GREEN ROOFS: SUSTAINABLE APPROACH FOR ENERGY SAVING IN BUILDINGS

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Abstract: *Green roofs are a passive cooling technique that stops incoming solar radiation from reaching the building structure below. Many studies have been conducted over the past 10 years to consider the potential building energy benefits of green roofs and shown that they can offer benefits in winter heating reduction as well as summer cooling. The advantages of the planned green roofs are undoubtfully numerous from both the ecological and social point of view. They act positively upon the climate of the city and its region as well upon the interior climate of the buildings beneath them. They give protection from the solar radiation which is the main factor in passive cooling, by reducing thermal fluctuation on the outer surface of the roof and by heat during the winter. Due to decrease of the thermal losses, the green roofs save the energy consumption. This paper highlights the brief history, types of green roofs thermal behavior of green roofs along with the advantages of green roofs.*

Keywords: *Climate, Energy, Green roofs, Thermal fluctuation*

INTRODUCTION

The roof of a building can be fully or part covered with a layer of vegetation known as a green roof. A green roof is a layered system comprising of a waterproofing membrane, growing medium and the vegetation layer itself. Green roofs often also include a root barrier layer, drainage layer and, where the climate necessitates, an irrigation system (not necessary in the UK climate). A green roof offers a building and its surrounding environment many benefits. These include storm water management [1,2], improved water run-off quality [3], improved urban air quality [4], extension of roof life [5] and a reduction of the urban heat island effect [6]. Other benefits also include enhanced architectural interest and biodiversity [7].The artificial heating that comes from major cities is another anthropogenic source of climate change that contributes to the greenhouse effect and global warming. This phenomenon is known as the urban heat island effect because cities are generally 1 to 5 degrees C (2 to 9 degrees F) warmer than the surrounding rural areas [8]. There are three major factors that can cause the extra urban heat. First, cities have less evaporation and transpiration of water from plants and soil than the countryside because of the lack of vegetation found in the urban environment. In the rural environment rainwater slowly percolates through the soil and slowly runs off to streams and lakes, but in the urban cities rainwater immediately turns to runoff and flows into the sewer system. Climatology states that "This leaves more available energy for sensible heat and less shading by trees" [8]. The water would normally linger at the surface and evaporate, but it is now taken away because the quick runoff on the impervious surfaces of city streets. The energy that was once used for evaporation creates a surplus for sensible heat to raise temperatures in the city environment. The next cause of the urban heat island effect is that buildings and streets are very successful at storing energy during the daytime and reemitting that energy back during the nighttime. The rural environments are allowed to cool down at night time much more effectively because they are composed of soils, grasses, shrubs, and trees and do not have materials like asphalt, concrete, and brick that absorb energy from the sun all day. The greater heat capacity of city materials absorbs more heat, and the thermal conductivity conducts the energy back into the atmosphere. The extra absorption and conduction of energy in cities leads to much higher average nighttime city temperatures compared to rural environments. Tall buildings also have a 18 major affect in the urban heat island effect because they have a canyon structure that traps and reflects solar radiation. This radiation is trapped in between tall buildings and they provide more opportunities to absorb energy compared to an open rural environment. Anthropogenic building materials and building geometry have a major impact on the urban heat island effect. The final difference between rural and urban environments that lead to higher temperatures is the amount of waste heat in cities. There is such a great concentration of human activity in major cities that waste heat originates from numerous activities such as industrial and domestic purposes, transportation, heating, and illumination.

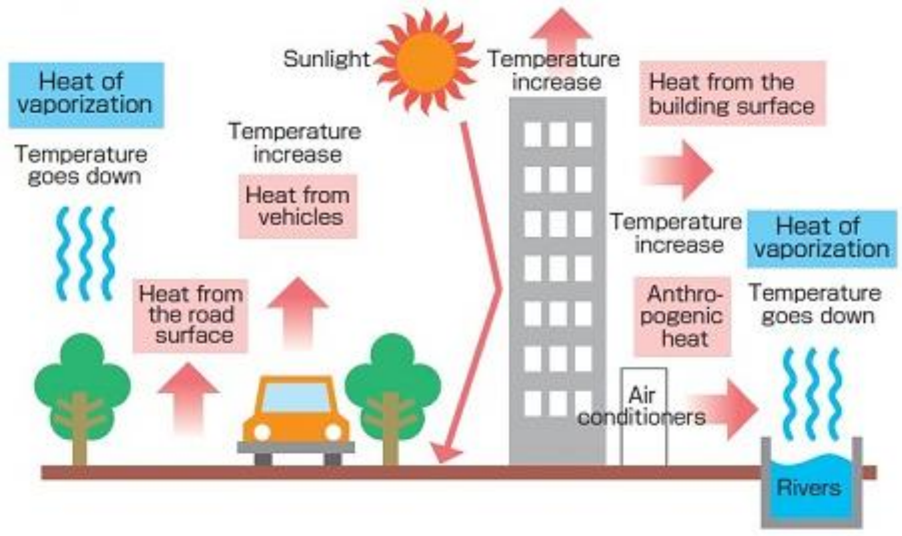

Figure 1: Heat island phenomenon

This diagram represents the causes of the urban heat island effect. The blue boxes represent the cooling that would take place in rural environments with trees and water bodies. The red boxes indicate the anthropogenic heat that cities add to the environment. One could imagine that on a hot and humid day in a city like New York or Chicago, there are tremendous amounts of air conditioners trying to cool the insides of buildings, but what people do not realize is that the air conditioners remove energy from air and release it as waste heat into the atmosphere.

GREEN ROOFING: HISTORY

The mitigating effects of vegetated rooftops are beneficial in addressing environmental and energy challenges in urban areas. Vegetated rooftops are known as green roofs and different types of these plant covered roofs have very ancient roots. In a Bioscience article it states, "The earliest documented roof gardens were the hanging gardens of Semiramis in what is now Syria, considered one of the seven wonders of the ancient world" [9]. Our ancestors were interested in having rooftop vegetation, but it is unclear of their purpose. In more recent history, green roofs have been implemented for more efficient rooftops compared to conventional roofs. Oberndorfer states: The modern green roof originated at the turn of the 20th century in Germany, where vegetation was installed on roofs to mitigate the damaging physical effects of solar radiation on the roof structure. Today, there are similar functions of the green roof with added efficiency due to the active and improving environmental action.

GREEN ROOFING: TYPES

To understand the plethora of benefits demonstrated by vegetated rooftops, one must first understand the different types. The two most common types of green roofs are intensive and extensive. Intensive green roofs are very similar to ground level gardens because they have thick soils and have substantial investment in plant care. The intensive green roofs have been constructed for international high profile hotels, business centers, and private homes. The intensive rooftop is not only functional, but it also has high aesthetically pleasing properties. Extensive green roofs are different because, "They typically have shallower substrates, require less maintenance, and are more strictly functional in purpose than intensive living roofs or roof gardens" [9] . Green roofs can be very different due to the wide variety of climates all over the world and the most successful have carefully selected plants to survive in specific areas.

Table 1: Comparison between different types of green roofs

Characteristic	Extensive roof	Intensive roof
Purpose	Functional: storm-water management, thermal insulation, fireproofing	Functional and aesthic, increased living space
Structural requirements	Typically within standard roof weight-bearing parameters, additional 70 to 170 kg per m^3	Planning required in design phase or structural improvements necessary, additional 290 to 970 kg per m^3
Substrate type	Lightweight, high porosity, low organic matter	Lightweight to heavy, high porosity, low organic matter
Average substrate depth	2 to 20 cm	20 or more cm
Plant communities	Low growing communities of plants and mosses selected for stress	No restrictions other than those imposed by substrate depth, climate, building height and exposure and irrigation facilities.
Irrigation	Most require little or no irrigation	Often require irrigation
Maintenance	Little or no maintenance required, some wedding or mowing as necessary	Same maintenance requirements as similar garden at ground level
Accessibility	Generally functional rather than accessible, will need basic accessibility for maintenance	Typically accessible, bylaw considerations

ENVIRONMENTAL ADVANTAGES

Air Quality

Extensive planting within cities is now widely recognized as a means of improving air quality. Therefore, green roofs contribute to the reduction of a number of polluting air particles and compounds not only through the plants themselves, but also by deposition in the growing medium itself. Plants reduce carbon dioxide in the atmosphere and produce oxygen . Green roofs reduce the heat island effect, which is the main cause of ozone production. Plant roofs remove heavy metals, airborne particles and volatile organic compounds. Being absorbed into the green roof system these polluting particles do not enter the water system through surface run off leading to improvement in water quality. Although green roofs are recognized as playing a positive role in improving air quality, this is linked to the positive effect they have on the urban heat island effect. Individual roofs in themselves will not have a great effect. However a large area of green roofs in specific areas of large cities or in Air Quality Management Zones would have a noticeable effect.

Energy Conservation improved thermal performance

Green roof systems are recognized as providing greater thermal performance and roof insulation for the buildings they are laid on. Eddine et al [10] proposed model was based on energy balance equations expressed for foliage and soil media. In this study, the influence of the mass transfer in the thermal properties and evapotranspiration were taken into account. A parametric study was performed using the proposed model to classify green roofs depending on the considered climate condition. Comparisons were undertaken with a roof slab concrete model, a significant difference (of up to 30oC) in temperature between the outer surfaces of the two roofs was noticed in summer. The model was experimentally validated according to green roof platform, which was elaborated. The mass transfer effect in the substrate was very effective in reducing the model errors. Simulation results showed that the use of vegetation in the roof building improves not only thermal This can vary depending on the time of the year and the amount of water held within the system. Cooling [summer] Poorly protected and insulated roofs can lead to substantial overheating of spaces beneath them. This can lead to the need for increased air-conditioning. A green roof not only acts as an insulation barrier, but the combination of plant processes [photosynthesis and evapotranspiration] and soil processes [evapo-transmission] reduces the amount of solar energy absorbed by the roof membrane, thus leading to cooler temperatures beneath the surface. Onmura et al [11] , in his studies in a three story building in Japan, investigated the evaporative cooling effect from roof lawn gardens and it was confirmed that the surface temperature of the roof decreased by 60 ^{0}C to 30^{0}C during day time which was estimated to be a reduction of 50% heat flux. A study conducted in Chicago, USA, recently estimated that building energy savings to the value of $100,000,000 could be saved each year if all roofs were greened, as the need for air conditioning would be reduced. Thermal Insulation [winter] Green roofs can help to reduce heat loss from buildings during the winter when root activity of plants, air layers and the totality of the specific system create heat and thereby provide an insulation membrane. However the efficiency of green roofs as thermal barriers is dependent on the amount of water held within the system. Water retention can increase the amount of heat lost through the system and therefore any efficiency gains are dependent on daily conditions. It is therefore difficult to provide accurate figures on the net effect of green roofs on energy efficiency during the winter months.

Green space

The value of green spaces to people living and working in towns and cities has increasingly been recognized by Government. Getter et al. [12], in his study in Michigan, USA over a period of two years estimated the carbon sequestered by four species of Sedum in a 6.0 cm substrate depth extensive green roof. The ground plant material and root biomass stored an average of 168 g C m^2 and 107 g C m^2, respectively, with differences among species. Substrate carbon content averaged 913 gcm^2. In total, this entire extensive green roof system net carbon sequestration totaled 378 g C m^2. The work of the Urban Green Spaces Taskforce demonstrated the various benefits that green space provide, such as ecological function, visually softening the built environment, supporting biodiversity, aiding people's mental and physical health and providing a communal focus and sense of place. Government has subsequently launched a raft of new policies, initiatives and funding to promote the good design and management of green spaces. English Nature has published research that suggests that an accessible natural green space should be no more than 300 meters from where anyone lives in order to meet people's needs for contact with nature. Evidence suggests that regular direct contact with natural green space (and elements of the natural world such as birdsong and seasonal color change) is good for people's health .There is a need for increased densities in urban residential development (>30 dwellings per hectare), which could result in terrestrial green space being reduced or lost. In the urban core the provision of green space is usually already severely limited, partly through historical circumstances and more recently very high land values; this makes the creation of new green space both important and difficult. Given the nature and pressures of urban regeneration, the creation of new spaces has to meet a number of interests; these generally result in highly formal spaces with little ecological benefit. Creating low-maintenance, terrestrial, naturalistic green spaces in the urban core are not popular; green roofs may provide one solution. Green roofs can provide both visually accessible and physically accessible green space. Roofs are largely visually 'dead' and unappealing and their appearance to those overlooking them can be softened by vegetation. There are instances where the sole justification of a green roof installation is for visual aesthetics. Areas of green roofs can also provide accessible space for people to enjoy and some can be landscaped to extend existing green space, for example at Canary Wharf station on the Isle of Dogs, London. Roof gardens are increasingly being proposed for new office and housing developments.

Health

There is a growing body of evidence that the visual and physical contact with natural greenery provides a range of benefits to people. These include both mental benefits (such as reduction of stress) and physical benefits (including the provision of cleaner air). Access to green space can bring about direct reductions in a person's heart rate and blood-pressure and can aid general well-being. A Texan study of post-surgery recovery in hospitals demonstrated that recovery was quicker and with less chance of relapse if patients could look out onto green space. A number of American hospitals have subsequently been redesigned to bring these benefits to patients. The thermal benefits that green roofs provide may also have indirect benefits for people living or working within the buildings. In the past 2-3 years, possibly picking up on the increasing interest in green roofs and Government's interest in green space, developers are increasingly showing green roof space as a component of their new commercial development proposals. The provision of specific accessible green roof space for future workers appears to be gaining currency and could help off-set the likely constraints of green space provision on the ground.

Urban Heat Island Effect [albedo effect]

The urban heat island effect is the difference in temperature between urban areas and the surrounding countryside. In large cities this can as much as a 5 ^{o}C difference between the city centre and the rural environs. Urban areas have large areas of hard reflective surfaces. This is referred to as the albedo effect. These surfaces absorb solar radiation and reflect this heat back into the atmosphere. Any reduction in this effect can have a positive effect on smog and airborne particles in the atmosphere. Roof areas are a significant part of urban hard surfaces. Plants on green surfaces absorb heat and then use it through evapotranspiration. Green roofs therefore would play an important role in reducing urban temperatures, and subsequent improvements in air pollution/smog, as associated with the albedo effect. In lare cities in India, the albedo effect increases the humidity within the city and this, with increased air pollution, is one of the main reasons for the growing tendency for very complex intensive green roofs on many buildings in that City. Research by NASA in Atlanta has compared temperatures of different surfaces. On a typical Atlanta day with maximum air temperature of 25 ^{0}C the temperatures of tree shaded grass , tree canopy, asphalt in full sun and membrane roof surface was 28^{0}C, 21^{0}C, 50^{0}C and 52^{0}C respectively. Research at Trent University has found on a typical day with a temperature of 18.4 ^{0}C a normal roof surface temperature was 32^{0}C while that of a green roof was 15 ^{0}C. The reduction in the protection of photochemical smog and subsequent improvements in air quality needs to be recognized as a powerful planning 'tool' and potential mitigation for polluting developments. Local Authorities may include green roof plans as part of their commitment to Air Quality Management Areas [AQMA].

Noise and sound Insulation

The combination of soil, plants and trapped layers of air within green roof systems can act as a sound insulation barrier. Sound waves are absorbed, reflected or deflected. The growing medium tends to block lower sound frequencies whilst the plants block higher frequencies. The amount of sound insulation is dependent on the system used and the substrate depth. Van Renterghem and Botteldooren [13], analyzed the effects of intensive and extensive green roofs on noise level. There is a linear relationship between the roof space covered with canopy and the reduction in sound A green roof with a 12 cm substrate layer can reduce sound by 40dB and one of 20 cm by 46-50dB. This could be particularly important in areas of high noise pollution such in the approaches to airports, as these levels are sufficient to provide noise insulation to buildings under aircraft flight paths.

Recycled Materials

A number of materials used in green roofs are from recycled sources, such as the membranes and growing mediums, such as crushed porous brick, which is used by some suppliers. In London, uniquely, there has been a move to use recycled secondary aggregate as the growing medium, preferably from the original site. This reduces the need for waste disposal to landfill and reduces the transport miles/distances for used for disposal of waste. This meets government targets for the reuse of secondary aggregates and where reuse from site can reduce the impact of lorries in terms of importation and exportation of materials.

Storm Water Amelioration

Green roofs store rainwater in the plants and growing mediums and evaporate water into the atmosphere. The amount of water that is stored on a green roof and evaporated back is dependent on the growing medium, its depth and the type of plants used. In summer green roofs can retain 70-80% of rainfall and in winter they retain between 25-40%.A study was conducted by Hilten et al [25], on the effectiveness of green roofs to mitigate storm water using computer simulation. It was shown that the green roof with growth media depth of 10 cm provides complete retention for storms up to 2.0 cm in depth, while providing detention for storms as large as 7.93 cm when assuming initial soil moisture content of 0.1. Detention time for storms between 5cm and 7.93 cm were approximately 12 hrs. Concerning the effectiveness of green roofs to reduce storm water runoff, simulations showed that green roofs are highly effective for small storms. For larger storms (>2.54 mm), green roofs can act to extend runoff duration thereby reducing surge normally evident with impervious surfaces.In Germany, the world leader in green roofs, 25 million m2 of green roofs were installed between 2000 and 2001. Green roofs also reduce and delay run off during times of heavy and prolonged precipitation. A study in Germany has shown that during a 10mm rainstorm, 200 liters of rainwater fell on an 18m2 extensive green roof and only 15 liters actually passed from the roof to the ground. Green roofs, therefore, reduce the impact of run off on the storm water drainage system, and reduce the likelihood of local flooding.

CONCLUSION

Green roofs are considered as a passive cooling technique and as a sustainable technology that offers benefits to the environment and society. The effectiveness of the green roof depends on type of plants, climatic conditions, geographic locations etc. The potential benefits of the green roofs are: reduction of energy consumption for energy driven air-conditioning systems, improvement in comfort of residential and commercial buildings, reduction in storm water run-off, reduction in CO_2 in atmosphere, reduction in noise level etc. Most of the researchers focused on the thermal performance and cooling potential of the green roofs whereas only few studies are seen on the mitigation of air pollution including reduction of CO_2, NO_x uptake etc. It is observed that most of the research works on cooling potential of green roofs were done in Europe, USA and Greece. Hence research in Indian context is more relevant today than ever before since climatic balance in India has been in turmoil in recent years. Therefore it is high time to carry out research on the effectiveness of green roof technology on cooling potential in Indian scenario with emphasis to their effect on attenuation of sound waves and storm water runoff.

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