

Green facades - Their use in the sponge city

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Abstract. Greenery in the urban environment is slowly disappearing and is being replaced by new construction. This trend has several consequences. One of them is the overheating of the urban climate and the associated increased need for energy for cooling. We are trying to eliminate this negative impact by creating green structures on buildings. As such, greenery brings a number of benefits. It helps to cool buildings, but also the urban climate, through the shading effect of leaves and the evaporation of trapped water. There are a number of studies around the world that investigate green roofs, or green facades. The effect of green leaf area index on cooling by shading and the effect of the distance of the façade from the envelope are investigated. Another influence is the orientation to the cardinal directions and the careful selection of plants. One of the main factors influencing the functionality of green facades is the choice of plants in relation to the climatic conditions in the country. In this article I discuss the adaptation of green facades to the climatic conditions in Slovakia. In Slovakia this issue is minimally studied and green facades occur only sporadically or only seasonally.

Abbreviations

ET - Evapotranspiration(mm/time)

1 Introduction

The surface materials of cities have a higher heat capacity than greenery, which causes negative impacts on the urban environment [1]. This phenomenon is called the urban heat island effect and causes overheating of cities and the associated increase in energy demand. Green areas are limited in urban environments and therefore structures such as green roofs and walls are a suitable solution to heat islands, restoring the hydrological cycle and many other environmental and social benefits. In [2, 3] While studying experimental studies, we learned about the effect of green facades on passive cooling by evapotranspiration [4]. In addition to water evaporation, shading also contributes to cooling, which depends on the type of plants used and the area of the green wall. The cooling effect is estimated to be 60-80% from shading and 20-40% from evapotranspiration. [5] An important element in

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evapotranspiration is the substrate used, often lightweight substrates with few fine particles and a higher mineral content are used in green facades [6].

In the design of green structures, it is important to understand the relationships between the different input media and the results in other experimental green structures. These green facades that we can base our designs on may be in other climates, the harmony between the facade design and a well set up irrigation system is important. Using continuous irrigation for these facades generates a daily water consumption of 0.5-20 l/m². This volume of water needed for irrigation is unsustainable in arid areas and therefore the use of other sources of fresh water of sufficient quality for irrigation should be considered. For example, grey water, which we produce on average 120 litres per person, meets this condition [7, 8].

Surveys designed to detect water flow are quite challenging. There are methods such as gas exchange chambers on the scale of a single leaf or lysimeters on the scale of the canopy [9]. Although these devices are considered relatively accurate, they are expensive and have significant maintenance requirements. ET can also be estimated empirically using a full water balance approach or alternatively based on temperature data or using energy balance equations. The Penmann-Monteith energy balance model is widely used on daily, weekly or monthly time scales [10, 11, 13].

This paper focuses on the comparison of green façades in different climates and their detailed designs and differences. The design of green facades is a complex process depending on the appropriate choice of structure, substrate and plants. Green facades are one of the elements that have the potential to improve the environment in the future and thus increase the quality of life in densely built-up areas. The aim of this paper is to deepen the knowledge of this issue and to apply new findings to research. Our task is to use the findings to define the issue to our climatic conditions and create research that will bring new knowledge about green facades.

2 Material and methods

2.1 Study area

The first of the facades is located in Central Europe, specifically in the Austrian capital of Vienna. The altitude at which this city is located is 171m above sea level and the average temperatures in summer are 26°C during the day and 14°C at night. Temperatures in winter are around 5°C during the day and -1 at night. In the months of August and September when the research was conducted the temperatures were 25°C and 20°C. The second city, Perth, is located in Western Australia in a Mediterranean climate. Temperatures average over 30°C in summer and 18°C at night. In the cooler months temperatures reach around 20°C during the day and 9°C at night. At this site research was conducted in March and April when average temperatures were 29.6°C and 26°C.

2.2 Experimental setup

Research in Vienna Fig.1 worked on two green facades installed on a school building. The first wall was made of aluminium gutters and a coffered system was used on the second. These façades face the south side of the world and are located in a dense urban area. The plants on these facades were selected from native plants [12].



Fig. 1 Green facade design in Vienna.

Compared to the facades in Perth, Australia, they use only one cardinal direction. Research in Australia Fig. 2 has focused on the north and west sides of the world. For the experimental green façades, both a façade shielded by a tarp and a façade without shading were placed. Climbing plants were planted in corten pots and aluminium trellises were applied for support. So-called groundcover plants were used and were selected from non-deciduous Australian and non-Australian species [13].

During the research in Vienna, the facades were watered with clean drinking water. In research in Australia, green facades were watered with fresh water on days off and with grey water on school days. The grey water came from handwashing sinks and from the drainage of drinking water fountains. The grey water was retained in a central storage pit. Three irrigation scenarios were identified: well irrigated (more than two irrigations per day) normally irrigated (two irrigations per day) and limited irrigation (no irrigation per day) [13].



Fig. 2 Green facade design in Perth.

2.3 Collection and analysis of data

The research in Vienna took place in the summer of 1.8.-31.9.2017. The authors of the research primarily selected the warm summer months. The amount of water that evaporated was calculated with the difference of inflow and outflow. To obtain the energy of evaporation, the value was divided by the mass of one mole of water (18.02 g/mol) and multiplied by the standard enthalpy of evaporation (43.99 kJ/mol), which is given at 25 °C [12]. PT 1000 sensors behind green structures were used to determine the temperature differences between shielded and unshielded façades.

Measurements were conducted on green walls in Australia from November 2020 to November 2021. Sensors for soil volumetric water content, temperature, solar radiation, wind speed and relative humidity were deployed in different areas of the façade. Together with the monitoring of inflows and outflow drains from the planters, a full water balance can be carried out [13]. Throughout the experiment, data were measured at 5 minute intervals. Air temperature, relative humidity, wind direction and wind speed, and precipitation were measured. Temperature sensors were installed at a height of 150 cm above the ground at a spacing of 20 cm. Sensors were placed before and after the green layer to measure wind speed [13].

3 Results

3.1 Results of research in Vienna

The evaporation value was not constant when measured, it depended on the amount of water received from rainfall or irrigation. The evaporation energy reached its maximum on 11 August at 121.80 kWh. Other results can be seen in the graphs.

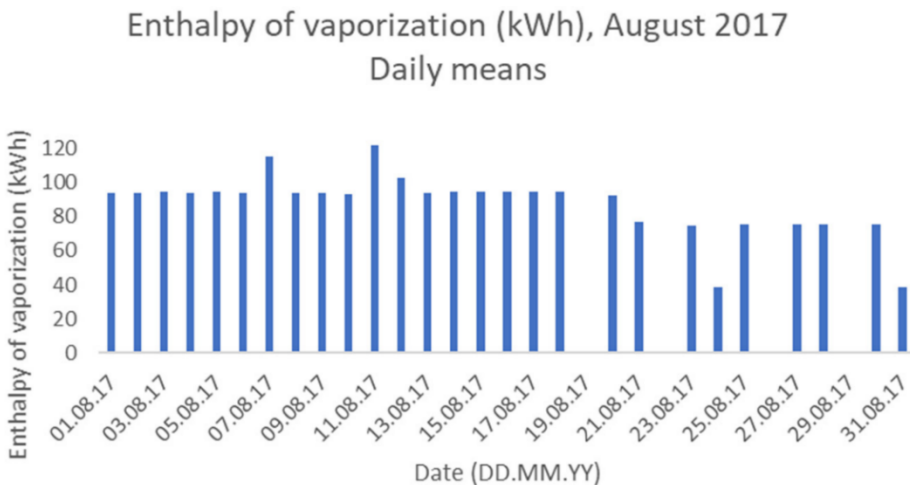


Fig. 3 Daily average evaporation energy values (kWh) in August 2017.

These diagrams Fig.3 show the daily amount of energy released by evapotranspiration. In order to regulate the irrigation of the plants, it was no longer applied daily from mid-August onwards and was further reduced in September. This can be observed on the evaporative energy balance, as the values are very close to zero. It can be assumed that with higher evapotranspiration and therefore higher evaporation energy, the environment and the building become even cooler.

According to the graph for September Fig.4 , the following results can be summarized. The lowest amount of evaporated water was -5.28 L. The highest amount of evaporated water was 170.26 L. The total amount of evaporated water was 2410 L. The lowest amount of evaporation energy was -3.31 kWh. The highest amount of evaporation energy was 106.83 kWh.

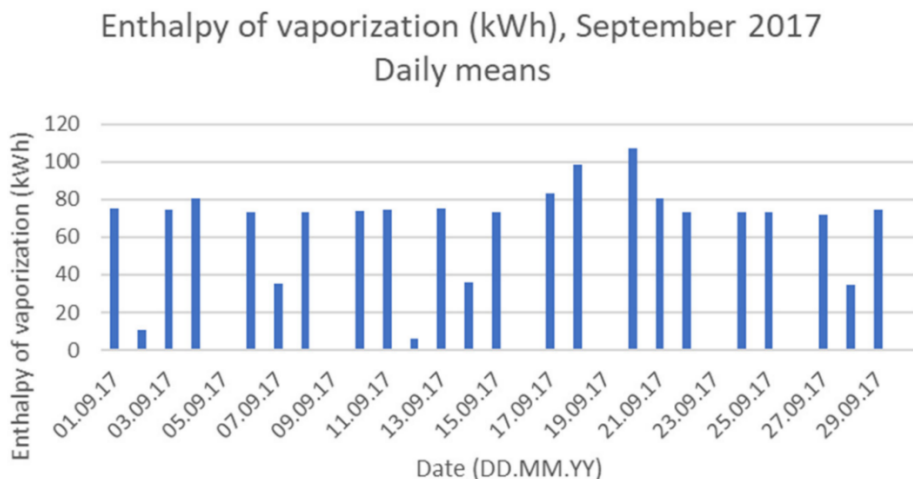


Fig. 4 Daily average evaporation energy values (kWh) in September 2017.

A summary of the results from the chart for August is as follows. The minimum amount of evaporated water was -0.49 L. The maximum amount of evaporated water was 194.12 L. The total amount was 3774 L. The minimum amount of evaporation energy was -0.30 kWh. The maximum amount of evaporation energy was 121.80 kWh. A summary of the results from the graphs is as follows. The minimum amount of water evaporated was -5.28 L. The maximum amount of water evaporated was 194.12L. The total amount was 6184 L. The minimum amount of evaporation energy was -3.31 kWh. The maximum amount of evaporation energy was 121.80 kWh. This evaporation process removes heat energy from the environment, so higher values are better for the cooling effect of the environment. [12]

3.2 Results of research in Perth

After evaluating the collected data, it was found that the volumetric water content decreased in drier environments, either with less irrigation or in drier periods. When irrigation was sufficient, the soil water content was close to the maximum values and there was more runoff. Measurements also showed that the water content increased with greater depth. Using the water balance equation, changes in water storage at different layers were applied. According to the evapotranspiration values, the day times from 7:00 am to 6:00 pm and the night times from 6:00 pm to 7:00 am were determined. Evapotranspiration values were lower at night times and reached the highest values between 12:00 and 16:00 when solar radiation was highest.

The lowest measured volumetric water content was 8 and 10%, which is 5% lower than the wilting point. This means that if the lowest value of volumetric water content of the substrate was measured, the ET was zero. These results are consistent with those of previous studies. If there is little water in the substrate ET is slow, if there is enough water in the substrate ET is fast. The ET phenomenon takes place in soil, on vegetation and on other surfaces. This process is expected to reduce facade surface temperatures. In this study, the temperature difference between the area behind the façade and the area behind the shading

sheet will be representative of ET. In this experiment, a significant negative correlation was obtained for relative humidity and ET rates of green facades (Pearson's coefficient -0.91) Strong positive correlations were found between solar radiation, ET rates and the resulting evapotranspiration cooling. All differences of significant statistical nature ($p < 0.005$, paired t-test) were found in the ambient air temperature range. [13] Using correlation analysis, it was shown that the coupling between volumetric water content and ET was less than the effect of climatic conditions. The water balance results showed significant differences for individual facades. The northern façade with non-native greenery and limited irrigation had a low ET, which gradually increased with normal and later good irrigation. For the west façade with native foliage, the lowest results were obtained with normal watering, then with limited watering, and the highest results were obtained with good watering. With good watering, increasing the amount of water did not work to increase evapotranspiration, only the volume of runoff increased. When water was available to the plants, that is, when it was between the wilting point and the point of full capacity, that is, between 10-20% for the north and 8-14% for the west facades, ET adjusted. For pots without ground cover plants, we reach the desired temperature 100 cm above the soil. The green facades limited the wind speed by approximately 50%. This shows that ground transpiration did not affect evapotranspiration cooling. The green facade was shown to cool the space behind the facade. The air was 10.6 and 7.9°C cooler on the north façade and 6.1 and 4.7°C cooler on the west façade. On average, 35 and 15% of the cooling was due to ET cooling.

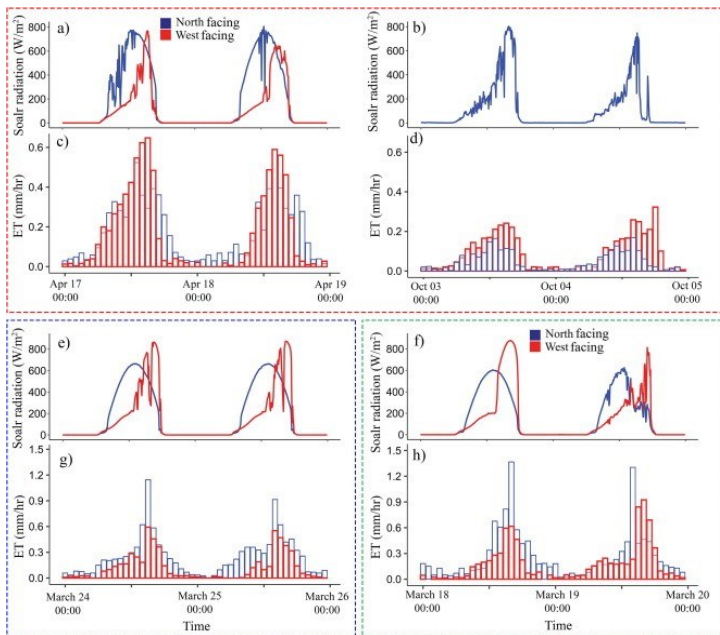


Fig. 5 Solar radiation and hourly ET rates of the façades, under the two days of limited-watered (red box; a-d); normal-watered (blue box; e, g); and well-watered scenario (green box; f, h).

Native plants on the west facade achieved more evapotranspiration cooling than non-native plants. The green facade is also largely influenced by climatic conditions such as air temperature, wind speed, humidity, and solar radiation and is most affected by any irrigation method. The highest ET cooling was achieved at temperatures above 30°C. The expected effect of volumetric humidity on evapotranspiration was not as strong as expected. This could have been caused by frequent irrigation, high humidity averaging above 50%. The results of

the measurements confirmed the results of previous studies, in which it was shown that the ET rate was better under good irrigation than under a condition with limited irrigation.

4 Conclusion

The study in the city of Vienna, Austria, was conducted inland. The main priority of the authors was to prove that a façade with greenery on it reaches lower temperatures than a façade without greenery. The temperature reduction was 9.3°C for the trough system and 11.6°C for the coffered system. The research demonstrates different results for the different façade systems. In terms of night-time cooling, the cassette system is more effective.

Research in the city of Perth, which is located in a Mediterranean climate, three irrigation regimes were monitored. Soil water and temperatures were investigated at four depths. During the study the following was found, limited irrigation and normal irrigation had constant moisture content, in contrast to good irrigation where runoff was variable and water drained away due to gravity drainage. The average evapotranspiration under limited, normal and good irrigation was 1.8, 6.9, 7.9mm per day on the north facing façade where non-native deciduous species were used and 2.4, 3.8, 4.0mm per day on the west facing façade where native non-native deciduous species were used. When comparing watering with normal water and good water, no positive results were found for evapotranspiration rates, but runoff was accelerated, up to 10 l/day. Evapotranspiration was closely related to solar radiation, air temperature and wind speed. Also, the rate of evapotranspiration and regeneration of green vegetation that was stressed by adverse conditions depended on the type of plants that were used.

Research shows that green facades can help combat heat islands. By designing green structures more frequently on buildings, we could achieve a noticeable cooling of the urban environment through the use of greenery. However, the issue of irrigation is still not solved. Not every city has enough drinking water, so the use of grey water is preferable. As the above-mentioned studies also show, the choice of greenery influences not only the durability but also the effectiveness of green walls. When designing and constructing these facades, it is necessary to observe all these aspects for the green facade to work properly. As is evident when comparing the two studies, exterior green facades cannot be generalised globally, but need an individual approach to their design according to climatic conditions. By applying the findings of these two studies, we intend to create an example of a green façade in our climatic conditions using plants typical for the Slovak Republic. And to propose the type of irrigation that will achieve the highest evapotranspiration rate.

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