Journal of Energy Technology

JET Volume 12 (2019) p.p. 19-26
Issue 2, September 2019
Type of article 1.01
www.fe.um.si/en/jet.html

URBAN GREENING AS A COOLING TOOL TOWARDS THE HEAT ISLAND EFFECT

OZELENJEVANJE MEST KOT ORODJE ZA ZMANJŠEVANJE UČINKA TOPLOTNEGA OTOKA

Anja Bubik[1ℜ], Lucija Kolar[2]

Keywords: air temperature, greening principle, heat island effect, pilot study, urban environment

Abstract

Roofs, as the top layer of the urban environment, significantly contribute to overheating and creating a heat island, which is known as one of the most critical global warming effects. There are several ways to mitigate the effects of such heat islands, among which greening is the most natural, sustainable solution, and also economically acceptable and socially valued principle. Vegetation is known to significantly improve the urban microclimate and directly reduce the effect of the urban thermal core.

At the Environmental Protection College in collaboration with the Institute Complementarium, both based in Slovenia, we conducted a pilot experiment to evaluate greening, in our case the principle of a flat green roof, as an effective and promising approach for reducing an urban heat island and its effects. Temperature measurements have shown that the green surface can lower both the surface temperature itself (e.g., the roof) and the air surrounding the green surface. We have presented an initial pilot case, which is planned to be upgraded in the future to confirm our current results and assumptions. In addition, we summarized data showing that Velenje is, in view of annual higher average temperatures, a highly suitable urban environment for the introduction of greening principles on the top urban layers.

ℜ Corresponding author: Anja Bubik, PhD, Environmental Protection College, Trg mladosti 7, 3320 Velenje, Tel: +386 3 898 64 24, E-mail address: anjabubik.vsvo@gmail.com

[1] Environmental Protection College, Trg mladosti 7, 3320 Velenje

[2] Complementarium, Institute for Research of Nature and Development of Environmental technologies, Lopata 60, 3000 Celje

Povzetek

Strehe kot zgornja plast mestnega okolja največ prispevajo k pregrevanju in ustvarjanju mesta kot toplotnega otoka. Le-ta je znan kot eden najpomembnejših učinkov globalnega segrevanja. Obstaja več načinov blaženja učinkov toplotnega otoka, med katerimi je ozelenjevanje najbolj naraven, trajnostno usmerjen način ter hkrati ekonomsko sprejemljiv in družbeno zelo cenjen princip. Znano je, da vegetacija znatno izboljšuje mestno mikroklimo in neposredno zmanjšuje učinek urbanega toplotnega jedra.
Na Visoki šoli za varstvo okolja smo v sodelovanju z inštitutom Complementarium – oba sta locirana v Sloveniji - izvedli pilotni eksperiment, s katerim smo poskusili ovrednotiti ozelenjevanje, v našem primeru princip ravne zelene strehe, kot učinkovit in perspektiven pristop k zmanjševanju urbanega toplotnega otoka in njegovih učinkov. S temperaturnimi meritvami smo ugotovili, da lahko zelena površina znižuje tako temperaturo površine same (npr. strehe) kot tudi zraka v njeni bližnji okolici. Predstavili smo začetni pilotni primer, ki ga želimo v prihodnosti nadgraditi in tako pridobiti podatke, ki bodo naše rezultate in predpostavke potrdili. Hkrati pa smo izpostaviti podatke, ki kažejo, da je mesto Velenje glede na porast letnih povprečnih temperatur zelo primerno urbano okolje za vzpostavitev zelenih površin na zgornjih plasteh mestnega pokrova.

1 INTRODUCTION

The urban heat island is a very well-documented phenomenon related to climate change. It defines the effect by which near-surface air temperatures are higher in cities than in nearby suburban or rural areas, *[1], [2].* The annual mean air temperature of a city with one million people or more can be 1–3 °C warmer than its surroundings. Moreover, the difference can reach 12 °C in the evening, *[3]*. Due to the overheating of buildings, urban temperatures can be up to 5-7 °C higher than in rural areas, *[4]*.
Heat islands affect the environment and communities by increasing energy consumption for cooling, the peak electricity demand, air pollution by forming an inversion layer and greenhouse gas emissions, water pollution and heat-related illness and death, *[1], [2]*. Many cities are already taking actions to reduce urban heat island effects. They follow various development and conservation strategies concerning the natural environment and human health protection and, as a result, cities become more livable and economically stronger. The energy demand and living costs are lowered, and the comfort of citizens and social relationships are improved, *[3]*.

1.1 Urban cooling

In general, an increased number of planted trees and other vegetative areas can lower surface and air temperatures. Trees and vegetation are providing additional shade and cooling through the transpiration and evaporation processes. The installation of cool roofs or pavements reflects more solar energy and contributes to lower roof or pavement surface temperatures. The surrounding air is also cooled, *[2]*.
Green roofs have also been proven to reduce and mitigate heat islands. The solar radiation balance on green roofs is much more favourable compared to conventional roofs, as they reflect 27% of total solar radiation, 60% is absorbed by plants and 13% by soil, while conventional roofs absorb 100% of the solar radiation on their surfaces, *[4], [5].* For example, in Chicago, summertime surface temperatures on a green roof were compared with those on a neighbouring building. In the summer, the green roof surface temperature ranged from 33 to

48 °C, while the dark, conventional roof of the adjacent building reached 76 °C. The near-surface air temperature above the green roof was about 4 °C cooler than that over the conventional roof. A study in Florida determined the average maximum surface temperature of a green roof of 30 °C while the adjacent light-coloured roof had a temperature of 57 °C, *[3]*. In addition, green roofs can reduce building energy use by 0.7% compared to conventional roofs, reducing peak electricity demand and leading to savings, *[6]*, *[1]*. Temperature reduction and energy efficiency benefits are key contributors to the growing popularity of green roofs. For example, the North American green roof industry experienced an estimated 10% growth in 2016 over 2015, *[7]*. However, green roofs also provide other environmental and especially social benefits, which increase the quality of life and are essential reasons for personal greening construction decision.

2 PILOT PROJECT

Education and awareness efforts also help to improve the attitude to the problems of global warming. At the Environmental Protection College (EPC), in collaboration with the Institute Complementarium, we performed two student projects that raised awareness of environmental protection and improvement, and that emphasized the greening potential as a possible environmental solution, *[8]*. With the primary goal of increasing general knowledge about it in Slovenia, mostly in the Savinja statistical region, and of evaluating the effectiveness of the extensive greening principle in the urban environment (e.g. Velenje), we constructed two pilot models (Figure 1). Based on annual monitoring of different physical and chemical parameters and by observing the growth of selected plants in two models using different substrates, we concluded that the implementation of our pilot models in the selected urban environment was successful and has great potential for future urban planning, *[9]*.
One of the main goals of our one-year pilot study was also to determine, how the surface (substrate) and air temperatures (approx. 0.50 m above the green area and 3 m away from it) are changed due to the greening. Here, we summarized our results and compared them with public data of air temperatures in the city of Velenje and three other Slovenian cities.

Figure 1: *EPC model of extensive green roof at the beginning (A) and at the end (B) of the experiment*

2.1 Analysis and Results

Air and substrate temperatures were not directly measured on the roof, but on the balcony of the 2nd floor, below the roof, were the models were placed during the experiment. Temperatures (T) of two different substrates ($T_{sub\ A}$ and $T_{sub\ B}$) in separate models and air temperatures (T_{air}) approx. 0.50 m above the model and approx. 3 m away from it were measured. On average, T_{air} was for 4.09 °C and for 4.00 °C higher than for $T_{sub\ A}$ and $T_{sub\ B}$, respectively. The difference between $T_{sub\ A}$ and $T_{sub\ B}$ was not expected and was minimal; an average annual T_{sub} differs by less than 0.075 °C. Plant adaptation was the same in both models. We did not observe any changes that could be related to differences in T_{sub}. However, T_{air} above the models and T_{air} at least 3 metres away from them differ annually by 0.1 °C, which correlates to 0.57% (Figure 2). If we consider that the experiment was set up in the first year of the greening process, in which plants started to proliferate and grow more significantly in the 7th month (in March 2016), *[9]*, and that the tested green area was relatively small compared to real roofs, the temperature difference could be significant. Namely, until March 2016, an average T difference was only 0.06 °C (0.37%), while the main increase was detected since March 2016 and was 0.13 °C or 0.73%.

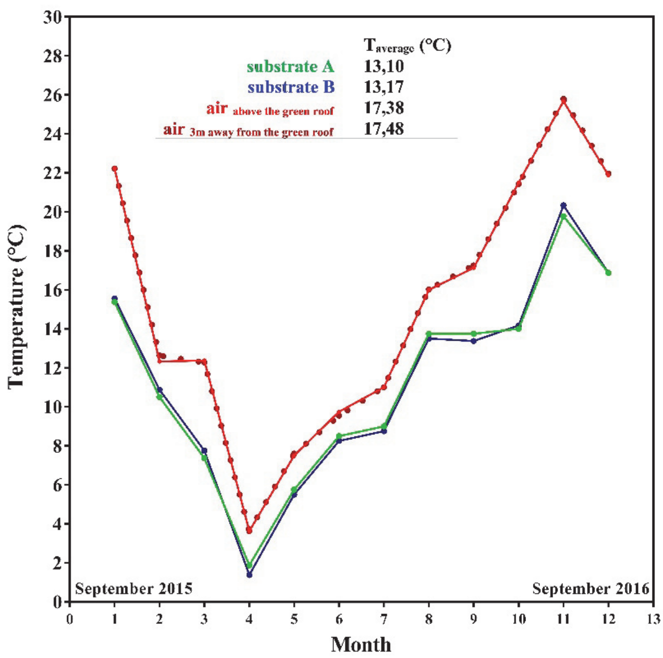

***Figure** 2: Average monthly temperature of two substrates (in blue and green) and approx. 0.50 m above the models (in light red, full line) and approx. 3 m away from them (in dark red, dashed line)*

In addition, we compared experimental monthly mean T_{air} with those measured at the automatic meteorological station (AMS) of the city of Velenje according to the standards of the World Meteorological Organization (2 m above the ground on as open a field as possible, overgrown with low grass) (Table 1). The temperature below the roof was on average 4.1 °C higher compared to public data from the AMS, and the temperature above the green models by 4.0 °C. Results indicated that the roofs are warmer and represent a significant factor for environment warming, especially urban environments. Still, the green area decreased T_{air} by 0.1 °C in our case and contributed to lower annual air temperatures above the green models (Figure 1, Table 1).

Table 1: *Comparison of average monthly air temperatures in Velenje*

Month	Velenje (°C) (experiment)^{1*}	Velenje (°C) (experiment)^{2**}	Velenje (°C) (AMS)	Δ T (°C) (1^{*}- AMS)	Δ T (°C) (2^{**}- AMS)
September 2015	21.8	21.8	15.4	6.4	6.4
October 2015	12.6	12.3	10.0	2.6	2.3
November 2015	12.3	12.4	6.5	5.8	5.9
December 2015	3.6	3.6	2.6	1.0	1.0
January 2016	7.6	7.5	0.8	6.8	6.7
February 2016	9.6	9.8	4.8	4.8	5.0
March 2016	11.0	11.0	6.3	4.7	4.7
April 2016	16.1	16.0	11.6	4.5	4.4
May 2016	17.3	17.1	14.7	2.6	2.4
June 2016	21.6	21.5	18.8	2.8	2.7
July 2016	25.8	25.7	21.7	4.1	4.0
August 2016	22.0	21.9	19.2	2.8	2.7

(experiment)^{1*} *approx. 0.50 m above the green roof model*
(experiment)^{2**}means T_{air} *approx. 3 m away from the green roof model*

We also calculated how our models reduce daily temperature variations between the four seasons (Figure 3). It was already confirmed in a Greek study that a green roof reduces daily temperature variation and thermal ranges between summer and winter, *[4]*. Our results indicate that daily temperatures above the models varied in winter/summer by 3.94/3.98 °C and 3 m away from it for 3.95/4.29 °C (Figure 3). The difference was negligible during the winter but increased during the summer (from 3.98 to 4.29 °C; arrows on Figure 3). This observation is logical, since the T difference was also higher and more obvious in the summer. Temperature variation above the green roof model was lower by approx. 1.24% compared to the variation 3 m away from them.

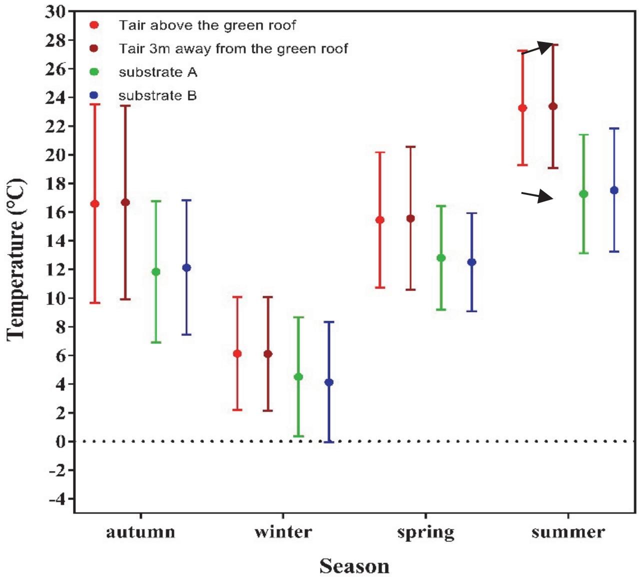

Figure 3: *Season temperature variation in both models (in blue and green) and approx. 0.50 m above the models (in light red) and approx. 3 m away from them (in dark red)*

In addition, we compared monthly and annual temperatures for Slovenian cities: Velenje, Celje, Maribor, and Ljubljana in the previous eight years. Although Velenje is the smallest city regarding the urban area and the number of inhabitants, *[10]*, annual air temperatures from AMS since 2010 showed that Velenje is the 2nd warmest city, just behind Ljubljana, the capital city of Slovenia, *[11]* (Figure 4). However, annual T in all four cities is increasing in previous years, but most drastically in Velenje – by 20% in 2018 over 2010 (Table 2). Such a trend indicates that it is necessary to adopt more development and conservation strategies concerning global warning heat island effects in the city of Velenje in the future.

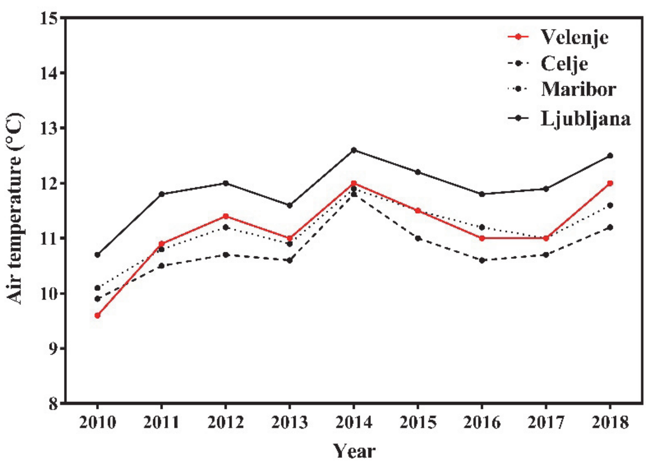

Figure 4: *Annual air temperatures in four Slovenian cities from 2010 to 2019*

An average T_{air} in Velenje, measured at AMS, was 11.03 during the experiment (Table 2) and was lower compared to T_{air}, measured by us (Figure 2). The difference can be attributed to the location of our experiment, in which temperatures correlated more to the temperatures near the roof. Nevertheless, the trend of temperature variation was the same. Compared to Celje, Maribor and Ljubljana, Velenje was not the hottest city during the experiment (Table 2).

Table 2: *Average temperatures in four Slovenian cities from the year 2010 till 2019*

	$T_{average\ (experiment)}$ (°C)	$T_{average\ (2010\text{-}2018)}$ (°C)	$\Delta T_{(2010\text{-}2018)}$ (°C)	$\Delta T_{(2010\text{-}2018)}$ (%)
VELENJE	**11.03**	**11.16**	**2.4**	**20.0 %**
CELJE	10.81	10.68	1.3	11.6 %
MARIBOR	11.36	11.89	1,5	14.4 %
LJUBLJANA	11.89	11.11	1.8	12.9 %

3 CONCLUSIONS

To improve the quality of life and reduce the negative environmental issues because of global warming, we must develop and support proper heat island reduction strategies. Vulnerability to heat is a global urban problem, since many aspects of life are burdened. The rising temperatures also mean that the first heatwaves of the year are coming earlier and catching us by surprise. These higher temperatures are bad for cardiovascular and respiratory diseases and pose severe stress to human health. Therefore, green areas, especially on the top urban layers, contribute positively to the improvement of the thermal performance of an urban environment and human health. Moreover, with increasing energy prices and very strict environmental policies, cheaper heating and cooling and lower energy consumption are essential construction and renovation requirements and give greening an added value. Consequently, with greening principles we can reduce building energy use and peak electricity demand, which leads to annual savings.

On average, in our experiment, T_{air} was by 4.09 °C and 4.00 °C higher than $T_{sub\ A}$ and $T_{sub\ B}$, respectively. The temperature below the roof was on average 4.1 °C higher compared to public data from AMS, and the temperature above the green models by 4.0 °C. To summarize, green area decreased T_{air} by 0.1 °C in our case and therefore contributed to lower annual air temperatures above the green models (Figure 1, Table 1).

Our results demonstrate how green roofs can positively influence the urban temperature. We showed that urban greening serves very well as a cooling tool towards the heat island effect and we tend to develop this research fact further. However, a study over a larger surface and time frame should be performed in the future, maybe on the flat roof of EPC in the city of Velenje, Slovenia.

References

[1] A Report of the United States General Services Administration: The Benefits and Challengesof Green Roofs on Public and Commercial Buildings, U.S. General Services Administration, 2011

[2] **M. Santamouris:** *Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments*, Solar Energy, Vol. 103, p. p. 682 - 703, 2014

[3] **U.S. Environmental Protection Agency**, Reducing urban heat islands: Compendium of strategies, Draft. https://www.epa.gov/heat-islands/heat-island-compendium, 2008

[4] **Knauf Insulation Slovenia**: Urbanscape. Sistem zelenih streh, https://www.knaufinsulation.si/sites/ki_si/files/pages/dokumenti-prospekti/KI_PROSPEKT_urbanscape_zelene_strehe.pdf, 2018

[4] **E. Ekaterini, A. Dimitris:** *The contribution of planted roof to the thermal protection of buildings in Greece,* Energy and Buildings, Vol. 27, Iss. 3, p. p. 29 - 36, 1998

[5] **T. Simonič, D. Dobrilovič**: Vloga ozelenjevanja streh in fasad pri prenovi objektov, AR; Arhitektura, Raziskave, Ljubljana, Vol. 2, p. p. 44 - 49, 2005

[6] **D.J. Sailor et al.:** *Exploring the building energy impacts of green roof design decisions – A modeling study of buildings in four distinct climates*, Journal of Building Physics, Vol. 35, Iss. 4, p. p. 372 - 391, 2011

[7] **Green Roofs for Healthy Cities:** 2016 Annual Green Roof Industry Survey: Executive Summary, https://docplayer.net/50928264-2016-annual-green-roof-industry-survey-executive-summary.html, 2017

[8] **A. Bubik, L. Kolar:** *Raising Awareness on Environmental Protection and Improvement trough Student Projects – A Case Study*, Journal of Engineering Management and Competitiveness (JEMC), Vol. 9, Iss. 1, p. p. 14 - 24, 2019

[9] **A. Bubik, L. Kolar:** *Greening as a Perspective Solution for Urban Microclimate Mitigation – A Pilot Study,* Annals of Faculty Engineering Hunedoara - International Journal of Engineering, Vol. XVII, Iss. 3, p. p. 19 - 22, 2019

[10] **SiSTAT:** Obtained on 12.8.2019: https://pxweb.stat.si/SiStatDb/pxweb/sl/

[11] **ARSO Meteo:** *Ministrstvo za okolje in prostor - Agencija Republike Slovenije za okolje,* Obtained on 12. 8. 2019: https://meteo.arso.gov.si/

Nomenclature

(Symbols)	(Symbol meaning)
T	temperature