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A Review of Green Roof: Definition, History, Evolution and Functions

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Abstract. In cities, buildings contribute large unused panels, especially on their wall and roofs. These external surfaces generally made from materials that listed as a reflector to the heat such as concrete, glass, and bricks. Covering the external surfaces with green vegetation could be a solution to many environmental, economic and social problems, especially in the urban areas. A review was directed of studies that reported and measured on the relationship between characteristics of vegetation and their influence on building thermal performance, air and water pollution, and building energy-efficient. A numerous of published studies were investigated for their: (a) definition based on roof typologies and combinations; (b) historical evolution periods; (c) observation the green system functions. These analyses cover to afford scholars with a review of conventional techniques to understand one of the passive cooling strategies adopted in warm and cold climates. The techniques provide a significant contribution to the field of sustainable architecture, also to improve understanding of the progressive developments of a green roof. Despite other new designs of green system, this conventional and simple green roof has remained to contribute significantly to provide indoor thermal comfort.

1. Introduction

Buildings construction is always moving together with economic development. By 2030, the number of megacities with more than 10 million populations is estimated to be 43 [1]. The growth of building sectors is directly reported to be related with an increase of the greenhouse gas by 3% between 2000 and 2010, alongside with the increase of energy consumption caused by human activities; where nearly 40 % of total global energy consumption is consuming by building sector [2].

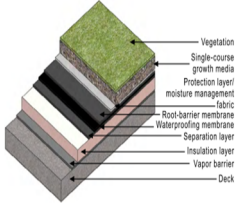


Due to the vulnerability of living area, it will be essential to implementing mitigation techniques across private and government sectors and countries, especially on sectors that substantially be contingent on fossil fuel use [3]. As building roof surfaces covers of 20–25% of the urban areas, they can effectively be used to lessen the surface and air temperature of the urban areas. A green roof is a horizontal living system, which helps to mitigate several environmental problems [4] [5].

The terms “green roof, living roof, eco-roof, vegetated roof, and rooftop garden” [6] [7] were used to define two types of green roof types extensive and intensive roof, with naturalistic or self-established vegetation. Jim [8], define the term green roof to refer to the human-made establishment product on the roof of a house, including erecting a structural framework with appropriate mechanical strength. Another definition mentioned by Yu *et al.* [9], is a building roof which is entirely or partially covered with vegetation and growth medium. It can be a sloped roof surface or a flat designed to sustenance vegetation besides working as a fully functioning roof.



A green roof consist of many components such as plants, furnish substrate to source nutrients, water system to help the root to grow, and a drainage layer to shed remaining water. Generally, a green roof offers an appropriate environment to sustain vegetal growth. Table 1 illustrates the classification and comparison of three types of a green roof, which broadly installed on building's roof base on required functions and cost. The comparison varies on the structure system, types of plants, prevalence, and the installation cost. It should note that the final cost might vary among countries and green roof installer between these green roof types.

Table 1. Types of green roofs according to classification [10] [11].

Green system	Comparison
<p>Single course extensive</p> 	<p>Thickness: 7.6 cm – 10 cm</p> <p>Drainage layer: No separate drainage layer</p> <p>Vegetation layer: Ornamental and Succulents plants</p> <p>Media type: Coarse media</p> <p>Irrigation layer: Not required</p> <p>Prevalence: Used in an area with sufficient precipitation</p> <p>Weight: 60 – 150 kg/m²</p> <p>Cost: 543 – 690 RM/ m²</p>
<p>Semi-intensive</p> 	<p>Thickness: 15 cm – 31 cm</p> <p>Drainage layer: Separate drainage layer</p> <p>Vegetation layer: Ornamental, meadow species, turf grass and woody perennial</p> <p>Media type: Multi-course media</p> <p>Irrigation layer: Required if meadow grass used</p> <p>Prevalence: Common and provide more plants choice</p> <p>Weight: 25% above or below 150 kg/m²</p> <p>Cost: 25% above or below 690 RM/ m²</p>
<p>Intensive</p> 	<p>Thickness: Over 31 cm</p> <p>Drainage layer: Separate drainage system</p> <p>Vegetation layer: Ground-level plants</p> <p>Media type: Intensive growth media layer</p> <p>Irrigation layer: Required</p> <p>Prevalence: Less common due to it is structure and maintenance factor</p> <p>Weight: 200 – 500 kg/m²</p> <p>Cost: 2259 RM/ m²</p>

2. History evolution of green roofs

2.1. Green roof in the 20th century

In the early modern era, different continents kept the idea of the green roof alive; this concept was broadly adopted in various regions and cultures. In the mid of 1880s, the new technology brought the idea of a living roof on the top of the concrete roof, the first model of this roof appeared in the World Expo in Paris in 1867. The model has illustrated a green roof with waterproofing and drainage system, which consider the first design of an extensive green roof [12].

During the 20th century, the originator of modern architecture (Le Corbusier, Alvar Aalto, and Frank Lloyd), start to implement the green roof and walls in their design to merge the natural with construction. Their famous designs are a clear sign of this concept (Villa Shodhan, Villa Mairea, and Millard House). Figure 1 presents famous buildings designed with a green roof between the 1920s and 1930s.

In the late of 20th century, the appearance of industrial era tracked back the concept of green roof in Germany, after the innovation of mixed gravel and sand with tar to produced non- inflammable waterproof by H. Koch. With the help of nature, the new materials became the base system to herbaceous plants that grow on building's roof, later in the 1960s, both sand and gravel layers were replacement with simple drainage system and new design of lightweight green roof [8]. The innovation and development of roof technology made German the first country in the world adopted the principle of green roof in the building followed by North Europe and North American and Finally a few countries in Asia.



Figure1. (A) Green gardens at the top of Rockefeller Centre in New York, (B) Roof garden at Villa Mairea designed by Alvar Aalto, (C) Green roofs at Monastery of La Tourette designed by Le Corbusier's.


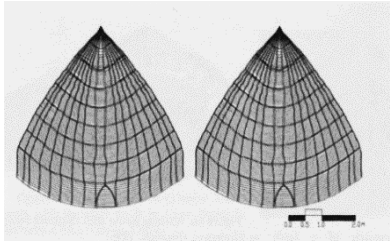


2.2. Green roof in a hot climate

The definition of a hot climate in this section refers to the Mediterranean, tropical, steppe, and hot climate. These climates adopted green roofs as construction elements or upper ground garden in both vernacular and monumental architecture in Asia, Africa, Eurasia, America, and Australia. The first appearance of the green roof was in Ziggurat of Ancient Mesopotamia [14], from the fourth millennium until 600 BC. The green roof located in the courtyard temples, shrubs and trees were planted at terraces formed by a gran-stepped pyramid. Whereas, the most famous type of green roof is which constructed at about 500 B.C. is "The Hanging Garden of Babylon" that known as the first botanic garden in the world, whereas various types of plants do not exist in the community were cultivate.

In the Mediterranean era, the existence of the green roof was found in Pompeian buildings were the patch of green in the heart of the city. The appearance of the green garden in the shape of Atrium not only found in public spaces and but on the roof of dwellings building. Villa of the Mysteries (Villa Dei Misteri) is evidence of intensive roof garden in Pompeii, according to Osmundson [14], the entrance of the house is clear evidence of the roof garden, while the façade is a kind of hanging garden.

The previous paragraphs presented a brief of some examples of green roof that existence in Monumental architecture, whereas used to mitigate the hot climatic condition, as a recreational area, or to express the social status of the owner. Not far away from the concept of green roof of Monumental architecture, the appearance of a dry roof in vernacular architecture due to the lack of water in some areas, the use of bamboo, grass, leaves, and reeds as construction element were found in different regions, times and civilization [13]. In table 2, a comparison of different type of green roof that exist in vernacular architecture in other regions and civilizations with hot climate is highlighted.

Table 2. Examples of a thatched roof found in vernacular architecture in a hot climate.

Figure	Description
	Dome-shaped dwelling made from dry reeds and covered by dry grass in Zulu Land [15]. Dwellings designed with round or geometrical shapes were covered with dry grass on the top of clay, stone houses or grass houses. The thatched roofs used since ancientness time until now, to cope with the hot climatic condition.
	In some Europe countries, the thatched roof used commonly to keep out the heat faraway from the indoor. The designs of the house are different from that area to another. As showing in figure two, grass hunts were used by the farmers in Greece as a temporary shelter and storing area [13].
	Dry turf used by Native Americans as construction materials even before the Spain invasion. The grass was used the steep cover roof, and to protect the palm leaves from outdoor weather. Later, the (Choza house see the figure), developed with the design of the square house after Spain invasion or by the Africans migrants to round hunts.
	In Asia, dry plants used as a raw material to construct their settlements in China, India, Japan, and Indonesia. Turf roof used by villagers to cover their straight, curved, or even pyramids roof shape. The figure shows pyramid shape thatched hut in Bay. Thatched roof and walls were considered a technique to mitigate the climate condition.




2.3. Green roof in cold climate

In a cold environment, there is plenty of green roofs existed; the lack of water usually is not an issue in this climate. Therefore, the green roofs are used as a type of insulation material, to lower the heat losses from inside to outside. The use of dry grass in construction materials in Europe has appeared from prehistoric time; it has used in central Europe in Germany, Poland, France, some Scandinavian countries, Ireland, and Britain. The existing of green roof shown in burial construction, while the burial location under a hill covered by grass and plants and has a bath way to chambers. The burial's layout could be small, large, single, twin or triple. These simple layouts help the prehistoric nation to draw their footprint on the landscape design.

The man-made burials also used by many ethnic groups, such as Vikings, Celts, Pagan Saxons and ethics groups of central Europe. The time estimated to be between 1500 to 800 B.C. for Scandinavia groups, and 1400 to 1200 B.C. for the ethics groups in the South of France [16], and continued to Christian periods. As adaption to the green roof that shows in burials since 1500BC, the reed roof mainly used in holy places, like a church in Christian's periods and mosques in Africa. An English traveler, John Barrow recorded a church built in 1796 called Thingvellir church applied the concept of a thatched roof. Besides, that Sifrastadir church (built-in 1842) in Northern Iceland and Vidmyri church was also designed with green living roof [13].

Thatched roof in vernacular architecture in cold climate is not the only elements that used was to cover buildings decks, but also the intensive roof. The weather condition it is possible of the grass to grow easily. Both techniques of the roof (hatching and living roof) were widely famous from prehistory ear until the 19th century in many areas around in central Europe, France, British Isle, and Russia. Excavations evidence revealed that between 3600BC until 2600 BC the implementation of the thatched roof on stonewalls, strawbale or brick walls was applied widely. This technique proved that the green roof and brown roof widespread through different types of building from churches, temporary sheltering industries, to houses. Even when people shifted to agriculture, and villages started to appear on 3900-3600 BC, the concept of green vegetation remains on huts and building [14]. In Table 3, some examples of the application of green roof in vernacular architecture in cold climate are presented.

Table 3. Examples of living/ green roof found in vernacular architecture in a cold climate.

Figure	Description
	Turf wall and turf pitched roof were essential elements used during the Viking era to protect the building from a low temperature during winter. This technique dated from 800 AD until the late 9th century. The figure presents a living roof in the Mallhaugen Open Air Museum in Lillehammer, Norway.
	The concept of turf roof and walls found in North America, L' Epaves Bay, Newfoundland, as well as L'Anse. According to [16]. Turf roof covering the ground and the top of winter house or oval family settlement appeared in Yup'ik Eskimo in Alaska. The attached figure shows large vertical dwellings cover with the turf at Yukon River, Alaska.
	This figure illustrates the living grass on the roof of a dwelling in Canada. During the 19 th century, the Russian migrants passed their green roof technique to Canada; also the turf walls and roof shown in miners dwellings at Thompson river valley, in Canada whereas dry twigs and turfs used as construction materials, to insulate indoor from the cold climate.

3. Adaption of a green roof to overcome environmental problems

The idea behind green roofs in the metropolitan for environmental benefits looks to be more accepted in the late of 20th century. Individuals become more conscious of environmental issues. The implementation of the green roof in buildings in some cities presented as an approach to developing the urban environment. The benefits of horizontal green systems under the three segments: environmental, social, and economic benefits are presented in table 4.

Table 4. The benefits of the implementation of a green roof in an urban area.

Benefit	Findings
Environmental	<ul style="list-style-type: none"> i. Natural filtration: green roof works as natural air filtration to absorb dust and clean the air [17]. ii. Plants have photosynthesis that consumes CO₂ emission and release oxygen; this makes the air fresh and reduces CO₂ dioxide emission [18] iii. The green roof could be trapped up to 4% of heavy metal city dust iv. Acoustics: The ability of green roof on controlling and reduce sound reflection [19]. The reduction of noise level could reach 8–10 DB. v. Stormwater management: Green roof acts as porous surfaces and control storm waters [20]. vi. Green roof or pavement could reduce 4 °C less than the original roof [21].
Economic	<ul style="list-style-type: none"> i. Energy: green roof has a benefit to reduce energy consumption through shading, insulation, evapotranspiration, and increase in thermal mass [22]. ii. Due to the capability of horizontal plants to lessen temperature, they are an appropriate technique for dropping cooling energy request and improving the energy efficiency of buildings [23]. iii. A green roof is lessening contraction and growth of building material due to temperature, besides works as a shield from acid rain and UV ray [24]. iv. Thermal comfort: Plants have severe effects of systems on reducing urban heat island which is a significant problem in cities and urban areas, due to it is capacity to absorb shortwave radiation and cooling the atmosphere [25]. v. Green roof nominated as a tool to mitigate urban heat island, the ambient temperature lower from 0.3 °C to 3 °C when used green roof vi. Green roof increases the life span of the building roof by protecting the roof from thermal, UV radiation fluctuations, and stress diurnal [22].
Social	<ul style="list-style-type: none"> i. The green roof creates places for recreation and rest [26]. ii. Green roof proved that contact with nature has a psychological impact and increases human health and wellbeing [27]. iii. Plants reduced stress and lower obesity achieved by proximity to green areas. iv. Plants: Have a positive impact on the people working or living around them. A report indicates that employee productivity in building with a sign of green plants is higher than in buildings that are less living environmental. v. Plants in urban areas and compound by buildings attract people more than plants in gardens [28]. vi. Roofs can offer very vital environments for expert rare or imperiled species [12]

4. Discussion

In this paper, it was shown that greening the roof for improving life and social activities in cities are not merely a scientific vision of the 20th century. The concept of the implementation of dry or living plants and grass on building roof and walls appeared in different climates as a construction element, or as a mitigation technique to lower the high temperature in a hot climate or to insulate building envelopes from cold weather. In some cultures, either the green roof showed the social status of dwelling owners,

used for socializing or enjoying the outdoor terrace garden, even the concept in some culture could be for bidden to more impoverished people. Whatever the use of a green roof to symbolize a social status or as to mitigate the climatic conditions, thatched roofs were found in permanent and temporary buildings since the prehistory era until the beginning of last century.

Since the early 20th century, visionaries have been trying to find a solution to improve the lives of urban dwellers. Despite their approach and social beliefs, vegetation is still a central element for the well-being of the inhabitants. At the beginning of the 20th century, the concern was more about people and society rather than the environment itself.

This paper concludes the evaluation of green roof started from its definition, system components, historical evolution, and the impact of green roof performance. The paper is a part of a complete study that focuses on the green system in building envelope. To present a level of understanding the effectiveness of these systems on the building environments as insulation materials in a hot, humid climate and passive techniques that is a help to reduce the energy consumption and increase thermal envelope performance.

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