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ORIGINAL RESEARCH ARTICLE

GREEN ROOFS: AN ALTERNATIVE FOR THE REDUCTION OF SURFACE RUNOFF IN THE CITY OF RECIFE, PE

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ABSTRACT

Constant flooding during periods of intense rain, aggravated by the impermeabilization of the soil, is a recurrent problem in many Brazilian cities, such as Recife, located in the state of Pernambuco. An efficient alternative that can mitigate this problem is the use of compensatory techniques such as green roofs. Adding a plant layer on the roof of buildings can serve to reduce atmospheric pollution, contribute to an improvement in thermal sensation, and absorb rainwater, reducing the intensity of flooding. Therefore, the objective was to evaluate the reduction in the volume of water drained from the surface in cities, through the implementation of green roofs. To carry out this evaluation, a green roof and a Pluviometer prototype were installed to collect data on the volume of water precipitated, drained, and absorbed by the prototypes. The results show that the volume of water drained by the green roofs can vary significantly, from over 100% down to complete absorption of the precipitation, i.e., 0% of the water volume, as occurred on some days in May, which is the month that presented the lowest rainfall of the analyzed period. In addition, the analyses also show that as well as the prototypes, the real green roof significantly reduces the flow of water from precipitation. The mean reduction of the total volume in the study was 50%, however, at longer intervals without precipitation, this reduction reached 78%. These results show that the impact of the implementation of compensatory techniques such as green roofs significantly reduces runoff, especially in a city that is flooded. Therefore, this study can serve as an incentive for public and private institutions to adopt the compensatory techniques of urban drainage for future or existing constructions, due to the aggregated social benefits, although they are not currently mandatory for all new constructions. The authors proposed the implementation of compensatory techniques, such as green roofs, in urban centers with high percentages of impermeable soil

1.0 Introduction

World population growth continues to drive the urban demographic explosion, leading to the disorderly occupation and use of space that consequently brings serious disturbances to quality of life and environmental balance. For instance the effect of heat islands (the increase in temperature of large urban centers), decrease in air quality, and increase in noise pollution due to the increasing number of motor vehicles in circulation and the occurrence of flooding due to the increased impermeability of the soil surface, mainly due to the construction of highways and buildings (Danni-Oliveira, 2000).

As cities have grown and industrialization has progressed, today's urban areas have experienced intense transformations, especially in the infrastructure sector through paving and construction of houses and buildings. A direct consequence of this transformation is the impermeabilization of the soil, that is, rainwater ceases to infiltrate into the soil and begins to flow across the surface towards the drainage networks. The more areas that become impermeable, the greater the volume of water that must be drained, increasing the chances of flooding.

Locatelli *et al*. (2014) observed in a study that green roofs are being widely implemented in Europe for the management of rainwater and to positively impacting the urban hydrological cycle, through their capacity for retention and evapotranspiration of precipitated water. In addition to this benefit, Dimitrijević *et al*. (2016) pointed out that this technology also acts as a passive cooling technique for concrete structures and cities, as there it reduces absorption of the sun's rays by the structure and reduces reflection of these rays, minimizing the heat island effect in urban centers. Another aspect, that of air pollution, was analyzed by Yang *et al*. (2008), who quantified the removal of air pollution by the Chicago green roofs, which reached 1675 kg of air pollutants over the course of a year in an area of 19 hectares.

According to Lee *et al*. (2013), the soil layer of the green roof allows for a temporary absorption of rainwater, slowing the flow of water compared to impermeable roofs of waterproofed buildings, able to retain 45% to 55% of the annual rainfall volume on green roofs of extensive type (with soil depth varying from 60 to 200 mm and weight varying from 60 to 150 kg m^{-2}). The amount of retention, however, depends strongly on the intensity of the rainfall during each precipitation event. It is therefore necessary to evaluate the conditions of the site where the green roof is to be implanted, in order to define the optimal layer depth and type of soil to be used (Korol and Shushunova, 2017).

However, results regarding the potential rainwater retention of the green roofs also vary according to the study region. For example, a study conducted in Breslávia, Poland by Burszta-Adamiak (2012) showed that the retention potential varies between 82.5% and 85.7% and, in cases of rainfall up to 1 mm per day, it is very close to 100%. Another study, conducted in Rio Grande do Sul by Tassi *et al*. (2014), analyzed a long-term period equivalent to 17 months, the green roof reduced the surface drained volume by an average of 62%. In Caruaru, in the semi-arid region of Pernambuco, Santos *et al*. (2013) performed a simulated study of intense rainfall at levels of 42 mm h^{-1} and 79 mm h^{-1}, obtaining retention rate results of 33.6% and 15.5%, respectively.

As expected, an inversely proportional relationship was found between the precipitated volume and the volume retained by the green roof. Thus, this study aims to evaluate the effects of extensive green roof implantation on the buildings along the Pernambuco coastline from the point of view of the reduction of the volume of surface water drained.

2. Materials and Methods

2.1. The Study Area

The city of Recife is located in the northeastern region of Brazil, which has two clear climatic periods, a dry one (August to February) and a rainy one. During the dry season, the city suffers from average temperatures of 27 °C and a daily photoperiod of up to 10 hours. Being a coastal city and full of very tall buildings, the relative humidity of the air is always high, creating heat islands and raising the average values of thermal sensation.

This city is an example of an urban center that suffers from frequent flooding problems, especially between the months of March and July, when rainfall reaches its highest volumes, over 200 mm per month. One of the alternatives adopted by the municipal government to alleviate these problems was the implementation of a law that obliges the implementation of green roofs in non-residential buildings having roof slabs larger than 400 m^2 or multifamily housing having more than four floors (Recife, 2015). The intention of the city hall is that, in addition to mitigating atmospheric pollution, these roofs will contribute to improving the thermal sensation, in the dry months, and the absorption of rainwater, in the rainy months, reducing the intensity of flooding.

To study the drainage of rainwater with green roofs, manually-prepared prototypes were placed at the top of Block J of the Polytechnic School of Pernambuco, and compared to a building in the process of executing this technology, located about 700 meters away from the prototypes, Figure 1a. These two study sites are located in portions of the Madalena neighborhood in Recife, which suffer from constant flooding, Figure 1b.

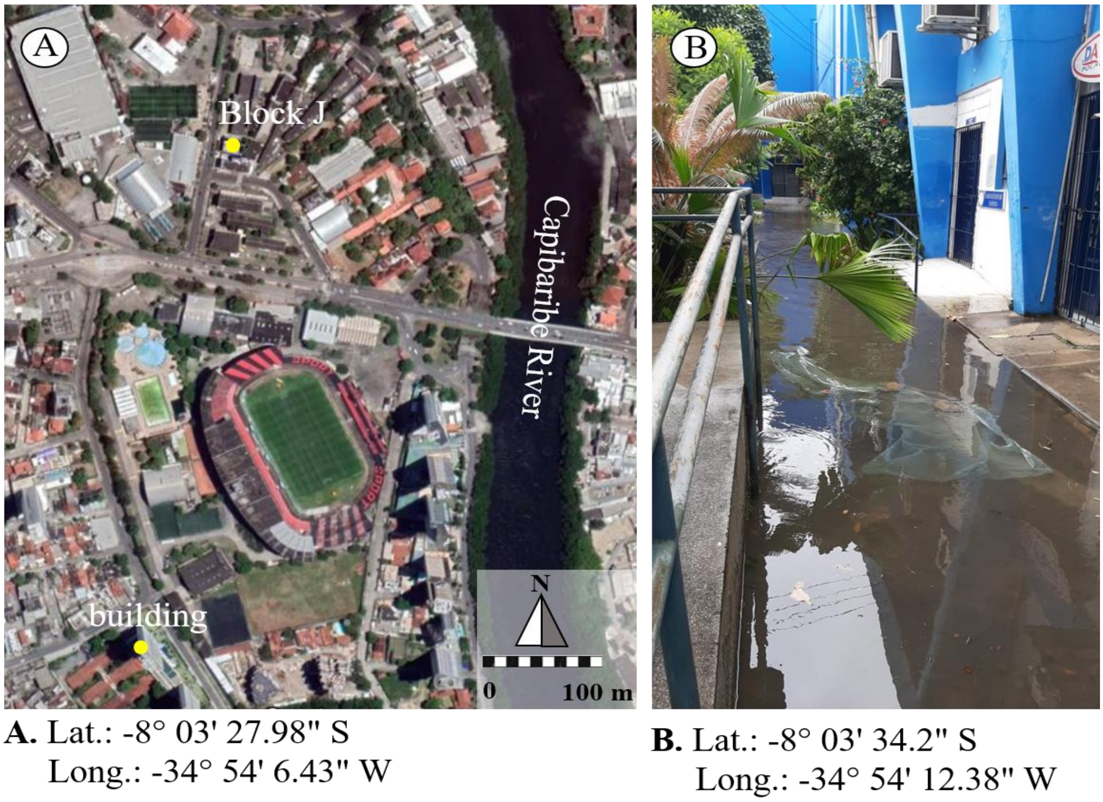

Figure 1. A Study area and **B** flooding of Block J facilities.

2.2. Prototypes

The green roof Prototype was elaborated based on the specifications for the real green roof executed and accompanied at the building site, following the same parameters for thickness of the real substrates. By stacking two identical containers and using the original lid as a basis for soil support, it was possible to practically measure the volume of water drained and deposited in the reservoir (lower vessel).

The first step was to remove the bottom of the upper vessel, so that all the water drained through it would accumulate in the lower vessel, which served as a reservoir. The second step was to decrease the circumference of the lid and attach it 24.5 cm from the top edge of the reservoir. The third step was to drill holes in the center of this lid so that the water could flow into the lower reservoir. The lid was attached using PU30 Sealant material. The fourth step was the placement of the green roof substrates, based on measurements for the real green roof, with 7 cm of expanded clay placed just above the lid. Subsequently, a layer of geotextile blanket was placed above the expanded clay followed by a 6 cm layer of fertile soil. Finally, a grass mat 4 cm thick was placed on top, cut to the circumference of the reservoir, with a diameter of 40 cm.

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This fertile soil is composed of 12.84% clay, 85.16% sand and 2% silt and has a saturated hydraulic conductivity (K_s) of approximately 0.04 m h^{-1}, residual and saturated volumetric moisture (θ_r and θ_s) of approximately 0.06 and 0.37 m^3 m^{-3}, respectively, and an α of 2.62 m^{-1}. In addition to the Prototype green roof, a nearly identical structure was also constructed without any substrate, in order to measure the total volume of precipitation for the same timer periods. This was called the Pluviometer Prototype.

The structure of the Pluviometer Prototype was built in a very similar pattern to that of the Prototype green roof, through the stacking of two identical containers. The first three steps were exactly the same as those described for the Prototype green roof, but the fourth step in this process was to attach a funnel through the PU30 Sealant material just below the central holes, coupled to a hose to form a siphon, whose purpose was to minimize the effects of evaporation of the water accumulated in the lower reservoir. A schematic drawing was made to illustrate the processes, Figure 2.

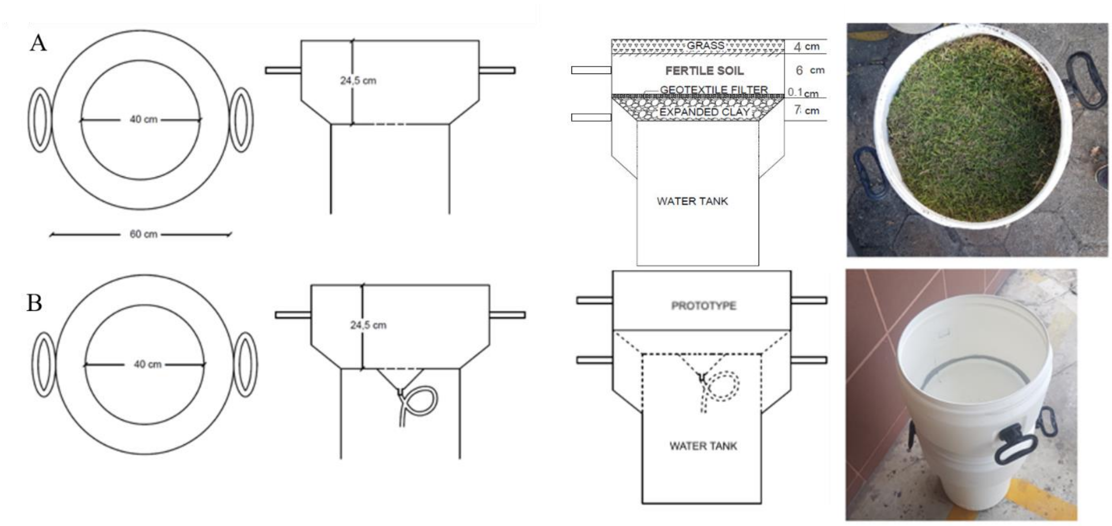

Figure 2. **A** Schematic drawing of the Prototype green roof and **B** the Pluviometer Prototype.

Unfortunately, as a public institution, the Polytechnic School of Pernambuco did not allow the installation of many prototypes without the authorization of the Rectory of the University of Pernambuco. However, as it is a time-consuming process, this request would cause the authors to lose the annual rainfall window that occurs in Recife.

2.3. Data Collection

The Prototype green roof and the Pluviometer Prototype were placed on the roof slab of Block J of the Polytechnic School of Pernambuco on March 23, 2018 and data was collected intermittently until July 25, 2018. This site was chosen for security and ease of access to the roof slab, plus the fact that the university is located less than 700 meters from the real green roof. This made it possible to more accurately estimate the positive impact caused by the green cover surrounding the worksite, with respect to surface runoff.

The measurements of the volume of water drained by each element were taken daily from Monday through Saturday. On Sundays and holidays, no measurements were taken because of university logistic reasons and, consequently, the values measured on subsequent days corresponded to the amount accumulated over the period.

3. Results and Discussion

The volume of water collected by the Prototype green roof and the Pluviometer Prototype between March 23 and April 30, 2018, with April 2, 9, and 23, 2018, being the dates having the highest rainfall amounts of 39.44 mm, 33.25 mm, and 34 mm, respectively, Figure 3. An important observation was noted on April 12, 14, and 24, in which the volume of water drained by the Prototype green roof was higher than that collected in the Prototype Rain Pluviometer, due to the tendency of the green roofs to delay and prolong the flow of precipitated water (Guimarães *et al*., 2020). In other words, even when precipitation has stopped, water will continue to follow the path of infiltration through the soil and leak potentially for hours afterwards. According to Filho *et al*. (2016), green roofs alleviate the public drainage system because the peak precipitation flows are attenuated.

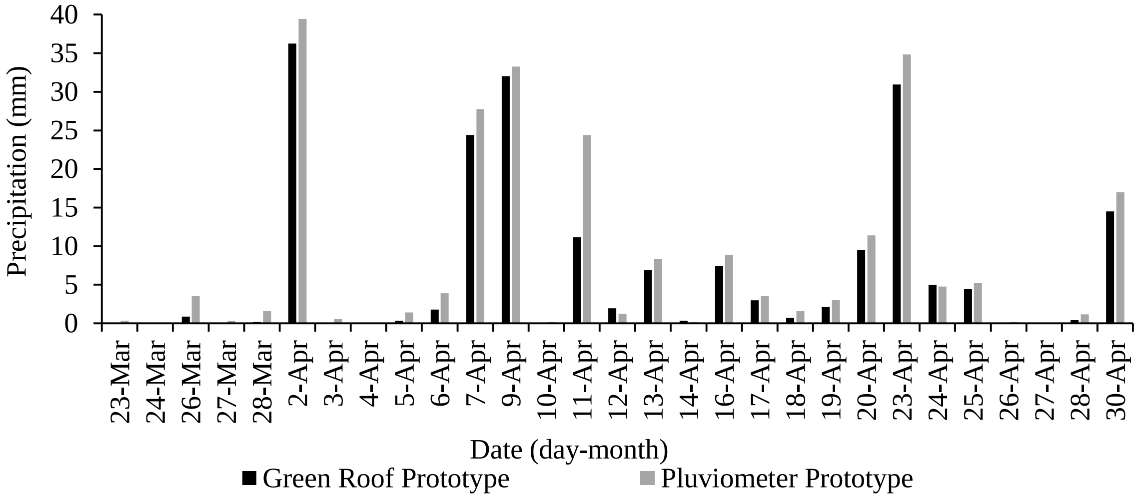

Figure 3. Comparison of volume of water precipitated to volume drained between March, 23 and April, 30, 2018.

The month of May (Figure 4) was characterized by a period of less voluminous rains compared to those at the end of March and during the month of April (Figure 3). Although this study does not allow for a more detailed analysis of the influence of rain on extensive green roofs for intervals of less than 24 h, the lower volume of precipitation is expected to promote a more rapid recovery of rainwater absorption potential by the green roofs. However, on May 3, 4, 5, and 7, 2018, the opposite of this phenomenon occurs, that is, the higher the volume of water during the day, the lower the rate of absorption of the precipitated volume, being 29%, 59%, 71%, and 74%, respectively. This is in agreement with the results obtained by Filho *et al*. (2016) who studied the hydrological efficiency of green roofs in reducing surface runoff.

The volume of water drained by the green roof can vary significantly, from over 100% as previously mentioned, down to complete absorption of the precipitation, i.e., 0% of the water volume, as occurred on May 10 and 11 (Figure 4).

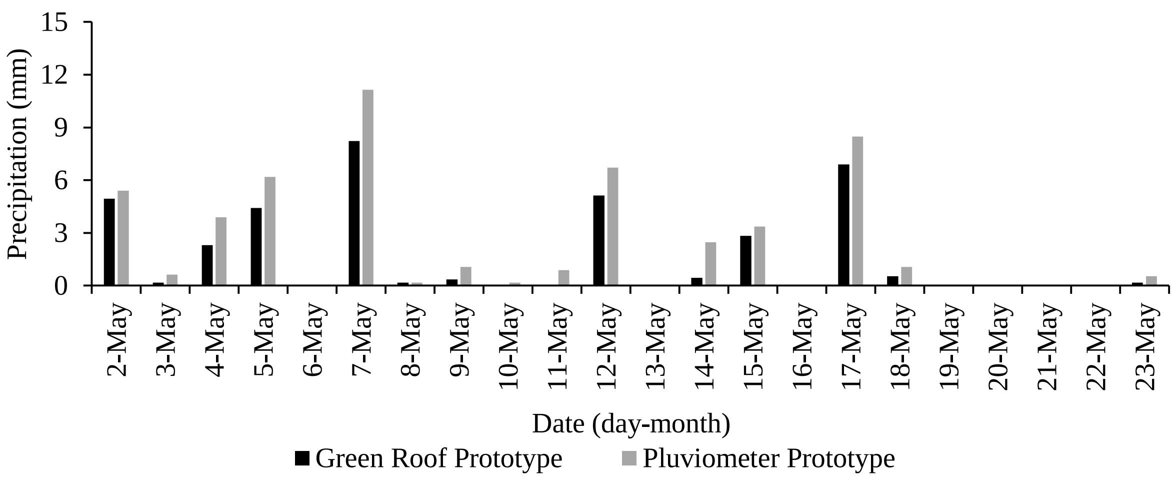

Figure 4. Comparison of volume of water precipitated to volume drained between May 2-23, 2018.

During the months of June and July (Figure 5), there are periods without rain that reach six days, such as the interval between June 9 and 13 and July 10 and 17, 2018. A noticeable effect of these drought periods was the significant reduction of water flow during later occurrences of precipitation, especially on June 14 and July 18, 2018, when 78% and 76% of the volume of precipitated water was absorbed by the green roof, respectively. These values corroborate with other previous studies that highlight this effect of the retention potential increases when the soil is extremely dry, with results being intermediate to those obtained by Tassi *et al.* (2014) of 62% and Burszta-Adamiak (2012) of 85.7%.

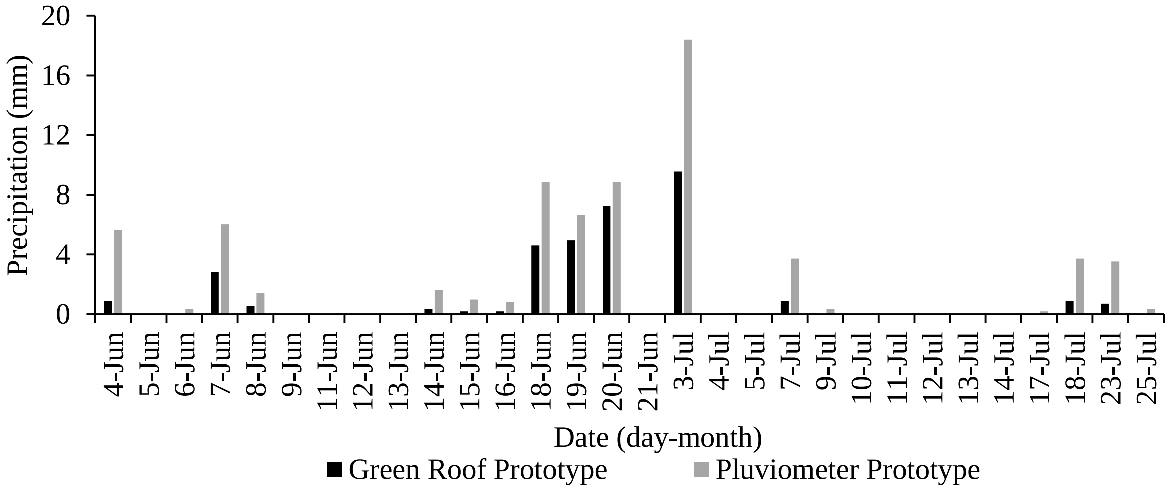

Figure 5. Comparison of volume of water precipitated to volume drained between June, 4 and July, 25, 2018.

It isnoteworthy that on July 3, 2018, an accumulated volume of 18.39 mm of precipitation was recorded with a flow of only 9.55 mm in an interval of 12 days with no record of precipitation, which also reveals the power of absorption of this compensatory technique over longer periods of drought.

According to the blueprints made available by the construction company, it was possible to verify that the real green roof is divided into three garage floor slabs, with a total area corresponding to 785.06 m^2. For the percentage calculations, 100% of the volume collected by the Pluviometer Prototype was considered for each precipitation event, and then compared to that of the prototype green roof and with the real green roof. Over the total 78 days of data collection, the Pluviometer and green roof Prototype had volumes of water drained of 361.48 and 264.62 mm, respectively. In this case, considering the total amount of water drained, the green roof provided a reduction of 26.79% in relation to the precipitated amount.

Therefore, it is clear that the real green roof significantly reduces the flow of water from precipitation, with a total average reduction of 50%, indicating that the flow from the green roof was, on average, only 50% of the total precipitation. In this case, the drained volume was only 180.74 mm, representing a difference of 83.88 mm between the values obtained with the prototype and with the real green roof. This difference may be directly linked to the lower exposure of the grass present in the real green roof to the sun, which means that the roots of the planted vegetation do not develop to the point of compromising the drainage layer, as well as with the prototype.

This result is similar with the results reported by Silva *et al.* (2020), who showed that green roofs can help to reduce flooding caused in urban centers, especially in a central neighborhood in the city of Recife. Therefore, green roofs or other techniques that help the urban drainage collection network are essential for the neighborhood of Madalena, since approximately 87% of it is composed of waterproofed surfaces (Holanda *et al.*, 2019).

However, some important caveats should be noted regarding the average calculation, as it is possible to verify that during the maximum precipitation events, in this observed period, the volume absorbed by the green roof tended to be smaller. For example, except for April 11, 2018, all other data having rainfall greater than 15 mm, had measured yields greater than 85%. This phenomenon occurs because, when rains are more intense, the green roof soil tends to saturate more quickly, causing the surplus to drain. When the volume of rainfall exceeds the saturation volume of the soil, the amount absorbed becomes less and less expressive. However, during moderate rains preceded by a period of dry days, the absorption capacity tends to increase, reaching up to 100% of the precipitation.

There are two possible explanations for the relatively low retention results found in this study compared to the articles cited above, where the reduction exceeded 50%. The first reason is the consecutive sequence of rains witnessed during the studied period, because as previously stated, the longer the period of drought preceding a rainfall event, the higher the rate of absorption of precipitated water. The second reason is the volume of rainfall, because, according to studies by Carter and Rasmussen (2006), the potential for water retention decreases significantly as precipitation volume increases, and according to Silva *et al.* (2020), a day with moderate rainfall in Recife is characterized as a day when rainfall is greater than or equal to 15 mm.

4. Conclusion and Recommendations

Despite the limitations associated with measurements made over a short period, this study identify the positive impact of green roofs on the local reality in Recife. Just in the surroundings of the building studied in the Madalena neighborhood, there was a 50% reduction in runoff, resulting in an approximate reduction of 180 m^3 of water in the local drainage networks during the studied period.

However, for periods of drought in which the soil has the lowest moisture content, the reduction in water runoff reaches 78%. In this case, the constant absorption of water by the roots of the plant layer and the low amount of material used in the soil layer used in the structuring of green roofs allow that in a few days that the soil is able to reduce the runoff values, exceeding the average 50%.

Thus, these data could serve as a parameter for other large urban centers and that the dissemination of the use of compensatory techniques, such as green roofs, can significantly reduce the large volumes of water carried by the networks of urban drainage collectors duringrainy days which would help to alleviate the socio-economic liabilities caused by constant flooding.

5. References

Burszta-Adamiak, E. 2012. Analysis of the retention capacity of green roofs. Journal of Water and Land Development, 16(1): 3-9. DOI: 10.2478/v10025-012-0018-8

Carter, TL. and Rasmussen, TC. 2006. Hydrologic Behavior of Vegetated Roofs. Journal of the American Water Resources Association, 42(5): 1261-1274.

Danni-Oliveira, I.M. 2000. Considerações sobre a poluição do ar em Curitiba-PR face a seus aspectos de urbanização. Revista Raega: O Espaço Geográfico em Análise, 4: 101-110. DOI: 10.5380/raega.v4i0.3342

Dimitrijević, DG., Živković, PM., Stojiljković, MM., Todorović, MN., Spasić-Djordjević, SŽ. 2016. Green Living Roof Implementation and Influences of the Soil Layer on its Properties. Thermal Science, 20(5): S1511-S1520. DOI: 10.2298/TSCI16S5511D

Filho, JEA., Manna, IBCB., Melo, NA., Caixeta, ACM. 2016. Eficiência hidrológica de telhados verdes para a escala de loteamentos residenciais. Sociedade & Natureza, 28(2): 257-272. DOI: 10.1590/1982-451320160206

Guimarães, MM., Silva, MP., Florentino, WG., Dias, RS., Junior, FCFO., Pereira, IA. 2020. Uso de telhados verdes na mitigação de cheias de uma bacia hidrográfica urbana com alta frequência de inundações. Brazilian Jornal of Development, 6(12): 98235-98254. DOI:10.34117/bjdv6n12-351

Holanda, MACR. and Soares, WA. 2019. Analysis of the effect of impermeability of urban soils on the infiltration of rainwater in the city of Recife, PE. Revista Ambiente & Água, 14(4): 1-10. DOI: 10.4136/ambi-agua.2386

Korol, E. and Shushunova, N. 2017. Green roofs: standardization and quality control of processes in green construction. Journal of Hydrology, 106: 3001-3017. DOI: 10.1051/matecconf/201710606014

Lee, J., Moon, H., Kim, T., Han, H. 2013. Quantitative analysis on the urban flood mitigation effect by the extensive green roof system. Environmental Pollution, 181: 257-261. DOI: 10.1016/j.envpol.2013.06.039

Locatelli, L., Mark, O., Mikkelsen, PS., Arnbjerg-Nielsen, K., Jensen, MB., Binning, PJ. 2014. Modelling of Green Roof Hydrological Performance for Urban Drainage Applications. Journal of Hydrology, 519: 3237-3248. DOI: 10.1016/j.jhydrol.2014.10.030 ISSN 0022-1694

Recife. Lei n° 18.112/2015. Dispõe sobre a melhoria da qualidade ambiental das edificações por meio da obrigatoriedade de instalação do "telhado verde", e construção de reservatórios de acúmulo ou de retardo do escoamento das águas pluviais para a rede de drenagem e dá outras providências. Diário Oficial, Recife, 12 jan. 2015. pp. 12.

Santos, PTS., Santos, SM., Montenegro, SMGL., Coutinho, AP., Moura, GSS., Antonino, ACD. 2013. Telhado verde: desempenho do sistema construtivo na redução do escoamento superficial. Ambiente Construído, 13(1): 161-174. DOI: 10.1590/S1678-86212013000100011

Silva, TB., Holanda, MACR., Soares, WA. 2020. Telhados verdes. Caracterização das condições ótimas para o microclima da cidade de Recife-PE. In XV Simpósio de Recursos Hídricos do Nordeste, Nov., 22-26, Caruaru. Proceedings... Caruaru: ABRHidro, 2020. pp. 1-10.

Tassi, R., Tassinari, LCS., Piccilli, DGA., Persch, CG. 2014. Telhado verde: uma alternativa sustentável para a gestão das águas pluviais. Ambiente Construído, 14(1): 139-154. DOI: 10.1590/S1678-86212014000100012

Yang, J., Yu, Q., Gong, P. 2008. Quantifying Air Pollution Removal by Green Roofs in Chicago. Atmospheric Environment, 42: 7266–7273. DOI:10.1016/j.atmosenv.2008.07.003