Urban Heat Island Scenarios – A Case study in Technical University, Košice

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Abstract. Artificial urban surfaces are commonly considered as main direct cause of Urban Heat Island effects. Most urban land covers are dark and impermeable and accelerating excessive heat absorption and storage. The paper 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, blue and green infrastructure on urban heat island mitigation. As a case study, analysis of surface strategy and its cooling performance was performed at Technical University of Košice campus. 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 reductions 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.

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

This research is based on the topic of cool surface strategy and its practical use. The findings not only provide the effectiveness of specific actions on Urban Heat Island 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.

2. Urban heat island effect
Urban areas are usually warmer than their rural surroundings, a phenomenon known as the “heat island effect” [1]. The urban heat island is an urban area or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities [2]. 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 [3]. The sketch of the temperature distribution in
downtown and surrounding suburbs is shown in Fig.1.

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 [4]. As a result of rapid urbanization as well as
industrialization, urban heat island is considered as one of the major problems in the 21st century [5].
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 [6]. One major effect of urban heat island 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 [7]. Sensitive populations, such as children,
older adults, and those with existing health conditions, are at particular risk from these events [8]. In
2003, the French heat wave increased mortality up to 137 % in Paris, with 14,800 excess deaths across
6 cities over 19 days [9]. 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 [10].

![Urban heat island profile](image)

**Figure 1.** Urban heat island profile.

3. Results and discussions
3.1. Cool surface strategies
The cooling mechanism can be determined only by knowing how urban energy balance works. Luck
Howard [11] 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’ [12].

3.2. Classification
Cool surfaces, normally addressed as “reflective surfaces” which can deliver high solar reflectance and
high thermal emittance [13]. 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 [14] 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% [15], meaning that cool surfaces can help to cool the cities.

3.2.1. 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, is the ability of a material to reflect solar energy from its surface back into the atmosphere. The solar reflectance 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 [16]. In general, solar reflectance value of standard roofs is close to 0.2, while as it for cool roofs, especially the white colored roofs, solar reflectance value can be 0.5 or 0.6, about three times more than conventional dark roofs [17].

3.2.1. Green roofs
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 urban heat island 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 [18]. 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 processes [19].

3.2.2. Permeable pavement
Permeable pavement 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 [20]. In general, permeable pavement 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 under drains [21].

3.3. TU campus
Campus of the Technical University of Košice (TUKE) was chosen as study area to experiment cool measures. TUKE is located incity of Košice - 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 [22]. Košice has a humid continental climate, the average warmest and wettest month is July, and coolest Košice is January. Figures 2 and 3 illustrate average monthly temperature and precipitation data of Košice in 2019 [23], Table 1 illustrates current surface material of the research area.

Figure 2. Average minimum and maximum temperature over the year [23] (World Weather & Climate 2019).
Figure 3. Average monthly precipitation over the year (rainfall, snow) [23] (World Weather & Climate 2019).

Table 1. Current surface material and corresponding area.

| Infrastructure Type | Category  | Type   | Surface Material                  | Surface area (%) | Surface area (m²) | Total area (m²) |
|---------------------|-----------|--------|-----------------------------------|------------------|-------------------|-----------------|
| Grey                | Roof      | Flat   | Asphalt                           | 10               | 56,400            |                 |
|                     |           | Sloped | Asphalt or brick/concrete tiles   | 11               |                  |                 |
|                     | Pavement  | Road   | Asphalt                           | 42               | 133,300           | 273,900         |
|                     |           | Parking | Asphalt                          | 5                |                  |                 |
| Green               | Vegetation| N/A    | Grass/tree cover                  | 32               | 84,200            |                 |
| Blue                | Water     | -      | -                                 | 0                | 0                 |                 |

Figure 4. Current surface distribution in TUKE campus.
3.4. **Economical perspective and ecological perspective simulation**

In order to analyze the influence of typical urban heat island mitigation strategies in TUKE, two measures using grey infrastructure and blue green infrastructure technologies are proposed, which are addressed as economical measure and ecological measure, respectively.

3.4.1. **Grey system – economical measure**

Despite the high effectiveness of blue-green infrastructure on urban heat island 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. Grey infrastructure 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 [24]. Thus, using grey infrastructure system to fight urban heat island 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 2 lists details of economical measure, and the layout of retrofit area is shown in Fig. 5.

**Table 2.** Color-oriented strategy–modification of hard surfaces in economical measure.

| Category | Type   | Target surface | Surface treatment      | Transformed area (m²) | Transformed area (%) | Surface area (%) |
|----------|--------|----------------|------------------------|-----------------------|----------------------|-----------------|
| Roof     | Flat   | Asphalt        | White-coated           | 46,136                | 82                   | 64              |
|          | Sloped | Cool tiles     |                         |                       |                      |                 |
| Pavement | Road   | Asphalt        | White topping          | 133,300               | 100                  |                 |
|          | Parking|                |                         |                       |                      |                 |

**Figure 5.** 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.
3.4.2. 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 [25]. Therefore, applications related to blue green infrastructure 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. 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 areas are transformed into blue green infrastructure system. Besides existing green area, the entire blue green infrastructure system coverage would reach up to 68 %. Table 3 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. 6 shows the layout of retrofit area on map.

Table 2. Green and semi-green strategy - modification of hard surfaces in ecological measure NC means no change.

| Category  | Type    | Target surface | Surface treatment | Transformed area (m²) | Surface area (%) |
|-----------|---------|----------------|-------------------|-----------------------|-----------------|
| Roof      | Flat    | Asphalt        | Green roof        | 27,390                | 100             |
|           |         | Brick/concrete | Green roof        |                       |                 |
|           | Sloped  | -              | NC                | -                     | -               |
|          | Pavement| Road           | Asphalt           | 57,519                | 100             |
|           |         | Parking        | Asphalt           | 13,695                | 100             |
|           |         |                | PICP              |                       |                 |
|           |         |                | CGP               |                       |                 |

Figure 6. 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 are and all sloped roofs.
4. Conclusions
The aim of this study was to apply surface strategies associated with grey infrastructure and blue green infrastructure to mitigate urban heat island impact in Technical University of Košice. The result of this work has achieved its objective, which are characterized by the utility of both measures. Based on value evaluation upon social, economic and environmental aspects, ecological measure indicates higher absolute value than 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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References
[1] UC Davis. 2010. “UC Davis Honors the Art of Saving Energy.” 2010. https://www.ucdavis.edu/news/uc-davis-honors-art-saving-energy/.
[2] Wikipedia. 2019. “Whitetopping.” Wikipedia. September 15, 2019. https://en.wikipedia.org/w/index.php?title=Whitetopping&oldid=915798904.
[3] Santamouris, M. 2013. “Using Cool Pavements as a Mitigation Strategy to Fight Urban Heat Island—A Review of the Actual Developments.” Renewable and Sustainable Energy Reviews 26 (October): 224–40. https://doi.org/10.1016/j.rser.2013.05.047.
[4] European Commission. 2018. “Worldwide Urban Population Growth.” Text. Knowledge for Policy - European Commission. October 2, 2018. https://ec.europa.eu/knowledge4policy/foresight/topic/continuing-urbanisation/worldwide-urban-population-growth_en.
[5] Rizwan, Ahmed Memon, Leung Y. C. Dennis, and Chunho Liu. 2008. “A Review on the Generation, Determination and Mitigation of Urban Heat Island.” Journal of Environmental Sciences 20 (1): 120–28. https://doi.org/10.1016/S1001-0742(08)60019-4.
[6] Morini, Elena, Ali Gholizade Touchael, Federico Rossi, Franco Cotana, and Hashem Akbari. 2018. “Evaluation of Albedo Enhancement to Mitigate Impacts of Urban Heat Island in Rome (Italy) Using WRF Meteorological Model.” Urban Climate 24 (June): 551–66. https://doi.org/10.1016/j.uclim.2017.08.001.
[7] Paravantis, John, Mat Santamouris, Constantinos Cartalis, Chrysanthi Efthymiou, and Nikoleta Kontoulis. 2017. “Mortality Associated with High Ambient Temperatures, Heatwaves, and the Urban Heat Island in Athens, Greece.” Sustainability 9 (4): 606. https://doi.org/10.3390/su9040606.
[8] Yoshikado, Hiroshi. 1996. “High Level of Winter Air Pollution under the Influence of the Urban Heat Island along the Shore of Tokyo Bay.” Journal of Applied Meteorology, 10.
[9] Filleul Laurent, Cassadou Sylvie, Médina Sylvie, Fabres Pascal, Lefranc Agnès, Eilstein Daniel, Le Tertre Alain, et al. 2006. “The Relation Between Temperature, Ozone, and Mortality in Nine French Cities During the Heat Wave of 2003.” Environmental Health Perspectives 114 (9): 1344–47. https://doi.org/10.1289/ehp.8328.
[10] Ashley, Erin, and Lionel Lemay. 2008. “Concrete’s Contribution to Sustainable Development.” Journal of Green Building 3 (4): 37–49. https://doi.org/10.3992/jgb.3.4.37.
[11] Howard, Luke. 1818. The Climate of London. W. Phillips, sold also by J. and A. Arch.
[12] Gunawardena, K. R., M. J. Wells, and T. Kershaw. 2017. “Utilising Green and Bluespace to Mitigate Urban Heat Island Intensity.” Science of The Total Environment 584–585 (April):
Pfannenstiel, Jackalyne. 2008. “2008 Efficiency Standards for Residential and Nonresidential Buildings.” Standard CEC-400-2008-001-CMF. California: CALIFORNIA ENERGY COMMISSION.

Akbari, Hashem, Surabi Menon, and Arthur Rosenfeld. 2009. “Global Cooling: Increasing World-Wide Urban Albedos to Offset CO2.” Climatic Change 94 (3): 275–86. https://doi.org/10.1007/s10584-008-9515-9.

Dean Steel Buildings, Inc. 2018. “Solar Reflectivity (R) & Solar Reflectance Index (SRI) by Color.” 2018. http://www.deansteelbuildings.com/products/panels/sr-sri-by-color/.

Akbari, H., and S. Konopacki. 2005. “Calculating Energy-Saving Potentials of Heat-Island Reduction Strategies.” Energy Policy 33 (6): 721–56. https://doi.org/10.1016/j.enpol.2003.10.001.

Cosco, Paul, and Larissa Larsen. 2014. “How Factors of Land Use/Land Cover, Building Configuration, and Adjacent Heat Sources and Sinks Explain Urban Heat Islands in Chicago.” Landscape and Urban Planning 125 (May): 117–29. https://doi.org/10.1016/j.landurbplan.2014.02.019.

Moody, Seth S., and David J. Sailor. 2013. “Development and Application of a Building Energy Performance Metric for Green Roof Systems.” Energy and Buildings 60 (May): 262–69. https://doi.org/10.1016/j.enbuild.2013.02.002.

“Permeable Pavement.” 2016. Green Building Alliance. 2016. https://www.gobga.org/resources/green-building-methods/permeable-pavements/.

“Košice.” 2020. In Wikipedia. https://en.wikipedia.org/w/index.php?title=Ko%C5%A1ice&oldid=940398483.

World Weather & Climate. 2019. “Climate and Average Monthly Weather in Košice (Košický Kraj), Slovakia.” World Weather & Climate Information. 2019. https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Kosice,Slovakia.

GuardTop. 2017. “New Light Roads Covering Los Angeles - The Truth About ‘White’ Streets.” GuardTop. October 31, 2017. https://guardtop.com/new-light-roads-covering-los-angeles-truth-white-streets/.

Corina Negrescu. 2014. “Urban Heat Island and Green Infrastructure.” Bachelor Thesis, Denmark: Copenhagen School of Design and Technology. https://www.grin.com/document/309261.

Gunawardena, K. R., M. J. Wells, and T. Kershaw. 2017. “Utilising Green and Bluespace to Mitigate Urban Heat Island Intensity.” Science of The Total Environment 584–585 (April): 1040–55. https://doi.org/10.1016/j.scitotenv.2017.01.158.

M. E. J. Cutler, D. S. Boyd, G. M. Foody, and a. Vetrivel, “Estimating tropical forest biomass with a combination of SAR image texture and Landsat TM data: An assessment of predictions between regions,” ISPRS J. Photogramm. Remote Sens., vol. 70, pp. 66–77, 2012.