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Energy-efficient urban design proposal in urban heat island formation: the case of CSA Climate

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Abstract. Nowadays, unplanned construction resulting from urban growth and population increase reduces the resilience of cities and their historical texture and increases the need for buildings for housing in cities. This situation, which increases the density/height of city buildings, increases the surface temperature and reduces the green tissue, causes urban heat island.

In this study, the Dumlupinar neighbourhood of Balıkesir, which attracts attention with its historical texture and where new buildings are designed in certain parts today, will be discussed. First, the areas with traditional and new buildings in the region are modelled parametrically in the Rhino/Grasshopper interface, obtained and compared through Dragonfly software and an urban prototype is created. However, in the computational design algorithms to be performed, not only today's weather scenario but also the weather scenario of 2050 was used. Models were created to minimise the urban heat island in 2050 climate conditions. This urban prototype is a proposal for sustainable cities to be built in cities in CSA climate types (Mediterranean climate). This proposal will guide municipalities in designing energy-efficient and carbon-neutral cities using the urban model of the urban heat island effect.

1. Introduction

The population in cities is constantly increasing. This situation brings with it problems such as increasing housing needs and energy demands in cities. As energy consumption increases, greenhouse gas emissions increase [1]. Greenhouse gas emissions trigger climate change, causing air temperatures to rise. The earth's average surface temperature increases daily due to CC [2]. Impacted by global warming, Urban Heat Island (UHI) is a critical factor affecting urban environments and energy demand of buildings. CC may cause adverse effects on outdoor and indoor thermal-visual comfort in urban areas. Urban users may experience discomfort while performing their activities [3, 4]. The increase in air temperatures will further increase the need for cooling energy, which is high in summer, especially in hot climates [5]. Experiences CSA climate characteristics and densely populated western region of Turkiye, residential heating/cooling energy use is linked to UHI. The urban heat island increases up to 8°C during the day and 6°C at night in summer in Istanbul [11]. The study that examined the UHI effect in Istanbul it was determined that the wind, speed, and cloud cover reduce the UHI intensity. In another study aims to reduce the UHI effect in Izmir; monitoring results showed levels of green areas and water



bodies are low. The study proposes 500-metre green belts around industrial areas to reduce the UHI impact in Izmir [10]. Building density and sprawl in urban areas that prevent the blue-green infrastructure strategy increase the UHI effect [12]. European Union (UN) aims to reduce greenhouse gas emissions to achieve climate-neutral cities by 2050 [6]. Sustainable solutions can be achieved by adopting blue-green infrastructure planning during urban planning [7]. The European Commission has stated that blue-green infrastructure adapts to climate and increases biodiversity [8, 9]. To leave a sustainable environment for future generations, studies in the literature aim to reduce the urban heat island (UHI) effect.

The form typologies of buildings in urban areas can also be effective on UHI. The study, which considers two cities in South Korea, Bundang and Pangyo, as plot regions, conducted the simulation process in these cities using Ladybug, Honeybee, Dragonfly, and UWG (Urban Weather Generator). At the end of the study, it was found that the UHI intensity was highest in the Rectangular type on the hottest day and the L type on the coldest day; the cross typology had the lowest UHI intensity in both cases [13]. Studies in the literature indicate that the accuracy rate of the GRU deep learning model is high in studies investigating the effect of building forms on UHI [14]. Nuruzzaman, who drew attention to surface properties in his 2015 study, found that using materials with high albedo effectively reduces UHI [15]. Morini, on the other hand, aimed to minimise UHI by increasing albedo in Terni. The results show that increasing urban surface albedo can reduce the UHI effect by up to 2 °C [16]. Santamouris, who also aims to reduce UHI, supports this study by stating that increasing albedo in urban areas will reduce the UHI effect [17]. Vásquez-Álvarez, in his 2022 study, suggested using concrete with a higher albedo value instead of asphalt material on roads to reduce the UHI effect in Cuenca. The study, which ran simulations using ENVI-met software, reduced the average air temperature by 0.83°C, reducing the urban heat island (UHI) effect [18]. Battista, who focused on Rome, also conducted simulations using ENVI-met software to reduce the UHI. Simulation results indicate that high-albedo materials could reduce temperatures by up to 2.5°C [19].

In hot climates, the cooling load required to achieve optimal thermal performance in building interiors during summer is higher than in temperate climates. The cooling load will increase further with the CC effect [20]. Increasing the energy required for cooling will increase the amount of greenhouse gases released into the atmosphere, thereby increasing the UHI effect in urban areas. The UHI, which causes thermal discomfort for urban residents, is a challenge that must be addressed. This study has developed computational optimisation to overcome the UHI. The study focused on Balıkesir (39° N), located in the mid-latitudes, where the CSA climate type, a hot climate type, is observed. The Dumlupınar neighbourhood, an area with high urbanisation in Balıkesir, was selected as the study area. Although the region has an old settlement area, it has new, multi-storey buildings. The study used a less densely populated area near the plot region as a reference region to demonstrate the UHI effect in the plot region. Considering cities have served users for many years, the importance of using future weather data in simulations when making design decisions cannot be denied. Optimisation aims to reduce the UHI effect in the region by balancing the parameters that affect the UHI in the city, such as building height and albedo effect. Thus, the study aims to propose an optimal city model over 30 years using computational optimisation in mid-latitudes where the CSA climate type is observed. The study's results guide local governments in mid-latitudes with the CSA climate type, taking into account the EU's climate-neutral cities target.

2. Material and Method

The study focuses on the Dumlupınar neighbourhood, a historic and highly populated area of Balıkesir. The first stage of the study involves analysing the green fabric, surface materials and number of storeys in the area. Rhino/Grasshopper was used to create a parametric model of the area under study and the reference area. Dragonfly used parametric models to simulate the UHI. Dragonfly utilised current weather data from Balıkesir and a 2025 weather scenario created by Meteonom. Dragonfly Urban Optimisation optimised the number of floors and albedo effect parameters influencing the UHI. Figure 1 shows the study workflow. Table 1 shows the parameters optimised by urban optimisation.

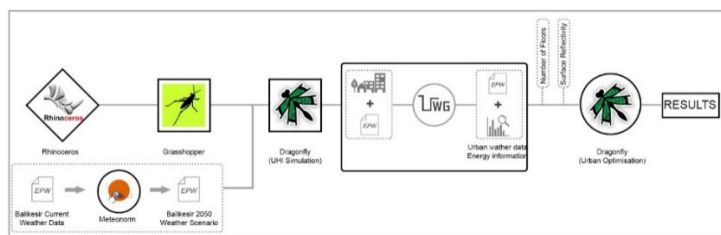


Figure 1. Workflow of the study.

Table 1. Optimised parameters.

Parameters	Explanation	Unit	Boundary
x1	Number of storeys	Number	[1 – 7]
x2	Albedo effect	%	[0.10 - 0.99]

Figure 2 shows the area covered by the study and the reference area. The map shows that the area covered by the field study has a higher rate of development than the reference area. In addition, the proportion of green areas in this area is lower than in the reference area.



Figure 2. Satellite image of Dumlupinar neighbourhood and reference area.

Figure 3 (a) shows the green areas in the plot and reference areas. The figure shows that the plot area has much more development than the reference area, and fewer green areas exist. Figure 3 (b) shows the building density of the neighbourhood. The building density in the neighbourhood is relatively high, and the scarcity of green areas is striking. Figure 3 (c) shows the building heights in the neighbourhood. While traditional buildings in the neighbourhood are generally 1-2 storeys high, newly constructed buildings have more storeys.



Figure 3. (a) Green areas in the fields, (b) building density of the neighbourhood and (c) number of storeys of the buildings.

Figure 4 shows the buildings in the Dumlupinar neighbourhood, which was the subject of the field study. The surface colours of the buildings in the area are mostly light colours with high reflectivity.



Figure 4. Visuals of some buildings in Dumlupinar neighbourhood.

3. Findings

In this study, Dragonfly primarily performed UHI simulation using current weather data from Balıkesir and the algorithmic model of the reference region and Dumlupınar neighbourhood. Figure 5 shows the algorithmic model of the reference and plot regions.

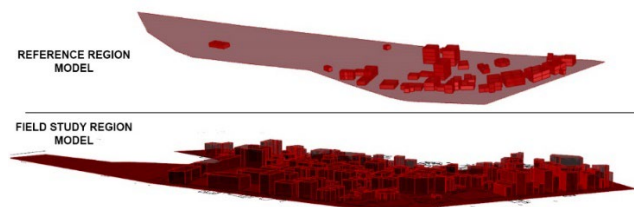


Figure 5. Algorithmic model of reference and plot region.

3.1. Simulation Results

The study was conducted to compare the temperature difference between the reference and plot area in the first stage of the simulation. The simulation compares data from July, the hottest month of the summer. Figure 6 shows the temperature difference between the two different areas simulated in the study in July. According to the figure, the average temperatures in the plot region are higher than those in the reference region. According to the simulation results, the average temperature in July is 32.13°C in the reference region and 33.30°C in the plot region. Therefore, the figure highlights the necessity of the study's aim to reduce the UHI effect in the plot region using optimisation methods.

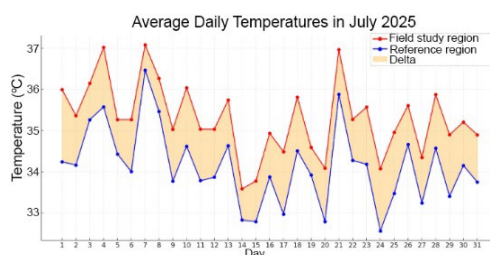


Figure 6. Temperature differences between the plot area and the reference area in July (°C).

The second stage involves the UHI simulation process using Meteonorm's 2050 weather scenarios for Balıkesir based on RCP4.5. Today, the average temperature in July for the plot region is 33.30 °C, while in 2050, it will be 34.42 °C (Figure 7).

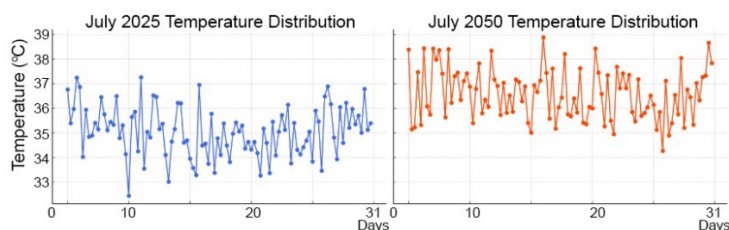


Figure 7. Comparison of temperature values (°C) in the plot region in July 2025 and 2050.

3.2. Optimisation Results

Simulations using Dragonfly's plot region's current and 2050 weather scenarios show that the region's temperature will increase by 1.12 °C over the next 30 years. In the simulations, the floor heights, number of floors, and surface albedo values of the buildings in the region are the same. In addition, the proportion of green space in the area did not change during the simulation. The cause of the temperature increase over the 30-year simulation period is the CC effect. In the CC effect, the importance of computational optimisation using future weather scenarios in urban planning adjustments to prevent temperature increases in cities cannot be overstated.

The computational optimisation process has adopted the Single-Objective Optimisation (SOO) method to reduce the UHI effect. In this context, regional buildings' number of floors and surface albedo values are parameters. In contrast, the region's average temperature ($^{\circ}\text{C}$) in July is the objective. The optimisation aims to minimise the region's average temperature ($^{\circ}\text{C}$) in July in 2050. The ratio of green space to buildings in the area remains constant during the optimisation process.

The optimisation process shows that the floor heights of buildings in the area have a significant impact on UHI. SOO has focused particularly on buildings with many floors to reduce the UHI throughout the process. Most of the buildings in the region are 2-3 storeys high. However, new buildings are seen to have 5 or more floors. In addition, the municipality's zoning plans allow for 4 or more floors for new buildings in the region. The optimisation has limited the number of floors in buildings, exceeding the average number of floors in the region by 4. Furthermore, the albedo effect of surface materials, a parameter of the optimisation, has been balanced in the process. The optimisation has achieved a reflectance value of 0.30–0.55 for surface materials. The plot shows that while the current temperature of the region in July 2050 is 34.42°C , optimising the parameters of the number of floors and the albedo value of the surface materials reduces the temperature in July 2050 by 1.73°C to 32.69°C . This temperature value is below the temperature value for July 2025 in the region (33.30°C). Figure 8 shows the temperatures of the plot region in July 2050 for the current and optimised models. Figure 9 shows the optimised model of the plot region.

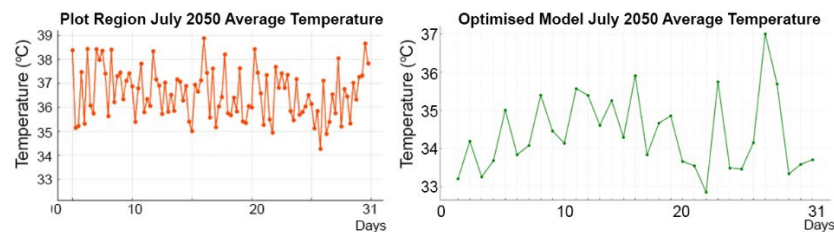


Figure 8. Comparison of temperature values ($^{\circ}\text{C}$) for July 2050 between the current and optimised models.



Figure 9. Optimised model of plot region.

4. Conclusion

Temperatures in cities are constantly rising due to the urban heat island effect. The low proportion of green spaces in cities, the density and height of buildings, and surface albedo values all impact the urban heat island effect. In line with the EU's climate-neutral city target, reducing carbon emissions in cities should be a goal for local governments. In this context, especially in hot climate regions, the increase in temperatures due to the CC effect will further increase the energy load required for cooling. The rise in energy consumption will also increase carbon emissions. Reducing temperatures in cities will both increase user comfort and reduce carbon emissions.

The results of the simulation conducted by Dragonfly show that the average temperature in July in the plot area with dense buildings is 1.17°C warmer than in the reference area. The simulation results show that the average temperature in the plot area in July 2050 is 1.12°C higher than in July 2025. The study optimised the plot area's urban design parameters within this scope, namely the number of floors and surface albedo values. The optimisation results determined the maximum number of floors in the region to be 4 and increased the surface albedo values. As a result, the study reduced the average July temperature by 1.73°C by changing the number of floors in only 5, 6, and 7-storey buildings in the region to 4.

Reducing the number of floors in existing buildings may not be easy. However, the study recommends that local governments in mid-latitudes ($35\text{--}40^{\circ}\text{N}$) with a CSA climate type develop optimisations that minimise UHI using future weather scenarios during the urban design phase to create carbon-neutral cities. Local governments should provide recommendations for the optimal number of

floors and building layout in new residential areas or plots where new buildings will be constructed, ensuring that the UHI is not increased. In addition, the study suggests that local governments in hot climate regions should enact regulations requiring building owners to use materials with high albedo values on the surfaces of buildings to reduce UHI in cities. Future studies could develop strategies to minimise UHI in cities with CSA climate types and different latitude zones. Using the SOO method, local governments could also determine green space/building area ratios in cities.

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