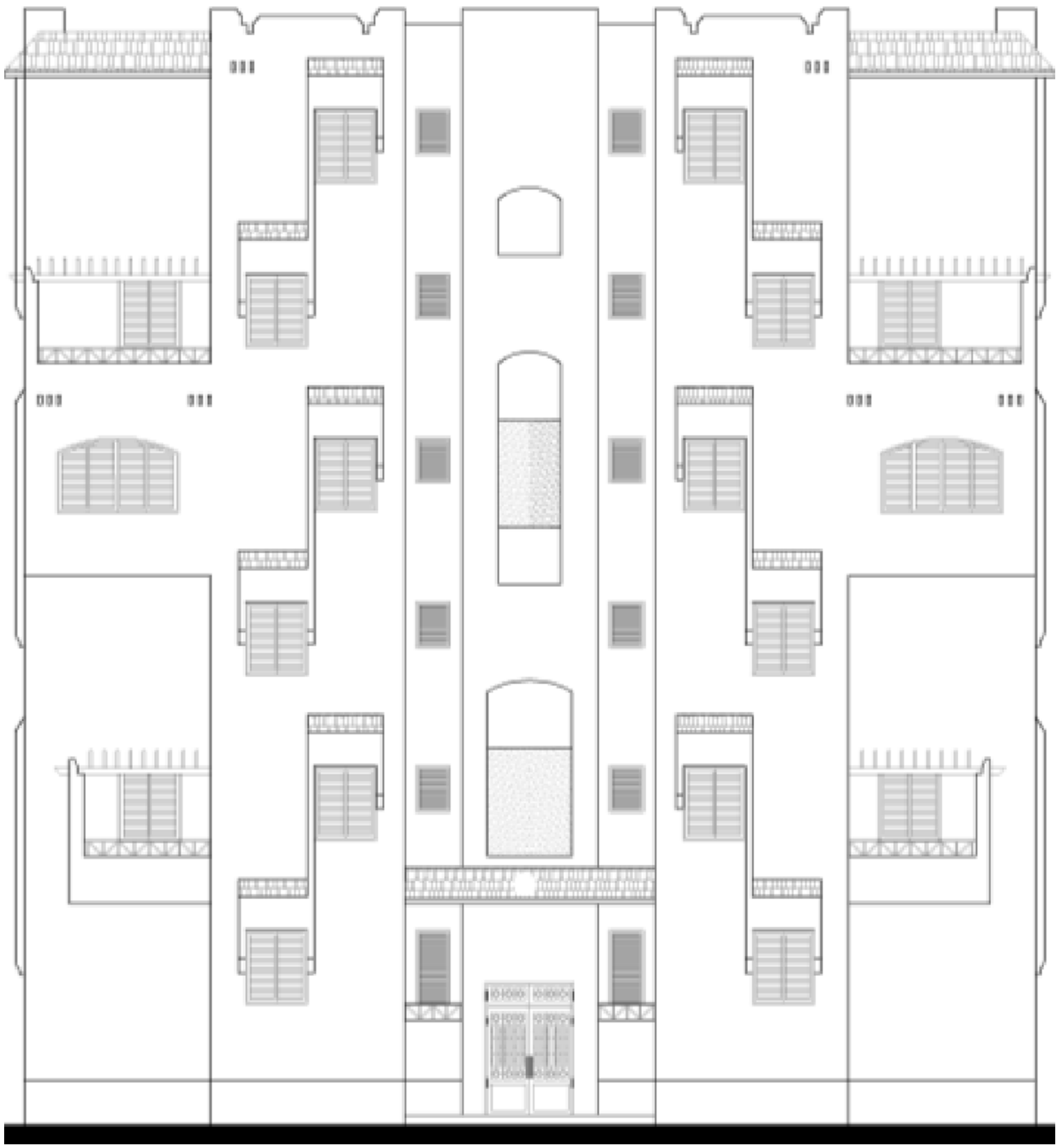

Fig. 13. The main façade of the youth dwelling shows the number of floors.

at the state level; if applying green roofs is successful, it will have a great chance of success in all other projects;

(2) An integrated system was created that combines the irrigation and drainage systems to rationalize water consumption and nonwaste;

(3) The valuable changes led to a more significant benefit from the roof by adding the main staircase, besides modifying the rainwater drainage process and its conversion from vertical to horizontal drainage;

(4) The most important base is to focus on the structural aspect of roof cultivation, as it involves execution, construction, and maintenance. Also, corridors, seating, and shaded areas must be designed;

(5) These two proposed systems are suitable for roof cultivation for all residential and public buildings, with some studied changes made for public buildings to become more convenient and compatible;

(6) The second proposal is suitable for existing residential buildings, buildings under construction, or designed buildings, besides its advantages previously mentioned when presented and discussed;

(7) A complete vision must be made of all the problems that may arise from constructing or operating over long periods and developing

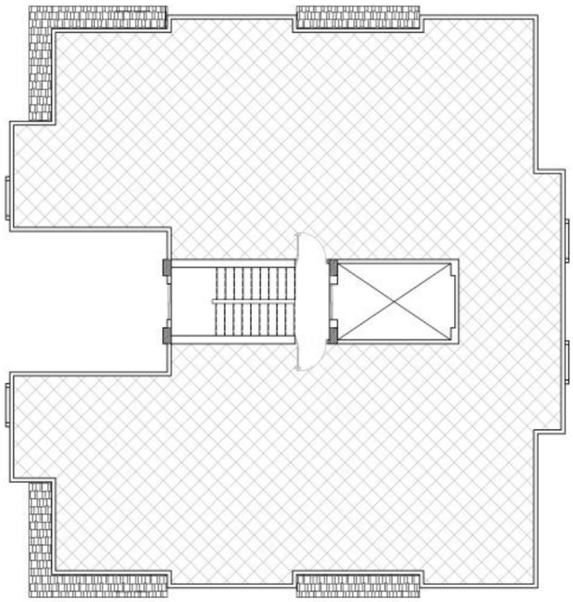

Fig. 14. The proposed roof modification through adding the main staircase for cultivation work.

solutions and proposals to treat these problems to apply this system well;

(8) Egypt could become among the international countries in an advanced position in the percentage of green areas if this technique is applied in a technical and studied manner to serve Egypt's 2030 vision.

In local reality, Egypt has established new dwelling projects to provide the residents of the slums with the basic requirements of life. However, it was built in a traditional manner that does not consider the economic, social, and environmental situation, enhance the link between the residents and the new residential places, or exploit roofs and open spaces in cultivation for improving the spirit of belonging and cooperation of the population and their economic situation. That caused some residents to wish to return to their old lives due to their financial inability to meet the requirements of the new life. All require the exploitation of the roofs of the projects that have areas exceeding many thousands of square meters.

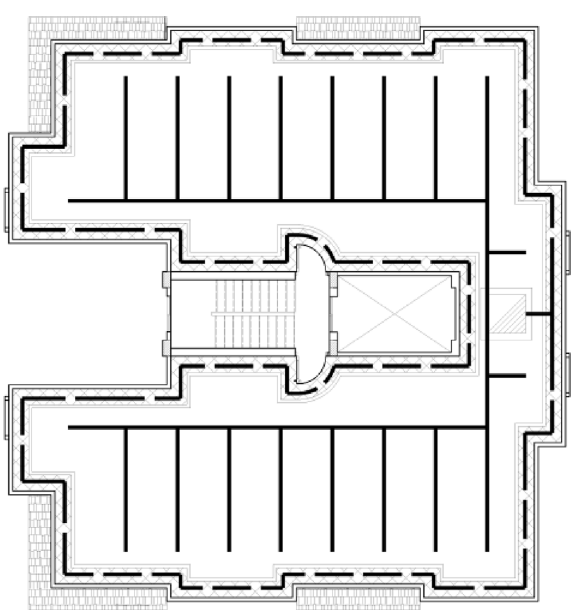

Fig. 15. The irrigation system (continuous line); the drainage system (Dashed line); and the tank location (near the courtyard).

Despite being mentioned previously, many studies agreed with what the study found: that the actual reality and surrounding conditions have many factors that create beneficial opportunities that encourage the use of green roof systems, the most important of which are:

(1) To confront climate change, energy crises, diseases, and epidemics (Mahmoud, 2022);
(2) To use green roof systems in new projects such as desert reconstruction, cities, and slums (Magill et al., 2011);
(3) To motivate citizens to plant the last roofs to secure their daily food requirements due to higher prices of vegetables and fruits (Almaaitah and Joksimovic, 2022); and
(4) To provide a natural environment for humans to help them with psychological balance and thermal comfort, then reconnect them with the land from which they separated due to population density (Vardhu and Sharma, 2023). It is an alternative to open and green spaces, which are difficult to provide due to land prices (Alim et al., 2022).

Through this study and previous studies, the limitations of using green roofs in applying and executing the cultivation of building roofs are as follows:

(1) The lack of existing buildings that can bear the large weights added to them; the cost resulting from strengthening them to carry these new weights (Mahmoud, 2022);
(2) The wildlife of green roof cultivation brings small insects and rodents (Dawson et al., 2022);
(3) The materials involved in executing green roofs are not readily available, such as the layers, as shown in Fig. 1;
(4) The initial cost of installing a green roof is roughly twice that of a traditional one (Alim et al., 2022).
(5) Organic vegetable varieties and fertilizer or nutrient solutions for grown crops are

constrained by a limited source, making it hard to obtain them (Mazzeo et al., 2023);

(6) Architects lack interest in applying green roofs to their designs for residential, public, service, and tourism buildings;

(7) There is no initiative in the architecture faculties and governmental and private educational institutions to devote the principle of green roofs to all types of projects (Dawson et al., 2022);

(8) The owner is unwilling to apply this technique;

(9) The population's awareness of the techniques for dealing with and caring for green roofs does not exist. The governing authorities and the media are responsible for explaining and training the population about these systems (Alim et al., 2022);

(10) Green roof systems were not included in local planning policies, although some countries took some actions to promote these roofs and passed motivated laws. Also, the importance of governments supporting them financially, technically, and socially was evident in evaluating the results of applying this technique to many projects, as shown in Table 4.

12. Conclusion

The main conclusion is the execution proposals for the green roof technique, which depend on specific technical steps within one of the local dwelling models commonly executed in all cities, the social young dwelling project, through the two executive proposals. These two proposals are to apply the green roof technique based on the principles, concepts, and steps extracted from all stages of the research study as an initiative to address the possible challenges and profit from opportunities associated with the cultivation of green roofs.

The comparative analysis of significant international experiences of countries such as Singapore, Spain, Germany, and Canada in cultivating rooftops confirmed the importance of individuals and governments adopting green roofs. This analysis revealed the importance of applying the concept of green roofs on a large scale within the Egyptian state, especially the motivating legislation and laws. Also, the study conducted a practical experiment on a green roof in the local Egyptian environment to compare its thermal performance with the traditional rooftop in most local buildings. Furthermore, the execution stages of this experiment will be utilized in the second proposal's execution, which is the type of urban cultivation. Therefore, the study explained and identified many details related to the types of green roofs, the systems of each one, their construction techniques, and many functions and operations of plants or green elements that control climate.

All of this relied on the concept and importance of green roofs and the benefits achieved at the architectural and urban levels according to the three pillars of environmental, social, and economic sustainability. Thus, green roofs will support and encourage the execution techniques, concepts, and principles of sustainable or green architecture as one of the modern trends in the construction industry. Then, the government would guarantee that cities, projects, and buildings would be established and developed to be environmentally friendly. Consequently, certifying and adopting the initiative to increase green spaces to mitigate the manifestations of pollution spread around us and treat local environmental issues has become one of the urgent work priorities in all parts of cities, according to Egypt's Vision 2030.

Conflicts of interest

None declared.

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