

Urban greening and cool surfaces: the effectiveness of climate change adaptation strategies within the context of Budapest

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1. Introduction

Regional climate projections for Central and Eastern Europe indicate a rise in summertime temperatures along with an increase in the frequency of warm temperature extremes by the end of the next century. In the case of Hungary, models indicate a 1.7–2.6°C rise in summer temperatures in the near future, and a 3.5–6.0°C increase is projected for the end of the twenty-first century—based on the A1B scenario. Besides rising temperatures, long term projections also signal a 20–40% decrease in summer precipitation in Hungary. In Budapest, the existing urban heat island (UHI) intensity of 4–8°C is expected to make these already adverse projections worse. Since the combined influences of these phenomena will be most pronounced in the densely built and populated areas of the city, identifying effective heat mitigation and climate change adaptation strategies for these areas is of primary importance.

Within this context, a research goal has been set to evaluate the effectiveness of popular heat mitigation strategies (cool roofs, cool pavements and different tree canopy cover ratios) on the urban canopy layer climate in different urban environments. Since the effectiveness of such strategies is highly context specific, the research argues for a sensible approach that starts with the analysis of existing conditions and proceeds with the assessment of mitigation approaches. This paper presents the preliminary results of this study.

2. Materials and methods

A numerical simulation study was carried out to assess the effects of shade trees and cool surfaces on the canopy layer microclimate of different built forms. The study utilized ENVI-met (Version 4.0 BETA II) for microclimate simulation (2014) and MATLAB (Version 7.12) for the analysis and visualization of the results. The adopted methodology consists of two key phases: (1) the development of cases and parameters as inputs to the numerical model, and (2) the analysis of the results.

2.1 Model configuration

Four dense urban block typologies from Budapest were selected as cases for the study: the nineteenth-century configuration consisting of attached courtyard apartment buildings (T1), the perimeter block built up at its edges (T2), the Zeilenbau design of parallel rows of buildings (T3), and the hybrid form composed of a set of short towers placed atop of a unifying base (T4). These built forms comprise the majority of the inner districts of Pest and are also characteristic of certain parts of Buda.

The cases and the corresponding model layouts are shown in **Fig. 1**. The urban blocks are 78 m wide and 150 m long, and are separated by 18 m wide roads. The buildings are 24 m tall uniformly, except for the hybrid configuration where the unifying base is set to 6 m. The models have a 6 m horizontal and 3 m vertical grid resolution. In terms of ground surface materials the roads are set to gravel asphalt, while the open areas within the blocks are left as unsealed silt-loam soil. The model domains consist of nine identical urban blocks arranged in a three-by-three grid layout.

The study utilized the simple forcing feature introduced with ENVI-met 4.0 (Huttner 2012). The diurnal air temperature and relative humidity cycles used in this process are those of a typical July day in Budapest (Bacsó 1959, Réthly 1947). A model configuration without buildings was also introduced to mimicking the rural (or background) conditions. This building-less model supplied the necessary canopy layer conditions applied as a baseline in the study. ENVI-met was run for 48 hours from July 7th to allow time for model spin-up.

This paper evaluates eight scenarios through four cases---in the complementary poster only six are presented. These scenarios are the combinations of cool roof, cool road, 15% canopy cover and 30% canopy cover schemes. In the case of cool roofs the initially defined 0.4 reflection of roof material is increased to 0.65, whereas in the case of cool roads the albedo of the asphalt is increased from 0.3 to 0.55. Two canopy cover schemes utilized 18 m tall shade trees, arranged in a more or less uniform manner within the model domain. The evaluated scenarios are as follow: (0) base cases without any heat mitigation enhancement; (1) high-albedo roofs; (2) high-

albedo road; (3) 15% canopy cover; (4) 15% canopy cover & high-albedo roofs; (5) 15% canopy cover & high-albedo roads; (6) 30% canopy cover; (7) 30% canopy cover & high-albedo roofs; (8) 30% canopy cover & high-albedo roads.



Fig. 1 The four selected historic urban block configurations from Budapest (top) and their model equivalents (bottom)

2.2 Method of analysis

The study uses established procedures in numerical modeling and analysis. In order to minimize the edge effect, the analyses were limited to the conditions at the central parts of models. The evaluated space---that encompass a characteristic section of a standard neighborhood---consist of the canopy layer above the central block and above half of the surrounding streets, adjacent to the block. Additionally, due to the model's long spin-up time, only the results of the second day were evaluated. Finally, to reduce systematic model errors, results are reported in relative terms---either relative to the baseline case (T0bl) or relative to the base configurations (T1 to T4) without heat mitigation enhancement (also referred to as scenario 0).

The key parameters governing human thermal comfort, surface and thus near-surface temperatures during clear and calm conditions are radiation and air temperatures. Therefore, the microclimate evaluations in this study are based on potential air temperatures and mean radiant temperatures (MRT). Three methods are utilized in the analysis of the described parameters and scenarios. First, overall mean values are computed for each scenario and parameter to compare the effect of heat mitigation strategies across the entire field of simulation (4 cases x 8 scenarios). These overall values are computed for the specified canopy volume relative to a baseline (T0bl or T1 to T4) and across the entire second day. When baseline case (T0bl) is used the overall impact of a mitigation strategies for different cases can be assessed and thus vulnerable, least responsive neighborhoods can be identified. When base configurations (T1 to T4) are utilized as reference, the effectiveness if different mitigation measures can be assessed relative to an existing condition or configuration. The latter assessment can also help in identifying important relationships between built form and land use characteristics and the effectiveness of mitigation measures. Second, volumetric median values are calculated to reveal the diurnal cycles of different cases and scenarios. Volumetric median values are calculated for the specified canopy volume relative to a baseline or rural model (T0bl) for the every half an hour of the second day.

The third means of assessment includes the areal average method, introduced earlier by the author to analyze urban canopy layer conditions in a concise manner (Gál 2014a, 2014b, 2014c). The concept consists of areal medians calculated for every elevation for the selected section of UCL and at every half hour through the second day (see **Fig. 2**). The values, expressed relative to a selected baseline, are then assembled into a matrix with results from different elevations arranged into columns and with results from different times assembled into rows. The magnitude of the assessed parameters is indicated by colors. The advantage of this representation is that it provides a relatively detailed overview of the diurnal evolution of conditions within the UCL, while at the same time retains the relative positions (and thus the interdependence) of adjacent air layers.

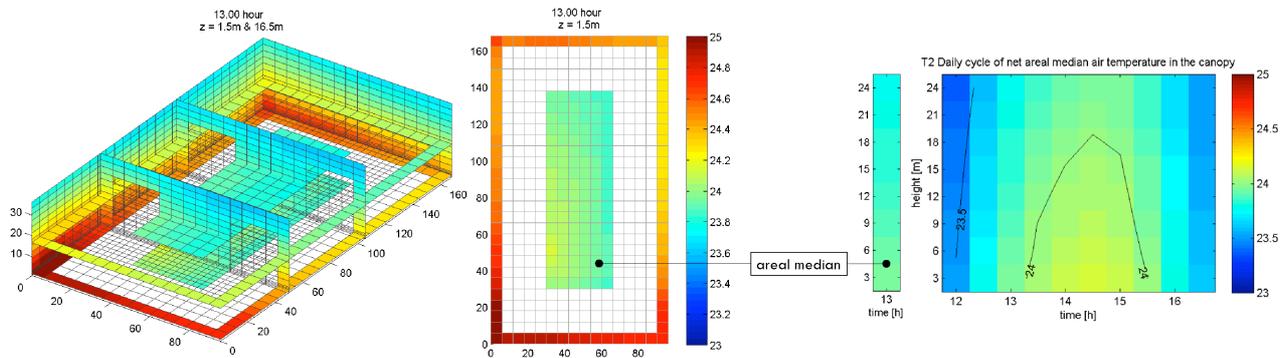


Fig. 2 The method of deriving an areal median matrix, illustrated on air temperature values

4. Results and discussions

The simplest way to compare the effectiveness of different heat mitigation measures across cases and scenarios is by means of overall mean values. Overall mean MRTs calculated relative to the baseline case (T0bl) and base configurations (T1 to T4) are shown on Fig. 3a and 3b, respectively. As expected, the most instrumental strategy in reducing MRTs within the canopy is the increase of tree canopy cover. The return in terms of decreased MRT decreases gradually with increasing the canopy cover (see the declining difference between 0% and 15% and also that of 15% and 30%). The effectiveness of shade trees to reduce radiant conditions is also lower in the case of configurations where building masses are distributed relatively evenly (T1 and T4), since shading from buildings is already present. At uniform building height, the modification of roof albedos leaves the conditions in the canopy intact, whereas high-albedo roads increase radiant conditions slightly. The impact of cool roads on the canopy layer MRT diminishes with increasing tree canopy cover, indicating a possible source of conflict between the two mitigation strategies.

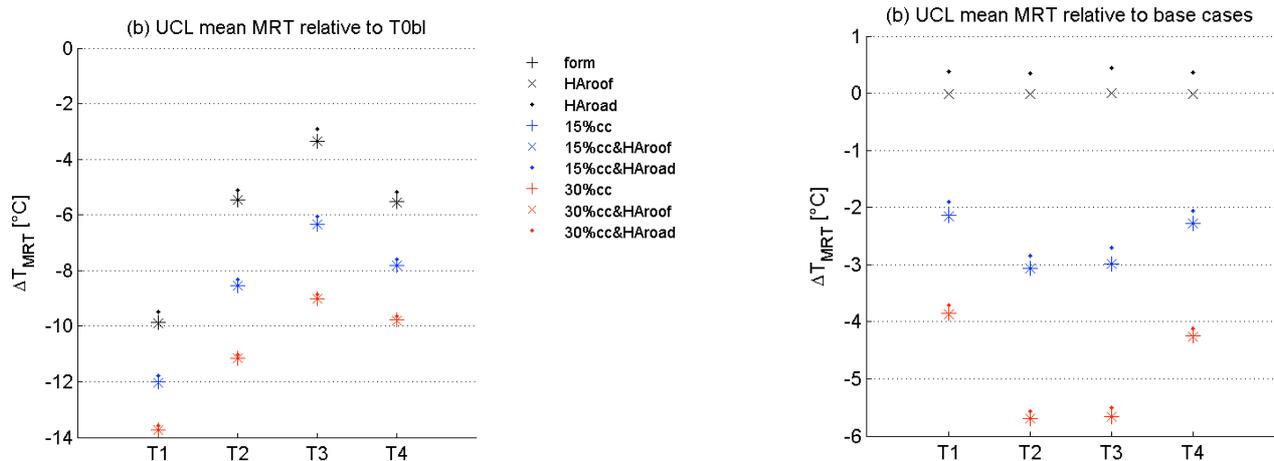


Fig. 3 Overall mean MRT calculated relative to the baseline case (left, Fig. 3a) and relative to the base configurations (right, Fig. 3b)

The overall mean potential air temperatures calculated relative to the baseline case (T0bl) and base configurations (T1 to T4) are shown on Fig. 4a and 4b, respectively. Similarly to mean radiant temperatures, the most influential heat mitigation strategy in the UCL is the increase of the canopy cover. However, unlike to those observed in the case of MRT, increasing the tree canopy cover increases the benefits of air temperature reduction. In relative terms (Fig. 4b), the measure is most effective in the case of the enclosed T1 configuration, and least in the case of the open T4 configuration. Both cases are characterized by the presence of mutual shading. The influence of shade trees in the case of T2 and T3 with large open spaces is rather similar. However, in absolute terms (Fig. 4a) the effect of enclosure in the case of T2---it is a large courtyard, after all---seems to remain an undiminishable advantage when compared to T3. A possible explanation to these results is that not only shading that plays an important role in achieving lower air temperatures in the urban canopy, but also enclosure. In the case of T1 and T2 enclosure is present from the start, whereas at T3 and T4 the increasing coverage of shade trees serves a similar purpose (i.e. provides wind protection). This would also explain why increasing the canopy cover increases the benefit in terms of air temperature reduction. Nevertheless, this phenomenon deserves further investigation in order to exclude the influence of tree species and the spatial layout of trees as possible causes for the above observed differences.

Compared to shade trees, the influence of high-albedo surfaces is rather negligent when evaluated for the entire urban canopy layer. The effect of high-albedo roofs increases with increasing roof area ratio: it is greatest at T1 and T4, and least influential in the case of T3 (see Fig. 4b). The impact of high-albedo roads is greatest in the case of T3 where shading is the least. As expected, its effectiveness to decrease canopy layer temperature decreases with increasing three canopy cover.

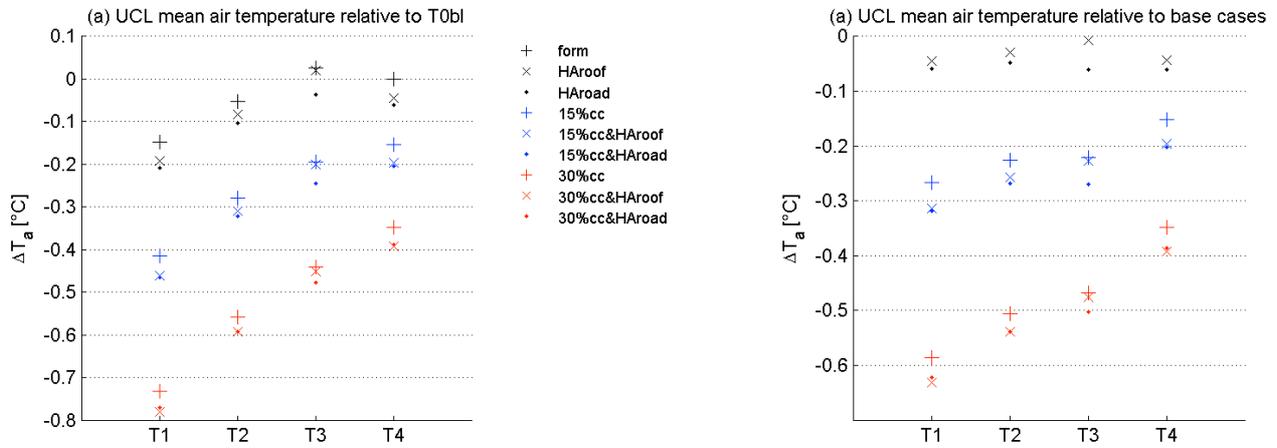


Fig. 4 Overall mean potential air temperature calculated relative to the baseline case (left, Fig. 4a) and relative to the base configurations (right, Fig. 4b)

Fig. 5a and Fig. 5b show the diurnal cycles of volumetric median canopy layer MRTs for different scenarios calculated in reference to the base case (T0bl) for T1 and T3, respectively. As already noted above, shade trees have the greatest effect on the canopy layer radiant environment, while high-albedo roads effect condition negative with slightly increasing radiation. In the case of high-albedo roads, the impact is greatest around midday, when the sun is high, irradiation is greatest and shading from trees and buildings is at minimum. The cross-comparison between the cases indicates that T1 from the start enjoys a greater mean radiant temperature reduction than T3.

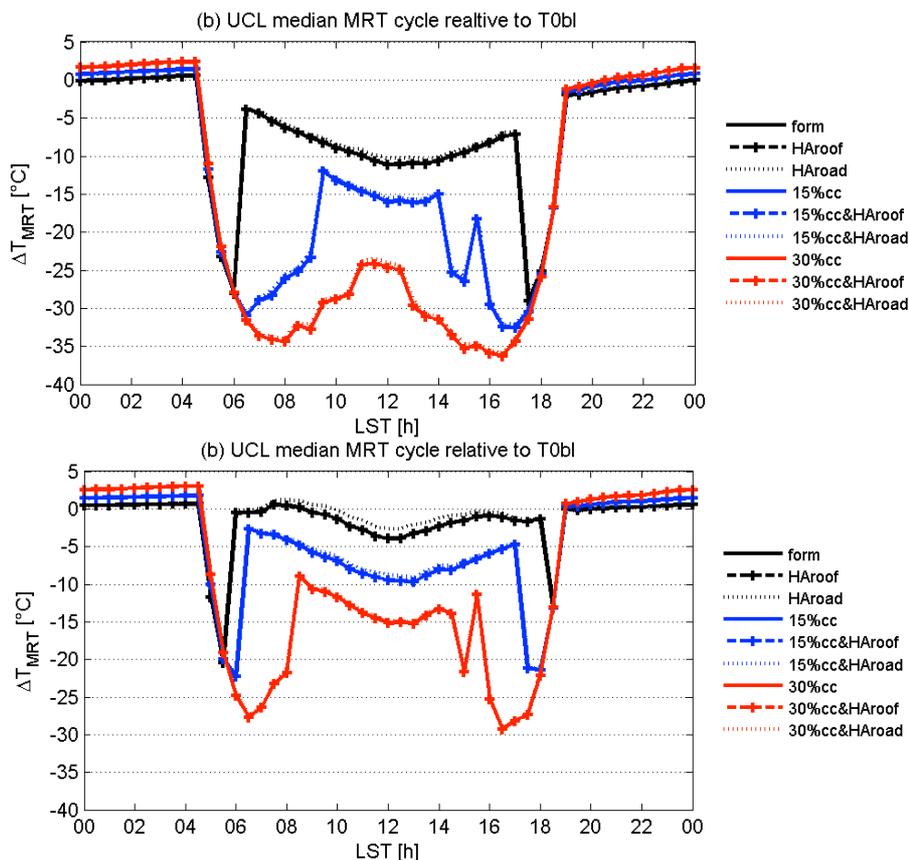


Fig. 5 Diurnal cycles of volumetric median MRTs in the UCL relative to the base case, for T1 (top, Fig 5a) and T3 (bottom, Fig. 5b)

Fig. 6a and Fig. 6b presents the diurnal cycles of volumetric median canopy layer air temperatures for different scenarios calculated in reference to the base case (T0bl) for T1 and T3, respectively. In both cases, increasing the tree coverage has the greatest effect on the canopy layer temperatures. As already noted, tree canopies exhibit a growing benefit of temperature decrease with every percentage increase. It would be interesting to know how far this increasing benefit grows, as it likely to top somewhere between 30% and 60% canopy coverage. In order to answer this question, further investigations are needed.

High-albedo surfaces have the greatest impact around midday. At high building surface fraction (such as T1), where roof surfaces have a greater share of horizontal surfaces, the impact of high-albedo roofs is similar to that of high-albedo roads. Nevertheless, their impact is marginal in the case of T3---the configuration characterized by lowest building surface fraction among the evaluated cases. At both presented cases, T1 and T3, the influence of high-albedo roads decreases with increasing canopy covers.

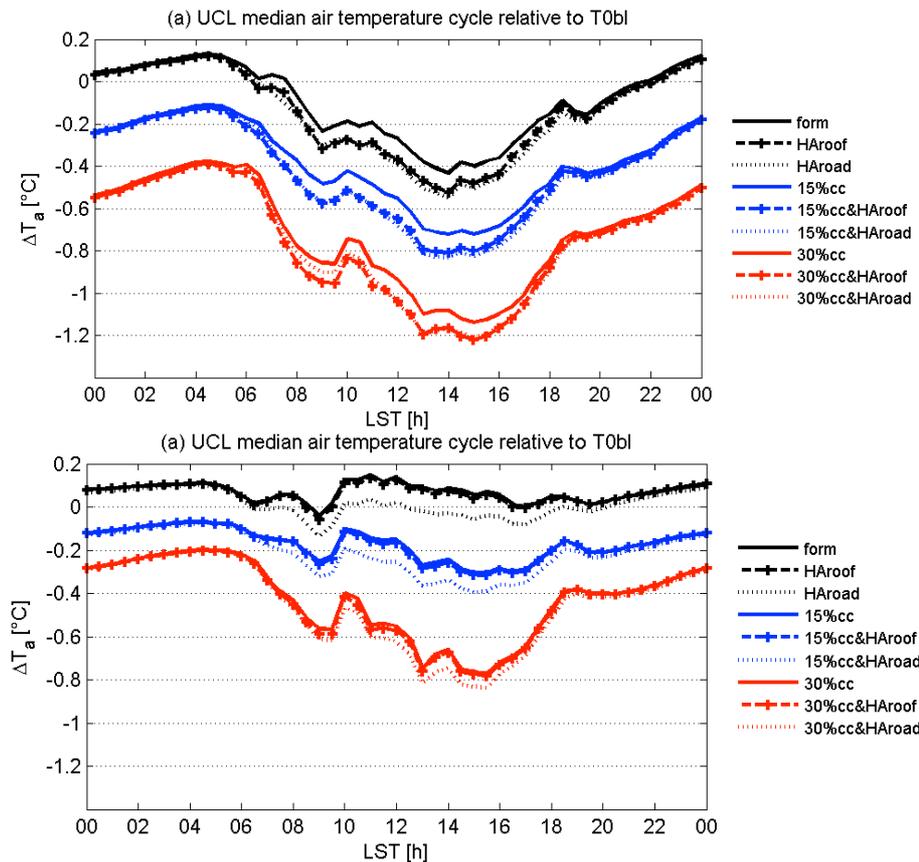


Fig. 6 Diurnal cycles of volumetric median potential air temperatures in the UCL relative to the base case, for T1 (top, Fig 6a) and T3 (bottom, Fig. 6b)

Since at this point, the analysis of areal average figures does not contribute to the understanding of canopy layer conditions and of the effects of heat mitigation strategies greatly, their analysis have been excluded from the current paper. Nevertheless, some of the results are presented in the complementary poster.

4. Conclusion

This paper presents the preliminary results of a numerical simulation study that intends to reveal the differing effectiveness of various heat mitigation strategies when applied in different urban environments. The study focuses on influence of shade trees and cool surfaces on the canopy layer microclimate as depicted by potential air temperature and mean radiant temperature. The analyses indicate that shading---both from buildings and from trees---plays a leading role in governing the climate within the urban canopy layer. Increasing tree canopy cover seems to be the most effective heat mitigation strategy for the evaluated cases. Trees improve the microclimate not only by decreasing radiation, but also by reducing turbulence and hence retaining the cooler batches of air in the urban canopy. High-albedo surfaces that aim to reduce near surface temperatures by decreasing surface temperatures are least effective when: (1) they remain shaded for the most part of the day (either by buildings or trees), and/or (2) when their surface ratio is relatively small compared to other surfaces (e.g. roofs in the case of low-density configurations). Certain heat mitigation strategies when applied jointly were found to diminish each other's mitigation potential. These findings thus signal that the effect of various approaches are not necessarily cumulative.

References

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