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Performance of green roofs with respect to water quality and reduction of energy consumption in tropics: A review

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ABSTRACT

Green roofs are an increasingly important component of water-sensitive urban design systems that can potentially improve the quality of urban runoff, reduce the energy consumption of buildings, and add esthetic value to the environment. The most important green roof abilities, which appear as a key feature in urban catchments are the ability of rainwater detention and retention and reduction in energy consumption. This paper aims to provide an overview of the effects of the application of the green roof strategy on the quality of runoff water and the reduction of energy consumption. The components of a green roof are discussed, and the advantages and disadvantages of different types of green roofs are assessed. In addition, the origins and concentrations of the main pollutants are discussed, moreover environmental cost-benefits of green roofs are also considered. In addition, the main factors that affect the quality of green roof runoff water, e.g., plant species, fertilization, pH, growth media as well as how green roofs could reduce energy consumption are discussed. Green roofs are considered as sustainable approach for runoff management with achieved aesthetical values and in combination with energy saving on heating/cooling. Hence, green roof causes a sufficient decrease in energy consumption and consequently in the related energy costs. It can help to improve the micro climate around the buildings and save money and also improve water quality. Therefore, green roofs may turn into a profitable investment. Some recommendations for future study also are proposed.

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1. Introduction

Currently, the growth of urbanization is intensifying, and it is anticipated to attain as much as 83% in 2030 in developed countries [1]. One significant consequence of urbanization is that percentage of the surface area that is impenetrable increases, and this can cause adverse consequences for the substructures of cities and the nearby environment [2]. The replacement of forests, grasslands, and croplands by impenetrable areas, such as buildings, driveways, and streets, significantly increases stormwater runoff, which decreases the replacement of groundwater and increases river erosion [1]. Due to increased stormwater runoff and increased impenetrable area, less water can be absorbed into the soil, and the frequency and severity of flooding in urban regions increase. Furthermore, studies have shown that global warming may cause more frequent occurrences of extreme precipitation in some regions [2], and this will also contribute to increases in urban flooding. There are two main tools for increasing the retention of water and decreasing runoff during rainfall. The first of these tools is ponds and storage reservoirs in which water can accumulate [3]. The second significant tool is the creation of more green areas to achieve urbanization that includes ecological concerns and preserves green, open areas that will allow water time to permeate the soil and evaporate rapidly [4]. Green roofs can be defined as a drainage layer (to discharge excess water) and a vegetation substrate layer in which water is preserved and plants cannot be easily uprooted [3]. In general, green roof systems are considered to be a green technology, and they can be incorporated into any type of roof. These systems consist of vegetated roofs [5], cool roofs [6], and roofs with solar panels [6]. Depending on the type of application, there are different names used to describe this strategy. For example, the green roof is also called an 'eco roof' because of the ecological benefits [7,8]. Other people refer green roof as a roof garden or a living roof [9].

In most cases, the green roof strategy can be defined as an efficient plan that reduces flood water runoff, produces some oxygen, and eliminates some carbon dioxide. The burden on water treatment facilities can be reduced by increasing the quality of runoff water. In addition, green roofs are an impressive remedy for the heat island effect due to their use of watered vegetation. Green roofs or living roofs provide sanctuaries for animals, prevent noise pollution, and can be used as part of a plan to decrease traffic noise. Moreover, energy designers and municipal planners are very interested in the effective application of green roofs due to their contributions to the improvement of the quality of urban environments and their ability to reduce energy consumption [3].

Green roofs can be an excellent solution to mitigate rainwater runoff. Due to the sorption of water in the green roof, part of the rainfall does not run off immediately, so the time required for complete runoff is extended by the relatively slow release of the additional water from the substrate layer [3]. Many factors can effect on the amount of water retained, including the intensity and volume of the rainfall, the amount of time that has passed since the last rainfall event, and the slope and the depth of the roof [10–12]. Teemusk and Mander [13] illustrated that green roofs can retain more rainwater in warm weather than in cold weather. Several research efforts [14,15] have shown that the substrate layer of a green roof will become fully saturated if rain events occur too frequently, so a green roof cannot delay the runoff from a heavy rain. Villarreal and Bengtsson [16] reported that greater volumes of rainfall are retained by initially-dry green roofs when the intensity and the slope of the rainfall are lower. Green roofs potentially can cause the release of pollutants into water from the soil, plants, and fertilizers, but they also may reduce the pollution associated with the runoff of urban rainwater by filtering and absorbing pollutants. The quality of the runoff from a green roof depends on the type of roof (thickness and composition of the substrate layer, type of vegetation, type of drainage); the age of the roof; how well the roof is maintained; the type of area that surrounds the roof; and the local pollution sources [17]. For the majority of the components of roof runoff water, the results differ depending on the different green roof systems and the composition of the substrate layer. Moran et al. [14] illustrated that high loads of nitrogen and phosphorus in green roof runoff were caused by compost in the substrate layer. Berndtsson et al. [17] discussed different types of green roofs that behave as sinks for nitrate nitrogen and that decreased ammonium nitrogen and total nitrogen. One major route towards environmental sustainability and the reduction of global green gas emissions into the atmosphere is integrated water and energy management in the urban context. The reduction of mass (water) and energy consumption between the building envelope and the surrounding environment is indeed a vital issue sustainability is to be achieved and comfortable living conditions in urban areas [13].

In general, green roofs are a substantial solution to increase the energy performance and the sustainability of buildings because they produce several different types of benefits. Depending on the climatic and urban context, it is possible to identify direct advantages either for the building itself or on a wider scale [18].

Reduction of the energy consumption and improving the comfort levels inside buildings during the spring and summer seasons can be achieved by using green roof systems. Therefore, designing more environmentally-friendly components of buildings leads to more energy savings and less depletion of natural resources [19]. Roofs are important components of buildings, and, given proper consideration, they can help produce sustainable outputs [20]. Covering a roof with soil, wetting the soil, and shading the surface of the wet soil have been used for centuries as passive cooling practices in hot and arid climates [21]. The green-roof strategy is a sustainable roof design that saves energy for cooling and heating purposes due to its insulation effects and the urban heat island effect [22–24].

This review defined the essential reasons that the use of green roofs can improve the quality of runoff water by reducing pollution and also analyzed how green roofs can help reduce energy consumption. This paper also provides a review of the scientific research related to this topic that has been published in the existing literature. The review includes results from implementation of green roofs on a large scale which have impact on urban