CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE
FACULTY OF ENVIRONMENTAL SCIENCES

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THE COMPARISON OF COOL SURFACE SCENARIOS ON URBAN HEAT ISLAND MITIGATION, A CASE STUDY IN TECHNICAL UNIVERSITY OF KOSICE

DIPLOMA THESIS

Heling Li

SUPERVISOR:
doc. Mgr. Lukáš Trakal, Ph.D.
CONSULTANT:
Ing. arch. Zuzana Poórová, PhD.

2020

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

DIPLOMA THESIS ASSIGNMENT

Heling Li, BSBA

Landscape Engineering
Landscape Planning

Thesis title

The comparison of cool surface scenarios on urban heat island mitigation, a case study in Technical University of Kosice

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Objectives of thesis

The thesis will serve as a practical guide to mitigate Urban Heat Island phenomenons in Technical University of Kosice. The result of the thesis should be applicable for similar projects in other regions.

Methodology

Using campus of Technical University of Kosice as study area, to apply the surface strategy associated with grey and blue-green infrastructure system for urban heat island mitigation. Corresponding thermal images for both economical and ecological measures are simulated, the results are compared to find out the optimal strategy for multiple values.

The proposed extent of the thesis

40 – 60 pages

Keywords

Urban heat island, climate change, cool surface, blue-green infrastructure, case study

Recommended information sources

AUSTIN, G. *Green infrastructure for landscape planning : integrating human and natural systems.* Abigdon: Gary Austin, 2014. ISBN 9780415843539.

C.A.B. INTERNATIONAL, ISSUING BODY., – DHANG, P. *Climate change impacts on urban pests.* Wallingford, Oxfordshire, UK: CABI, 2017. ISBN 9781780645377.

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Expected date of thesis defence

2019/20 SS – FES

The Diploma Thesis Supervisor

doc. Mgr. Lukáš Trakal, Ph.D.

Supervising department

Department of Environmental Geosciences

Advisor of thesis

Ing. arch. Zuzana Poórová, Ph.D.

Electronic approval: 23. 3. 2020

prof. RNDr. Michael Komárek, Ph.D.

Head of department

Electronic approval: 23. 3. 2020

prof. RNDr. Vladimír Bejček, CSc.

Dean

Prague on 29. 03. 2020

DECLARATION

I hereby declare that I wrote this diploma thesis independently, under the direction of doc. Mgr. Lukáš Trakal, Ph.D. I have listed all literature and publications from which I have acquired information.

In Prague, ______________________ Signature: ______________________

ACKNOWLEDGEMENTS

I would like to express sincere gratitude to my supervisor doc. Mgr. Lukáš Trakal Ph.D., and Ing. arch. Zuzana Poórová, Ph.D., who acted as my supervisor, for her great support and guidance at the expense of her own free time. I'm grateful to RNDr. Pavel Zhanal, Ph.D. for his solid advices on this work, and being a reliable partner in my life. I would also like to thank my colleague Muhammad Merei for his kind help throughout entire study period. Last but not least, I wish to extend my appreciation to my family and friends, who support and encourage me during my studies.

ABSTRACT

Artificial surfaces of urban fabric are commonly considered as main direct cause of Urban Heat Island (UHI) effects. Most urban land covers are dark and impermeable, which accelerate excessive heat absorption and storage. This thesis characterizes cool surface strategies in criteria of definition, classification and application approach, as well as proposes of a framework to guide applications associate with grey infrastructure and blue-green infrastructure on UHI mitigation. As a case study, analysis of surface strategy and its cooling performance was conducted at campus of Technical University of Kosice. On perspective of economic and ecological feasibility, two proposals were simulated. The results show that both measures have significant impact on surface cooling, although the maximum and average temperature reduction vary between measures. In addition, overall value of each proposal is provided as reference for decision makers to meet their best interests. All these findings can support climate change adaptation strategy in Kosice, should be also applicable for similar projects and proposals in other regions.

KEYWORDS: Urban heat island, climate change, cool surface, grey infrastructure, blue-green infrastructure, permeability, case study

CONTENTS

1 INTRODUCTION

In the context of global warming, Urban Heat Island (UHI) has raised attention rapidly due to its intensity of adverse impact on urban environment. Grey infrastructure (GREI) and blue-green infrastructure (BGI) are widely accepted as common measure to beat UHI phenomenon. Although many studies have examined variety of materials and techniques on UHI mitigation and hydrological performance within designated test area, there is still lack of publications on comparison of cooling measures associated with GREI and BGI system.

This thesis is developed based on the topic of cool surface strategy and its practical use. The findings not only provide the effectiveness of specific actions on UHI mitigation, but also share the benefits and possible challenges to implementation. The principles of this study provide adaptable strategy and a useful decision-making tool for planning and design of projects in other regions, hopefully raise awareness of UHI effects for policy makers.

This thesis is divided into four chapters. First chapter is about theoretical background and literature review. This chapter describes the characteristics of UHI, relevant policies and representative measures applied in worldwide. Follows with key applications of grey and blue-green infrastructure systems in practical use, such as reflective material, green roof and permeable pavement, which become theoretical and technical background to identify cool surface strategy for further development. The experimental procedures are described in the next chapter. The campus of Technical University in Kosice was selected as study area, proposals were made from economical and ecological perspectives. The comparison of main achievements for each method is provided in result chapter. The results are presented in two directions: simulated thermal performance and weighted values overview. At the end, the final conclusions, the main achievement and limitations are summarized.

2 LITERATURE REVIEW

2.1 Urban heat island

Urban areas are usually warmer than their rural surroundings, a phenomenon known as the “heat island effect.”(US EPA 2014b). The urban heat island (UHI) is an urban area or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities (Wikipedia 2019). It is a land-use phenomenon caused directly by interruption of human activities, related to the positive thermal balance created over urban environments, where nature land covers are gradually replaced by dark and impervious surfaces like buildings, roads and other infrastructures (Santamouris 2013). The sketch of the temperature distribution in downtown and surrounding suburbs is shown in Fig.1.

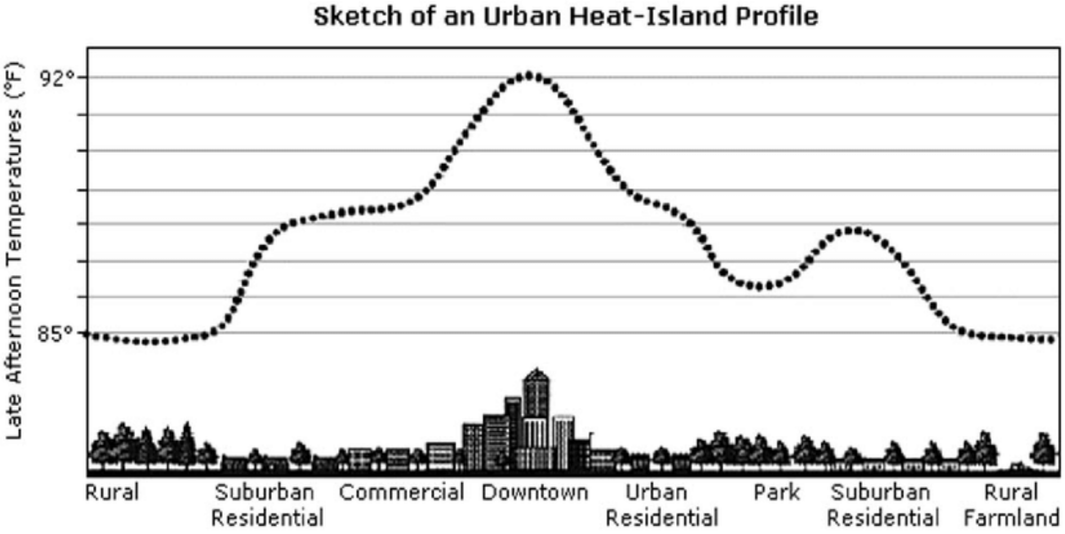

Figure 1: An urban heat island profile (Frumkin 2002).

According to characteristics of heat flow in different layers of urban atmosphere, UHI is divided into three categories: surface urban heat island (SUHI), canopy urban heat island and boundary urban heat island (Voogt and Oke 2003). Most studies have focused on the characterization of UHI in urban surface and urban canopy layers (UCLs) (Arnfield 2003). UCL contains air between the urban roughness elements, layer of air from the ground to the roofs’ level. It is a micro scale concept, and its climate is dominated by geographical factors and effected by the nature of the immediate surroundings (Unger, Savić, and Gál 2011). One the other hand, urban boundary layer (UBL) is located directly above UCL. It is considered as a local or intermediate scale concept, which represents the city’s layer of air from above the roofs to the point where urban activity no longer influences the atmosphere (Corina Negrescu 2014).

Various direct and indirect methods, and numerical models are used to identify and describe UHI, mostly via measuring of surface and atmospheric temperatures. Surface temperature (ST) represents the temperature of exposed urban surfaces like streets, pavements, facades and roofs. ST has an indirect, but significant influence on air temperatures, especially in UCL. Researchers often use satellite-based thermal image, which is an indirect measurement technique as monitor of SUHI to estimate surface temperatures (Corina Negrescu 2014); Atmospheric temperature is defined by the air temperature measured between UBL and UCL, where air temperature is typically measured through a dense network of sampling points from fixed stations or mobile traverses, throughout urban and rural stations (Hu et al. 2019).

2.1.1 Formation of UHI

To understand UHI phenomenon, series of physical processes and relevant interactions need to be taken into account. Urban surfaces are affected by shortwave and long wave radiation, and energy is exchanged between the urban canopy and the atmosphere in various forms, including sensible and latent heat fluxes. These fluxes in turn, together with boundary layer processes and large scale synoptic conditions, affect the turbulent flow of air (Resler et al. 2017). There are two major factors causing heat island effect in urban space: Firstly, the urban materials, such as roadways and rooftops, have high heat absorption capacity of sunlight and as a result, reradiate heat as thermal infrared radiation to surroundings. Meanwhile, these surfaces are usually in dark colors with low albedo which further exacerbate urban heat. Furthermore, urban areas relatively lack vegetation cover to provide moisture and shades, which helps to cool the surface and air temperature through “evapotranspiration” (Frumkin 2002).

However, other “controllable” factors in urban built environment which contributed to UHI formation gradually bring attention to researchers and public, for instance: urban geometry and anthropogenic heat emissions. The complex geometry of the urban surface, height and spacing of buildings, affect the amount of radiation received and emitted by urban infrastructure. The effects of urban geometry on urban heat islands are often described through the “sky view factor”, which is the visible area of the sky from a given point on a surface. During the day, vertical canyon walls trap (i.e., reflect and absorb) short wave radiation. Night-time losses of heat are also hold-back due to the decreased sky view factor below roof level. Sources of anthropogenic heat include cooling and heating buildings, manufacturing, transportation, and lighting (Shahmohamadi et al. 2011). Several studies have indicated the impact of anthropogenic heat on formation of UHI (Ichinose, Shimodozono, and Hamilton et al. 2009). Urban centers, high-density areas tend to have higher energy demands than surrounding areas which result in higher production of anthropogenic heat (Shahmohamadi et al. 2011). The air temperature around buildings tends to be higher due to rejected heat from cooling systems (Hsieh, Aramaki, and Hanaki 2007). The role of urban fabrics in UHI formation is showed in Fig. 2.

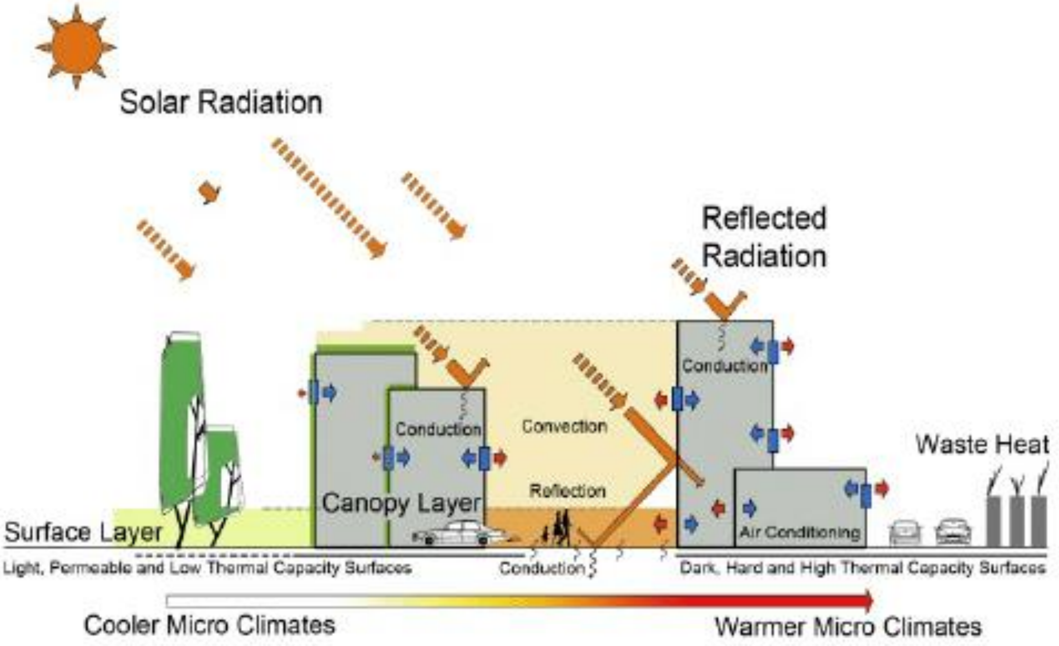

Figure 2: The role of urban structures contributes to Urban Heat Island effect (Sharifi and Lehmann 2015).

2.1.2 Effects of UHI phenomenon

According to European commission, the ratio of the world's urban population is expected to increase from 55 % in 2018 (about 4.2 billion people) to 68 % by 2050, which means that the world's urban population is supposed to nearly double (European Commission 2018). As a result of rapid urbanization as well as industrialization, UHI is considered as one of the major problems in the 21st century (Rizwan, Dennis, and Liu 2008). Although some heat island impacts seem positive, such as lengthening the plant-growing season, heat energy consumption in winter, etc. The large amount of heat generated from urban structures, which is known as urban heat waves, are showing substantially negative impact on public health, energy consumption, air and water quality (Morini et al. 2018). One major effect of UHIs is the endangerment on public health. Overheating in cities combined with increased pollution levels rises significantly the levels of heat related mortality and human discomfort (Paravantis et al. 2017). Sensitive populations, such as children, older adults, and those with existing health conditions, are at particular risk from these events (Yoshikado 1996). In 2003, the French heat wave increased mortality up to 137 % in Paris, with 14,800 excess deaths across 6 cities over 19 days (Filleul Laurent et al. 2006). Between 1979 and 1998 the Center for Disease Control and Prevention in United States, reported about 7,421 deaths that caused by exposure to excessive heat in the US (Ashley and Lemay 2008).

Meanwhile, the UHI plays a dominant role in local climate systems. The heatwaves in summer that results from UHI over cities is an example of local climate change. Elevated temperatures in fact lead to an increase in energy demand for cooling and peak electricity demand (Hashem Akbari and Sezgen 1992). According to IEA, by 2017, about 65 % global wide electricity generation from fossil fuel sources (IEA 2019), the energy generation events directly caused increase of greenhouse gas and pollutant emission. The key result is known as global warming syndrome. In the turn, global warming also enhances intensiveness of UHI effect worldwide. The research of (Yoshikado and Tsuchida 1996) shows that UHI seems to be the main cause of increasing ozone concentrations above the controllable level. Thus, advanced measures to mitigate UHI are demanded to address regional and global climate change.

2.1.3 Policies against UHI

Many local and state governments have included urban heat island mitigation strategies in policies or regulations, which range from strategic planning guidelines to building codes. During last decades, a number of actions have been carried out in worldwide.

New York City, NY, USA

In New York city, an important plan called PlaNYC 2030 was implemented in 2007, since then about 1 million trees have been planted throughout city area, and 185,000 m^2 of black asphalt roofs have been upgraded to green roofs, which increased the total green area up to 14 % (City Hall NYC 2014). In addition, project called “Green light for Midtown” was enabled in Manhattan district, NYC, that aims to increase green areas in midtown and lighter surface color of streets and pathways to reduce the heat for pedestrians (New York City 2010). Another on-going program called NYC °CoolRoofs, also known as white-roof project, has goal to transform most of black asphalt felt roofs into white, by covering roofs with a highly reflective paint, of minimum 0.75 albedo as stated in the project law (NYC Service 2012). The program has coated over 613,000 m^2 of building roofs with white reflective paint, to reduce energy cost and carbon emissions caused by cooling process (Carleton and Hsiang 2016). Fig. 3 shows the cool roof demonstration project taking place on top of municipal buildings in New York City.

A recent project called “green roof tax abatement program” was launched in 2019. As a part of green building legislation, building owners in New York City who install green roofs on at least 50 % of available rooftop space can apply for a one-year property tax credit of up to $100,000 (The Copper Union 2018).

Figure 3: Project staffs are painting dark roof to white in NYC (Ben Huff 2012).

Vienna, Austria

Vienna is one of the first cities in Europe to integrate UHI-sensitive actions to city planning and urban development strategies. Urban Heat Island Strategy for Vienna (Vienna UHI Strategy) which was developed by the Vienna Environmental Protection Department MA 22, aims to build Vienna as a climate-resilient city against extreme climate change. In 2014, Vienna city Council promoted “STEP 2025” as a long-term umbrella strategy to 2050, initiate “Urban Greening instead of Air-Conditioning” as core strategy for beneficial impacts on the urban climate (MA22 2018). As a pilot project, facades greening program was launched in 2016, relevant regulations of green walls and facades installation were carried out the next year. In total, 850 m^2 of facade with about 17,000 plants were mounted on public buildings. Follow-up data shows green walls in Vienna has improved thermal insulation by 21 % (McKenna Davis 2016). Fig. 4 illustrates the prevision of “Facade greening” model in Vienna.

Furthermore, MA22 has successively monitored condition of green areas in Vienna’s urban area every five years since 1991. In recent, digital map of city green roof potential in Vienna was conducted to provide fundamental support for future green roof development (MA22 2018).

Figure 4: Model of “Facade greening” program in Vienna (McKenna Davis 2016)

2.2 Grey infrastructures

The “Grey infrastructures” (GREIs) are usually considered as urban engineering infrastructures such as roads, drains, sewerage, water reticulation, telecommunications, and energy and electric power distribution systems (Yeang 2009). However, GREI can be defined varies upon specific subjects. On perspective of water management, GREI refers to conventional storage and distribute structures used to manage drinking water and sewer system. Such as water and wastewater treatment plants, as well as pipes and underground structures (Alves et al. 2016). In transportation sector, GREI can be defined as ‘sidewalks, pedestrian crossings, street characteristics, and traffic signals’ (Marlon G. Boarnet et al. 2011). Most GREIs are made of conventional dark materials, such as asphalt, concrete, and brick, stone, etc. These materials averagely absorb 80-95 % of sunlight and radiate heat into the atmosphere that warm the local air temperature. Because of that, GREIs are usually considered to aggravate UHI formation and global warming (Berkeley Lab 2020).

2.2.1 Cooling mechanism

The cooling mechanism can be determined only by knowing how urban energy balance works. Luck Howard (Howard 1818) firstly proposed that the climate in cities and relation with their rural surroundings are determined by the energy exchanges between urban surfaces. The incoming and outgoing energy flux from an urban surface system create ‘urban energy balance’ (Gunawardena, Wells, and Kershaw 2017). In 1988, Oke (Oke 1982) proposed a formula to calculate components of surface heat balance in urban area, expressed as equation[1]

$$Q^* = Q_H + Q_E + \Delta Q_S \tag{1}$$

that Q* is the net radiation, which is related to long-wave and short-wave reflection, Q_H is sensible heat flux, Q_E is latent heat flux, ΔQ_S is heat storage. Therefore, according to equation[1], cooling mechanism of UHI mitigation can be generated by increase of solar radiation reflection for both long-wave and short-wave, increasing heat storage and minimizing anthropogenic heat release (Qi et al. 2019).

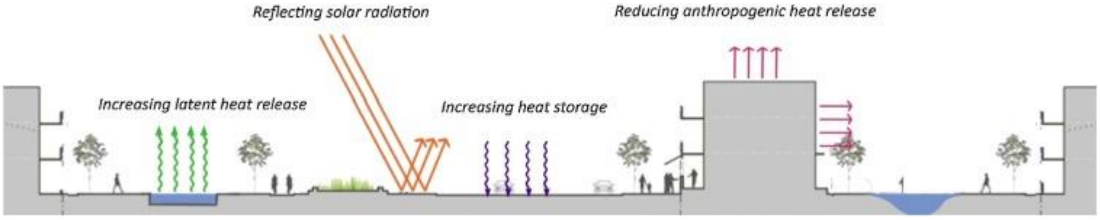

Figure 5: Cooling mechanisms to achieve urban energy balance (Qi et al. 2019).

Every dense and non-transparent surface reflects some incoming sunlight and absorbs the rest and turning it into heat. However, GREIs can also contribute to achievement of “cooler city”, by using reflective materials to increase surface albedo and heat storage materials to hold heat, that either discharge heat to supplement low temperature at night, or transfer heat to other types of energy sources (Qi et al. 2019).

2.2.2 Cool surfaces

Cool surfaces, normally addressed as “reflective surfaces”, which can deliver high solar reflectance and high thermal emittance (Pfannenstiel 2008). Thermal emittance is the ability to radiate absorbed, or non-reflected, solar energy. Solar reflectance is the proportion of sunlight that a surface reflects, considered as the most important factor in determining a cool surface. A study (Akbari and Levinson 2008) shows that over 60 % of surfaces of urban fabric are generally covered by pavements and roofs, which absorb and store heat without evaporative cooling. Existing technologies of reflective treatment can increase urban hard surface albedo by around 10 % (Hashem Akbari, Menon, and Rosenfeld 2009), meaning that cool surfaces can help to cool the cities!

Cool roofs

By adapting roof color, most roof surfaces can be highly reflective and minimally heated by the sun. White is obviously the “coolest” roof color option. Solar reflectance (SR), is the ability of a material to reflect solar energy from its surface back into the atmosphere. The SR value is a number from 0 to 1. A value of 0 indicates that the material absorbs all solar energy and a value of 1 indicates total reflectance (Dean Steel Buildings, Inc. 2018). In general, SR value of standard roofs is close to 0.2, while as it for cool roofs, especially the white colored roofs, SR value can be 0.5 or 0.6, about three times more than conventional dark roofs (H. Akbari and Konopacki 2005). As an example, Fig. 6 shows comparative thermal effect on average roof surface temperatures between white acrylic elastomeric paint surface and uncoated black asphalt surface (Chui et al. 2018).

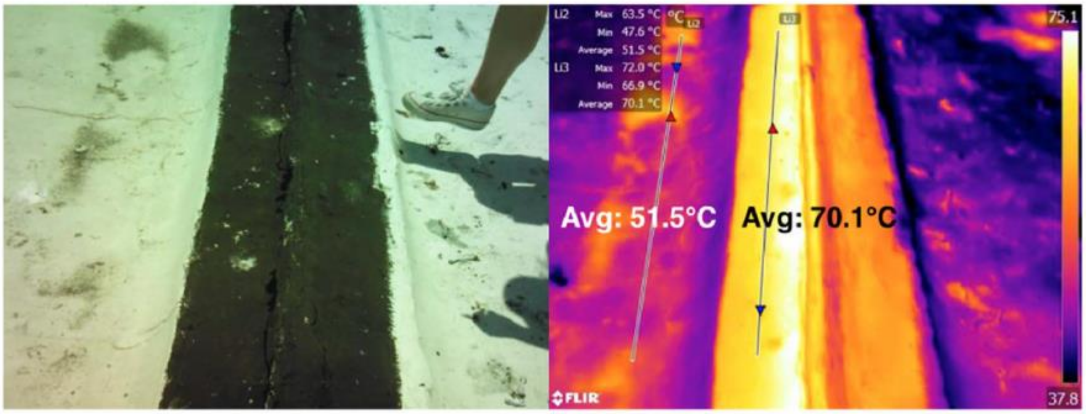

Figure 6: Thermal image of a white-paint coated, asphalt roof in New York city, USA (Chui et al. 2018).

Therefore, white roofs are ideal for most commercial and high-rise residential buildings. While, in many parts of the world, white is not a popular color for residential roofs. In order to maintain the color and aesthetics of traditional nonwhite roofing, conventional tiles with reflective coating are designed to cover the demands especially for low-sloped roofs of residential households (Berkeley Lab 2020).

Reflective pavements

Paved surfaces in Europe and USA, consist mainly of concrete and asphalt which lead to high surface temperatures during the summer period (Santamouris 2013). Nowadays, several techniques are commercially available to modify conventional dark materials to cool reflective pavements, in particularly, concrete on building and asphalt pavements. For example, white topping, covering of an existing asphalt pavement with a layer of cement concrete (Berkeley Lab 2019), applying light color surface coatings (Karlessi et al. 2011), or a proper binder as chip or sand seals (Pomerantz 2000). Experiments have confirmed that reflective pavements effectively decrease the pavement surface temperature of flat brick samples or those of pavements in open areas (Santamouris 2013). Fig. 7 shows an example of surface cooling effect of lighter-color coated pavements comparing with dark asphalt surface during hot summer days.

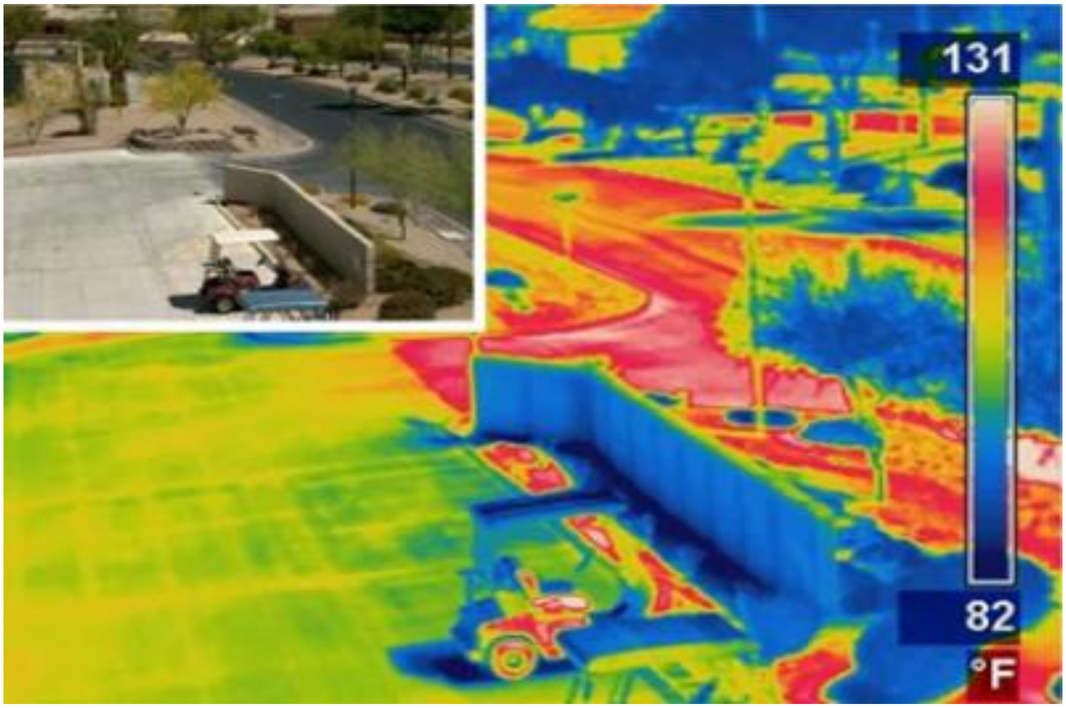

Figure 7: Thermal image of lighter-colored pavement in parking lot (Harrington et al. 2012).

2.2.3 Case study - Cool roof programs in California

California has a long history of implementing cool roof related research and projects. In 2001, California Energy Commission initiated cool roofs program as recommended measure in Building Energy Efficiency Standards, also well-known as “Title 24” building code. In the late 2005, these cool roof strategies became mandatory legislation for all new non-residential construction and re-roofing projects which involve more than 180 m^2 or 50 % replacement (Pfannenstiel 2008). In California, flat-roofed houses are now required to have white roofs (see Fig. 8). The cool roofs program was designed to reduce energy consumption for cooling process in newly constructed and existing buildings, by installing roofing materials with high solar reflectance and thermal emittance. According to the study (Clean Energy Solutions Center 2020), in a hot climate, a cool roof can reduce air conditioning energy use by approximately 15 %. For buildings without air conditioning, a cool roof can improve sense of comfort and prevent installation of air condition system.

As response to state cool roof program, a “zero net energy” community was built in the University of California at Davis, California, which targets to generate as much energy as it consumes. In order to meet this goal, several energy efficiency measures like cool roof, shaded windows, thick exterior walls, etc. were implemented (Forbes 2011). Most of the buildings in campus are covered with white roofs to fight against heat wave combined with intensive climate change. Fig. 9 shows satellite map of UC Davis. Note the amount of white roofs on campus. The utilization of reflective white roofs efficiently reduces building heat, which directly leads to lower energy consumption. Thus, BGIs offer a cost-effective solution for mitigating UHI effect (UC Davis 2010).

Figure 8: In California, flat-roofed houses are now required to have white roofs (LA Weekly 2009).

Figure 9: Satellite map of UC Davis, source: Google map.

2.3 Blue-green infrastructures

Facing with climate change and environmental degradation, many cities are turning to Blue-Green Infrastructure (BGI) solutions to enhance climate resilience and to restore the health of ecosystems (Brears 2018). BGI is closely related to green infrastructure, which is defined as a strategically planned network, of natural and semi-natural areas, that are designed and managed to deliver a wide range of ecosystem services (European Commission 2019). In urban context, BGI often refers to the combination of blue (water) and green (vegetation) components, from rain gardens, vegetated rooftops to green streets, in distinction to gray infrastructure, such as roadways and buildings. (Well and Ludwig 2019)

BGIs have multiple impacts on sustainable development in built environment, especially when it comes for storm water and flood management strategies (Venkataramanan et al. 2019). As an alternative to traditional water management systems, BGIs offer a sustainable solution, due to the interrelationships between vegetation and the water cycles (NRDC 2019). BGIs provide essential functions of "detention and retention" in urban hydrological systems (Ghofrani, Sposito, and Faggian 2017). As natural water retention measure, BGIs capture rainfall and uses natural elements such as soil and plants to turn storm water into a resource instead of directly discharge to the sewer system during and after extreme rain events. Soil and plants can also help remove pollutants from storm water to improve water quality. Meanwhile, BGIs store water by increasing infiltration to ground water, improve water quality, and achieve environmental benefits (Eckart, McPhee, and Bolisetti 2017).

BGI can also be highly effective on UHI mitigation (He and Zhu 2018). BGI is considered as the best tool for both urban heat mitigation and thermal comfort enhancement of city residents in most regions in the world (Solecki et al. 2005). Both of green and blue infrastructures can increase urban roughness and enhance latent heat release through evapotranspiration, having high potentials of urban cooling (Gunawardena, Wells, and Kershaw 2017). For instance, urban trees can provide shades lower temperature of air below it; vegetation coverage on green roof and rain gardens allows water to flow through into the sub-layers where evaporation of the water helps to reduce the temperature of ground surface; open surface water can most effectively emit longwave radiation to cool the surface because of its high emissivity, and efficiently consume shortwave radiation through evaporation (Wu et al. 2019). While study in Beijing, China shows that the temperature difference between wetland and surroundings ranged from 0.7 °C to 5.8 °C in August, and cooling distance can reach as far as 2,500 m (Sun and Chen 2012). Therefore, GBI could be the most environmental resilient approach for both UHI mitigation and sustainable water management.

2.3.1 Green roof

A green roof is a partially or completely vegetated layer grown on a rooftop of a building. It may also include additional layers such as a root barrier and drainage and irrigation systems. Nowadays, green roofs are widely applied to mitigate UHI effect, particularly useful for lowering the temperature of areas impacted by high impervious pavement surface area - rooftops, which contribute to a city's majority area of impervious pavement (Coseo and Larsen 2014). Vegetation grown on a green roof provide shades, plants combined with support layers create a unique thermal mass to store heat and discharge through evaporative process (Moody and Sailor 2013).

The pervious vegetative green roofs stay much cooler than conventional roofs. Environment organization NRDC (NRDC 2019) announced that, if half of Toronto’s available roof space were covered in green roofs, the roof surface air temperatures would be lower by about 16 °C in citywide. Study from Green roof research group of Michigan State University (lives, Zion, and Illinois. 2009) indicates that different roof surfaces of green roofs, on average, retained more than 60 % of rainfall, whereas conventional roofs retained only about 27 %. This semi-natural system helps city produce a range of ecosystem services beyond UHI mitigation, such as reducing storm water run-off, rainwater collection, microclimate preservation and aesthetic values, which make green roofs a more dynamic solution than reflective roof covers (Getter and Rowe 2006).

Type and Performance:

a: Extensive and Intensive Green roofs

Based on construction techniques, there are two major types of green roof: intensive and extensive. The difference is the depth of the material implemented on the roofs (The Renewable Energy Hub 2018). Extensive green roof system is designed to be light weight and simple maintain once it is established. The soil thickness of extensive green roofs usually around 100-150 mm. Therefore, more adaptive plants like mosses or grasses, or a combination, are applied to resist extreme climate condition. In some case, it may also not require permanent irrigation system, which make extensive green roof easier and cheaper to install (The Renewable Energy Hub 2018). However, when grown on roofs with slopes of 30° or more, additional structural support would be needed, which increase the cost for retrofitting an existing structure (US EPA 2014a).

Intensive green roof is more like a conventional garden, substrate depth of intensive roofs is from 120 mm up to over 500 mm. Due to the higher soil volume, it allows to support a greater range of vegetation, such as ground cover, medium shrub, trees, as well as water features (The Renewable Energy Hub 2018). In most of cases, irrigation system requires to be installed, to capture and absorb rainwater. Compare with extensive green roofs, intensive green roofs are heavier, require a higher initial investment for functional structures and more intensive maintenance across whole lifespan (US EPA 2014a). However, intensive green roofs provide sustained supply of ecosystem service. Ecosystem service is defined as the multitude of benefits that nature provides to society, which provides material benefits, regulation of air quality, control of flood and inspiration, cultural identity to well-beings (FAO 2020).

b: Others

Blue-green roof is a combination of blue roof technologies with green elements. Instead of conventional drainage, blue-green roof aims to increase both the volume of water stored and control the amount of water released. This smart system can increase the overall benefits of greening roofscapes, and considered as a sufficient tool for stormwater management (Livingroofs 2018).

Solar green roof also called Biosolar green roof, is usually green roof combined with solar panels. Supporters consider it a future roof trend – as this approach provides the greatest range of benefits for biodiversity, energy generating and ecological sustainability. However, all the solar elements intend to have priority over the green roof element, which may lead poor condition for vegetation to growth (Livingroofs 2019). Fig. 10 shows a biosolar green roof used in Lausanne, Switzerland.

Figure 10: Biosolar green roof of the Palais Beaulieu in Lausanne, Switzerland (Catalano and Baumann 2017)

All types of green roofs provide ecological and economical values to urban environment. Table 1 shows the ability of water retention from different types of green roofs under the German Guidelines.

Table 1: Water retention performance of various green roofs (Gilbert and Clausen 2006).

Green Roof Types	**Depth (mm)**	**Vegetation**	**Water Retention Annual Average (%)**
Extensive	20-40	Moss/Sedum	40
	40-60	Sedum/Moss	45
	60-100	Sedum/Moss/Herbs	50
	100-150	Sedum/Moss/Grass	55
	150-200	Grass/Herbs	60
Intensive	150-250	Lawns/Shrubs	60
	250-500	Lawns/Shrubs	70
	500+	Lawns/Shrubs/Trees	90+

Case – Tokyo, Japan

In Japan, many cities suffer from the severe effects of UHI. In city of Tokyo, the average annual temperature has risen by 3 ºC in the last century. This is four times higher than any effect attributive to global warming. In order to mitigate UHI effect, Tokyo has introduced policies that 20 % of all new flat surfaces on government buildings and 10 % of all flat rooftops on private resident buildings are required to transfer to green roof system. (Livingroofs 2016). On rooftop of the Keyakizaka Complex in Tokyo, 1,300 m^2 of gardens, including farmland of rice and vegetables are planted. All of the "Hills" buildings around Tokyo have implemented roof gardens, the initial drive force behind is to develop "Vertical Garden Cities", to maximize open space for social activity in Tokyo's high-density centers. The integration of urban farm on roof garden not only provide a solution for storm water management and UHI mitigation, but also offer city alternative for urban food production (roppongihills 2016). Fig.11 shows the rice field on green roof of the Keyakizaka Complex in Tokyo.

*Figure 11: Roppongi Hills Rooftop Garden of the Keyakizaka Complex, Tokyo (*roppongihills *2016).*

2.3.2 Green wall

A green wall, usually considered as a vertical garden or living wall, is defined as a vertical planting system that includes an integrated substrate, live plants, and in some cases an automated watering system (McCullough, Martin, and Sajady 2018). Green wall provides building insulation by direct shading on wall surface. It creates cooler microclimates and improve local air quality, and provides the possibility of growing plants in locations that would not normally support vegetation (Hall et al. 2011). Another vertical greening system, which is often seen in urban context, is called “Green facade”. The growth mediums in this case are rooted in the ground, using building surface as structural support to climb. Greenery of facades can take a long time to grow enough to cover an entire wall, while green wall can be pre-grown, thus installed at any time (Mustonen 2017).

Benefits

Green wall performs thermal benefits for cooling building surface, by shading, evapotranspiration, and insulation (Lee and Jim 2019). Unlike the general greening measures, the insulation created by green wall provides air gap to prevent the convection between warm ambient and cold air backwards (Perini and Rosasco 2013). Recent research examined the possibility of impelling the cool posterior air indoors, achieving a 26 % reduction in air-conditioning load (Perini et al. 2017). Another study (Bianco and Slaughter 2016) shows that green wall presents a 40 % reduction of thermal transmittance value than a conventional wall. In some regions, air temperature around plant coated wall surface can be up to 9 °C cooler than a concrete wall in hot summer (Vox et al. 2016).

Green wall can be installed not only outdoors but in an interior environment. Vertical living walls purify air, provide moisture and a healthy indoor environment. The connection with natural green elements could reduce stress and mend mental fatigue (Mustonen 2017). Therefore, this technique is widely placed interior of public space, for example schools, office buildings, public transport hubs, etc. Evergreen plants are usually preferred for green walls plants due to their longevity and looks. Most houseplants and tropical plants are suitable for indoor green walls. A study (Reggev 2018) also indicates that living walls can be used to purify gray water, or gently used water from bathroom sinks, showers, tubs, and washing machines.

Green walls also show ability to retain a significant amount of storm water. Researchers from the Pennsylvania State University ran a storm water flush experiment on green walls, the result shows that during small rainfall events, green wall systems can easily capture half of rainfall during study period, and water cistern from irrigation system can store water and dispose it back to plants instead of discharging it to sewer system (Kew, Pennypacker, and Echols 2014). Such process makes green walls comparable to extensive green roofs for on-site storm water management. However, all types of green walls require constant irrigation, while the green roof and the greened facade are dependent only on rainfall. So green wall system is considered highly demand on water consumption (Gerhardt and Vale 2010). Moreover, green wall is expensive measure for mitigating UHI effects, as they need careful monitoring and management for irrigation, often inclusive of fertilizer (Perini and Rosasco 2013). A comparison of multiple values between green wall, green roof and green facade area listed in Table 2.

Table 2: Comparison of values between green wall, green roof and green facade (Gerhardt and Vale 2010).

	Green wall		**Extensive green roof**		**Greened facade**	
	Substrate based	Hydroponic	Festuca	Sedum	Evergreen	Deciduous
Heat island effect	++	+++	++	++	++	++
Water retention	+++	+++	+++	+++	+	+
Thermal insulation (winter)	+	+	+++	++	+	-
Thermal insulation (summer)	++	++	+++	+++	++	++
Sound absorption	++	++	++	++	++	++
Wildlife	+++	++	+++	+++	++	++

Case – Madrid, Spain

The Caixa Forum's green wall (see Fig. 12) was installed in 2008, as a part of Madrid's new strategy called “Madrid + Natural”, city of Madrid aims to cover as much of its surface as possible with greenery, such as rooftops, walls and empty lots, to deal with the hot and dry summer. The goal is to create a so-called "green envelope," protecting Madrid from the effects of climate change (NPR 2017). The entire building surface is covered by 460 m^2 of plants from 300 native species. In summer, this giant vertical garden shows incredible panel of colors, which makes it both work of art and practical measure to cool down the building. Green wall also contributes a considerable amount of oxygen to surrounding environment. A study (NPR 2017) shows that if 10 % to 25 % of city buildings in Madrid were to coat their roofs or facades in greenery, it could reduce temperatures by up to 8 °C.

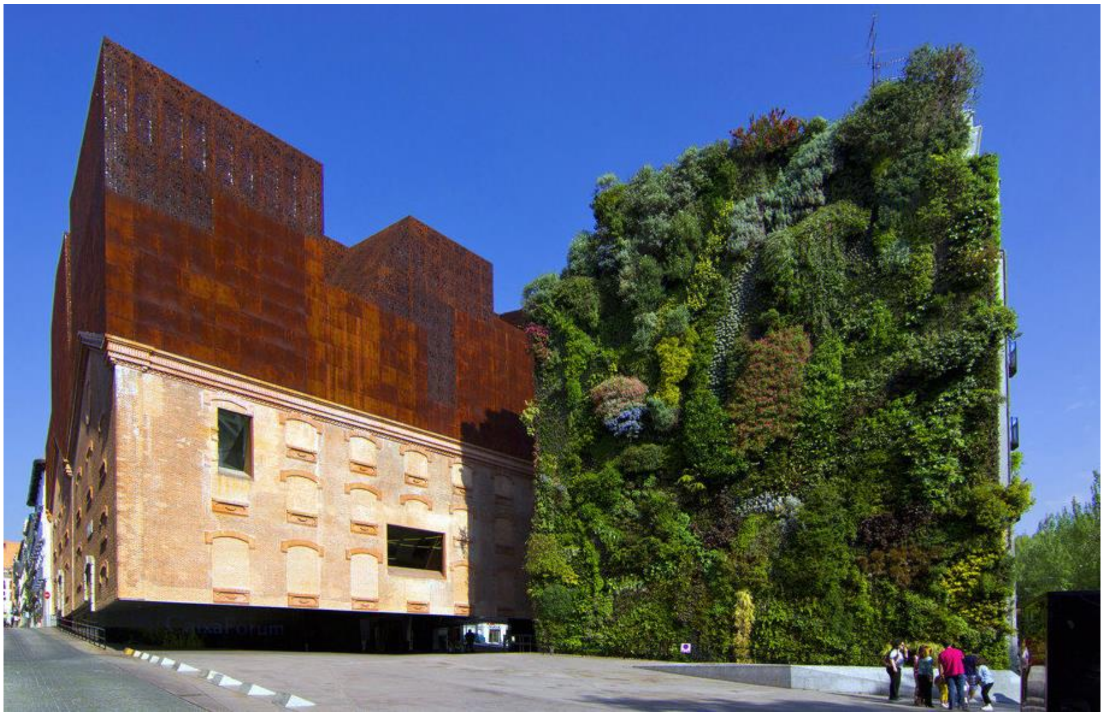

Figure 12: Green wall of Caixa Forum in Madrid (NPR 2017).

2.3.3 Permeable pavement

Permeable pavement (PP), known as pervious or porous paver, is a pavement type with a high porosity that allows rainwater to pass through into the ground below, rather than fast run-off (Green Building Alliance 2016). In general, PP system consist of, from top to bottom, a surface layer of permeable pavement, such as asphalt, concrete, etc., one or more layers of aggregate with void space up to 40 %. Air voids in the pavement are interconnected and create an underlying reservoir, water can travel from the surface, through the reservoir, from where water get stored, then slowly infiltrate to subsoil and eventually recharge groundwater or flow downstream through underdrains (USGS 2018).

Pervious surfaces have been installed across Europe and North America for many years, mainly for stormwater management. The evaporation process at surface and in the reservoir layer suppress surface heat, which make PP a potential method of UHI mitigation (Liu, Li, and Peng 2018). Therefore, PP is also considered as green pavement. Studies show that when in full infiltration, PP can reduce runoff volume by more than 90 % (Gilbert and Clausen 2006) and reducing the loads of suspended solids, metal pollutants and nutrients by 75 %, 94 % and 27 % respectively (Fassman and Blackbourn, 2010). Compare with conventional impervious paver, average surface temperature for wet PP is approximately 1.2 °C to 1.6 °C lower in general. However, when comes to dry season, the cooling performance of PP remains controversial (Li, Harvey, and Jones 2013). PPs are commonly used in parking lots, sidewalks, low-traffic areas and driveways (GreenBlue Urban 2017).

Type and performance

There are four major types in practical use: Permeable interlocking concrete pavers (PICP), Concrete and plastic grid pavers (CGP and PGP), Porous asphalt (PA), Porous concrete (PC) (Mullaney and Lucke 2014).

PICPs are generally designed to keep sufficient open space between the pavers, by either customized paver with small holes on surface or laid pavers in geometry pattern with wide joint in between. Instead of blinding it with sand or other blinders for conventional pavers, the spaces between PICPs are usually filled with 2–5 mm aggregate, allows water to infiltrate through the gaps. PICP surfaces have at least 9 % open or void, which provide reduction of runoff volumes and peak flow by up to 60 % compared to conventional asphalt from car-park pavements (Scholz and Grabowiecki 2007). Fig. 13 presents two commonly used PICP types.

Figure 13: PICP with wide joints (a) and apertures (b) (Scholz and Grabowiecki 2007).

CGP and PGP (Fig. 14) are generally similar as PICPs, but with much larger open space, allow vegetation to grow in between. The proportion of surface void can reach from 20 % to 50 % for CGPs and up to 98 % for PGPs. Study shows that vegetated PGPs can reduce runoff volumes by 93 % compared to a conventional asphalt surface (Scholz and Grabowiecki 2007).

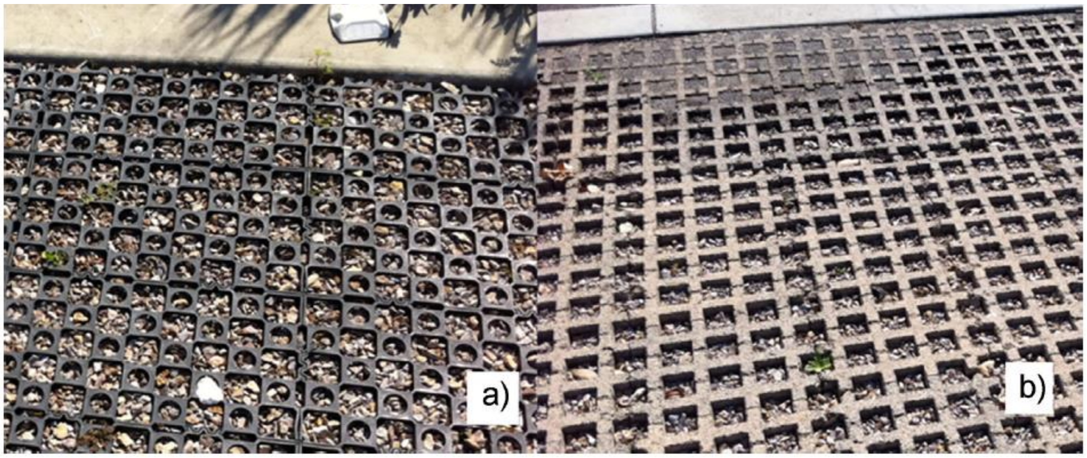

Figure 14: (a) Plastic grid pavers and (b) concrete grid pavers (Scholz and Grabowiecki 2007)

PA and PC started to be used in the USA since mid-1970s, mostly used for parking lots and roads with light traffics. The surface of PA and PC allow water to drain through into a stone recharge bed and infiltrate into the soils below the pavement (Scholz and Grabowiecki 2007). PA shows highly effective in removing pollutant from storm water, with 99 % removal of suspended solids and petroleum contamination. In winter, with the same coverage of snow and ice, PA can reduce 75 % salt application than conventional dense-mix asphalt (NAPA 2009). PC shows positive effects on growth of street trees, as PCs consist of 15 % to 40 % voids, which allows both water and air to pass through to root system (Elizondo-Martínez et al. 2020). Fig. 15 visually presents the hydrological performance of PA.

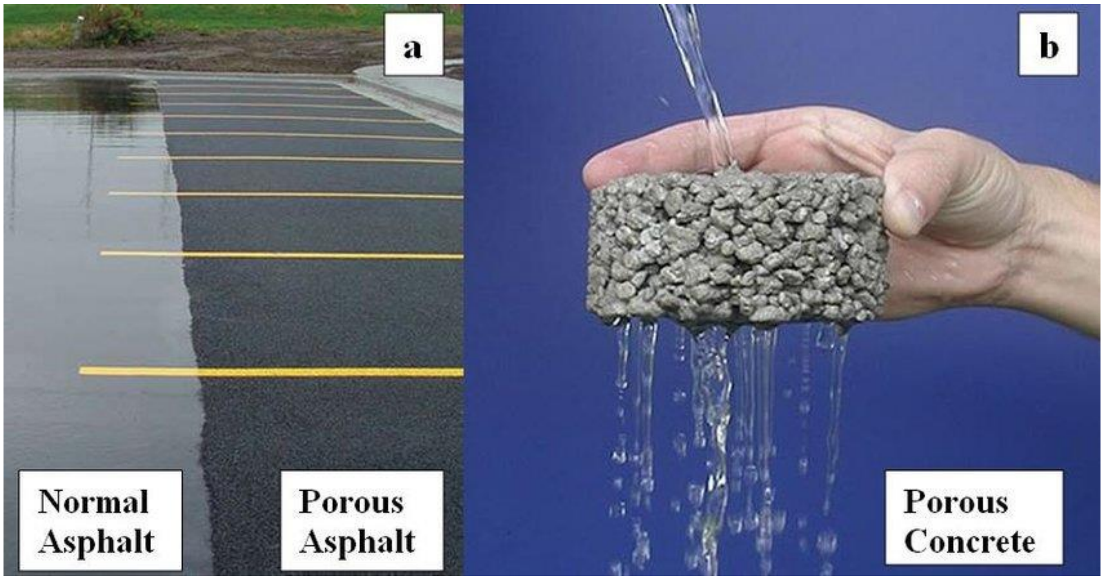

Figure 15: Normal and Porous Asphalt; b) Porous Concrete (Lucke et al. 2013).

According to standards of commercially used PP products in Copenhagen Municipality (Støvring, Dam, and Jensen 2018), general porosity and annual surface evaporation rate are summarized in Table 3.

Table 3: The parameters of PP surfaces used in city of Copenhagen (Støvring, Dam, and Jensen 2018)

PP Types	Porosity (%)	Annual surface evaporation rate (%)
PICP	10	8
CGP	20-50	N/A
PC	7	12
PA	15-24	7

Drawbacks

Like all other things in the world, there are some disadvantages that come along with PPs. Compare with traditional pavements, PPs are more expensive, due to high demands of maintenance. When sand, trash or other small fine particles stuck into the joint space between pavers, cleaning process need to be applied in time to prevent water and pollutants to run off over surface. Moreover, PPs aren't as strong as asphalt pavements. When facing consistent pressure from heavy vehicle or extreme climate condition, PPs may collapse or deform which highly reduce their lifespan. Therefore, PPs are not suitable for building intensive driveways, such as airport runways and highways, etc.(Green Blue Urban,2017) .

Case – London, UK

In city of London, under framework of The Mayor's Climate Change Adaptation Strategy (GLA 2011), a sustainable drainage system (SuDS) approach has been designed to manage surface water quality, volume and deliver amenity and biodiversity in London context (City Hall London, 2016). In 2016, three streets in west London were selected for the SuDS Retrofit Pilot Schemes - 'Healthy Streets' program. On Mendora Road, a total of 3,600 permeable void cells were installed, along with a channel on one side to create nearly 136 m^3 of stormwater storage beneath the surface (City Hall London, 2016). This new system provides 'water tanks' to retain rainfall within urban fabrics, and all of these actions provide opportunities for London to moderate UHI effects. Fig. 16 shows the permeable paving along Mendora Street after retrofit.

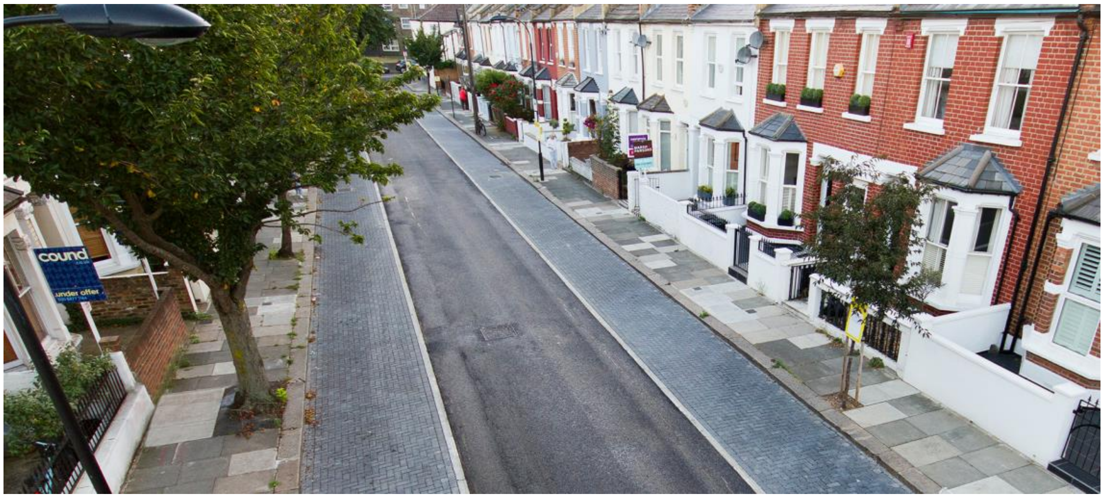

Figure 16: Permeable paving retrofit on Mendora Road, London (2016) (FM Conway 2020).

3 MATERIALS AND METHODS

3.1 Study area

Campus of the Technical University of Kosice (TUKE) was chosen as study area to experiment cool measures. TUKE is located in city of Kosice - the second largest city in Slovakia, right after the capital Bratislava. The city lays at an altitude of 206 m above sea level and covers an area of 242.77 km², along the river Hornád at the eastern reaches of the Slovak Ore Mountains, near the border with Hungary ("Košice" 2020). Kosice has a humid continental climate, the average warmest and wettest month is July, and coolest month is January. Figs. 17 & 18 illustrate average monthly temperature and precipitation data of Kosice in 2019 (World Weather & Climate 2019).

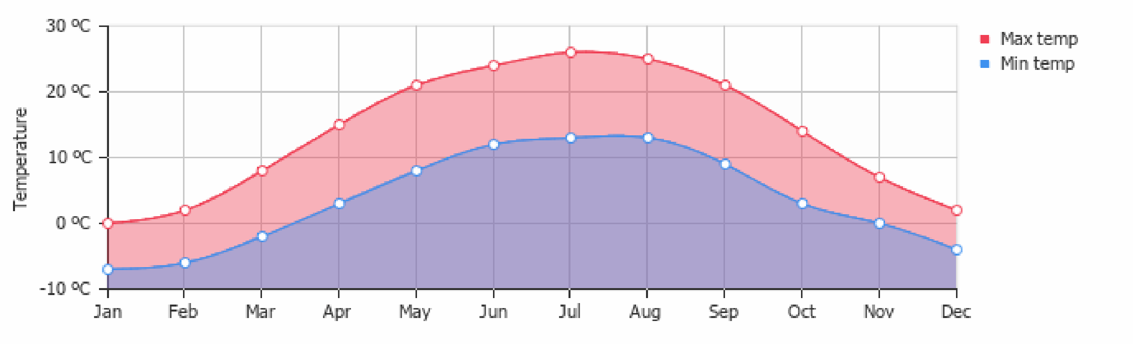

Figure 17: Average minimum and maximum temperature over the year (World Weather & Climate 2019).

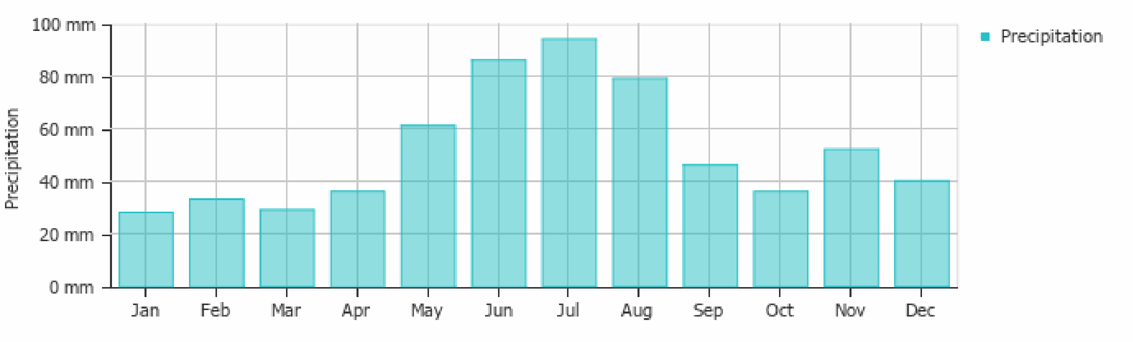

Figure 18: Average monthly precipitation over the year (rainfall, snow) (World Weather & Climate 2019).

In recent years, Slovakia experienced heat waves in hot summer. In Kosice, ten hottest years in the last 150 years have occurred since 1990, and the annual mean temperature between 1881 and 2010 has increased by 1.6 °C. Number of tropical days (average temperature above 30 °C) has increased in the last 20 years from 12 to 20 days, in the year 2012 it was 37 days, and the maximum temperature frequently exceeds 34 °C (Climate ADAPT 2018). In 2019, the Slovak Hydrometeorological Institute issued two first-level warnings on the heat wave on August 29 and 30, the temperature reached out between 33 °C and 34 °C in many Slovakian districts from south spread to north Slovakia, including Kosice (Slovak Spectator 2019). Due to all those critical facts, a project called “Climcross Development” was conducted as a part of Climate Change Adaptation Plan (CCAP) in Kosice. The CCAP aims to use green and blue tools to cope with urban heat, and establish early warning systems to monitor UHI in city and national wide (Climate ADAPT 2018). As response to CCAP, my study focuses on heat wave adaptation measures in TUKE campus.

Table 4: Current surface material and corresponding area.

Infrastructure Type	**Category**	**Type**	**Surface Material**	**Surface area**		**Total area(m^2)**
				(%)	**(m^2)**	
Grey	Roof	Flat	Asphalt	10	56,400	273,900
		Sloped	Asphalt or brick/concrete tiles	11		
	Pavement	Road	Asphalt	42	133,300	
		Parking	Asphalt	5		
Green	Vegetation	N/A	Grass/tree cover	32	84,200	
Blue	Water	-	-	0	0	

3.2 Surface identification and area calculation

According to base map of TUKE from cadaster maps in Kosice, the entire foot area of campus is about 273,900 m². Based on functional and geographical characteristics, surface type in this study was classified into 5 basic categories (shown in Fig. 19.), which are flat roof, sloped roof, road, parking lot and green (nature cover). Surface area was calculated using auto CAD software, relevant material and area data are listed in Table 4. Most rooftops are covered by various form of asphalt materials, ground covers of hard surface are asphalt for both roads and parking lots. The proportion of roof, pavement and green area are about 21 %, 47 % and 32 % respectively. There is no blue infrastructure (water surface) at campus.

Figure 19: Current surface distribution in TUKE campus.

3.3 Surface strategies

In order to analyze the influence of typical UHI mitigation strategies in TUKE, two measures using GREI and BGI technologies are proposed, which are addressed as economical measure and ecological measure, respectively.

3.3.1 Grey system - economical measure

Despite the high effectiveness of BGIs on UHI mitigation, there are barriers to implement green and blue system over all surfaces in the real world, especially when it comes to the consideration of budget. According to the study in literature review section, GREI involves cool roofs and reflective pavements. The key cooling technique is to apply light color on dark surface to reduce heat absorptivity by increasing surface albedo. The cost of asphalt-based seal coating and follow-up maintenance is similar as normal street programs. When using on road, it is usually light-grey and dries with a matte finish which does not cause glare for drivers or pedestrians (GuardTop 2017). Thus, using GREI system to fight UHI can be essential economical choice for decision makers. In this proposal, all dark surfaces (asphalt) in study area are designed into a light color coated surface. As a result, 82 % of rooftops and 100 % of pavements are transformed, which consists of around 64 % of entire land cover. Table 5 lists details of economical measure, and the layout of retrofit area is shown in Fig. 20.

Table 5: Color-oriented strategy – modification of hard surfaces in economical measure.

Category	**Type**	**Target surface**	**Surface treatment**	**Transformed area**		**Surface area (%)**
				(m^2)	**(%)**	
Roof	Flat	Asphalt	White-coated	46,136	82	64
	Sloped		Cool tiles			
Pavement	Road	Asphalt	White topping	133,300	100	
	Parking					

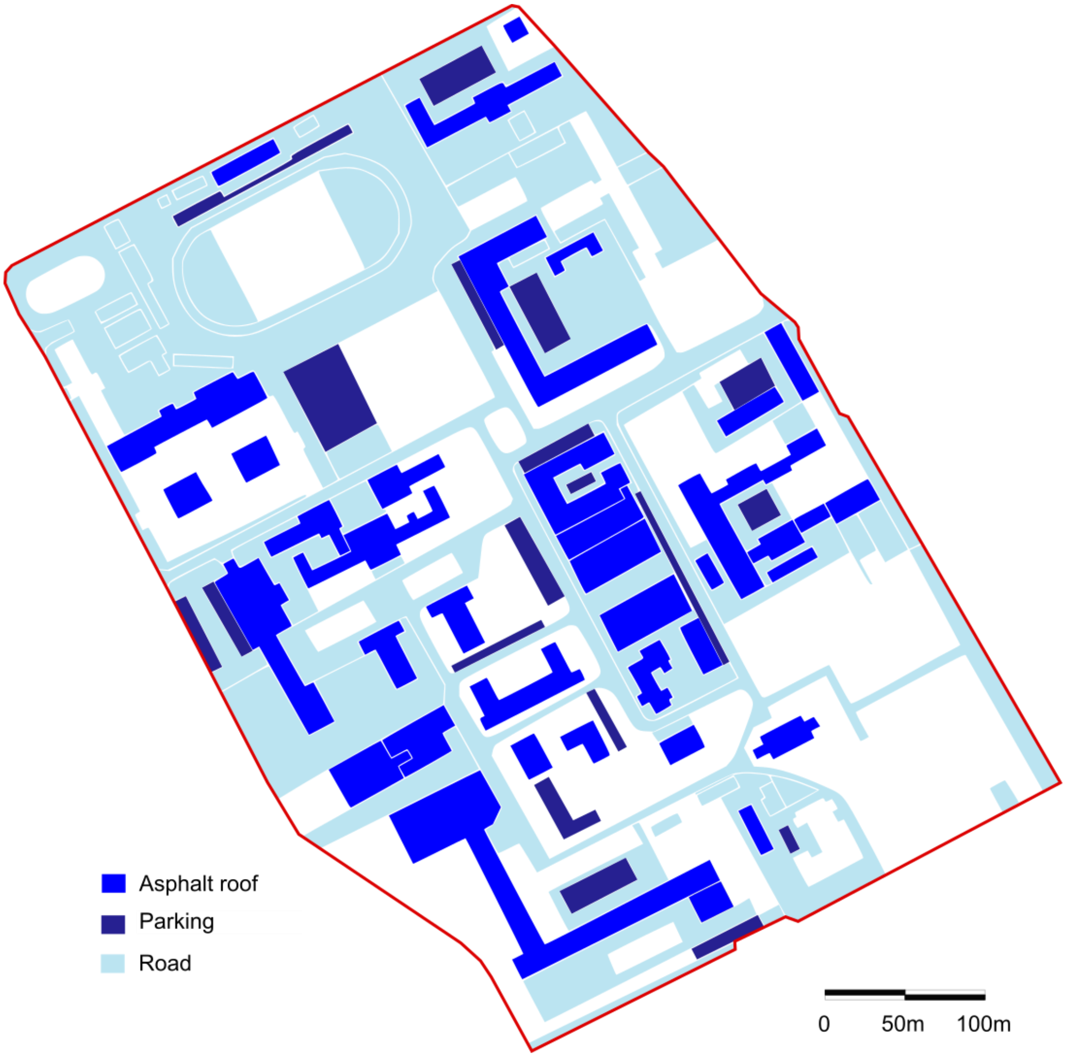

Figure 20: Layout of retrofit surfaces – all asphalt rooftops and pavements (parking lots and roads). Blank area presents the non-modified surfaces as existing green area and non-asphalt roofs.

3.3.2 Blue-green system - ecological measure

Compared with concrete and asphalt, vegetated land is a living component. It is cooler due to water infiltration and high solar reflectivity (Corina Negrescu 2014). Therefore, applications related to BGI system, such as green roofs and permeable pavements are also considered as cool surfaces, as they reduce heat by increasing urban roughness and enhancing latent heat release through evapotranspiration (Gunawardena, Wells, and Kershaw 2017). In addition, these permeable surfaces provide capacity of water retention and ecological service. In this proposal, all flat roofs are transformed into green roofs, all parking area and roads are designed into semi-green permeable pavers. As a result, about 36 % of entire surface area are transformed into BGI system. Besides existing green area, the entire BGI system coverage would reach up to 68 %. Table 6 shows the proposal of surface retrofit for ecological measure. As reflection of reality, mostly due to the high cost, there is no action for sloped roofs, although technology is commercially available to apply green roof on most kinds of sloped roofs. Fig. 21 shows the layout of retrofit area on map.

Table 6: Green and semi-green strategy - modification of hard surfaces in ecological measure NC means no change.

Category	**Type**	**Target surface**	**Surface treatment**	**Transformed area**		**Surface area (%)**
				(m^2)	**(%)**	
Roof	Flat	Asphalt	Green roof	27,390	100	57
		Brick/concrete	Green roof			
	Sloped	-	NC	-	NC	
Pavement	Road	Asphalt	PICP	57,519	100	
	Parking	Asphalt	CGP	13,695	100	

Figure 21: Layout of retrofit areas – all flat roofs to green roofs and all pavements (parking lots and roads) to semi-green surfaces. Blank area presents the non-modified surfaces as existing green area and all sloped roofs.

4 RESULTS

4.1 Comparison of thermal perfomance

In order to compare the influence of each proposal on UHI mitigation, a series of simulation were processed to conduct thermal profile for each scenario. In this study, surface temperature (ST) is used, STs of different materials were collected from a study carried out at the University of California, Berkeley. The obtained values of surfaces were measured during the warmest time of day, which are for asphalt 40 °C, concrete 34 °C, brick paver 37 °C and grass 25 °C (Guan 2011). Based on an experimental result from cool roof program in NYC, that STs of white-coated and conventional asphalt were at 51.5 °C and 71 °C, respectively (Chui et al. 2018), the absolute ST of white coated asphalt pavement was calculated from following equation:

$$T = \frac{71+273.15}{40+273.15} \cdot (51.5 + 273.15) - 273.15 \doteq 23\ ℃ \tag{2}$$

The ST of asphalt roof was set 5 °C higher that of asphalt pavement due to the result presented from (Griffith and McKee 2000), the rooftop is about 3.9 °C to 6.1 °C warmer than ground at the maximal ST during a day. Thus, the considered STs of all materials used in TUKE campus are listed in Table 7.

Table 7: Surface temperature applied in the study.

Material		Surface temperature (°C)
Asphalt	Pavement	40
	Roof	45
Concrete		34
Brick		37
White-coated asphalt	Pavement	23
	Roof	28
Grass		25

Three thermal images (Fig. 22 & 23 and 24) were created using python script. The value range is set from 25 °C to 45 °C for all three scenarios, which allows their direct comparison. Over-heated areas are determined as surfaces with temperature exceeding 40 °C in initial thermal simulation (red color in Fig. 22), which covers over 60% of entire campus. The corresponding land cover is dark asphalt on rooftops, roads and parking lots (see Table 7).

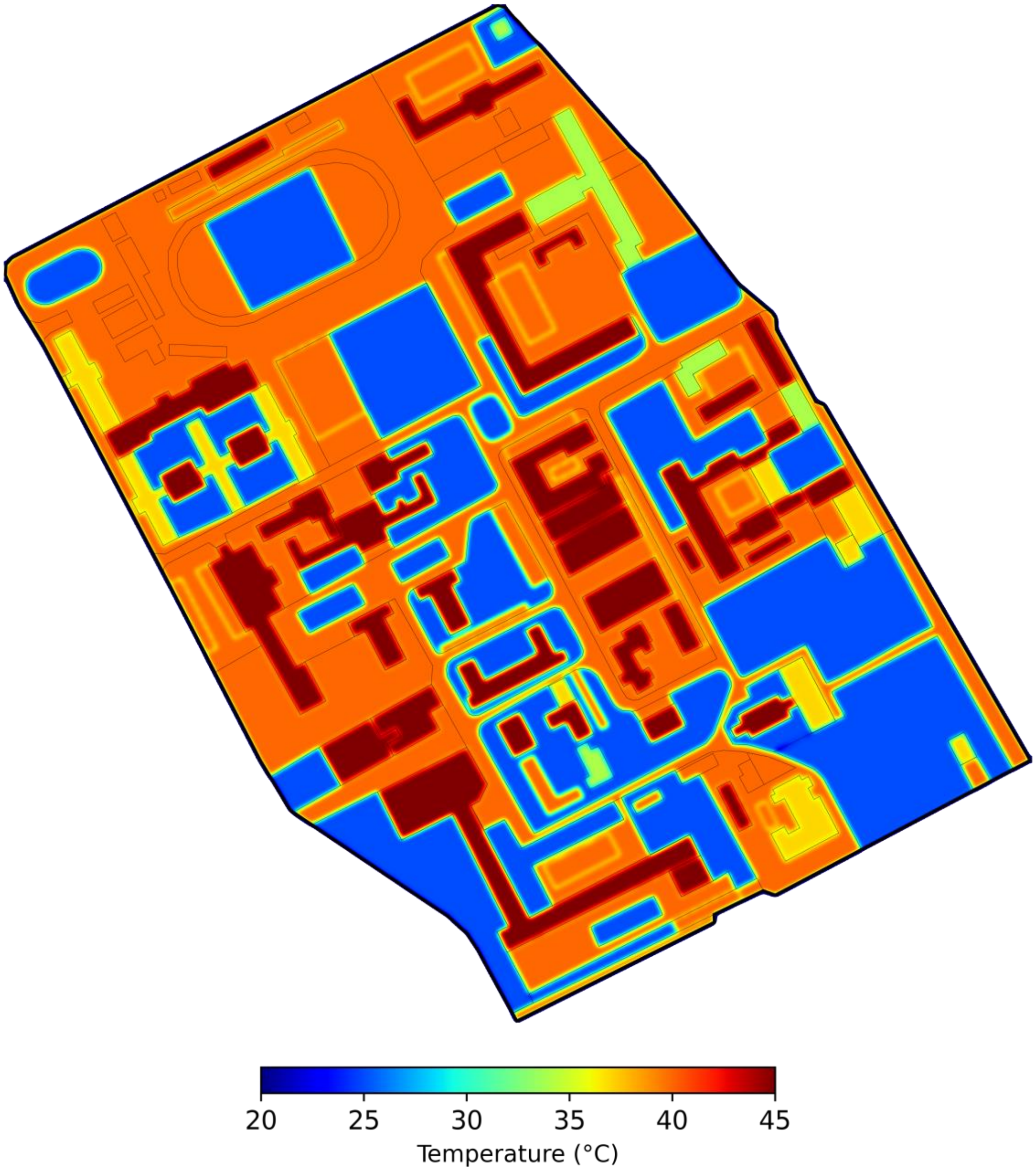

Figure 22: Simulated thermal image of current surface status.

Both strategies present significant impact on surface cooling (cf. Fig. 22 vs 23 and Fig. 22 vs 24). In economical measure, STs in initial over-heated area all dropped to below 30 °C (blue color in Fig. 23), and the highest ST decreased from 45 °C of asphalt roof to 37 °C of brick tiles. In ecological measure, STs in most area result in between 30 and 35 °C (blue and green color in Fig. 24). There is no action applied on sloped roofs, their STs remain at 45 °C, the same as the highest ST in the initial case.

In addition, the average surface temperature (AST) for each scenario was calculated. ASTs are approximately 35 °C, 27 °C and 30 °C for initial case, economical measure and ecological measure, respectively. Tables 8 and 9 list the STs applied in simulation across all materials for economical measure and ecological measure.

Table 8: ASTs applied for economical measure; NC means no change.

Material	**Average Surface temperature (°C)**	
	Before	**After**
Asphalt (Roof)	45	28
Asphalt (Pavement)	40	23
Concrete	34	34 *(NC)*
Brick	37	37 *(NC)*
Grass	25	25 *(NC)*

Table 9: ASTs applied for ecological measure; NC means no change.

Material		**Average Surface temperature (°C)**	
		Before	**After**
Asphalt (Pavement)		40	33
Asphalt	Flat roof	45	25
	Sloped roof	45	45*(NC)*
Concrete		34	25
Brick		37	37 *(NC)*
Grass		25	25 *(NC)*

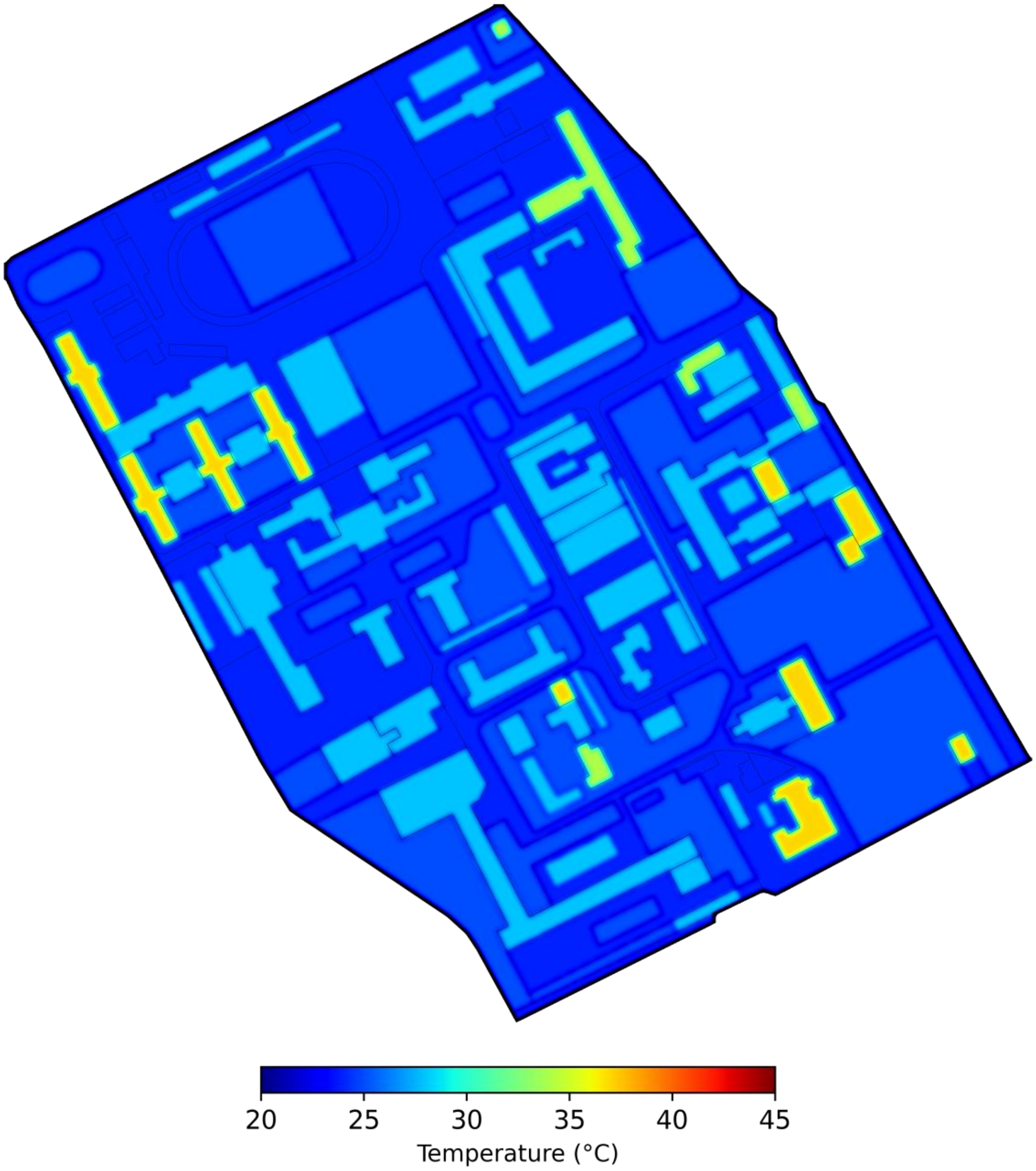

Figure 23: Simulated thermal image of economical measure.

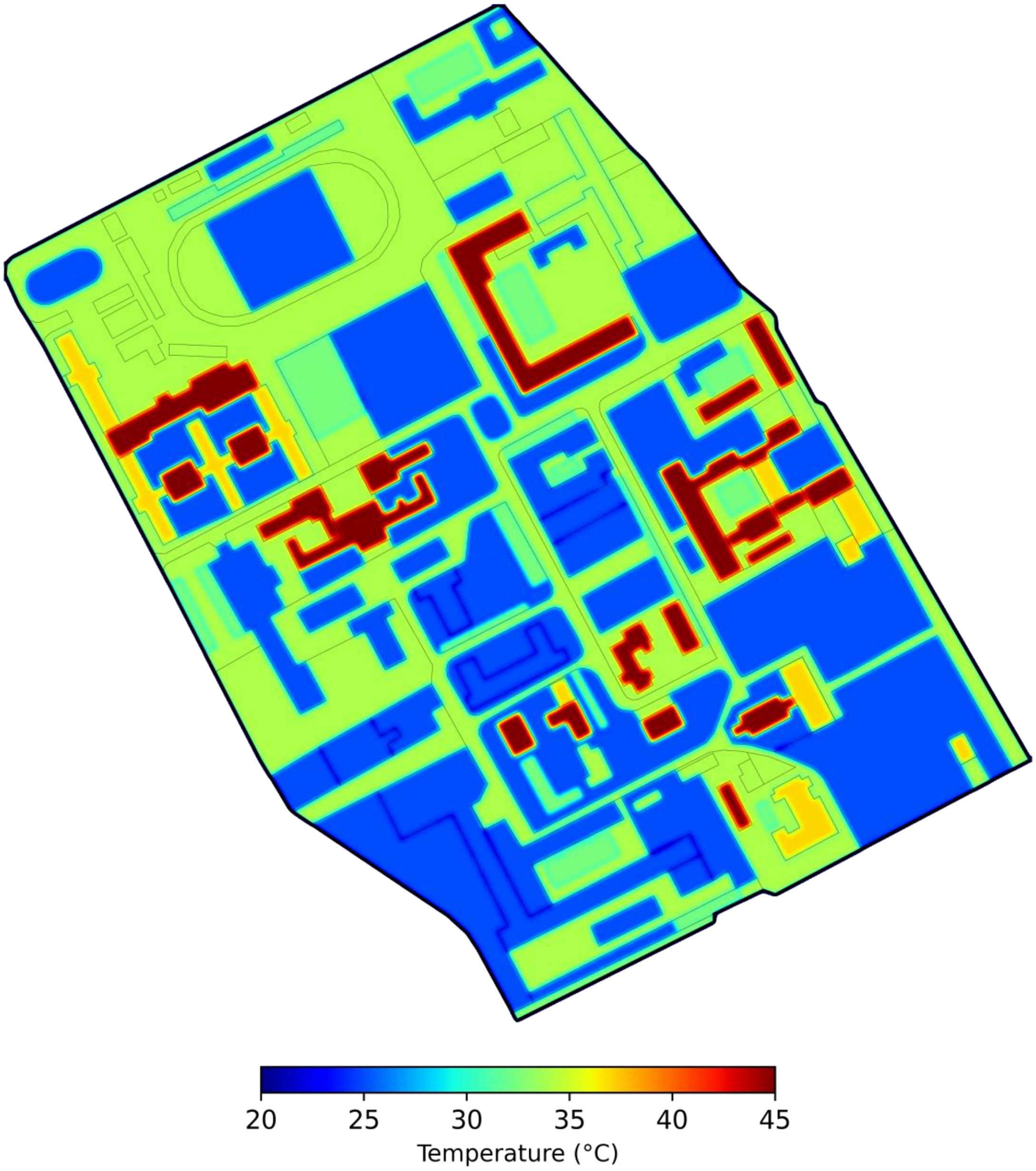

Figure 24: Simulated thermal image of ecological measure.

4.2 Comparison of values

In order to compare the overall value for two measures, a multi-level evaluation of potential benefits and impacts was conducted. Based on assessment method and relevant data from the Vienna UHI Strategy (MA22 2018), evaluation is developed under five categories: local climate, cost efficiency, biodiversity, eco-resilience and life quality. Local climate, in this case, represents direct influence on thermal comfort in local climate zone, which is determined by surface temperature from simulating result. Cost efficiency includes costs for construction and maintenance. Eco-resilience refers to the ability of an ecosystem to maintain key functions and processes by resisting damage or stresses and recovering quick or adapting to change. Resilient ecosystems are characterized as adaptable, flexible, and able to deal with change and uncertainties (The Nature Conservancy, 2020). Biodiversity, eco-resilience and life quality, based on a long-term perspective, indicate the capacity of ecosystem service in ecological and social aspects. Each category is graded a numerical value from -1 to 2, the corresponding values are assigned at following levels in Table 10.

Table 10: Value gradation under five categories.

Categories	**Grades**	**Values**
Local climate, Biodiversity Eco-resilience Life quality	3	Significant improvement
	2	Improvement
	1	Slight improvement
	0	Negligible effect
	-1	Deterioration
Cost efficiency	3	Very low (or no cost)
	2	Low cost
	1	Medium cost
	0	High cost
	-1	Very high cost

The value overview is visualized in a spider diagram (see Fig. 25). Regarding the evaluation result, the higher number of rating, the better result is. Both measures show high value to improve local climate, ratings are between 2 and 3. Ecological measure (using BGI system) presents significant improvement on categories of biodiversity, eco-resilience and life quality, scores all reach up to 3 (top). On the other hand, economical measure shows limited value under those categories. Particularly for eco-resilience, score of -1 (bottom) indicates the potential degradation in long term. Economical measure shows high value on cost efficiency with score of 2 (low cost), as the action only involves light-color coating. On contrast, the implementation of green roofs and innovated permeable pavements makes ecological measure in a high level of cost, score drops to 0. Ecological measure has higher comprehensive value among social, economic and environmental aspects, overall scores of ecological measure and economical measure are 10.5 and 5 respectively.

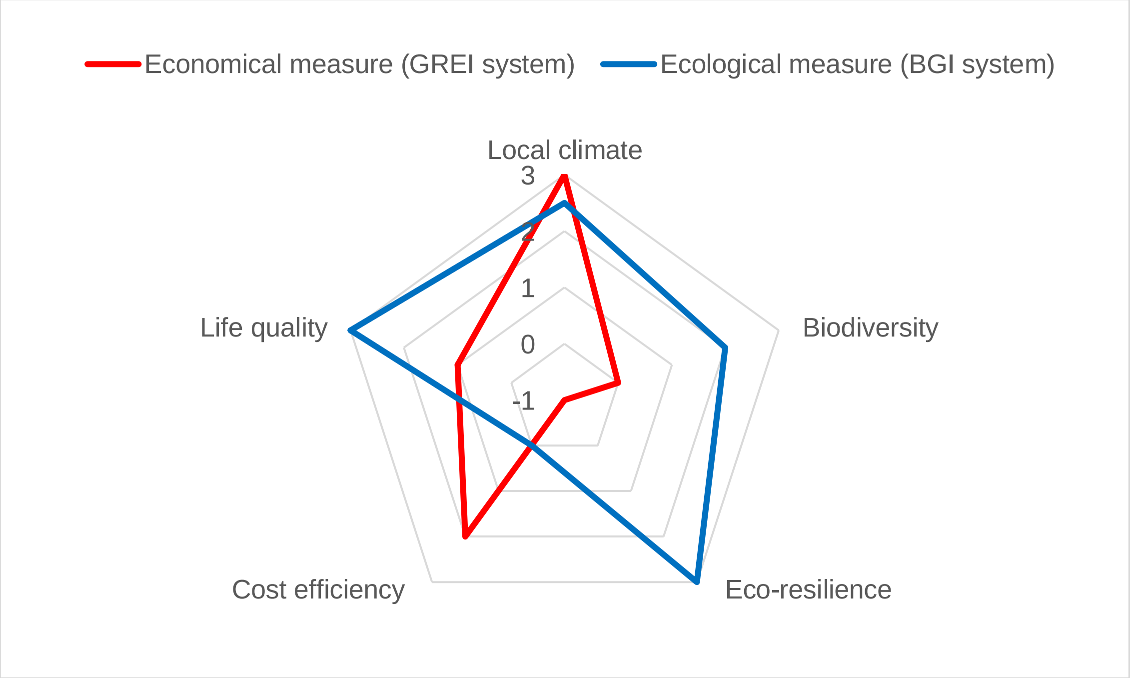

Figure 25: Value overview for economical and ecological measure.

5 DISCUSSION

5.1 Interpretation of results

According to initial thermal plan, asphalt on rooftops and roads with ST exceeded 40 °C is considered as over-heated area. which covers more than 60% of entire campus. The highest ST in such area reached up to 45 °C, which is 20 °C more than it for grass. AST of overall campus is about 35 °C. The measures are designed to lower the highest ST so as contribute to reduction of AST. In economical measure, the highest ST dropped down to 37 °C, which result in elimination of over-heated area after application. On the other hand, highest ST of ecological measure remains at 45 °C from non-modified asphalt on sloped roofs, but over-heated area narrowed down to approximately 6% of entire campus. Meaning that ecological measure fails to cool down the initial highest ST. The main reason for such limitation is due to the spatial constrains for implementing green roofs on sloped roofs, and its likely high cost. Otherwise, economical measure shows better adaptation to variety of spatial conditions. Regarding AST reduction, both measures successfully decrease it from initially 35 °C to or slightly lower than 30 °C. These findings, which are summarized in Fig. 26, clearly indicate that economical measure is preferable method for direct effectiveness of surface cooling, including reduction of highest and average ST and over-heated area.

Economical measure is recommended as primary strategy for low-cost initiatives, because of its fast implementation, low cost and high effectiveness of surface cooling. However, in long-term perspective, economical measure may trigger series of environmental complications. Concerning overall value, economical measure shows potential of degradation on biodiversity and eco-resilience, which leads to further decay of an ecosystem service. The use of impermeable surfaces and lack of vegetation lead to a vulnerable environment to cope with critical climate impact, such as storms and floods. Despite economical measure being costly, the permeable surfaces associated with green elements support an ecosystem in maintaining resilience to major disturbances. Thus, ecological measure is more likely the durable and sustainable approach to UHI mitigation.

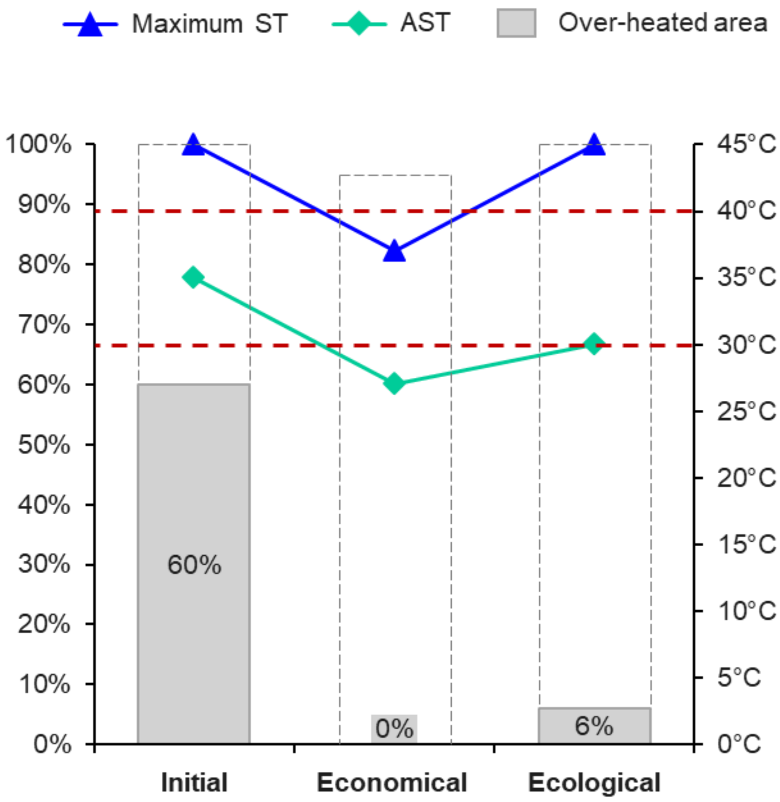

Figure 26: Before-after analysis maximum ST, AST and "over-heated" area.

5.2 Bariers and enablers

The barriers represent constrains and difficulties that directly affect successful implementation. Enablers provide possibilities to overcome such barriers, thus achieve expected profits. In economical measure, the major barrier is the negative user perception, due to white (light colored) surfaces and lack of vegetation. As the perception of white color highly depends on individual, education of residents about UHI effects and functions of application may encourage a wide acceptance (Aleksandrova 2016). In ecological measure, spatial constrains and high cost are considered as the most common barriers in practice. There is no action applied on sloped roofs mainly due to spatial related constrains. Meanwhile, the use of green roofs and innovative pavements will lead to considerable increase on overall cost. According to (Larrard et al., 2013), a comprehensive consideration of cost effectiveness at all benefits (e.g. social, economic and environmental) over long-term life cycle could be potential enabler to achieve final decision. The major barriers and potential enablers for each measure are summarized in Table 10 & 11.

Table 11: Barriers and enablers for economical measure.

Barrier		**Enablers**
Negative user perception	White surfaces,	Education
	Lack of vegetation	Integration design with green elements

Table 12: Barriers and enablers for ecological measure.

Barrier		**Enablers**
Spatial constrains	Sloped roofs	Innovative infrastructures
High cost	Permeable pavement roof garden	Cost effectiveness

5.3 Limitations and future work

This study is considered as simplified version of real case, which does not take in account many variables. For instance, the surface conditions are not considered, although material life cycle and maintenance condition could directly affect its thermal performance, especially for asphalt and PICPs; The transformed surface material is not specified in detail, which may lead to deviation on cooling result from actual. Furthermore, blue surfaces are not designated in surface retrofit strategy. According to experimental result from (Yang and Zhao 2015), absolute surface temperature of water bodies could be 5 °C lower than grass. Meanwhile, the high heat capacity of water can moderate peak surface temperature, with approximately 2 °C difference between day and night, while the same may reach up to 20 °C for concrete. Thus, the application of water feature may contribute to UHI mitigation. However, the magnitude of overall cooling impact and associated influencing parameters, such as attainable proposition and presence form, worth to be investigated in future work. In addition, further study on collaboration of blue, green and grey elements may lead to optimal solution for UHI mitigation.

It is also necessary to note that white coated asphalt presents lower ST than it for grass in economical measure. The reason for such perversely counter-intuitive outcome may due to incomplete initial dataset. ST of white coated asphalt was calculated from data from study (Chui et al. 2018), while the STs of other materials were obtained from research (Guan 2011). If a complete set of STs of present and proposed materials could be available, the calculated thermal profile would be much closer to real case. To obtain such dataset was out of the scope of this study. However, field measurement with respect to all intended modifications should be initiated in future work.

6 CONCLUSIONS

The aim of this study is to apply surface strategies associated with GREI and BGI to mitigate UHI impact in Technical University of Kosice. The result of this work has achieved its objective, which characterized by the utility of both measures. Economical measure gains optimal cooling result for both peak and average temperature, that maximum peak temperature decreased from initial 45 °C to 37 °C, and AST dropped from initial 35 °C to 27 °C, slightly lower than 30 °C for ecological measure. Based on value evaluation upon social, economic and environmental aspects, ecological measure indicates higher absolute value than economical measure. The overall weighted score for ecological measure is 10.5, which is two times more than it for economical measure. In summary, different surface strategies produce varying degrees of each characteristic, neither of measure in this study is ideal for all situations. Therefore, project needs and goals must be thoroughly considered when choosing suitable measure.

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lives, About the Author Nancy Riggs Nancy Riggs is a freelance writer who, works in Mt Zion, and Illinois. 2009. “Ongoing Green Roof Research & Studies at MSU.” *Turf Magazine* (blog). April 1, 2009. https://www.turfmagazine.com/maintenance/green-roof-research/.

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8 LIST OF TABLES AND FIGURES