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Resumen:

In temperate climates green roofs have proven to be beneficial for urban water management. Green roofs retain stormwater, ease flooding and reduce combined sewage overflows. Green roofs can have a positive effect on stormwater quality and alleviate groundwater recharge. In the last decade an increasing amount of green roofs have been installed in dry and Mediterranean climates. This paper surveys the potential benefits of green roofs as part of urban water management strategy in these climates. It comes to the conclusion that green roofs can have hydrological benefits if certain conditions are given. Their usefulness might increase due to predicted changes induced by global warming. In regions of water scarcity, green roofs can only be installed if their irrigation is part of a sustainable water regime. Besides hydrological advantages other benefits of green roofs, like cooling effects, might be of equal or higher importance in hot and dry cities.

Palabras clave: green roofs, urban hydrology, Mediterranean and dry climates.

Water and Green Roofs in Dry Climates – A Speculation

INTRODUCTION

Green Roofs consist of thin layers of soil (4 to 20 cm) which supports the growth of succulents and herbaceous vegetation. Green Roofs have been built for hundreds of years in many different climate zones. The historical reasons for construction were waterproofing protection and temperature modification. In the vernacular architecture of the Northern countries of Europe layers of sod were placed to insulate against extreme cold. In Tanzania mud was placed onto huts to shield from summer heat (Stifter 1988). Poor farmers in the American Midwest covered their dwellings with sod in lieu of better building and insulation materials. In central Europe underground cellars were covered with grass to keep beer and wine at stable temperatures. Water treatment plants were covered with soil in order to keep water cool.

While historically these roofs were mostly seen as vernacular relics, their usefulness for the contemporary city was rediscovered in the late 1970s. In the German speaking countries of Europe, horticulturalists were studying spontaneously colonized roofs in 1957, and eventually started to plant thin layers of soil on the bare roofs of modern buildings (Bornkamm 1961). In the following twenty years researchers, landscape architects and contractors tested different techniques to build green roofs and studied their benefits. They found a multitude of advantages for the individual building, as for the whole city. Storm water retention, climate moderation (inside and outside), visual improvement, noise reduction, increased roof life, dust filtration and wildlife value were the main attributes accredited to green roofs. Based on these findings, major German cities and many municipalities started to offer incentives for green roof installation, some even making it a requirement in their zoning plans. Industry and academy developed in collaboration with the German Research Society for Landscape Construction (FLL) technically sophisticated, lightweight green roofs with minimal maintenance needs. Leakage fears subsided with the large number of installed non-leaking green roofs. Although modern green roofs have not been around long enough to set a maximum lifespan, the current belief is a 40 years minimum (traditional water proofing has to be replaced every 15 to 20 years).

Over the last 20 years around 130 km^2 of green roofs were installed in Germany at a rate of about 13 km^2 per year (Hämmerle 2005). Germany's green roof industry grew into an annual 430 million Euro enterprise. Seven percent of all new roofs, and 14 % of all new flat roofs are now green.

In the last ten years green roofs have started to raise worldwide interest. In 2006, over 280,000 m^2 of green roofs have been built in North America with Chicago, Portland, Washington DC and Toronto leading the charge (Greenroofs.com). Large cities like Mexico City, Singapore, Tokyo or Rio de Janeiro have started green roof programs. Other countries are in the very beginning stages such as Australia or the UK where there is a lot of interest but not many built projects. As green roofs are now installed worldwide, they are increasingly built in climates that are different than the temperate zones where they were developed. Especially in Mediterranean and dry climates an increasing amount of green roofs have been built in the last decade. In the US a total of 85,000m^2 in the dry West and Southwest have been built or are under construction (Greenroofs.com). Some of the larger roofs can be found in California with the Premier Automotive North American Headquarters in Irvine (4,000m^2), the GAP headquarters in San

Bruno (6,000m^2), the California Academy of Sciences (15,000m^2) and the planned Transbay Terminal in San Francisco (22,000m^2). Many smaller roofs can be also found in Texas, Arizona and drier European regions like the green roof for the Valdemingómez Recycling Plant (15,000m^2) in Madrid. The current largest green roof in the world is on top of the new Santander Bank in Madrid (100,000 m$^{2)}$.

With the different climatic context the hydrological design and benefits of green roofs have to be reassessed. In regions characterized by water scarcity, innate conflicts between resource conscious water management and green roof irrigation have to be evaluated.

URBAN HYDROLOGY AND GREEN ROOFS IN TEMPERATE CLIMATES

Green Roofs in temperate climates are typically non-irrigated, reduce stormwater run-off and peak flows during heavy rain events, ease groundwater recharging and improve the water quality of roof run-off in cities.

Irrigation

One of the basic design principles of extensive green roofs in temperate climates is the ability for the roof to survive without irrigation. The majority of green roofs in Germany are planted with drought tolerant succulents (mostly Sedum species) that can survive on less than 2mm of water per day (Koehler 2005). These succulents have an advantage over other plants, because they can close their stomata during hot periods and transpire less during the day (Crassulacean Acid Metabolism). Most of the modern green roofs have a retention layer below the substrate that retains water after heavy rainstorms. This reservoir can be accessed by plants during dry seasons. Many green roofs have provisions for emergency watering during dry spells. Some highly visible or accessible green roofs are irrigated to maintain a defined aesthetic, but the majority of green roofs in temperate climates are non-irrigated.

Stormwater Retention

A regular roof typically releases between 80 to 100% of the annual precipitation into the storm drain system. In contrast, green roofs have proven to retain between 40 and 70% of the annual rainfall in a temperate climate (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. 2002). Therefore green roofs are valued for their capacity to ease stress on urban sewers and flooding. Many German cities require the mandatory construction of green roofs based on these hydrological benefits.

Several factors determine the rainwater retention capacity of a green roof: Depth and consistency of substrate, vegetation type and density, the inclination of the roof and regional temperature and rainfall patterns, Most of the rainwater is retained in the green roof substrate. Tests have shown that between 10 and 50% of a green roof substrate are open pores. During a rain event the water is stored in these pores. Consequently a 15cm deep substrate on a flat roof with 50% of open pores can store 70% of the annual rainfall in Germany (650 to 800mm) (Roth-Kleyer 2005). Once a rainstorm is over and the pores are filled with water, the water begins to slowly evaporate from the substrate or is used by plants for photosynthesis and transpiration. Not all rainwater infiltrates the substrate. Depending on the density and surface coverage of the green roof vegetation, a small proportion of a rainfall directly evaporates from plant surfaces. Additional rainwater storage capacity can be created by adding an artificial water reservoir that is installed below the growing medium.

Peak Flow Reduction

The total annual rainfall retention of a green roof is dependent on the rainfall patterns of a region. A regular rain event in Germany is rarely above 10mm per day. A heavy rainstorm is considered to be over 25mm. A properly designed green roof is able to store an event of 35mm under consistently dry conditions (Koehler 2005). If there is unusually heavy rainfall or rain continuously falls over several days, the pores in the substrate will at some point be fully saturated and not accept any more water. Additional rainwater will then slowly run off the roof and enter the urban drainage system. In a heavy rain event, the release of this excess water typically occurs several hours after the peak of rain, allowing for a delayed discharge into the drainage system. When drainage systems are at full capacity during a heavy rainstorm, this peak flow reduction can prevent flooding. Besides helping diminish floods, green roofs also help to decrease overflow of raw sewage into rivers in older sewer systems where sewage and stormwater is combined in the same pipe system.

Groundwater Recharge

German researchers note that the delay of roof run-off in a rainstorm is also desirable in areas where groundwater needs to be recharged. In heavy rainstorms rainwater infiltration trenches and wells can reach maximum capacity. By reducing the run-off from green roofs these infiltration areas will have more capacity during a storm and can receive the delayed run-off from green roofs after a storm has peaked (Kolb, Schwarz 1999).

Water Quality

Green Roofs can also have a positive effect on the water quality of roof run-off if the substrates are designed accordingly. Heavy metals, nitrogen and phosphorus accumulate as dust on roofs and get washed down in rainstorms, thereby polluting waterbodies in the city. This nutrient heavy run-off can cause algae blooms in urban rivers and lakes. Studies in Berlin have shown that green roofs can specifically be designed to bind these pollutants. At the Potsdamer Platz development in Berlin green roofs improved the quality of roof run-off and contributed to the decrease of deadly algae blooms in the Spree river (Schmidt, Hauber 2005). These roofs had a specifically designed substrate with an extremely low organic content and fairly coarse mineralic composition. In contrast, green roofs with high amounts of organic contents can be counterproductive to the quality of run-off, because nutrients can leach out of the substrate (Moran, Hunt & Smith 2005).

Impact on Watershed

Green roofs cannot stay in the realm of being luxury additions on high profile projects. Many of them have to be built in order to create significant impact on an urban watershed. Although a large number of green roofs have been built over the years, their cumulative benefit on an urban watershed has not been comprehensively studied or documented. Mostly speculative calculations have been made in order to determine how many of the existing and new roofs in a city have to be greened in order to create a measurable impact on city-wide stormwater management.

In Karlsruhe a study was performed to assess four different city quarters for their potential to be retrofitted with green roofs (Steusloff 2005). In these four areas the study looked for roofs with an inclination of not more than 5º, because steeper roofs are more costly to be greened. It was found that between 5 to 20% of all roofs in the various quarters could potentially be greened. This low percentage stems from the fact that flat roofs are not part of the German building tradition, and the majority of existing buildings in these quarters had gabled roofs. Only in a dense industrial quarter 20% of all roofs were below 5º inclination. It was calculated that if 20% of all the roofs in this industrial district were greened and retain 60% of the annual rainfall, the overall reduction of roof run-off for the whole area is 4%. The study concludes that the combined hydrological effect of green roofs is only significant in dense cities with a high percentage of flat roofs.

In the US, where flat roofs are more abundant, another study looked at the effects of greening old and new buildings together in Washington DC (Deutsch et al. 2005). It was calculated that 80% of all new and 20% of all existing buildings (with a roof area greater than 10,000 sf) have to be greened, in order to reduce city wide run-off by 1.7% (not to be confused with total roof run-off). Although the overall reduction seems small, up to 15% of all combined sewage overflows into DC water bodies could be avoided. On a local scale some creeks will experience 39% less sewage overflows. The DC water and sewer authority considers these benefits as significant. The study concludes with the proposition to green 20% of all Washington DC roofs in the next 20 years based on the fact that most roofs have to be replaced every 10 to 20 years.

Both studies lead to the conclusion that the overall impact of green roofs on urban water management is defined by the particular roof conditions and building density of an urban area. The biggest hydrological effect on the watershed is in areas of high urban density (ultra-urban), where flat roofs make up at least 20% of all roofs. It becomes clear that a more significant combined impact on a watershed will be more easily achieved in new developments than in existing city quarters, where not all roofs are suitable to be greened. Policies that make green roofs mandatory could push implementation rates well above 20% for new developments (like at the Potsdamer Platz in Berlin) creating a significant impact on the watershed.

URBAN HYDROLOGY AND GREEN ROOFS IN MEDITERRANEAN AND DRY CLIMATES

As mentioned, the installation of green roofs dry climates is in the beginning stages. Few have been monitored and not much data has been gathered yet. Some of the following discussion is speculative.

Irrigation

Water and Green Roofs in Dry Climates – A Speculation

Most extensive green roofs in regions with less than 500mm rainfall need to be irrigated during the annual dry season. Even succulents must receive supplemental water in order to survive in dry climates. As water conservation is a prerogative key in dry regions and water shortages are projected to be more pronounced due to global warming, green roof designers are exploring ways to minimize irrigation of green roofs.

In most cases designers install drip irrigation inside the substrate which consumes less water than spray irrigation. When available they use non-potable water sources such as recycled city water. Water from underground cisterns that collect excess roof water during the rainy season is used to irrigate green roofs in the dry season (Transportation Center in Tempe, Arizona). Others irrigate with excess water of air conditioning condensing units that are already on the roof (Palomar Pomerado Hospital, San Diego). Environmental engineers currently test methods to desalinate ocean water on green roofs and use it for irrigation (Rehbein Environmental Solutions). English researchers are prototyping green roofs that clean greywater from showers, bathtubs, and bathroom sinks (Shirley-Smith 2005). The "green" water is then returned to flush toilets. Almost all designers try to forgo or minimize irrigation by testing native plants that are adapted to the regional climate (Rana Creek Ranch). Most of these roofs are still in the establishment phase and there are no conclusive results yet.

The current water saving schemes are laudable efforts, but uncertainties remain. In dry climates underground cisterns have to be fairly large in order to sustain a green roof through the rest of the year. There is also the question of whether the cistern water is better used for grey water needs inside the building than for roof irrigation. The reliance on condensate from air conditioners for irrigation is also problematic. Modern green buildings seek to achieve cooling of interior space mainly through passive means (shading, ventilation, greening) in order to avoid energy- and water-intensive air conditioning units. Other promising approaches that use rainwater several times in the same building like green roof irrigation with grey water are still in the beginning stages and not ready for widespread application.

It is also questionable if the ideal of a green roof without irrigation is desirable in dry climates. A study in Arizona has shown that a non-irrigated green roof can be detrimental to the interior climate of a building (Lerum, Thakare 2005). Preliminary tests have shown that plants on a non-irrigated roof did not provide a continuous cover of the substrate. During daytime the substrate was fully exposed to the sun and substantially rose in temperature. The hot layer of soil on top of the building trapped hot air within the building, preventing the space below from cooling out over night. In comparison, the irrigated green test roof substantially cooled the inside and outside of the building through evapotranspiration. Evapotranspiration not only cools the individual buildings (and saves energy), but also contributes to a healthier city climate by cooling the ambient air above buildings. In Berlin, tests have shown that green roofs transfer 58% of the radiation into transpiration in summer and evapotranspiration rates on a green roof can vary from 0.6 to 2.5mm per day (Koehler 2005). This cooling effect is probably the most important contribution of irrigated green roofs for cities in dry and hot climates. Therefore irrigation of green roofs is actually desirable, if a cooling effect is wished and if recycled water is used whose provision does not compete with other essential water demands in the region.

Water and Green Roofs in Dry Climates – A Speculation

Stormwater Retention and Peak Flow Reduction

It can be expected that green roofs retain at least 70% of the annual rainfall in climates with an annual precipitation less than 500mm (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. 2002). The question arises if stormwater retention and evaporation of green roofs is needed in regions where there is scant rainfall. One could argue that roofs in those areas should catch the sparse rainfall and drain it as fast as possible to underground cisterns that supplement the grey water needs of a building (actually a practice that has been done for centuries and was abandoned in modern times). This might be true in situations where water collection and reuse is the overriding factor and other benefits of green roofs (cooling, wildlife habitat, visual enhancement) are not critical.

In other situations, the stormwater retention and peak flow reduction benefits of green roofs can be very useful, especially in cities prone to flooding or in developments that cannot afford the large cisterns needed to store the accumulated annual rainfall. In dry climates where there might be less overall rainfall annually, the incidence of individual heavy rainstorms can create serious flooding. When surface soils are completely dried out and the falling rain cannot infiltrate the ground, flashfloods occur in concurrently with the erosion of streambanks, roadsides, the bottom of slopes and mudslides. In 2007, Madrid experienced a storm with 30mm of rain falling in one hour. Widespread flooding followed. Green roofs could contribute to ease peak flows in larger storm events. It is predicted that heavy rain events will further increase in incident due to climate warming in all regions of the world (Intergovernment Panel on Climate Change 2007). For dry regions this means that there is less overall rainfall, but the few individual rain events are more intense. Flooding events in dense urban areas where up to 70% of surfaces are impervious, will become more common. Green roofs could be part of a decentralized flood defense strategy.

Groundwater Recharge

Many urban areas in dry regions face water shortages and rely heavily on the use of ground water. In the last decades ground water tables have sunken due to overexploitation, mostly by agriculture. Some regions seek to artificially recharge their groundwater resources. Cities like Nevada divert spring flows of rivers to leaching fields that let water slowly infiltrate the ground. Other cities have started to reinsert heavily cleaned sewage water into the aquifer (Orange County, California). Some cities seek to reduce their quantities of impervious surfaces and allow stormwater to recharge the aquifer via infiltration trenches and wells (Freiburg, Germany). As in temperate climates, green roofs could ease the stormwater load on these infiltration devices during heavy rain storms.

Water Quality

The potential cleaning function of roof run-off by green roof substrates can be also helpful in dry climates. In areas where many months go by without precipitation large amount of pollutants and nutrients can accumulate on roof surfaces. The first rain after a dry season washes these pollutants into water bodies. By binding these pollutants in the substrate green roofs could help to mitigate the pollution of rivers.

CONCLUSIONS

In dry or Mediterranean climates green roofs can have hydrologic benefits, when urban areas struggle with problems like

- flooding
- combined sewage overflows
- restricted groundwater recharge
- urban river pollution

The combined effect of many green roofs on an urban watershed starts to be effective in dense urban areas

- where more than 70% of all surfaces are impervious and
- where roofs comprise more than 30% of all impervious surfaces and
- where more than 20% of these roofs are structurally suited for greening.

Individual cities should undertake calculations to determine the effectiveness of green roofs for their particular conditions. These calculations should take into account predicted effects of climate change, such as the likelihood of fewer but more intense rain events.

Most green roofs in dry and Mediterranean climates need to be irrigated to allow plant survival or be effective (cooling function). Only recycled water should be used, provided this does not compete with other essential water demands in the region.

In dry and Mediterranean climates hydrological benefits cannot be the single overriding factor for the implementation of green roofs. In specific situations other benefits can be more important such as the creation of wildlife habitat, an increased roof lifespan or aesthetic benefits. In particular the cooling of the individual buildings, as well as the whole city through green roofs can be very attractive for dry and hot cities. As in temperate climates, the whole range of green roof benefits has to be evaluated before making a decision.

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