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Decrease of pollution using the green roofs

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Abstract: Green roofs involve growing vegetation on rooftops and are one tool that can help mitigate the negative effects of pollution. This paper encompasses the date on how green roofs can help mitigate pollution, how green roof materials influence the magnitude of these benefits, and suggests future research directions. The discussion concentrates on how green roofs influence air pollution, carbon dioxide emissions, carbon sequestration, longevity of roofing membranes that result in fewer roofing materials in landfills, water quality of storm water runoff, and noise pollution. Suggestions for future directions for research include development of improved growing substrates, plant selection, water quality of runoff, supplemental irrigation, the use of grey water, air pollution, urban rooftop agriculture, effects on human health.

In Europe, 10% of flat roofs in Germany are covered with vegetation. In recent years, the Germans have built over 10 million square meters of green roof, or 7% of new roofs. 12% of swiss homes also have vegetation on roof. Fashion catch in other parts of the world. In Japan, the new regulations stipulate that 20 % of the projects over 900 square meters will be dedicated green space. City of Toronto officially supports a study on the subject, following that 6% of flat roofs are covered with vegetation. In Europe, there are already laws for greening roofs, some governments have introduced taxes on pollution, such as owners, to escape the fines , they began to turn to the organic solution.

Keywords: Air pollution, reducing runoff, water quality energy conservation, storm water quality, vegetated roofs

1. INTRODUCTION

Green roofs entail growing plants on rooftops, which partially replaces the vegetation that was destroyed when the building was constructed. In doing so they provide numerous benefits that can help offset the negative aspects of pollution, especially in the urban environment. They can improve stormwater management by reducing runoff and improving water quality, conserve energy, mitigate the urban heat island, increase longevity of roofing membranes, reduce noise and air pollution, sequester carbon, increase urban biodiversity by providing habitat for wildlife, provide a more aesthetically pleasing environment to work and live, and improve return on investment compared to traditional roofs.

Depending on the plants chosen for coatings, differentiates two types of roofs: extensive intensive type, semi intensive (Fig 1). The difference in the thickness of the earth taking into consideration the structural strength of the project, its weight can vary from 50kg/m^2 up to 200-500 kg/m^2 depending on thickness.

Extensive roof type involves a very thin layer of soil that plants grow extremely tolerant involves not require special care or hardly care. It is generally recommended for cultivation native and resistant to extreme temperatures which take root in a shorter time to avoid drying and strengthening soil.

In contrast, intensive roof type implies the existence of a much thicker layer of soil and loose and that may look like any other garden with trees and bushes. Modern technology allows even growing trees [6], [8], [9].

Some roofs are true vegetable greenhouses and garden ornaments. The roof requires the same care as an ordinary garden and can only be achieved if it supports loading solid roofs.

Figure 1. Semi-intensive Green Roof example (fotoby Graeme Hopkins)

They are generally categorized as either 'intensive' or 'extensive'. Intensive green roofs are frequently designed as public places and may include trees, shrubs, and hardscapes similar to landscaping found at ground level (Fig. 2). Intensive roofs also tend to be more expensive than extensive roofs because of the need for a more structurally sound building to support the weight. In contrast, extensive green roofs often never seen, require minimal maintenance, and are generally built with substrate depths less than 15 cm (Fig. 3).

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Figure 2. An intensive green roof on the Coast Plaza Hotel in Vancouver, British Columbia (Photo by Brad Rowe).

Figure 3. Portion of extensive green roof on an assembly plant at Ford Motor Company in Dearborn, Michigan. Plant material consists of 13 species and cultivars of Sedum (Photo by Brad Rowe).

2. AIR POLLUTION

In urban areas, trees have been shown to provide a significant contribution to the reduction of air pollutants [1]. In the U.S. alone, Nowak (2006) estimated that trees remove 711,000 metric tons per year. However, in many urban sites there is little space to plant trees or cultivate an urban forest because of the plethora of impervious surfaces such as streets, parking lots, and rooftops. For example, in the mid-Manhattan west section of New York, 94% of the land is covered with impervious surface which leaves little room for planting trees at ground level [2]. However, rooftops which often comprise 40–50% of the impermeable area in an urban area provide an opportunity to replace impermeable surfaces with vegetation [3].

It is estimated that 2000 m^2 of uncut grass on a green roof can remove up to 4000 kg of particulate matter [4]. In practical terms, a gasoline powered automobile produces approximately 0.01 g of particulate matter for every mile driven. If a vehicle is driven 15 000 m per year, then 0.1 kg of particulate matter is then released annually into the atmosphere. Thus, one square meter of green roof could offset the annual particulate matter emissions of one car.

Regarding specific pollutants, are estimate that if 20% of all industrial and commercial roof surfaces in Detroit, MI, were traditional extensive sedum green roofs, over 800,000 kg (889 tons) per year of NO2 (or 0.5% of that areas emissions) would be removed [5]. In Singapore, sulphur dioxide and nitrous acid were reduced 37% and 21%, respectively, directly above a green roof [4].

In Toronto, Currie and Bass (2008) studied the effects of green roofs on air pollution using the Urban Forest Effects dry deposition model developed by the USDA Forest Service. The model quantified levels and hourly reduction rates of NO_2, SO_2, CO_2, PM_{10} (particles of 10 μm or less) and ozone as well as their economic value[10].

Trees and shrubs were more effective in removing contaminants than herbaceous perennials largely due to greater leaf surface area. Although intensive green roofs with trees and shrubs are more favorable in terms of reducing pollution, extensive green roofs can still play a supplementary role in regards to air quality (fig. 4).

Figure 4. Sydney Conservatorium of Music

Although trees found at ground level or on intensive garden roofs play a much larger role in improving air quality than grasses or succulents that are often found on extensive green roofs, the added loading requirements and cost of intensive roofs make it unlikely that they will be implemented on a large scale [6]. Shallow green roofs can augment the urban forest, but cannot replace it. The benefit is difficult to quantify in dollars since the improvement in air quality and thus human health is a benefit to society and not the individual building owner [1],[5]. Reduction in air pollution quantified economically through emission reduction credits could help offset the cost gap for installing green roofs (fig. 5,6).

As a strategy to remove air pollutants, intensive green roofs are comparable to urban forests. If 20% of all existing “green roof ready” buildings in Washington DC, installed green roofs, the resulting plantings would remove the same amount of air pollution as 17,000 street trees [7]. However, green roofs are much more expensive. A 19 m^2 extensive green roof can remove the same quantity of pollutants as a medium sized tree, but the planting costs are approximately \$3059 and \$400, respectively. Even so, green roofs provide numerous other benefits in the long-term.

Figure 5. Finger Warf, Sydney

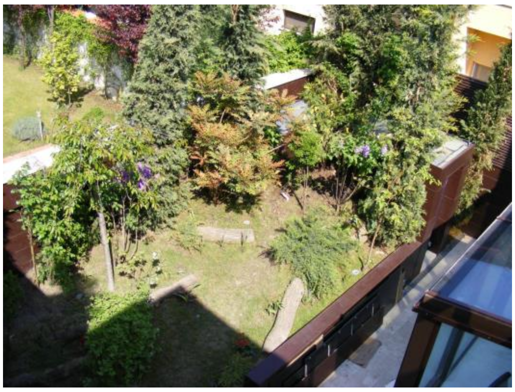

Figure 6. Green roofs in Japan

3. CARBON DIOXIDE

There is little doubt that the earth is warming. Part of this may be due to natural cycles, but the increase in temperature has coincided with the industrial revolution and the burning of fossil fuels. Burning fossil fuel releases CO_2 as a by-product of combustion and CO_2 is often implicated as a cause because it is one of the atmospheric gases that keeps terrestrial energy from escaping into space, thus resulting in higher temperatures due to the greenhouse effect. In the future, emissions of CO_2 due to fossil fuel combustion will probably continue to increase.

Green roofs can play a small part in reducing CO2 in the atmosphere in two ways. First, carbon is a major component of plant structures and is naturally sequestered in plant tissues through photosynthesis and into the soil substrate via plant litter and root exudates. Second, as stated above, they reduce energy needs by insulating individual buildings and by mitigating the urban heat island. A green roof will eventually reach a carbon equilibrium (plant growth = plant decomposition), but initially this man-made ecosystem will serve as a carbon sink. [3], [4]quantified the carbon sequestered by four species of Sedum in a 6.0 cm substrate depth extensive green roof in Michigan over a period of two years.

Although, a green roof can act as a carbon sink, one must also consider the embodied energy (total energy consumed, or carbon released, of a product over its life cycle) that goes into constructing it. The components of a green roof likely have a CO2 'cost' in terms of the manufacturing process over and above those of a conventional roof. Hammond and Jones (2008) analyzed many building materials from the beginning through the entire production process. Assuming a generic industry root barrier, drainage layer, and 6.0 cm of substrate consisting of half sand and heat expanded slate by volume, since the roof reaches an equilibrium where carbon assimilation equals carbon decomposition, there will be essentially no additional net carbon sequestration on this roof.

Net sequestration could be improved immensely by altering species selection, substrate depth, substrate composition. Increasing substrate depth would not only provide a larger volume for carbon storage, it would also enable a wider plant palette that could include larger perennials and even trees. In addition, the composition of the growing substrate could be altered [3], [8].

By using alternate materials, the embodied energy could be reduced substantially. For example, in the Pacific Northwest of North America, volcanic pumice is readily available and is often used as a component in substrates. The pumice has been heat expanded by nature and thus its embodied energy is vastly reduced. Furthermore, management practices such as fertilization and watering would have an impact on embodied energy and carbon sequestration.

The mechanical lifespan of a typical conventional roof is approximately 20 years. When these roofs are replaced the old roofing materials must be removed, transported, and will likely be placed in a landfill where they not only take up space, but may also leach pollutants (Fig. 7).

Figure 7. Elevated landscape Japan (Foto by Graeme Hopkins)

On the other hand, green roofs are estimated to last 45 years or longer in terms of mechanical lifespan. This estimate is based primarily on empirical evidence as modern green roofs are a relatively new practice. Supporting this statement is the roof of the water treatment facility in Zurich, Switzerland, that was installed in 1914 and repaired for the first time in 2005, a period of 91 years.

Green roofs last longer because the bituminous roofing membranes are protected by the growing substrate and plant canopy from ultraviolet radiation and the extreme fluctuations in membrane temperature between night and day.

4. WATER QUALITY OF STORMWATER RUNOFF

The reduction in runoff generally ranges from 50% to 100% depending on the type of green roof system, substrate composition and depth, roof slope, plant species, preexisting substrate moisture, and the intensity and duration of the rainfall. For example, if 20% of buildings in Washington, DC, had green roofs, they could store approximately 958 million liters of rainwater in an average year [8]. Water retained in the substrate will eventually evaporate or will be transpired back into the atmosphere. In addition, water that does runoff is delayed because it takes time for the substrate to become saturated and to drain. Because runoff is released over a longer period of time, green roofs can help keep municipal stormwater systems from overflowing and reduce potential erosion downstream.

In the U.S. there are 772 communities that do not have separate sewer and stormwater systems. Because sewage and stormwater are funneled through the same pipe in these communities, heavy rain events can result in a Combined Sewage Overflow (CSO) when the volume of runoff exceeds the capacity of the stormwater system. Under these circumstances, raw untreated sewage flows out of relief points into rivers. In New York City, about half of all rainfall events result in a CSO event and collectively they dump 40 billion gallons of untreated wastewater into New York's surface waters every year [9] (Cheney, 2005). Even in communities with separate stormwater managements systems, impervious surfaces still contaminate waterways by collecting pollutants such as oil, heavy metals, salts, pesticides, and animal wastes that wash into waterways. By retaining stormwater, green roofs decrease the chance of a CSO event and also reduce the cost associated with stormwater systems because they do not have to be as large.

The quantity of roof runoff influences water quality downstream after it exits the roof. The other side of the equation is how green roofs influence water quality of the effluent as it runs off the roof. Many contaminants present in common roofing materials already leach into the runoff and these contaminants will still be present in membranes on green roofs.

But, do plants and growing substrates influence runoff in a positive or negative way? Do they filter pollutants or provide an additional source of contaminants that exacerbate water quality? Heavy metals and nutrients are contaminants of interest. There is also the possibility that particulate matter cleaned from the air that adhered to leaf surfaces will be washed off by rain and eventually leach into the stormwater system, thus trading air pollution for water pollution.

Overall, it appears that green roofs can have a positive effect on water quality. Based on the data available, green roofs that were a source of pollutants tended to be new, whereas those that were older with established vegetation were not a problem. The initial nutrient load likely is due to decomposition of organic matter that was incorporated into the original mix. Established vegetation and substrates can improve the water quality of runoff by absorbing and filtering pollutants [4,5].

Of course, water quality of the effluent is dependent on several factors such as substrate composition, substrate depth, plant selection, age of the roof, fertilization and maintenance practices, the volume of rainfall, local pollution sources, and the physical and chemical properties of those pollutants.

Also, the use of soluble conventional fertilizers should be avoided due to the adverse impact on stormwater runoff. If nutrient loading is a problem green roofs could be coupled with other low impact development practices such as rain gardens and bioswales.

5. NOISE REDUCTION

Excess noise is not only annoying, it can lead to health problems such as hearing impairment, hypertension and ischemic heart disease, sleep disturbance, and decreased school performance. In urban areas, high noise levels are often a problem in enclosed spaces surrounded by tall buildings, along street canyons, and near industrial areas and airports [7].

Conventional roofs are generally hard surfaces so the potential to reduce sound pressure from roads and other sources in these areas by implementing green roofs is promising. Vegetation in combination with the growing substrate will absorb sound waves to a greater degree than a hard surface.

In 2009 the man of science found a linear relationship between the percentage of roof space covered with vegetation and the reduction in sound pressure on the opposite side of the building from the noise source or street canyon. Because green roof growing substrates tend to be coarse, sound waves enter the pore space and are attenuated by the numerous interactions with the substrate particles.

Relative to a non-greened roof the reduction is most pronounced at frequencies in the range from 500 to 1000 Hz with a maximum reduction of 10 dB. Increasing substrate depth improved noise reduction up to a depth of 15–20 cm [6]. Roofs with deeper substrate layers provided no further benefit. Of course, many variables influenced noise attenuation including the width–height ratios of the canyons, façade absorption, diffuse reflection, and building-induced refraction of sound.

On the inside of a building noise levels also depend on façade insulation, the sound pressure level outdoors, and whether windows are open or closed. Thus green roofs can have a positive influence on buildings near airports, industrial areas, and in urban settings.

6. THE GREENHOUSE EFFECT

The biggest problem is the global greenhouse effect. Global warming is caused by the increasing amount of CO_2 and other gases such as ozone (O_3) that meet the hot air in the atmosphere , warming the earth attract the sun's heat.

Human activities over the last 150 years have led Growth of the amount of CO_2 in the atmosphere causing negative effects on the entire global climate. Vegetation green roofs and the remaining vegetation using CO_2 for respiration process and thus reduce the negative effects of pollution.

This effect can directly influence the temperature in cities, so urban space is recorded temperatures much higher than in rural areas. The main cause of the current situation is the accumulation of large quantities of stone, concrete , asphalt in cities absorb solar heat during the day and at night exudes. Add to this the lack of vegetation, the trees in the big cities. So it is that at night the temperature rises and people cannot sleep because of the heat.

Costs of using air conditioners are growing. There have been cases in which elderly people have died from the very high temperatures.

In this context, the green roof can be a beneficial choice because it offers shade stops storing heat in the roof membrane and by the wet sweat exudes an air plants that help improve the local climate.

Certainly not just green roofs will be able to reduce overall pollution levels, but with other solutions and projects we could move in the right direction so as to provide better living conditions for our children.

7. WATER QUALITY, IRRIGATION, AND THE USE OF GREY WATER

Additional research is needed to substantiate claims regarding water quality of the runoff from roofs with various substrates and types of vegetation. Also, can grey water be used or will there be a buildup of salts in the substrate that will harm vegetation. Along those lines, will phosphates and other pollutants in grey water be filtered by the green roof or will they end up in the effluent?

Regarding irrigation, proper plant selection relative to substrate depth can eliminate the need in most cases. However, sometimes supplemental water is necessary to keep plants alive during drought episodes so the roof can function at its optimal level. Irrigation may also be positive in terms of energy savings as evapotranspiration from a green roof surface not only helps moderate internal building temperatures, but also may be a cost effective method of temperature control. This is because water that is needed to produce electricity is a significant portion of the cost. The cost of cooling air using the local potable water supply is between 41 and 93 times lower than using electric powered air conditioning to obtain the same level of cooling.

8. COMPLEMENTARY RELATED TECHNOLOGIES

Green roofs are only one technology that can help mitigate pollution. Green walls show much promise because they can cover four sides of a building instead of just the top (Fig. 8, 9, 10). A similar option is a vine covered trellis suspended over a roof known as a green cloak. In Maryland, Schumann and Tilley reported that a green cloak reduced maximum daily indoor temperatures by as much as 3.1 °C during July. This reduction is comparable to a green roof in terms of energy savings and has the advantage of being without most of the additional weight of a green roof [10].

Figure 8. Green walls

What is the impact of green roofs on the efficiency of photovoltaic cells in various climates? How can green roofs be combined with other low impact development practices such as rain gardens? We need to ask if green roofs are the most sustainable and cost effective technology for mitigating urban pollution in each situation.

Figure 9. Green wall at the Universidad del Claustro de Sor Juana in the historic center of Mexico City

Figure 10. Green wall

Reflective roofs are probably the most logical choice in desert areas such as Arizona. Even so, one must consider all the benefits that green roofs provide. Reflective roofs may be the best and most cost effective choice for energy conservation of an individual building, but they do not do anything for stormwater management, clean the air, deaden sound, or add anything for aesthetics [4].

Furthermore, growing a lush garden with high fertilizer and water inputs may be aesthetically pleasing and provide greater air pollution and energy savings benefits, but it could also result in a higher risk of water pollution.

9. CONCLUSIONS

First of all, green roof investment recovers in time because it is more durable and protects the roof structure and help cool the building in summer by plant transpiration, which ultimately involves savings in cooling solutions of your home temperature variations from the roof are much lower, so its life is extended considerably.

Moreover, green roof insulates sound, gives you a great look capita and maintenance costs are reduced. These types of roofs significantly reduce winter heat loss and summer maintains a low temperature in the house. And last but not least, contribute to improving living conditions in our community by reducing temperature and mitigating global warming.

The advantages of such roofs are obvious: the environment recovers. They absorb water from rain and dirt. Plant Leaves filter the air, purify it. Considerably decreases the temperature of the roof and the entire building.

It turned out that green roofs help to limit the effects of urban heat island generated by this massive concrete. "New York Times" shows that in cities where temperatures reach up to 35 degrees Celsius roofs reach temperatures of about 80 degrees Celsius. Surfaces covered with grass kept, but cool less than 25 degrees Celsius.

Not to mention the improve urban landscape aesthetics offers economic advantages of green roofs because they have a greater lifespan than conventional roofs

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