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A REVIEW OF THE CONCEPT AND APPLICATION OF GREEN ROOF AS A THERMAL PART OF GREEN BUILDINGS

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Abstract

The rapid growth of the human population and urbanization is believed to be one of the contributors to climate change and global warming. The increasing energy consumption by the cities and their inhabitants and the consequent greenhouse gasses emissions are key drivers of global temperature change. One of the important urbanization-related factors that make the atmosphere warmer is the phenomenon of urban heat island (UHI), which is an urban area significantly warmer than its surrounding areas due to human activities. The use of green roofs is known as an environmentally friendly solution for the UHI issue. A green roof is a roof completely or partially covered by plants with a waterproof membrane under the vegetation layer. In this paper, the concept of energy conservation in buildings was explained and the previous works related to green roofs and their components were reviewed. Finally, some useful equations about the heat transfer conductivity in different basic parts of a green roof were presented and explained.

Keywords: Climate change, Energy conservation, Green roof, Heat transfer.

1. Introduction

Global warming is one of the main challenges of the 21st century, which adds significant stress to human societies and to the environment [1]. Risks related to several extreme events (e.g., extreme heat) leads to a warmer temperature [2]. Over the last 50 years, the rate of global warming (0.24 ˚F per decade) is almost double the rate of warming over the last 100 years (0.13 ˚F per decade) [3]. Estimations show that the increasing rate in atmospheric temperature will continue in the coming decades [4]. 41% of the Earth's land areas are occupied by drylands where 2 billion people are living [5]. In the next 30 years, global warming is expected to create dry conditions and increasingly high temperatures across much of the globe, particularly in large parts of Australia, Eurasia, and Africa [6] while northern high latitude regions warming faster than elsewhere [7].

By covering the landscape with buildings and paved surfaces such as roads and parking lots, the urban areas, which often have more radiation absorption and a higher capacity for releasing heat and thermal conductivity, are quickly expanding [8]. The cities are generally warmer than the surrounding rural parts due to the increased thermal capacity of the urban areas and the lack of water, which increases the local temperature. As a result of this relative warmth, a city may be called an urban heat island (UHI) [9]. As the number of urban buildings increases, cities contribute more to climate change [10]. To return urban areas to the ecological functionality that existed before urbanization, expanding green infrastructure is necessary [11].

Sustainable urban and land-use planning, particularly in developing countries, could mitigate the consequences of UHI [12]. Around 20%–30% of the impervious areas in urban environments are occupied by conventional roofs (black roofs) [13-15]. In a study, it has been estimated that roof-level low temperatures reduce the sensible heat flux to the atmosphere and add to the alleviation of the UHI [16]. Heat island intensifies the current energy problem of urban areas and endangers the vulnerable population like elders and sick people in summer [17]. The shaded surfaces emit less long-wave radiation and due to lower surface temperature, they contribute to lowering energy consumption and mitigating the UHI effect [18]. The roof greening can increase the shaded surface of the urban roofs.

According to Yang et al. [19], roof greening in urban areas is very important because it provides habitats and migration space for the creatures, improves the microclimate around the buildings and the ecological utilization of rainwater, reduces the building energy consumption, and ensures sustainable development of the environment. Mathematical modelling and simulation studies of heat exchange in buildings have shown that energy-efficient building design is an effective step to address environmental challenges [20, 21] such as UHI.

Sahnoune and Benhassine [22] presented a decision model to calculate the best green-roof ratio based on empirical data. They found that when using the green roof on a city scale, the average ambient temperature could be reduced by 0.3 to 3 °C. Green roofs and rooftops that have been purposefully vegetated [23] either with wildflowers, low growing Sedum plants, shrubs, grasses, or trees, are emerging green technologies that are becoming ever more popular in urban environments due to the various benefits they provide [24].

2. Energy Conservation using Green Architecture

Modern architecture and energy-efficient buildings in general, and green roof concept can be utilized to reduce energy consumption in buildings.

2.1. Green roof

Green roofs can be used to reduce some of the negative environmental impacts of cities and therefore, are constantly attracting great attentions from scientists and policymakers [25, 26]. Green roofs are beneficial for cities and the environment; they can contribute to sustainable water management, greenhouse gas reduction, biodiversity protection in urban livings (flora and fauna), the Earth's crust protection, keeping the building from the ultraviolet radiation, temperature balancing in hot weather, reducing the influence of electromagnetic radiation, improving the quality of climate and air conditioning in the cities, creating a beautiful landscape, making desirable urbane spaces, energy conservation, noise pollution reduction, reducing the cost of maintenance and replacement of the building roof, and creating a peaceful environment in overcrowded urban areas [8]. Green roofs provide an efficient way of decreasing the cooling load [27, 28]. Modern green roofs in developed countries can mitigate stormwater peak flows in order to reduce pressure on urban sewerage and drainage systems [29, 30].

Among other benefits of green roofs are the runoff reduction [31], temperature moderating inside the buildings, energy efficiency and greenhouse gas emissions reduction [32] as well as dust capturing [33]. Performance of a green roof is higher in dry climates and is more effective during day times [18] although its effect on the night time sensible heat flux is also important because it influences the preparation of the heat island cycle [33, 34]. In a recent study conducted in the drought-prone regions of Northwest China, Wang et al. [35] examined the thermal performance of a building in summer using a self-made simulation experimental platform by comparing the internal surface temperature with and without green roofs. The results of their study highlighted the high insulation effect of green roofs. In addition, they showed that the thermal insulation characteristic can be enhanced as the outside temperature increases, so they concluded that outdoor temperature has a strong positive correlation with the thermal insulation properties of green roofs.

Green roofs exist in two major types: “extensive roofs”, which are light and have a thin layer of vegetation; and “intensive roofs”, which are heavier and have shrub and small trees [36] in substrate depth of more than 20 cm [34, 37]. Some green roofs mostly utilize precipitations for supplying water [38]. However, in arid and semi-arid areas like South Australia, depending on the plant types and the materials used in the green roof, it is necessary to include supplementary irrigation water in the system [39]. In other words, in such areas, green roofs need to be resilient to both heat stresses and moisture [40].

Installing green roof involves three potential changes namely increasing the thermal mass, adding porous substances with moisture-holding capacity, which can raise specific heat capacity, and lifting thermal conductivity when the green roof substrate is moist while depressing it when the substrate is dry [41]. The extent of these changes depends on the characteristics of the green roof. Applying green roof is not only recommended for newly built projects but also is suggested

as a lucrative and feasible solution for retrofitting projects [42, 43]. In this regard, the life span of green roofs, which is estimated between 40 and 55 years is important [44]. Some studies suggested that green roofs can substitute building thermal-insulation (BTI) to save the costs as it can push more heat downward to induce indoor warming [34]. Monitoring the heat flux can provide a holistic and comprehensive assessment of the thermal services for a closer approximation of real-world situations, which depends on different seasons under different weather conditions, good or poor thermal insulation of the buildings, and different vegetation types and transpiration physiology of the green roofs.

Jim and Tsang [45] have used the experimental and theoretical analysis of different layers of the green roof in a wet and tropical region and found that the modern green roof aquatic components significantly contributed to the thermal effect and cooling of long green spaces. As a result of large net radiation and latent heat flux by evaporation, the sensible heat flux on some green surfaces is lesser [17].

2.2. Definition and history of usage

A green roof or eco-roof is a rooftop that supports vegetation and plantation. Green roofs vary in depth of growing media, types of plants (climate-dependent), infrastructure, and intended use [46]. Green roofs in general, consist of four main components, namely (1) waterproofing membrane and filter membranes, (2) drainage films, (3) growing medium (soil), and (4) landscape materials i.e. plants [47, 48] (see Fig. 1).

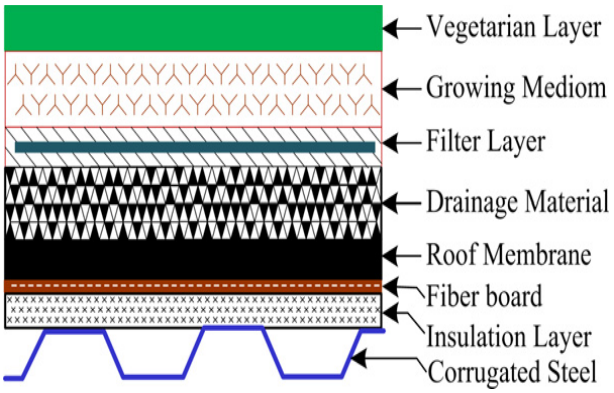

Fig. 1. Schematic view of a green roof [17].

This roof type decreases the energy demand of building through the enhancement of thermal performance [49]. Green roofs are beneficial to the buildings through the thermal impacts including direct and indirect impacts. The direct impacts are related to the components of the building such as the shading impact on decreasing the surface temperature. Indirect impacts are related to the surroundings of the buildings such as reducing the outdoor thermal environment [17].

Green or vegetated roofs have been in existence since ancient times. The first known man-made gardens above grade were Ziggurats (stone pyramidal stepped towers) of ancient Mesopotamia, built from the fourth millennium until around 600

B.C. [50]. In France gardens planted in the 13th Century thrives atop a Benedictine abbey. Sod roofs historically were built by Norwegian to thermally insulate their buildings. Sod homes are still used against enormously cold winters in Norway and the United States.

Between 1933 and 1936, five roof gardens were built on the seventh floor of the Rockefeller Center in New York City. Designed to be 'views capes' for the enjoyment of skyscraper tenants these gardens continue enhancing the view in New York City [51]. Historically, Europeans were the paradigm in the utilization of green roofs in their building led by Germany as a pioneer [17]. Many cities in North America recognize their potential and are now installing green roofs at an unprecedented rate with the help of incentive programs, bylaws, construction standards and support from the public, government, and all levels of industry [23].

A field study was carried out in Singapore by Wong et al. [52] to investigate the thermal impacts of an intensive green roof in a tropical climate, which showed that the maximum daily variation of surface temperature was less than 3 °C indicating that reduction of temperature is dependent on the thermal protection of plants. This study revealed that green roofs can contribute to the reduction of ambient air temperature [52] and hence, mitigation of UHI [53]. Using the thermal simulation program TRNSYS, it has been found that with the installation of a green roof the building cooling load of a nursery school building in Athens was reduced by between 6% and 49% [47]. A study in America by comparing a green roof and an adjacent conventional roof found that surface temperature of the green roof ranged from 33 to 48 °C, while the conventional roof was 76 °C and the near-surface air temperature above the green roof was about 4 °C cooler [54].

2.3. Different parts of a green roof

Buildings are the major component of cities and roofs play a critical role in energy transfer. The green roof serves to provide more thermal comfort and reduces the roof surface temperature. Two important functions of green roofs are direct shading of roof surfaces and cooling down the ambient air that provides additional thermal advantages. This thermal benefit is the result of consuming solar heat for transpiration and photosynthesis [18]. Selecting and optimizing each layer of green roof is important for getting the desired cooling result and for saving the cost and energy. The amount of savings depends on different factors such as type of green roof, depth and composition of growing media, climate, plant selection, type of irrigation, and insulation specifications [55].

As aforementioned, there are two main green roof types, namely extensive and intensive. The extensive green roof can support lighter plants and needs less maintenance. Intensive roof gardens are normally designed for the use of human and entertainment, which requires extra structural reinforcement [56]. Jaffal et al. [57] coupled a green roof thermal behaviour model with a building code simulation for a single-family house with both black roofs (conventional roof) and green roof in three different climates.

The result showed that the green roof reduces the total energy demand in all three studied climates. Reductions of 32% for the Mediterranean climate of Athens, 6% for the temperate climate of La Rochelle, and 8% for the cold climate of Stockholm were observed [57].

2.3.1. Plant

Vegetation can suppress temperature fluctuation. The effect of vegetation on the temperature of the environment is through different ways such as direct shading, heat usage of transpiration and photosynthesis in summer, and providing an additional insulation effect in winter [40]. Some grasses and vegetation species perform well in roof cooling because of having high transpiration rates and aboveground biomass and cover [52, 58]. Vegetated surfaces almost always have greater albedo values than non-vegetated surfaces [59]. In general, albedo increases with increasing peak cover and biomass and using the species with the greatest albedo (for instance, *C. argyranthra*, *C. nigra*, *D. spicata*, *S. tridentata*, and *F. Virginiana*) results in lower surface temperature. These observations were confirmed by Lundholm et al. [55] who found that albedo was related to biomass and canopy cover, where greater biomass corresponded to the overall greater reflection of solar radiation [60]. A study has shown that the establishment of perennial plants on green roofs is possible and that these plants can survive over two growing seasons [24].

Green spaces in urban areas are denominated as "park cooling islands" because these spaces create a cooling effect [61]. By large shading of plant canopy [62], insulation of the soil, and transpiration cooling of roof gardens' plants reduce the magnitude of heat flux in green roofs [40, 63]. Introducing plants and landscapes to building surfaces is regarded as a method, which decreases building temperature [64] up to 20 °C and decreases the energy required for air conditioning between 25% and 80% [17]. Plants that are able to penetrate the waterproof layer of the roof should not be selected. Instead, plants with the following features are recommended [58]:

- Plants with slow growth rate and easy for transplant, trim, and maintenance;
- Plants that can survive in pollution and can absorb or detain deleterious gases or pollutants;
- Plants that can survive under a large amount of water, as there are no good drainage systems on some roofs.

Experimental measurements carried out by Yang et al. [19] showed that cooling and humidification has little correlation with transpiration, however, they have a close relationship with leaf area. The thermal performance of green roofs is ultimately reflected on its cooling and energy-saving effects on the buildings. The cooling effect is mainly due to water evaporation. The plants prevent solar radiation from hitting the roof directly [58]. Based on the origin of the plans, three types of plant species can be used for roof greening: native plants, which are those that grow spontaneously in a region without the man care, exotic plants, which are located outside of their natural region because they were accidentally or intentionally introduced by humans in a new region, and naturalized species, which have been introduced over a long period of time [59, 60].

In selecting plant types, it is important to investigate their endurance, physiology, and environmental thermal regulatory effects [65]. The energy balance in green roofs depends on the selection of plants and substrates suitable for the area [66]. For example, introducing exotic plants carelessly in urban areas can lead to dysfunctional ecosystems [60]. It was found that green roofs adapted to receive spontaneous wild species could promote urban biodiversity dynamics if

they continue to be developed at large scales [67]. If green roofs are properly designed and installed with plant communities adapted to the local conditions they can both contribute to mitigating the effects of impervious rooftops and restore the ecology of highly developed urban areas [68]. Among suggested species for green roofs are *Gramineous* crop, *Labiatae*, *Caryophyllaceae*, *Scrophulariaceae*, *Leguminosae*, and *Liliaceae* family. When selecting the species the regional climate should be taken into account. Some plant species are recommended for Mediterranean climates, which can have a permanent cover throughout the year [69]. *Sedum* species are drought resistant so they are well adapted for green roofs [70]. A list of suitable plants for Los Angeles has been provided considering the climatic conditions like drought and wind [64].

In Basel, Switzerland, as part of the city's biodiversity strategy, green roofs are now mandatory on new buildings with flat roofs, and guidance is provided on suitable plant types [71]. For metropolitan areas of Mexico, 18 native species were proposed considering the climatic conditions [60]. Results of a study through thermal effect measurements in Taiwan, located in a subtropical monsoon region with relatively dried autumn-winters and warm summers, indicated that plants from CAM type families, *Portulacaceae*, *Crassulaceae*, and *Euphorbiaceae*, are more drought-tolerant [65]. In different areas, the design of green roofs with the aim of maximizing their biodiversity value should take into account using proper plan types [72].

A test on the thermal performance of *sedum* in green roofs was performed during summer and showed that *S.tomentosum*, is the preferred choice to minimize cooling load [66]. It has been found that the more extensive the foliage density of a particular plant, the more the heat flux through the roof decreases [46]. According to a study, Ivy can reduce the peak-cooling load by 28% on a clear summer day [73]. If suitable species are selected, green roofs can contribute more to the improvement of microclimate.

2.3.2. Growing medium

The most effective substrate for plant biodiversity varied over time, however, admixes (blends of two or more different aggregates) performs particularly well in terms of both coverage and plant species richness. In particular, clay pellets, red brick, and a combination of the two give very promising substrates for the maximization of plant diversity and a more even establishment of plants [24]. A substrate layer made of artificial material can be used as a growing medium like *C* + Clay or *C* + Brick, which have properties such as high porosity, admissible water holding capacity, and a great number of water-soluble nutrients [63]. The depth is the most important factor in plant species richness. It has been suggested that increasing substrate depth may not increase the water retention capabilities of certain substrate types because of the availability of inter-particle and intra-particle pore spaces for water holding [74].

There is a linear relationship between the volumetric specific heat and density [66] as shown in Eqs. (1) and (2).

$$k(\text{wet}) = 0.0016\rho - 0.7485 \quad (1)$$

$$k(\text{dry}) = 0.0003\rho - 0.0405 \quad (2)$$

where ρ (kg/m^3) is the density of the substrate.

2.3.3. Building roof compartment

Buildings' roof compartment can vary in different jurisdictions, however, commonly includes concrete slab protected by a waterproofing membrane, thermal insulation panels, screed, and cement tiles [75]. According to Kusuda [76] the different issues for which, building heat transfer calculation can be applied are heat loss and heat gain through the exterior envelope, interior environmental analyses, and material or building element-related problems. Conduction heat transfer problems relevant to the buildings include exterior wall conduction, interior mass conduction, conversion from heat gain/loss to cooling and heating load, and ground heat loss from the slab-on-grade floor and basement walls [76].

Convective heat transfer problems relevant to buildings include the followings [76]:

- Heat transfer at the exterior surface considering both wind and surface roughness characteristics,
- Convection in and through the cavity walls,
- Convection between the window glass panes,
- Inter- and intra-space air motion due to temperature and pressure gradient,
- Convection heat transfer due to air leakage through exterior walls.
- Convection heat transfer within the porous insulating structure.

On the other hand, European and Japanese engineers have predicted indoor temperature as a function of the ever-changing outdoor climate conditions [76]. Branco et al. [77] and Mendes [78] suggested that experimental results should verify influencing factors, proposed a prediction model as a function of the roughness of the concrete surface and the velocity of the wind. The dependence of relative humidity on heat transfer coefficients is assumed as a linear relationship in order to simplify the prediction equation, and the dependence of wind velocity assumes a multinomial relationship to simplify the prediction equation. That is:

$$h = av^2 + bv + cR_h + d \tag{3}$$

where, v denotes wind velocity, m/s; R_h the relative humidity, %; a, b, c, d the constant parameters obtained by in situ tests.

Heat transfer coefficient (h) increases with the wind velocity as well as relative humidity. A prediction model about heat transfer coefficient considering wind velocity and relative humidity is given based on experiment results by Guo et al. [79].

Basic testing programs demonstrate that the coefficient of thermal conductivity of concrete is dependent on the aggregate types used in the concrete mixture, which are correlated to concrete density (d) [80] as given below:

$$K_c \text{ (oven - dry)} = 0.072 * e^{0.00125d} \tag{4}$$

$$K_c \text{ (oven - dry)} = 0.0865 * e^{0.00125d} \tag{5}$$

In both equations, K_c the thermal conductivity of concrete and d is density (kg/m^3).

Based on the experiments and equations it can be concluded that being dried in air exposure provides a 20% increase in K_c. Moisture affects the heat conductivity in concrete by 6% for each 1% of moisture by weight [81]. In some cases in order to build the roof compartment natural minerals are used. Thermal conductivities of some minerals are given in Table 1.

Table 1. Thermal conductivity of some natural minerals [82].

Mineral	Thermal conductivity	
	Btu/hr ft^2 (°F/in.)	**W/m °C**
Quartz (single crystal)	87, 47	12.5, 6.8
Quartz	40	5.8
Quartzite	22 to 37	3.2 to 5.3
Hornblende-quartz gneiss	20	2.9
Quartz-monzonite	18	2.6
Sandstone	9 to 16	1.3 to 2.3
Granite	13 to 28	1.9 to 4
Marble	14 to 21	2 to 6
Limestone	6 to 22	1 to 3
Chalk	6	0.9
Diorite (dolerite)	15.6	2.25
Basalt (trap rock)	9.6 to 15	1.4 to 2.2
Slate	13.6	2

3. Heat Transfer Methods for Soil used in a Green Roof

It has always been believed that something flows from hot objects to cold ones called “heat”. The overall driving force for these heat flow processes is the cooling (or levelling) of the thermal gradients within the universe [83]. Among various statements of the second law of thermodynamics, Clausius words are notable, which indicates “no process is possible whose sole result is the transfer of heat from a body of lower temperature to a body of higher temperature” [84]. The heat exchange and energy transfer have been discussed in previous studies [85-88]. Heat transfer processes are categorized into three types: conduction, which is the transfer of heat occurring through intervening matter without bulk motion of the matter; convection, or heat transfer due to a flowing fluid (the fluid can be a gas or a liquid); and radiation, which is a method of heat transfer that does not rely upon any contact between the heat source, i.e., the transmission of energy through space without the presence of matter [89].

3.1. Non-uniform soil

For many years, lots of methods and models have been developed to determine the heat transfer depending on various factors. The equation below is recommended for non-uniform soils [90]:

$$K(z) = \omega \sin \frac{2\varepsilon}{\left[2\left(\frac{\partial \varphi}{\partial z}\right)\left(\frac{\partial \beta}{\partial z}\right)\right]} \quad (6)$$

where K is the apparent thermal diffusivity $\left(\frac{m^2}{s}\right)$, ω is radial frequency, φ is the phase angle of temperature wave at the soil surface, z is the depth (m), and ε can be obtained through the following equation:

$$\varepsilon(z) = -\cot[(\partial\varphi/\partial z)/(\partial \ln A/\partial z)] \quad (7)$$

where A is the amplitude; also β can be calculated from the following equation:

$$\beta(z) = \varphi - \varepsilon \quad (8)$$

A and φ are temperature-related parameters.

3.2. Uniform soil

For uniform soils, two equations have been introduced [91]. The first is the amplitude equation:

$$K_n = \left(\frac{n\omega}{2}\right)\left[\frac{\Delta z}{(\ln x)_n}\right]^2 \quad (9)$$

where K_n is the thermal diffusivity as a function of harmonic n, Δz is the distance between two depths (upper and lower depths), and x is the ratio between the amplitudes of the temperature wave at the upper and lower depths.

The second is the phase equation:

$$K_n = \left(\frac{1}{2n\omega}\right)\left[\frac{\Delta z}{(\Delta t)_n}\right]^2 \quad (10)$$

where Δt is the difference between the times of maximum temperature occurring at the lower and upper depths. In order to provide a single value of thermal diffusivity at each harmonic, the two values of thermal diffusivity obtained from the two mentioned equations are averaged.

A parameter, which is useful in the soil thermal analysis is a soil flux heat density that can be estimated as:

$$G_1 = -G_2 + C_v\left(\frac{T_{sf}-T_{si}}{t_f-t_i}\right)\Delta z.W.m^{-2} \quad (11)$$

where G_2 is the heat flux plate measurement (Wm^{-2}) at depth Δz in the soil (m), C_v is equal to c mentioned above, T_{sf} and T_{si} respectively are the mean temperatures (K or °C) of the soil layer between the flux plate level and the soil surface at the final (t_f) and initial (t_i) time (s) of sampling (e.g., $t_f - t_i$ = 1800 s for a 30 minutes period), W is the weighted mean temperature that is measured by two or four wired thermocouples [92].

A formula to estimate C_v ($J\ m^{-3}\ °C^{-1}$) is as follows [93]:

$$C_v = (1.93\ V_m + 2.51V_o + 4.19\theta)10^6.W.m^{-2} \quad (12)$$

where V_m, V_o and θ are the volume fractions of minerals, organic matter and water, respectively.

3.3. Isotropic soil media

The heat transfer in anisotropic media is described through a heat flow equation [90] as follows:

$$c.\frac{\partial T}{\partial t} = \frac{\partial\left(\lambda.\frac{\partial T}{\partial z}\right)}{\partial z} \tag{13}$$

where c is the volumetric heat capacity (J/m^3 °C), T is the temperature (°C) t is time (s), and λ is thermal conductivity (W/m °C)conductivity.

The above equation can be rewritten [94] as follows:

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K\frac{dT}{dz}\right) \tag{14}$$

where K is equal to λ/c. It is obvious that λ and c are not constant and soil water content and density affect their value. Then, because of the presence of water, the heat transfer takes place by both conduction and convection.

Significant studies have been done on the relationship between green roof, urban cooling, and building. Issa et al. [95] performed an experimental study on green roofs under semi-arid climates in the West Texas region. They found that soil type and proper moisture content can significantly improve the heat transfer in green roofs. Becker and Wang [96] examined the effect of a green roof on the thermal performance of buildings. The results of their study showed that green roofs reduced the heat by 26% in warm months of the year. Figure 2 shows the effect of green roof on the interior and exterior temperatures of the ceiling at different times of the year.

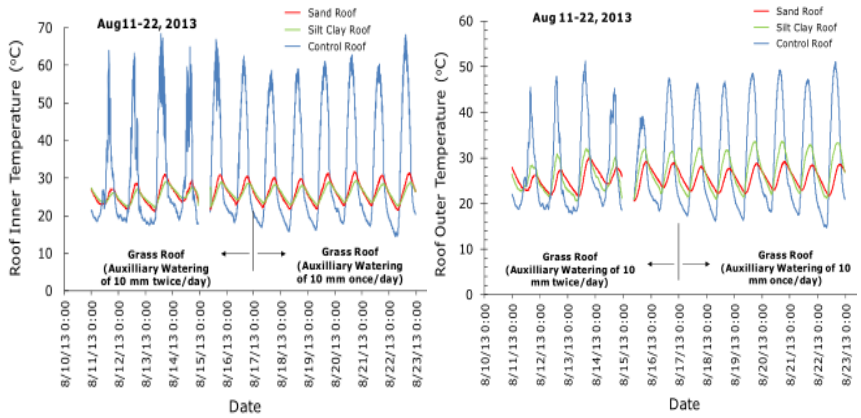

Fig. 2. The effect of green roof on the control ceiling at the internal and external temperature of the roof at different times of the year [95].

4. Conclusion

In this paper, we reviewed the applications of green roofs to reduce UHI and greenhouse gas emissions from urban areas. In addition, we provided heat transfer equations to show the mechanisms of cooling of the buildings by using green roofs. The contents presented in this study lead us to the following final remarks:

- UHI is a major issue in urban areas, which can be moderated by using green roofs in constructions. Green roofs can be useful for maintaining urban beauty, improving the quality of climate and air conditioning in the city, reducing greenhouse gas emissions, reducing the impact of electromagnetic radiation, saving energy, and reducing noise pollution.

- Utilizing green roofs instead of dark roofs has a cooling effect on both indoor and outdoor air. Each part of a green roof can be critical and by knowing how to use materials in buildings and in designing a green roof, the efficiency can be increased. In addition, the plant species should be selected consciously and according to the area's climate.
- Selection and optimization of each green roof layer are important to achieve the desired cooling results and save cost and energy.
- An appropriate plant layer, which has features such as high porosity, acceptable water storage capacity and a large number of water-soluble nutrients, can increase thermal capacity and heat. On the other hand, the plant layer must be selected on the basis of the buildings' roof components, which vary in different areas.
- We suggest future studies investigate the thickness of the growing medium, waterproofing membrane, and soil thickness with considering the amount of load that can be given on the roof.

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