The contribution of green roofs to mitigate urban heat island effect in Rio de Janeiro

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ABSTRACT: Green roofs represent the reintroduction and inclusion of vegetation and biodiversity in the built urban environment. The integration of vegetation through green roofs; for example, using grasses, succulents, flowers, shrubs, and trees in urban areas is particularly important to maintain cool built urban environment because buildings, streets and other infrastructures increase the heat absorption, which results in the urban heat island effect. In addition to mitigating the warm urban climate, green roofs reduce energy consumption, provide spaces for recreation, and preserve biodiversity, which is probably one of the greatest challenges of our time, considering climate changes and environmental degradation by massive urbanization. This paper demonstrates results of air temperature, air humidity, and surface temperature measurements between a conventional roof and an extensive green roof located in Rio de Janeiro. The objective of this study is to evaluate the contribution of green roofs to mitigate the urban heat island effect through monitoring.

Keywords *green roof, urban heat island effect, built-up area, temperature*

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1. INSTRUCTION

According to the report of Millennium Ecosystem Assessment (2005), at the beginning of 20th century, 15% of the world population lived in cities. Currently, with rapidly growing world population, more than half of the population lives in urban areas, which is approximately 2.8% of total land of the Earth. While the major cities offer many opportunities; their habitants are exposed to the higher temperatures, pollution, noise, and the remoteness from nature. The inclusion of the vegetation can contribute to the built urban environment by minimizing its negatives impacts.

Reintroducing greenery in cities provides many advantages for habitants, mainly enhances the quality of their lives and connects the buildings with their unique local environment. One of the possibilities how to incorporate the vegetation in the building envelope is in the form of green roofs. Green roofs offer multiple environmental benefits by integrating the natural cooling, insulating, and water retention properties of soil and plants into urban buildings. There are many potential benefits of green roofs, but this paper focuses on green roof as a possible mitigation strategy of the urban heat island effect.

2. URBANIZATION CAUSING THE LOSS OF GREEN SPACES

Cities occupy a small proportion of our planet, but they are the most concentrated areas of population in the world. The percentage of the population living in cities continues to increase, as the rural population decreases. Most of this growth occurs in developing countries (United Nations, 2004), especially in tropical areas, where urban infrastructure has to be built yet. Thus, in the near future, the largest proportion of humanity will live in areas where the local environment has been profoundly modified by the cities, which are already constructed or will be constructed.

Latin America is the third most urbanized region in the world. In the past, cities in this region were mostly characterized by simple structures, which in recent years have passed thought an enormous development. There are cities where urbanization, economic and political processes are concentrated disproportionately in relation to other cities in the same country. In Brazil, São Paulo and Rio de Janeiro belong to these cities (Bouteligier, 2012).

Brazil has experienced rapid urbanization during the 20th century, when the cities acquired the growing importance in the territorial organization of the country. This staggering grow of cities caused that in these days 80% of Brazilians live in urban areas (Logan, 2015). The process of industrialization began in the first half of the twentieth century, and it has always been strongly linked to urbanization, with a direct influence on the structure and formation of the urban network. This urban network currently consists of regional systems located mainly along the coast, mostly in the south and southeast, such as Rio de Janeiro, Sao Paulo, and Salvador.

In the last decades, Rio de Janeiro has undergone a process of urban expansion, when the vegetation was largely replaced by concrete and asphalt surfaces. Despite the fact that Rio de Janeiro has the largest urban forest in the world, the built-up areas have been progressively modifying the city landscape. The city lost at least thousands hectares of green

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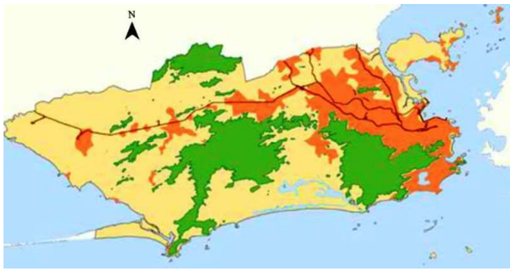
spaces during last 50 years (Platonow, 2012). The urban growth of Rio de Janeiro between 1940 and 2009 is demonstrated in Figures 1 and 2. From the figures, it can be seen an augmentation of urban areas, when urban development occupied almost every non-built-up area. This fact has a significant impact on creation of heat islands in Rio de Janeiro, especially in the city center.



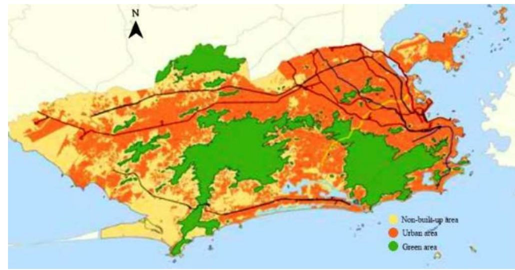


Figure 1, 2. Rio de Janeiro 1940 and 2009, Source: Rio em Mapas, http://portalgeo.rio.rj.gov.br

3. URBAN HEAT ISLAND EFFECT

A built-up environment has significant influence on urban temperatures, which has been found to be noticeably warmer than its surrounding rural areas. This phenomenon is called the urban heat island (UHI) effect (Oke, 1987), where urban structures absorb solar heat during the daytime and release it slowly back to the environment at night.

The urban heat islands occur in cities all around the world, and it is a result of the different thermal properties of urban surfaces. In Rio de Janeiro, especially during the hottest period of the year, up to 25°C differences can be observed in comparison to rural areas of the city (Reynolds, 2015). There are several types of heat islands depending on the topography and climate. Cities at higher latitudes face the urban heat island effect at night when the stored heat within the urban structures is released. In contrast, cities in tropical latitudes, such as Rio de Janeiro, face this effect during the daytime.

3.1 Green roof as one of most effective strategy for mitigating UHI effect

Green roofs have a positive contribution for mitigating the urban heat island effect for two main reasons: (i) protecting buildings from solar radiation by the physical act of shading; (ii) causing the process of evapotranspiration and photosynthesis (Niachou et al., 2001). It is well established that plants have a cooling effect and therefore they can be used strategically in built-up areas to reduce the air and surface temperatures. Integrating vegetation in cities is seen as the most cost-effective strategy for mitigation the urban heat island effect, because greenery makes the environment cooler though a process of evapotranspiration; where large amount of solar radiation can be converted to latent heat.

Nowadays, there are several studies, which established the correlation between increasing of urban vegetation and reducing of local temperature (Takebayashi et al., 2007). Thus, it can be concluded that augmentation of green roofs can represent as an effective tool to mitigate UHI effect. For example, in Singapore, the integration of vegetation into architecture has been successfully used for more sustainable urban development, cooling urban environment and reducing the energy consumption of buildings. The study reported by Gill et al. (2007) demonstrates that increasing by 10% of urban green cover in

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Manchester, UK, could amortize the predicted rise by 2.5°C of the temperature by the 2080s. Green roofs are mostly fully covered by vegetation, for this reason; there are one of the most promising strategies to reduce urban heat island effect.

4. STUDY AREA

The city of Rio de Janeiro (22 ° 54'10 "S 43 ° 12'28" W) is a Brazilian city, located in the southeast of the country, at an altitude of about 10 meters in relation to the mean sea level. Rio de Janeiro is the capital of the state of Rio de Janeiro, the third most populous state in Brazil. The city's metropolitan area is the second most populous metropolitan area in Brazil and seventh most populous in the Americas, which has 1197 km^2 surface area. In 2014, according to Brazilian Institute of Geography and Statistics (IBGE, 2014) the population of Rio de Janeiro was 6 476 631.

The city of Rio de Janeiro consists of an exceptional urban setting encompassing the key natural elements that have shaped the development of the city, from the highest points of the Tijuca National Park's mountains down to the Atlantic Ocean and Guanabara Bay in the east. The diverse terrestrial landscape contributes to the great variability of temperature, precipitation, humidity, wind, cloud cover, and evaporation.

According to the Köppen-Geiger climate classification system, climatic condition of Rio de Janeiro is Atlantic tropical with an average air temperature of 16°C throughout the year and a dry season in which the average monthly precipitation is less than 60 mm for at least one month of the year. The average annual temperature varies between 23°C and 24°C, where the highest monthly average occurs during summers in February (28.7°C), and the lowest monthly average occurs during winters in July (21.3°C) (INMET, 2015).

4.1 Case study: Copacabana

Copacabana is a neighbourhood located in the south of the city of Rio de Janeiro between the Atlantic Ocean and São João, Cabritos and Cantagalo hills. It is known for its beach that is one of the most famous in the world and carries the same name as neighbourhood. In 1892, the inauguration of the tunnel Velho, which connected neighbourhood Botafogo with Copacabana, allowed to integrate Copacabana with rest of the city (Kaz, 2010). Due to the demand to live in Copacabana by growing middle class, the neighbourhood began to expand vertically up to twelve-story and became one of the most densely populated parts of the city. According to IBGE (2014) total population of Copacabana was 147 021 inhabitants in 2014. The lack of green spaces inside of the densely built-up area of Copacabana causes many heat islands. For this reason, Copacabana was chosen as the study area for demonstrating the possibility to mitigate the urban heat island effect by using a green roof.

The software ENVI was utilized for the purpose of determination of the roof systems applied in Copacabana district. Three systems of conventional roofs were defined through satellite images; flat concrete roof, pitched roofs with ceramic tile, and tin roof. Three representative areas of the district have been subjected to a proportional analysis of construction systems, considering the colour of the roofs. This analysis resulted in a conclusion that estimated that 85% of roofs are flat concrete roofs, 13% of pitched roofs with ceramic tiles, and 2% of a tin roof.

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During the analysis, the green roof was not found in any of the randomly selected areas, only vegetation in the form of flowers or palm trees on rooftops. In the process of searching a green roof for this case study, one was found through the local news, on the building of supermarket Zona Sul. Since the installation of the green roof was finished recently and probably satellite images were not actualized, it was not possible to find it by Google Earth.

5. METHODS

The mitigation effect of the green roof on urban heat island was assessed by using meteorological measurements, which were collected by two automatic weather stations that were installed on two types of roofs; an extensive green and a conventional roof in Copacabana, during 22nd of February to 28th of February of 2016.

The selected study area is a densely urbanized area of Copacabana, which is characterized by ground-floor shops, restaurants, cafes, and bars. This part of Copacabana was selected based on the only green roof that was found in the neighbourhood, on the supermarket Zona Sul (Figure 3). Finding green roof in Rio de Janeiro is arduous, as the matter of fact, just a few green roofs are installed in whole city. After all, getting permission to carry out measurements is complicated, too. Based on the experimental green roof, the conventional roof of reinforced concrete slab was found in the same area to undertake a fair comparison analysis (Figure 4). The distance between the two buildings is approximately 200 meters. Both buildings have similar geometric characteristics; the number of floors, side of street, environment, and sun path direction.

Figure 3: Green roof, Source: Author, 2016

Figure 4: Conventional roof, Source: Author, 2016

The three-story supermarket Zona Sul has an extensive green roof covered by grasses and low plants, which are not demanding high maintenance. The supermarket Zona Sul is located at 29 Dias da Rocha Street. The green roof system consists of drainage system leading to rainwater harvesting tanks to reuse the water for the irrigation system. The supermarket is surrounded by lower building in the Northwest and the higher building in the Southeast. The nearest obstruction around the green roof is just twelve-story building in the Southeast, but the direction of this building prevents the creation of shadow during day. The weather station was installed one meter above the roof surface and was located three meters away from the Northwest and Northeast edge of the green roof.

Second two-story residential building with a conventional roof is located at 572 Barata Ribeiro Street. The surrounding neighbour buildings are situated in the Northwest and

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Southwest. Seven-story building located in the Northwest in relation to selected conventional roof creates a shadow at the end of afternoons. The nearest vegetation is in the form of flowers and trees on the street. The roof consists of reinforced concrete slab and concrete tiles. The weather station is installed one meter above the roof surface and is located three meters away from the Southwest and Southeast edge of the roof.

The two weather stations were borrowed from the metrology laboratory of UFRJ. The metrological stations are comprised of perforated plywood shelter, tripod, thermometer, and thermocouple. Waterproof HOBO Pro Series-onset sensor was used to provide information about air temperature and relative air humidity. HOBO sensor has an integrated data logger, which is fully automatic to collect data on a 24-hour basis. Data logger was programmed to measure air temperature and relative humidity every 10 minutes. The data logger with the full battery could record data for 151 days, and then it is important to download all the data through the Box Car software and program the data logger again. Thermocouple wire with data logger Log Box Novus was chosen to measure surface temperature. The sensor at the end of the wire was calibrated based on the method using hot and cold water with the utilization of another thermometer. The data logger was programmed to measure surface temperature also every 10 minutes. The data logger with the full battery could record data for 227 days, then it is important to download all the data through the Log Chart II software and program again because all previous data will be removed. Both data loggers are placed inside the shelter to be in shadow, only the thermocouple is fixed on the surface of the roof.

6. RESULTS

The collected results demonstrate that the average air temperature of the green roof is cooler than the conventional roof during the selected period of February. The average air temperature results for the entire period demonstrates that the average air temperature of the green roof of supermarket Zona Sul was 27.30°C and the conventional roof of the residential building was 29.62°C. The difference in average air temperature between two sides is 2.32°C (Figure 5). The maximum difference reached a value of 3.47 at 5:22.

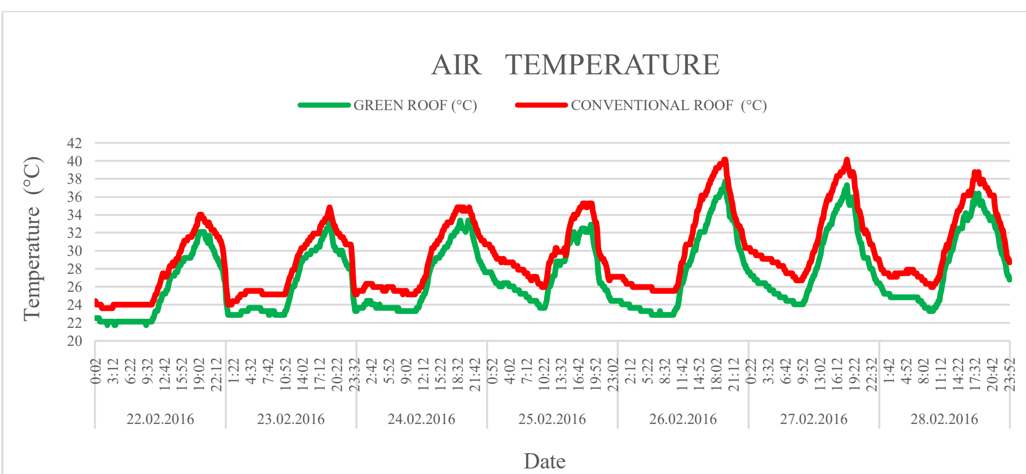

Figure 5: The air temperature, Source: Author, 2016

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As can be seen from the Figure 5, the air temperature of the green roof is below that of the conventional roof almost all the time. The factors behind this result are evapotranspirational shading and cooling (Taha, 1997). The greatest reduction in air temperature occurred between 00:00 and 12:00.

In February, the relative humidity varies between 60% and 90% in Rio de Janeiro (Leal, 2013). Based on collected data, Figure 6 shows the relative humidity of green roof and conventional roof. The results reveal that the average relative humidity of green roof was 77.04% and the conventional roof was 68.78%. The difference in average relative humidity between the two samples is 8.27%. The maximum differences occurred between 24:00 and 12:00 and reached up to 12.8% at 6:12.

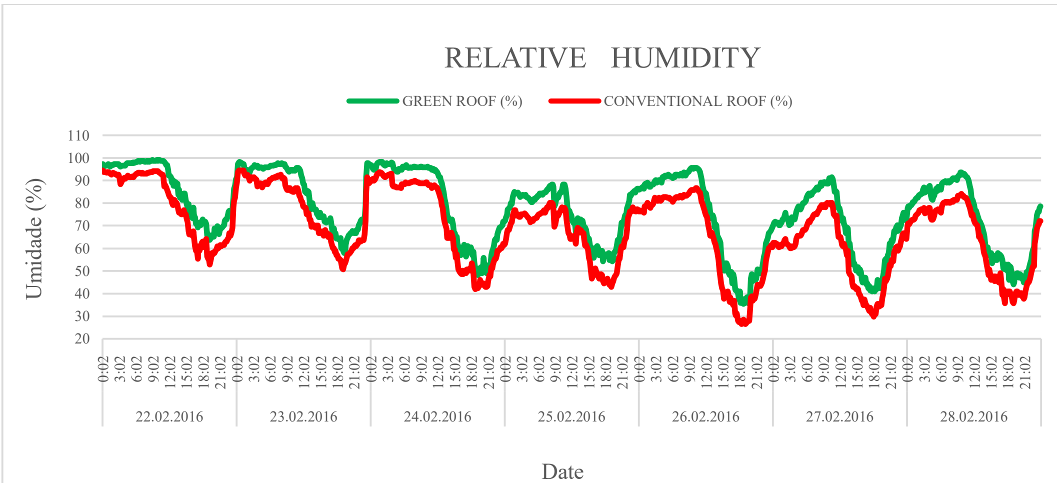

Figure 6: The relative humidity of air, Source: Author, 2016

Figure 7 demonstrates the surface temperatures that were obtained from data logger of thermocouple wire during the same period of the summer. As can be seen from the figure, the average surface temperature of green roof was 31.41°C and the conventional roof was 36.35°C. The difference in average surface temperature is 4.93°C. The maximum differences occurred between 20:00 and 8:00 and reached up to 19°C.

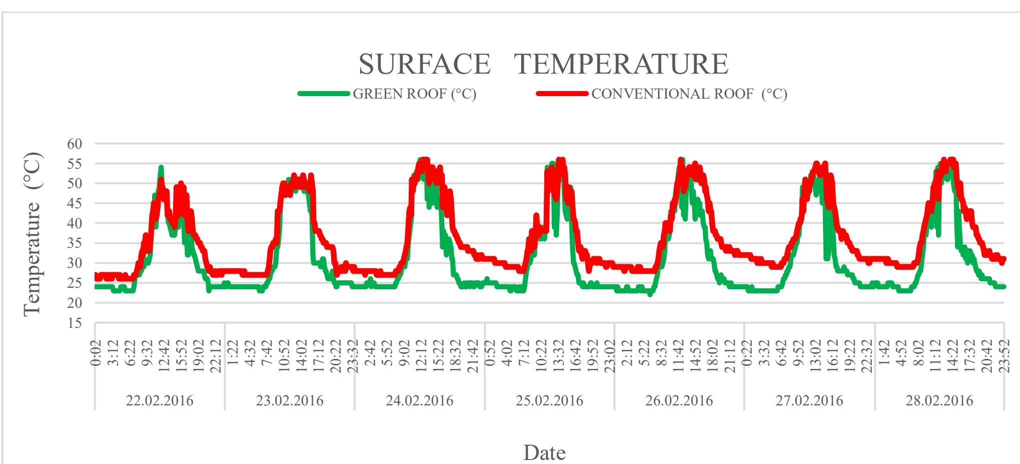

Figure 7: The surface temperature, Source: Author, 2016

The presented results in these figures prove that the green roof can significantly reduce the surface temperature, which supports the fact that concrete in contrast to the vegetation of green roof absorbs and retains solar energy more, also does not rapidly release the heat back into the atmosphere. Further, the green roof can cool down air temperate and increase humidity above roofs and in their surrounding environment. These results support many studies that suggesting the increase of urban vegetation as a method to mitigate the urban heat island effect. Considering that, the green roofs are the practical way to integrate urban vegetation in a densely built-up area.

7. CONCLUSION

Urbanization has various impacts on the residents' quality of life, and one of the most noticeable consequences is the rise of temperature. The replacement of vegetation by artificial land covers and anthropogenic activities tends to be the main factors responsible for the temperature increases in the urban area of Rio de Janeiro. The presented results in this paper show that green roofs have a significant contribution to mitigate heat islands, and for this reason should be considered as one of the most effective mitigation strategies. In some densely urbanized cities, where is not possible to create public green spaces e.g. parks or small green areas of lawns and trees, the green roof represents the best alternative for returning the nature to these cities for making them cooler.

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