Investigating the effects of SMA 8G+ mix to ambient weather conditions

Research paper

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Abstract

The Urban Heat Island (UHI) effect is a phenomena where urban areas experience warmer temperatures relative to their rural counterparts due to its built environment. The effect increases the energy demand for cooling, and with the expanding urban areas, cities will experience warmer temperatures from more emissions created by the increasing energy use for cooling. As such, methods such as reflective coating and cool pavements (Kappou et al. 2022; Faragallah & Ragheb 2022) have been deployed as methods to cope with the UHI effect. An innovation by a Dutch construction company is using light colored aggregates in the asphalt mix, known as the SMA 8G+ for a road maintenance in Bosweg, Enschede. The research highlights how vegetation play in affecting the temperature of an urban area through a data collection, while displaying the contribution of the asphalt mix through a simulation model.

1. Introduction

The Urban Heat Island (UHI) is a phenomenon occurring in urban areas, where the changes in land use to accommodate human activities cause the area to be warmer compared to its rural counterparts. With the urban areas projected to expand by 0.6 to 1.3 million km^2 between 2015 to 2050 (Huang et al., 2019), cities must explore methods that can cope with the ever-increasing energy demand to cool down cities. The IRENA (International Renewable Energy Agency) stated that the global energy demand to cool down cities is expected to reach 12 exajoules by 2050, a 45% increase from 7 exajoules in 2016 (Status, n.d.), and this demand is sure to cause more emissions from the increased use of energy.

The implications from the UHI effect are not to be underestimated as the higher temperatures from the effect can lead to societal health problems. The United States Environmental Protection Agency (2023) reported that for every 2°F increase in temperature, countries will use 1-9% more in electricity to cool down cities. This increase in energy use can lead to:

- Decrease in air quality: The production of electricity to meet the increased energy demand for cooling mainly relies on fossil-fuel power plants, with oil, gas and coal accounting for 61% of the electricity generated in the Netherlands (CBS, 2023). As a result of the increased demand, emissions of carbon dioxide, carbon monoxide, nitrous oxides, fine particulate matter and methane will be produced at a higher rate and decrease the air quality due the formation of smog and acid rain from such emissions.
- Compromised human health and comfort: The reduced outdoor thermal comfort and a decrease in air quality from increased levels of emissions can target anyone across the different age groups. Young children can suffer from aggravated asthma and several lung diseases (Ebi et al., 2008), while older adults tend to isolate themselves from the outdoors due to their vulnerability to extreme heat, causing them to be less mobile, more sensitive to extreme heat and live on reduced incomes (Gamble et al., 2013). Furthermore, populations with low-income who lack the resources to afford proper air conditioning and living spaces are put at greater risk of heat-related illnesses.
- Impaired water quality: Aside from compromising human health and comfort, the UHI effect can also compromise water quality, as a study by Somers et al. (2016) revealed an increase over 4°C in urban stream temperatures during storms due to heated runoff from urban materials. The increase in water temperature will disturb biological processes on marine ecosystems such as their metabolism and reproduction.

Past research (Ikechukwu, 2015) shows that, in terms of material, asphalt has the biggest impact in exacerbating the UHI effect by increasing the air temperature by 4°C. In other words, the most common material making up the biggest transport infrastructure, i.e., roads, has been shown to be the biggest contributor to the UHI effect. For reference, a research done in the United States revealed that paved surfaces which include roads, streets, driveways, parking lots, runways, plazas and playgrounds account for 30% of typical urban areas and is larger in cities with higher population density (Akbari & Kolokotsa, 2016). The increase in temperature is caused by asphalt stems from its dark-colored nature which allows more solar radiation to be absorbed, thus causing the surface temperature to increase, and consequently, the surrounding air temperature to increase by heat transfer. Considering the rapid expansion of urban areas mentioned earlier, it is important for urban city planners to come up with methods to cope with the UHI effect before it becomes a problem too difficult to solve. While there are several established methods to cope with the increase in temperature due to the expanding urban areas such as reflective coating and cool pavements, a method yet to be explored is using light-colored aggregates in asphalt mixes. In their research, Kappou et al. (2022) shows that a change from using gray-colored concrete to light-colored concrete for roads has the potential to decrease the minimum and maximum air temperature by 0.97°C and 1.38°C respectively. However, this data is taken from a model simulation, and this research aims to provide measurements from road maintenance of how ight-colored aggregates in asphalt mixes, specifically the SMA 8G+ mix, on the air temperature in urban areas. While the data from the simulation is valuable to the field of UHI research, the opportunity to do a research on an asphalt mix that is very rarely used can serve as a genesis for another world of research. The project area for this research is located at Bosweg, Enschede, a road surrounded by shade and vegetation.

1.1. Problem context

Within the Dutch province of Overijssel, Enschede is a municipality located in the eastern region of the Netherlands, close to the Dutch-German border. It is also close to several other important Dutch municipalities, such as Almelo, Hengelo, Oldenzaal, and Zwolle, and borders the German city of Gronau. Spanning 142.8 km^2 in area (citypopulation.de, 2024), it is considered to be a moderately large productive city, as shown by having 104121 out of its 161741 (64.6%) population in the working age. Enschede finds itself home to several important industries such as sports, entertainment, technology and education. This is shown by the existence of *De Grolsch Veste* (home stadium to the Eredivisie club FC Twente), Kinepolis Movie Theatre, Aspen Valley NightClub, DEMCON Engineering office, Saxion *Hogeschool* and the University of Twente.

In this city, lies a street near the premises of the University of Twente (UT) called Bosweg. Bosweg is a street spanning approximately 1 km, surrounded by plenty of greenery and shade, allowing the street to remain cool even in the summer season to ensure a comfortable and enjoyable experience for its users. Figure 1 shows a network of streets surrounding Bosweg that gives a picture of the study area of the research.

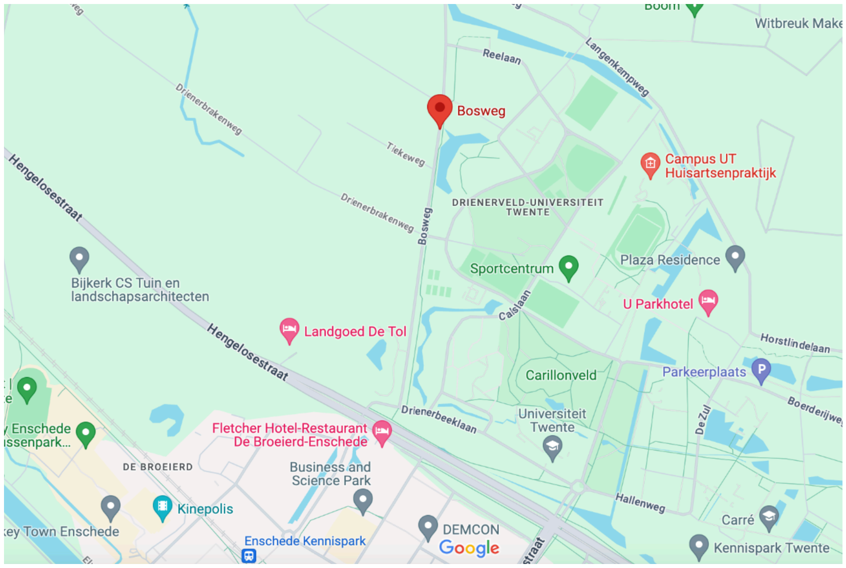


Figure 1: Bosweg and its vicinity.

As a result of being located within the premises of a campus and nearby important public facilities such as the Kinepolis Theatre, Kennispark train station, and several bus stops, Bosweg finds itself as an adequately busy street that is used by UT staff and students alike, especially to the staff and students who depart from Hengelo (a city located northwest of Enschede) and Gronau. It is thus important to keep the street accessible all year around, with Figure 2 describing the extra distance cyclists need to cover in a hypothetical situation where Bosweg is not available for use.

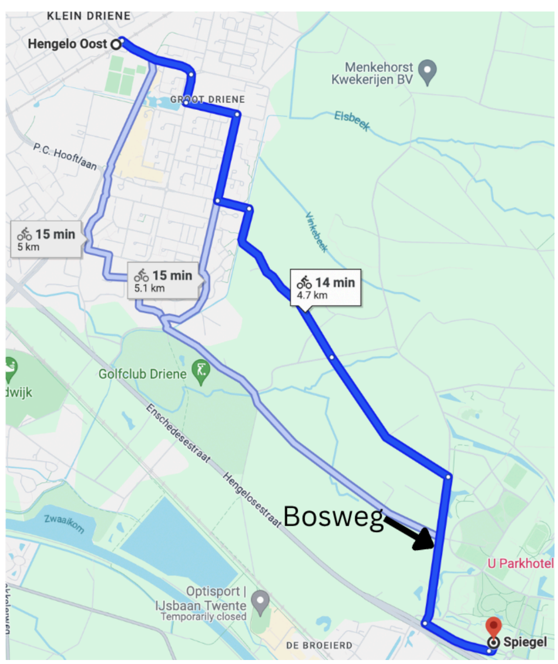


Figure 2: a hypothetical situation where a cyclist needs to travel from Hengelo to the Spiegel building on campus.

In the road maintenance Bosweg is put in by the municipality, a construction company called Strukton has decided to test one of its light-colored aggregates in asphalt mixes, called SMA 8G+. While Bosweg is surrounded by greenery that can keep itself cool even during the summer, applying a new asphalt mix presents an opportunity to investigate its impact on the air temperature in its surroundings. The current asphalt used in Bosweg is dark-colored, which allows it to absorb more light and heat, and in the evening when the air temperature drops, the warmer asphalt emits more heat, creating a UHI. These characteristics include higher heat and light absorption and higher thermal emittance, both of which are found in urban areas. This property is not present in SMA 8G+ however, where its light-colored nature reflects more heat and solar radiation, and also emits less heat. Furthermore, Faragallah and Ragheb (2022) stated that, "In hot climates, asphalt pavements have high summer temperatures which can greatly increase the risk of rutting (permanent deformation), aging and cracking, if not properly designed." This information suggests that SMA 8G+ can also indirectly increase the durability of asphalt with less heat absorbed by its color.

It should be noted that while Bosweg is located in Enschede which can be described as an urban area, Bosweg lies in a place surrounded by greenery which may not have the same effects performing this asphalt research in another study area where the conditions are different, e.g., where the greenery is less dense. Nevertheless, Bosweg's narrow width and short length make the perfect testing grounds for the impact of the asphalt mix. This is because the amount of asphalt mix needed to complete the road is significantly lower compared to larger roads in the city center or even the highways. In this case, the asphalt mix has little or no impact on the surrounding air temperature, or if the asphalt mix is very prone to breaking down, the financial consequences are minimal. Moreover, testing the asphalt mix on main roads can lead to traffic flow issues due to road maintenance. This can be easily worked around in the case of Bosweg, for example, road maintenance can be performed during the summer holiday when the street is not as busy.

This research looks to investigate the effects of SMA 8G+ mix on the air temperature of Bosweg. The following sections will list the research questions relevant to investigating such effects.

1.2 Research objectives and relevance

In 2015, a framework for sustainability was formed by the United Nations to address global challenges such as climate change and environmental degradation, as well as developing innovations to solve such global challenges. This framework is called sustainable development goals (United Nations Department of Economic and Social Affairs, n.d.). This goal is elaborated further in goal 9, where it strives to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. According to the UN website regarding SDGs, each goal has targets that further explain how each goal is achieved, thus acting similarly to sub-goals.

The relevance of using light-colored aggregates in asphalt mixes such as SMA 8G+ is shown in goal 9 of the SDG, where it not only investigates the potential of innovation but also builds more resilient roads and reduces the effects of UHI (as mentioned in the previous section), allowing for cooler temperatures to occur. Furthermore, it also has the potential to improve the durability of the road, thereby reducing maintenance needed and thus less emissions from less asphalt produced needed for maintenance, if replacing the asphalt was needed. This industry is heavy in emissions, with Oliviera & Silva (2022) reporting that the industry released 99.4 kilotons of CO_2 emissions to the environment in 2020. Using SMA 8G+ will hopefully help in reducing the emissions and contribute to the MIDDEN project, a project that has been formed aimed at decarbonizing the asphalt industry.

Moreover, the decision to use SMA 8G+ in Bosweg was organized by the municipality of Enschede, with them collaborating with the Dutch construction company Strukton. The company that has been testing the effects of this particular asphalt mix seeks to prove the effectiveness of the innovation. This collaboration of actors is in line with Köhler et al.'s (2019) framework of sustainability transitions. This framework states that the transition to a sustainable society is a multidisciplinary field that involves the actions of multiple actors. The involvement of Strukton was done by the municipality to provide a chance for the experts in the field to have an influence on the decision-making process regarding the maintenance of Bosweg. From this framework, it is also in line that more actors will be involved in the research, and this can be done, for example, by asking the local Enschede community what the ideal situation feels/looks like.

With frameworks proving the relevancy of the research, the main research objective is to investigate the effects of SMA 8G+ on the air temperature in Bosweg. Sub-objectives can also be defined to formulate the research questions, which are:

- Identifying the geographical factors that affect air and surface temperature in an urban area
- Investigate the effectiveness of physics-based modeling programs in simulating the conditions of Bosweg
- Identify the properties of SMA 8G+ that help lower the air temperature in Bosweg
- Formulate policy recommendations for cities that look to lower their local air temperature based on the effectiveness of SMA 8G+.

1.3 Research and sub-research questions

The research questions can now be defined based on the formulation of the relevancy and research objectives. The methods and key concepts that will be discussed in later sections are used to answer these research questions.

The main research question in this research is “Can SMA 8G+ have a positive impact on lowering the air temperature in Bosweg?”, with three sub-research questions designed to lead up to the answer to this question, which are:

- What are the geographical factors affecting air and surface temperature in an urban area?
- What is the desired situation in Bosweg, and how can SMA 8G+ asphalt mix help reach such a desired situation?
- Can the SMA 8G+ asphalt mix be used as a recommendation in policies that plan to lower temperatures in urban areas and improve asphalt durability?

1.4 Research boundary

To make the goals of the research specific, realistic, and time-bounded, research boundaries must be applied to the paper. The boundaries are:

- The study area will be limited to the length of Bosweg, Enschede
- The mix in interest is SMA 8G+
- The research focuses on the impact of the asphalt mix on the air and surface temperature of the area it is applied to, mostly forgoing the durability-enhancing potential that it has due to the lack of research practicality at the University of Twente.
- To prevent the overcomplication of the simulation model and research analysis, anthropogenic heat, i.e., heat produced by the traffic passing through Bosweg will be ignored. This means that traffic will not be modeled in the simulation processes.

2. Literature review

As mentioned in the introduction, there are several established methods to cope with the UHI effect. This section serves as the literature review, which summarizes the information and findings the sources have and gives context to the research to describe how the paper can contribute to the current understanding of this field of study. Two sources will be reviewed in this section, which are Kappou et al. (2022) and Faragallah & Ragheb (2022). Furthermore, the literature review will expand on the health implications of the UHI effect which was briefly discussed in the introduction, showing the importance of coping with the effect.

Both Kappou et al. (2022) and Faragallah & Ragheb (2022) mentioned the importance of cool pavements in their respective research. Cool pavements that have high albedo values and high thermal emissivity are seen as a practical way of making cities more comfortable and reducing the severity of heat islands because they have light colors that reflect more sunlight while absorbing less heat. Cities can effectively reduce surface temperature, the heat released into the atmosphere, and UHI mitigation by using cool pavements with improved reflective properties. This underscores the importance of papers in cool pavements' potential to contribute significantly to improving urban environmental quality and promoting sustainability.

Cool pavements are essential for creating sustainable urban environments that consume less energy because they use materials having lower surface temperatures. According to Kappou et al. (2022), replacing normal pavements with cool pavements can reduce a region's highest air temperatures. The study highlights the importance of cool streets in combating the UHI effect which uses higher convection coefficients to limit heat loss both during the day and at night. In the case of a high-density urban environment in Marousi, Athens, the significance of cool streets was established following a project that involved the construction of high-reflective pavements and the creation of vegetation in a 16000 m^2 area leading to a possible temperature drop of between 1.2 and 2.0 °C.

To increase temperature regulation and thus reduce high temperatures, particularly on building surfaces, the research is targeting the development of cool materials for controlling microclimates in the streets. The research by Faragallah & Ragheb (2022) evaluated the effect of different cool roof materials on the surface air temperature using the software ENVI-met 4.0 through simulations. These cool pavements have reduced the air temperature significantly according to the findings: -0.1°C in green areas and water bodies; -1°C on bright surfaces like colored asphalt or brick; -2°C on gray concrete; -3°C for basalt and light-colored concrete, and 3.5°C for basalt or granite pavements. The results from the ENVI-met simulation are summarized in table 1 below, where they investigate the effects of road material, sidewalk material, presence of vegetation, and water bodies on the air temperature.

Table 1: the simulation results using ENVI-met to investigate geographical factors of air temperature by Faragallah & Ragheb (2022)

Case	Road Material	Sidewalk Material	Vegetation & water bodies	Air temperature (°C)	Windspeed	Relative humidity (%)
A	Conventional asphalt	Conventional interlock tiles	No	27.72 30.38	3.21	49.40
B	Conventional asphalt	Conventional interlock tiles	Yes	27.58 30.32	3.10	50.17
C	Colored asphalt	Brick		27.16 29.53	3.11	51.16
D	Colored asphalt	Concrete grey color		26.89 28.52	3.12	51.20
E	Basalt	Concrete light color		25.92 27.14	3.13	52.89
F	Basalt	Granite stones		25.79 26.97	3.15	53.19

From this table, it is seen that all cases except A have present vegetation and water bodies and these cases consistently lower the air temperature, showing the impact on the environment. This is proven by comparing the differences in cases A and B, where the difference only lies in the presence of vegetation and water bodies that lower the minimum and maximum air temperature by 0.14°C and 0.06°C respectively. In later cases, where the sidewalk and road material is modified from case A, the difference in air temperature grows larger and highlights the importance of urban planning to include more greenery to combat the UHI effect.

While this result has been validated by using empirical meteorological data from ETMY (Egyptian Typical Meteorological Year), the research does not perform real-life data collection due to a lack of application of the proposed cases. In this paper, the research offers to provide data from real-life applications of the SMA 8G+ mix and provide an analysis using a physical simulation model to prove or disprove its effectiveness similar to the literature in review. This will hopefully expand the insight into the field of study and as a reference to the effectiveness of SMA mixes.

Expanding on the health implications of the UHI effect will be done by reviewing the research done by Heaviside et al. (2017). Extensive research findings have correlated the strong link between the UHI effect and negative health consequences. Increased temperature levels in urban areas can exacerbate heat-related illnesses such as heat exhaustion and heat stroke, particularly against the elderly, kids and people with existing health conditions. Stone et al. (2014) demonstrated that adaptation strategies could significantly reduce heat-related deaths in urban areas, and this calls for proactive measures to be taken to mitigate the health effects of UHI. Additionally, the combination of UHI and air pollution results in increased heat, which consequently leads to the rise of pollutants and thus the number of respiratory and cardiovascular issues.

Findings in this literature all lead to the fact that socio-economic factors have a crucial influence on the determination of the vulnerability of the population to UHI effects. Regions with poverty, a large number of people living in a given area, and limited resources are the ones that usually tend to have the highest surface temperatures and greatest health risks. For example, suburbs with a large number of minorities and lower educational levels, are oftentimes not equipped with air conditioners which would help to diminish the heat exposure. This gap reflects a social perspective on the social determinants of health, which would be the basis for the measurement of UHI and the development of tailored interventions, and in the case of this research, the use of SMA 8G+ mix.

Before the use of the SMA 8G+ mix, however, various studies have explored different mitigation strategies to cope with the health implications of the UHI effect. Green infrastructure, such as urban vegetation and green roofs has been employed as viable strategies to reduce surface temperatures and improve air quality. Studies done in Melbourne (Chen et al., 2014) showed that an increase in vegetation cover would result in the noticeable decline of heat-related deaths, thus showing the potential health benefits of urban green initiatives. Additionally, the inclusion of science and data-driven regulations that prioritize health issues is crucial for getting the results needed for the UHI mitigation. Collaboration among researchers, policymakers, and community stakeholders is important for developing appropriate strategies that will address both the environmental and health challenges of the UHI.

The studies on UHI and its health consequences highlights the immediate necessity for approaches to counter its impacts, especially in the most at-risk urban communities. Since the cities continue to expand and the climate change becomes even more intense, finding the link between urban design, socio-economic conditions, and public health will be crucial for building healthier, resistant urban communities. Next research should concentrate on measuring the UHI's long-term health effects and assessing the efficiency of the different mitigation measures to bring the policy and practice on the right track.

3. Theoretical framework

In this section, the key concepts and terms relevant to the research will be discussed, which are, albedo, UHI, thermal emittance, thermal capacity, and the SMA 8G+ asphalt mix. These concepts give a further theoretical explanation of how light-colored asphalt mixes will help lower the air temperature in Bosweg. The concepts and how the theoretical framework is formed are heavily influenced by literature reviews from Kappou et al. (2022) and Faragallah & Ragheb (2022).

The knowledge from the theoretical framework will then be used to explain the findings in a literature review, covered in the last subsection of this chapter. It serves as a justification for how this research can contribute to this field of study.

3.1 Urban Heat Island (UHI)

According to Faragallah and Ragheb (2022), the UHI phenomenon where significant alterations in surface features and atmospheric conditions in urban areas causes the air temperature to be warmer relative to their rural counterparts. They further cited that the UHI effect consists of two main layers: the urban boundary layer (UBL) and the urban canopy layer (UCL). The UBL covers the entire air mass above the city, affected by surface characteristics and human activities, extending vertically up to ten times the height of buildings in the city. On the other hand, the UCL exists within the atmosphere, resulting from the transfer of thermal energy that raises surface temperatures. This phenomenon at the local neighborhood scale has widespread impacts on urban environments. Figure 3 explains the interaction between the UBL, UCL and the built environment.

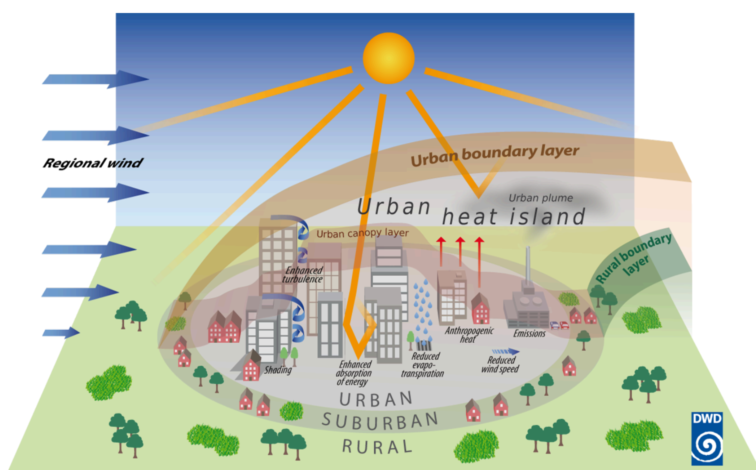


Figure 3: the interaction between the layers of UHI and the built environment. Taken from dwd.de (n.d.)

The UHI effect is influenced by several factors, including the presence of dark surfaces like asphalt and concrete that absorb heat and raise temperatures. The layout of buildings and their height impact the UHI by changing air flow and trapping heat. Plants and greenery help reduce the UHI effect by providing shade and releasing water vapor into the air. Human activities, like transportation and energy use, also contribute to the buildup of heat in cities, making the UHI effect more severe.

The use of dark-colored asphalt in urban areas worsens the UHI effect because of its ability to absorb solar radiation and trap heat. According to Faragallah and Ragheb (2022), cities with a high percentage of dark asphalt pavements contribute to higher surface temperatures, particularly in the summer. Asphalt has a low albedo, which means it absorbs solar radiation instead of reflecting it, leading to the pavement heating up and raising the surrounding air temperature. Moreover, dark pavements are inefficient at dissipating heat, acting as heat trappers at ground level. The ability of asphalt to hold onto heat for longer periods worsens the problem of retaining heat, causing it to be released into the environment even at night. This means that having dark asphalt in cities increases the UHI effect by raising surface temperatures, changing the local climate, and affecting how comfortable people feel when walking or living in the area. To lessen the impact of the UHI effect and support sustainable urban development that values the environment and people's well-being, it is important to switch to lighter-colored asphalt mixes.

3.2 Albedo

According to Kappou et al. (2022), albedo is the ratio of reflected radiation to the incident solar radiation at a surface, averaged across the entire solar spectrum. This is expressed by a dimensionless constant from 0-1, with higher constant values representing materials that can reflect more light. The reflectivity of a surface plays a key role in determining how much solar radiation is absorbed and influences the surface's ability to deflect incoming solar radiation. Figure 4 visualizes the concept of albedo.

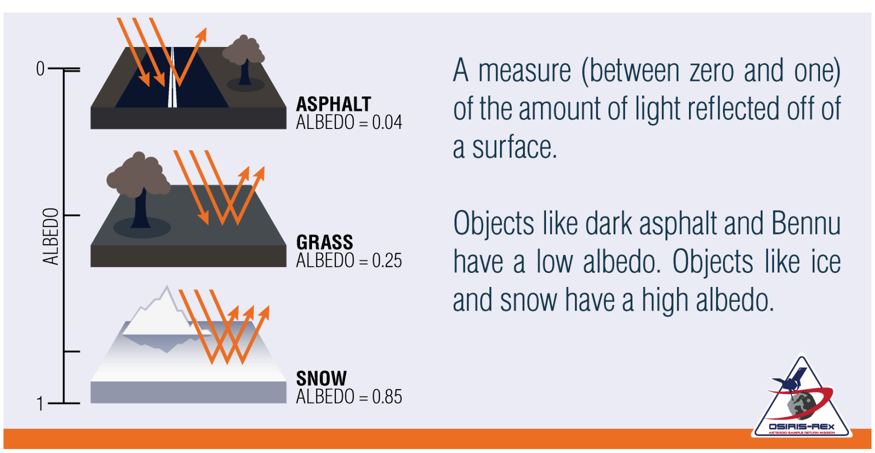


Figure 4: Concept of albedo and how color plays a role in determining the albedo of a surface

As seen in figure 5, different materials have different albedo values which are mainly determined by the material's color. Darker-colored surfaces, such as asphalt, reflect less solar radiation and consequently result in increased temperatures in urban areas. Along with asphalt, there are several materials commonly used in urban areas that can also contribute to the UHI effect. The albedo value of these materials, along with some other relevant materials are represented in table 2. The information is taken from Duhis & Alkafaji (2023).

Table 2: the albedo values of common surfaces and materials found in urban areas

Surface	Albedo	Surface	Albedo
Corrugated roof	0.1-0.15	Red/brown roof tiles	0.1-0.35
Colored paint	0.15-0.35	Brick/stone	0.2-0.4
Trees	0.15-0.18	White paint	0.5-0.9
Asphalt	0.05-0.2	Old snow	0.65-0.81
Grass	0.25-0.3	Fresh snow	0.81-0.88
Ice	0.3-0.5	Concrete	0.25-0.7

To understand the relevance of albedo to this research, Kappou et al. (2022) explore the important link between light and dark-colored asphalt mixes and how they affect pavement performance and urban heat regulation. Several studies have contrasted various pavement materials under summer conditions, uncovering notable temperature differences depending on color. For instance, the authors cited the works of Doulos et al. (2004), showing a significant temperature gap of up to 19°C between dark granites and white marbles, highlighting the significance of color in affecting surface temperatures. Similarly, pavements in colors like yellow, beige, green, and red have been found to have lower surface temperatures compared to black asphalt. This highlights the cooling benefits of using lighter-colored materials for pavements. Additionally, the authors emphasize the importance of pavement color in combating the UHI effect. By increasing the albedo of light-colored or white pavements, the amount of solar radiation reflected in the visible spectrum can be increased. This results in lower surface temperatures and reduced heat absorption. Research conducted in cities such as Athens has revealed temperature differences among various pavement materials, with asphalt showing higher temperatures than concrete, marble, and stone surfaces.

3.3 Stone Mastic Asphalt (SMA) Mixes

While this research focuses on the impact of a specific type of stone mastic asphalt (SMA) mix, that is, SMA 8G+, the theoretical framework over this topic will discuss SMA mixes in general and the framework is heavily influenced by Hainin et al. (2012).

SMA is a special type of asphalt mix that has become popular for its distinct features and advantages in construction projects. SMA is a type of wearing course mix that is gap-graded, with a large amount of coarse aggregate content that forms a stone-on-stone skeleton, which helps to resist permanent deformation (Hainin et al., 2012). The mix is made up of a mastic of bitumen and filler, with added fibers to improve stability and prevent binder drainage during transportation and placement. This combination creates a strong, fatigue-resistant, and durable asphalt surface that is perfect for areas with high traffic (ASTM International, 1992).

Stone Mastic Asphalt has a significant advantage in reducing air temperatures in cities. This cooling property is made possible by several factors in SMA mixes. The high proportion of large stones in SMA, which is three to four times greater than in traditional dense graded asphalt, gives it better durability. These large stones have a greater capacity to absorb and retain heat, which is released gradually at night after absorbing it during the day (Kappou et al., 2022). This helps alleviate the UHI effect. Additionally, incorporating mineral fibers into SMA mixes has the potential to cool down air temperatures in urban areas. These fibers play a key role in thickening the film on the aggregate, which enhances mix stability and minimizes the risk of draining down while being transported and paved. By improving the overall stability of the mix, mineral fibers can also decrease maintenance requirements and extend the lifespan of the pavement. This, in turn, indirectly aids in creating a more comfortable and cooler urban environment.

3.4 Thermal emittance

Thermal emittance is a fundamental concept of thermal radiation in materials and is important for understanding heat transfer processes (Li & Zhou, 2016). It can be described as the efficiency with which an object emits thermal radiation compared to that of a black body at the same temperature. As such, each material's thermal emittance is expressed with a dimensionless constant ranging from 0-1 and is denoted by the Greek letter ε. The emissive power (E) of a surface or body is expressed by the equation:

$$E = \varepsilon E_b$$

Where E_b emissive power of a perfect black body with ε = 1, and $E_b = \sigma T^4$ with σ being the Stefan-Boltzmann constant (5.6693e-8 $Wm^{-2}K^{-4}$) and T as the body's temperature in Kelvin.

In the realm of urban planning, city planners have preferred materials with higher emissivity as such materials can emit radiation more efficiently. In contrast, materials with low emissivity tend to trap heat instead of emitting it to the environment. Thus, city planners will opt to use more non-metallic materials that have ε values ranging from 0.8 to 0.95 (Kappou et al. 2022).

The use of materials with higher thermal emittance is following the Strukton's decision to implement a light-colored aggregates in the asphalt mix of Bosweg. White surfaces usually have greater emittance than dark surfaces. This means that they are better at emitting thermal radiation and eliminating heat. When rays from the sun fall on a light-colored surface, a large fraction of the solar energy is reflected, and the amount of heating of the surface is reduced. Moreover, the high emittance of the light-colored asphalt mix enables it to efficiently radiate the heat back to the atmosphere, hence, there will be no heat accumulation on the surface. By selecting a light-colored asphalt mix that has high thermal emissivity, the urban areas can experience cooler surface temperatures compared to the traditional dark-colored asphalt surfaces. This can help in solving the UHI effect where cities undergo higher temperatures as a result of dark surfaces and buildings absorbing and storing heat. It is important to note, a change of thermal emissivity from 0.7 to 1 led to a decrease of 5 °C and 8.5 °C in the maximum and minimum surface temperatures respectively (Gui et al., 2007), highlighting the importance of using materials with high emissivity.

Aside from using a light-colored asphalt mix, it is important that urban areas also surround themselves with vegetation and greenery. A study by Ikechukwu (2015) reveals that grass has the least impact as a pavement material on the UHI effect, and this effect is portrayed by grass increasing the air temperature by 1°C compared to asphalt, concrete and soil respectively increasing the air temperature by 4 °C, 3 °C and 2 °C.

3.5 Summary

The theoretical framework section provides the understanding of key concepts that are necessary for analyzing the UHI phenomenon and the benefits of using SMA 8G+ asphalt mix in urban environments. Below are some insights that are gained from this section:

- Understanding UHI: UHI brings higher air temperatures in urban areas when compared to the rural counterparts due to the changes in the surface materials and human activities. This phenomenon is further divided into two layers, i.e., the UBL and the UCL. The UBL covers all the air mass above the city while the UCL is the one that is affected by the thermal energy transfer from the urban surfaces which might have a large influence on the local climate conditions.
- Role of albedo: The albedo effect is relevant in this instance because there is a connection between the reflectivity of surfaces and the surface temperatures. The albedo value is greater for light-colored materials such as the SMA 8G+ asphalt mix, reflecting more sunlight and heat than other surfaces. The temperature reduction effect of this property plays a part in mitigating the UHI effect as this can translate to lower air temperatures in

the urban areas, thus, enhancing the thermal comfort of the city inhabitants and said users of the urban area.

- Thermal Emittance: Similar to albedo, the concept of thermal emittance is also critical in understanding how different materials respond to temperature changes. High thermal emittance materials can release absorbed heat more effectively, while materials with high thermal capacity can store heat, influencing the temperature dynamics in urban settings. The SMA 8G+ asphalt mix is designed to optimize these properties, contributing to a cooler urban environment.
- Literature Review Insights: The theoretical framework is completed with literature reviews, which provide context and justification for the research. Studies by Kappou et al. (2022) and Faragallah & Ragheb (2022) highlight the effectiveness of light-colored asphalt mixes in reducing air temperatures and mitigating the UHI effect. This evidence supports the argument for implementing such materials in urban planning and road maintenance strategies, such as the use of the SMA 8G+ mix.

In conclusion, the theoretical framework provides researchers and urban planners with the necessary concepts to understand the UHI phenomenon and the potential benefits of innovative materials like SMA 8G+ asphalt mix. By leveraging these insights, cities can develop more effective strategies to combat rising temperatures and enhance the quality of urban life.

4. Research methodology

To answer the main research question formulated in section 1.3, a methodology section will be designed to discuss the required procedures. Figure 5 shows the outline of the methodology section.

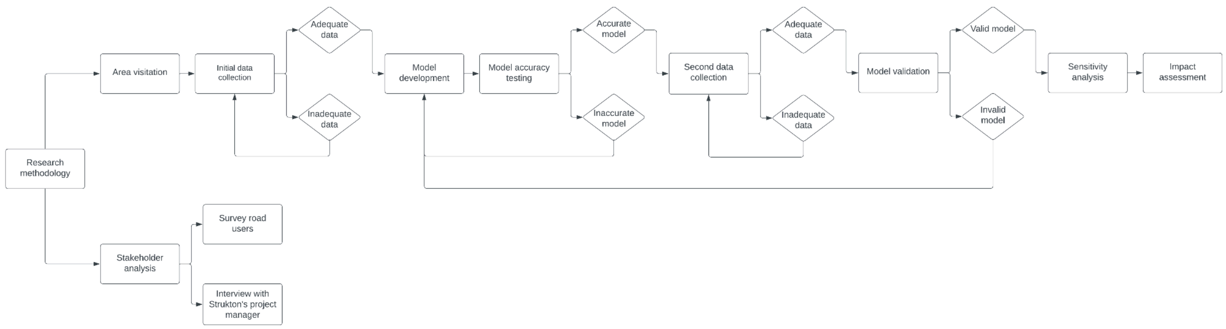


Figure 5: an overview of the methodology's order

4.1 Area visitation

As mentioned in the first section, the study area is at Bosweg, a street in Enschede, the Netherlands. While the introduction discusses the surroundings of Bosweg and its road network, an area visitation before the road maintenance starts will be performed to analyze the geographical factors that affect Bosweg's conditions. The factors listed will be backed by sources. Furthermore, a physical visitation also serves as an opportunity to measure the geometry of the study area, which includes measuring the width of the road and recognizing the vegetation density, tree types, and soil types, and also a suitable section of the road that can be picked as the location of the data collection.

4.2 Data collection before the road maintenance

Since data is needed to analyze the effectiveness of the SMA 8G+ mix and the current situation, it is important to design a data collection process. To perform this, it is important to list the precise location data relevant to the research, the equipment needed to gather such data, and the data collection procedures.

Initial data collection must first be held to understand the properties of Bosweg before the maintenance and gather necessary data for analysis. It will be held at the points 52.249033668522365, 6.845952228889065 (LF4 Midden, Bosweg and Reelaan intersection), going south until points 52.24782, 6.84578 (Drienerveldweg and Bosweg intersection). This particular 100 m section of the road was selected due to its varying canopy density. A varied canopy density is important to demonstrate that the created simulation model can accurately represent dense and sparse vegetation areas. The bounds of the data collection are visualized in figure 6.

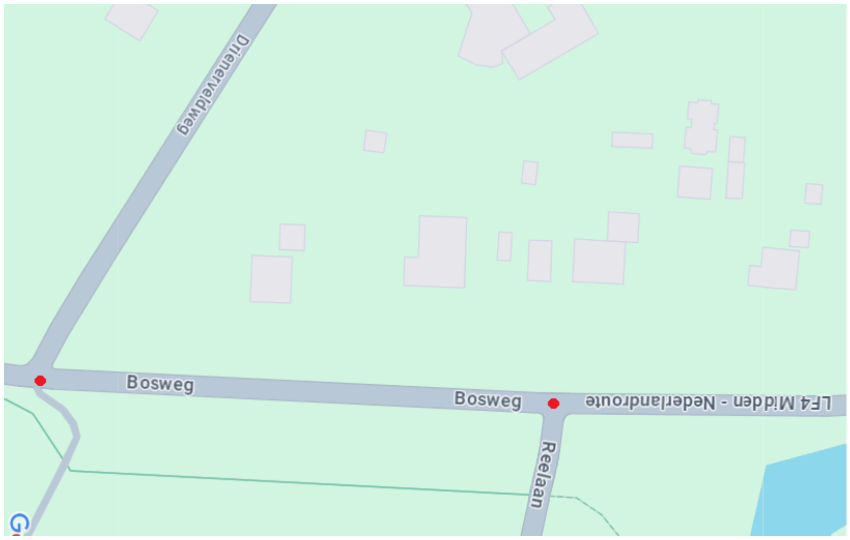


Figure 6: the start and end points of the data collection is marked with a red dot. Data will be collected between those two points.

The data needed for model simulation and analysis are the surface temperature of the asphalt road, the air temperature surrounding the asphalt road, the local relative humidity, and local temperature. The air and surface temperature data will be taken with a thermal imaging camera, and validated by an infrared pointer. The infrared pointer will also be used to take the relative humidity of the study area.

In the section of Bosweg where the data collection will take place, 6 lamp posts will be defined as the exact locations where data will be taken. The section of the road with the locations of the lamp posts is depicted in figure 7. Each lamp post is represented with a red dot, and the location of each lamp post will be named location A, B C, D, E, and F.

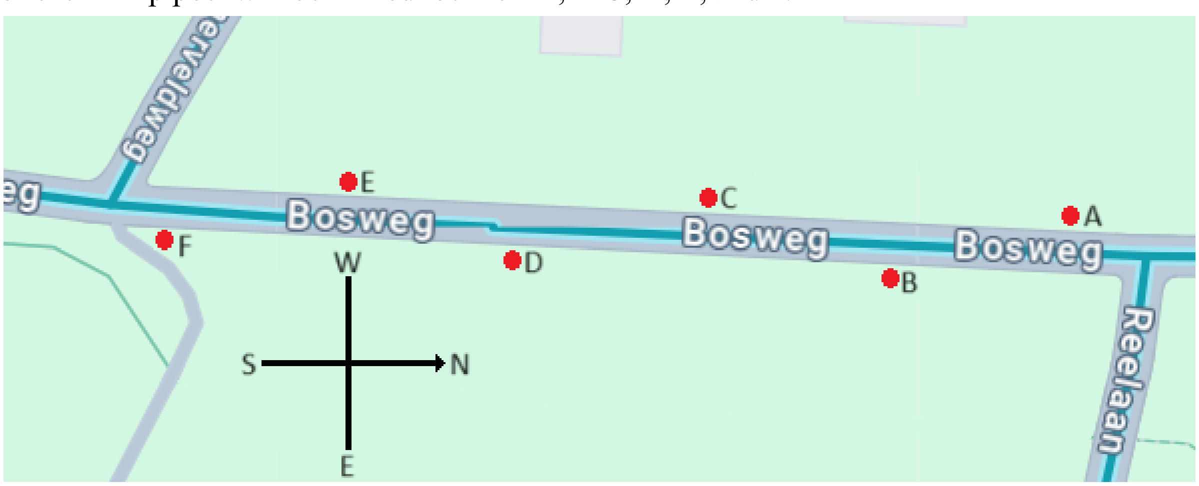


Figure 7: the exact locations of the lamp posts that will be used as spots to collect data

In each location, 9 data will be taken, which are described below:

- **Asphalt temperature (Data 1)**: This will be taken in the middle point of the road, taken with the thermal imaging camera, and used as the surface temperature.
- **Air temperature due west (Data 2)**: This will be taken by pointing the thermal camera west, thus registering the air temperature at the vegetation
- **Canopy temperature (Data 3)**: This will be taken by pointing the thermal camera up, thus registering the air temperature at the canopy. It should be noted that at location 1, this data will not be taken as it has little to no canopy.
- **Air temperature due east (Data 4)**: This will be taken by pointing the thermal camera east, thus registering the air temperature at the vegetation
- **Air temperature due south (Data 5)**: This will be taken by pointing the thermal camera south, thus registering the air temperature at the viewing level of the road.
- **Air temperature due north (Data 6)**: This will be taken by pointing the thermal camera north, thus registering the air temperature at the viewing level of the road.
- After taking 6 temperature measurements, the data will be assured using the infrared pointer and will be pointed to the middle of the road, similar to the first data taken. The infrared pointer can record **surface temperature (Data 7), air temperature (Data 8), and relative humidity (Data 9)** at once. Taking the surface temperature twice with different equipment assures the accuracy of the measurement.

The data collection will then take place in three days for accuracy reasons. It is important to take these measurements at the day's peak temperatures as the UHI effect is most relevant during warmer temperatures. The results of the data collection before the road maintenance is found in appendix 1.

4.3 Model building

The physical visitation of the study area also serves to gain insight into what it looks like and the important elements of Bosweg that need to be replicated in the simulation model. The important elements are the tree and soil types, vegetation density distribution, the locations of the lamp posts used as the spot of data collection.

Along with the elements of Bosweg, it should be noted that the research student is limited to the trial version of ENVI-met 4.0, which means that this version will not facilitate model area sizes greater than 50x50x40 (**xxyxz** format) meters. Hence, a 50 m section of the 100 m road depicted in figure 7 will be taken. In the model, x measures the length of the road and goes from south to north, y measures the width of the area and goes from east to west, and z measures the "height" of the study area and goes from the ground up. Two types of models will be created in Spaces, the geometric model of Bosweg and the soil profile of Bosweg.

The temperatures obtained in the data collection will be used in ENVI-guide to set up the meteorological conditions of the simulation, which produce a SIMX file. This file is then used with ENVI-core to run simulations on to produce the output of the model, which are maps that show the temperatures in the study area. The simulation maps are generated by Leonardo.

4.4 Model accuracy testing

After an initial model is produced, it will undergo testing to show that the model is accurate as it ensures that the physical conditions in Bosweg are replicated. Testing the model's accuracy will be done by comparing the temperature data from the simulation maps and the temperature data from the data collection. The procedures of this test will be explained further in section 5.4.

4.5 Stakeholder analysis

Stakeholder analysis will be performed as sustainability transitions cannot happen unless various actors are involved in the decision-making process (Köhler et al., 2019). Furthermore, stakeholder analysis will help reveal the demands of the municipality and the road users, which will aid in answering the sub-research question 2. Therefore, the analysis to find out the demands of the municipality of Enschede and the road users will be completed by performing an interview with the project manager of the road maintenance and a survey of Bosweg's road users.

4.6 Data collection after the road maintenance

Another round of data collection will be held after the road maintenance to give baseline temperature readings for the initial impact of the SMA 8G+ mix to the air and surface temperatures in Bosweg. This data will also be used to validate the model. The procedures of this data collection will be exactly the same as the procedures described in section 4.2.

4.7 Model validation

After temperature data is obtained after the road maintenance, the model will undergo validation to ensure that the model's accuracy still holds when it is tested against a different set of data. Similar to model accuracy, the procedures of model validation will be further explained in section 5.4, and the results of the model validation is found in section 5.8.

4.8 Sensitivity analysis

Sensitivity analysis is the final testing done on the simulation model. This analysis gives insight into the impact of the SMA 8G+ mix on the air and surface temperatures of the study area. This test will be performed by duplicating the surface found in the ENVI-met Database used to model the asphalt in Bosweg, however, the albedo of the surface will be changed to a suitable amount. This amount is later revealed in section 5.9.

5. Results

The results section proceeds after the methodology section is properly defined and serves as the chapter where the *results* of the procedures described in the previous section are shown.

5.1 Area visitation

The visitation of the study area was carried out to analyze the geographical factors that affect the conditions and the geometry of Bosweg. This section reports the findings that the research student is able to find.

As mentioned in the first section, the study area is at Bosweg, a street in Enschede, the Netherlands. While the introduction discusses the surroundings of Bosweg and its road network, this section delves into further details of what the study area looks like. The study area can be described as an asphalt road 5.6 meters wide, spanning 1 kilometer surrounded by dense greenery and vegetation forming a canopy, as depicted in the figure 8 below, a Google Maps street view of the study area. The dense greenery and vegetation allow Bosweg to remain cool even in the summer heat, ensuring its usage at any time of the year for cyclists and car users and its importance for UT students and staff alike mentioned in the introduction.

Figure 8: the Google Maps street view of Bosweg, surrounded by trees and grass.

Aside from the greenery and vegetation, lamp posts and traffic signs can be found across the length of the road, providing visibility and safety to its users at night. Several addresses are located here, such as a tourist home called *Het Huuske*, solidifying its status as an urban area.

As of 26th February until 24th of July (Gemeente Enschede, 2024), the municipality of Enschede has decided to put Bosweg under maintenance planning a collaboration with Strukton to implement the SMA 8G+ mix, an innovative light-colored asphalt mix designed to replace the road of the study area to help cope with the UHI effect.

The description of Bosweg is now complete and it will provide clues to determine the geographical factors that affect air and surface temperatures. This analysis will be found in the discussion section.

5.2 Data collection before the road maintenance

The first data collection was held to provide air and surface temperature data before the maintenance and to analyze the impact of the SMA 8G+ mix. This was held on the 24th, 25th, and the 27th of May at 10:00, 12:00 and 14:00 of each day as at these times, the temperature of the day was at its highest. This means that there are 9 sessions of data collections. While appendix 1 shows the full results of the first data collection, the results section will show the trends of the surface, greenery and canopy temperature of each session.

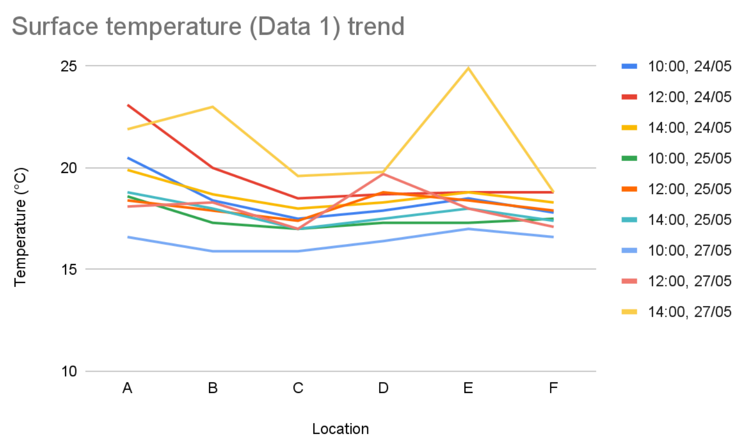


Figure 9: the trend of the surface temperature based on the first data collection

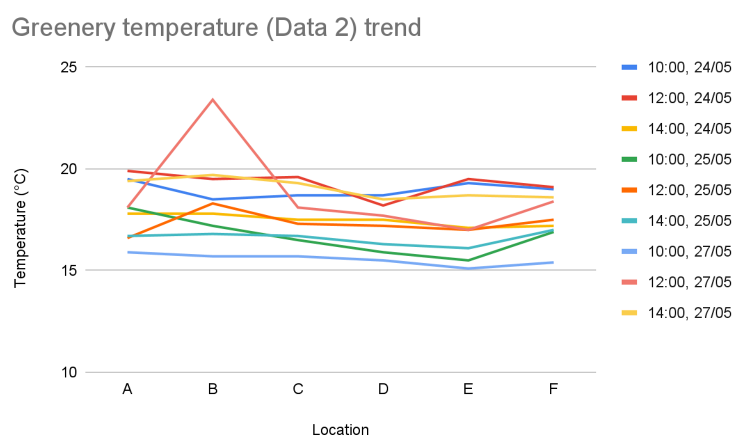


Figure 10: the trend of the greenery temperature due east based on the first data collection

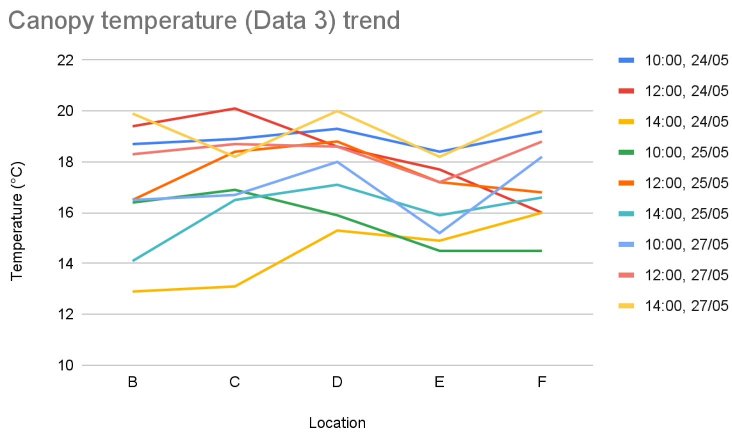


Figure 11: the trend of the canopy temperature based on the first data collection

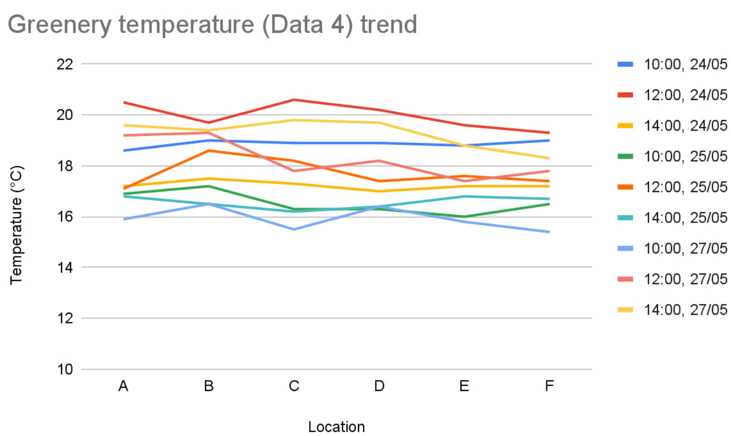


Figure 12: the trend of the greenery temperature due west based on the first data collection

The analysis of the data is found in the discussion section.

5.3 Model building process

Replicating the physical conditions of Bosweg in a simulation model will be used to analyze the impact of the SMA 8G+ mix. As mentioned in the previous sections, the software used to facilitate the simulation model is known as ENVI-met as it is a physics-based program that can take the meteorological conditions of the study area, and along with the built model, it can output the air and surface temperature of the area in a map.

Limited to the free version of ENVI-met 4.0, the study area cannot exceed 50 m by 50 m by 40 m in size. This leaves a problem as the length of Bosweg's section which data was taken from is 100 m. Hence, a 50 m section of the road must be taken. The data from locations A, B and C are taken, as location A has no canopy above the asphalt road, and along with locations B and C, Bosweg's varying canopy density can be modeled in the simulation. Furthermore, it has been determined that the soil type and tree type found in Bosweg are respectively sandy soils and mostly deciduous trees. It should be noted that the tree placement in the model is not to replicate the tree geometry in Bosweg, but rather replicates the canopy density of the vegetation. Figure 13 shows the model of the study area made in Spaces at z=0.

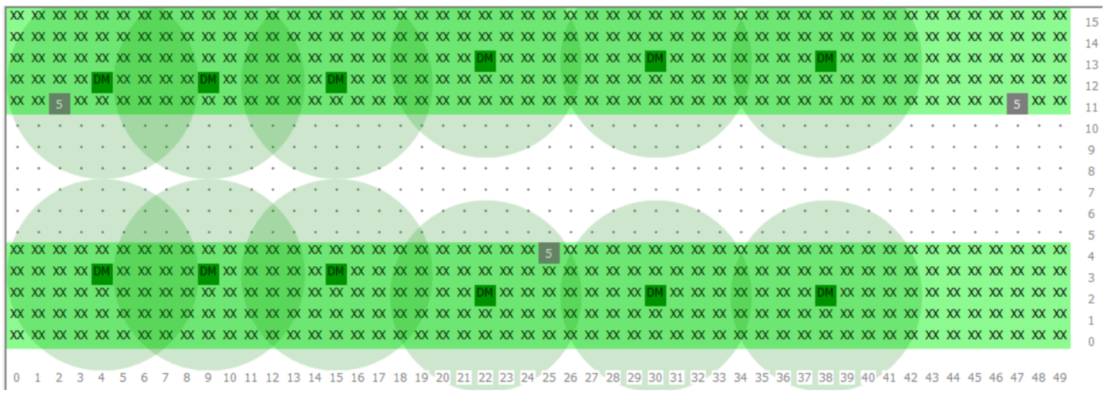


Figure 13: the ENVI-met model of the study area

The numbers placed in the horizontal and vertical axes respectively represent the x (going north-south) and y (going east-west) coordinates. In the figure, there are codes that represent what each tile is occupied by. The green XX tile represents grass, the green DM tile represents the deciduous trees, the gray tile with the number 5 represents the lamp posts located in the area. The white tiles are supposed to represent the asphalt road, but in the modeling process, this is left out as blank tiles. This is because the asphalt road, along with the soil profile of Bosweg will be modeled separately. Figure 14 shows the soil profile of Bosweg.

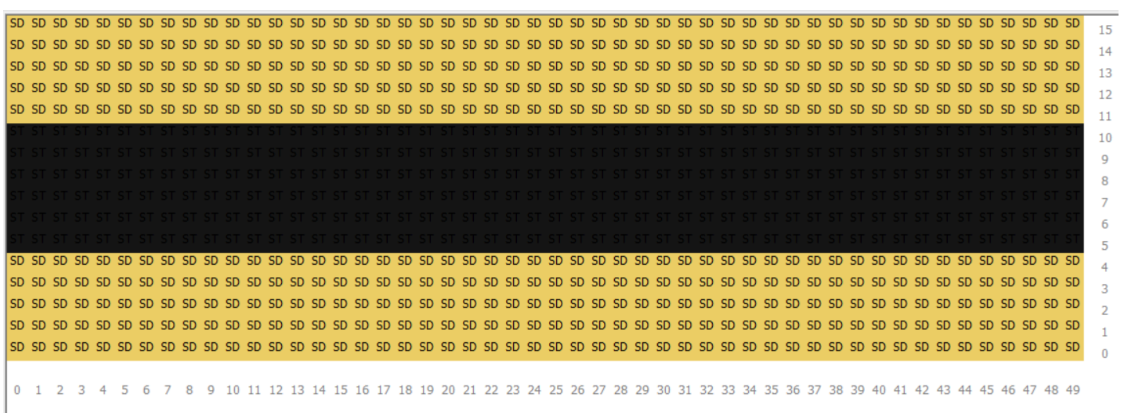


Figure 14: the soil profile model of Bosweg

Similar to figure 13, the numbers placed in the horizontal and vertical axes respectively represent the x (going north-south) and y (going east-west) coordinates. The yellow SD tiles represent the sandy soil that make up Bosweg, while the black portion of the soil profile represents the asphalt road. With the model and the soil profile created, simulation can be run on the model to obtain the air and surface temperature data maps.

To obtain the air and surface temperature data maps of the study area, a SIMX file containing the local temperature and humidity must first be created as an input in ENVI-guide. The local temperature data of Bosweg is provided in appendix 1. While the humidity data is also provided in the same table, ENVI-met does not allow different humidity data for each hour. Hence the average relative humidity data of locations A, B, and C will be used for the simulation. Table 3 shows the summary of the local temperature and relative humidity data used for the simulation.

Table 3: temperature and relative humidity

Date/time	Temperature (°C)	Relative humidity (%)
24/05, 10:00	16.5	69.97
24/05, 12:00	16.5	59
24/05, 14:00	16.5	81.1
25/05, 10:00	19	79.5
25/05, 12:00	20	64.97
25/05, 14:00	21	80.07
27/05, 10:00	16	70.43
27/05, 12:00	17	62.33
27/05, 14:00	18	50.93

The results of the simulation are shown in appendix 3.

5.4 Model accuracy testing

With the modeling results revealed, the model accuracy can be assessed to make sure the model is deemed worthy of use in the sensitivity analysis. The model will undergo validation later in this section.

Assessing the model accuracy will be done with the first data collection and the modeling results shown in appendix 3. Faragallah and Ragheb (2022) utilized the minimum and maximum temperature from their ENVI-met models to analyze the impact of vegetation and high-albedo materials to the local temperature. This method will be used in the analysis. Aside from the temperature data, it is also important to know where in the model this data is located. An example case will be shown in figure 15 to elaborate this point:

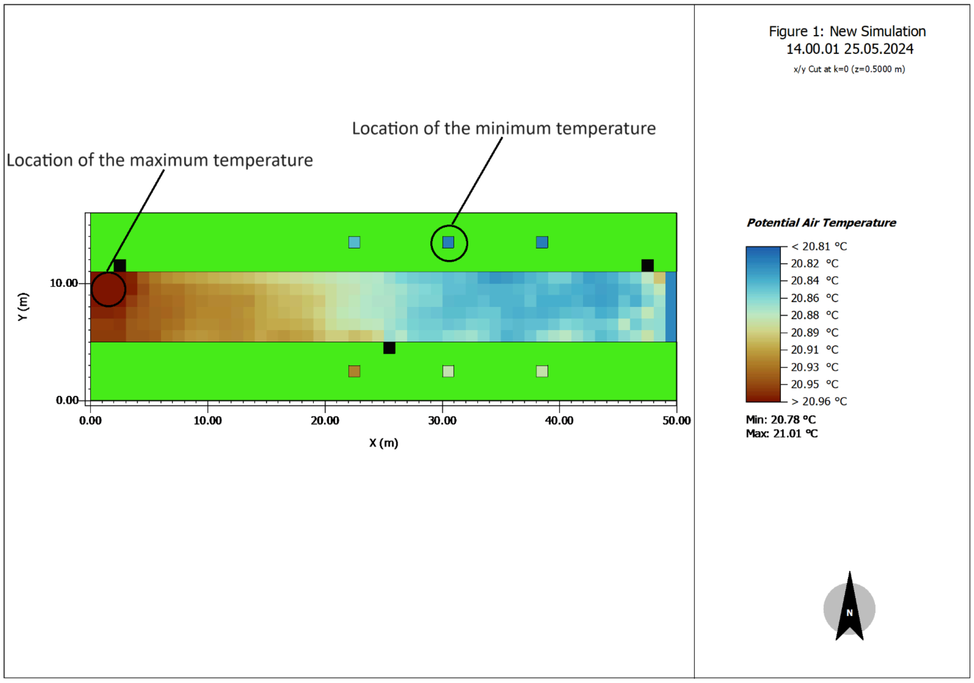


Figure 15: the simulation results from 25th of July, 14:00, used as example

In the figure, it can be seen that the bottom right side of the result has the maximum temperature (marked with dark brown square), while the minimum temperature lies on the right side of the road (marked with blue square). The maximum temperature lies on the greenery of the spot that is closest to location C, while the minimum temperature lies on the road closest to location B. In other words, data 1 in location C and data 2 in location B respectively has the maximum and minimum temperature data. The identification of this data will be done for both model accuracy and model validation. Table 4 shows the maximum and minimum temperature from each simulation result, the location of the data, and the corresponding temperature data from the data collection.

Table 4: data needed to test the model's accuracy

Date/time	Min temp (°C)	Location of data	Temp from DC (°C)	Max temp (°C)	Location of data	Temp from DC (°C)
24/05, 10:00	17.41	B, Data 1	18.4	17.81	A, Data 2	19.5
24/05, 12:00	17.49	B, Data 1	20	17.89	A, Data 4	20.5
24/05, 14:00	17.49	A, Data 1	19.9	17.90	A, Data 4	17.2

25/05, 10:00	19.19	C, Data 1	17	19.43	A, Data 1	18.6
25/05, 12:00	19.98	B, Data 2	18.3	20.20	A, Data 1	18.4
25/05, 14:00	20.78	B, Data 2	16.8	21.01	C, Data 1	17
27/05, 10:00	16.98	C, Data 1	15.9	17.46	A, Data 4	15.9
27/05, 12:00	17.77	B, Data 1	18.3	18.16	A, Data 4	19.2
27/05, 14:00	18.85	A, Data 1	21.9	18.8	C, Data 1	19.6

From this table, it can be seen that the model has an inaccuracy of 2-3°C, meaning that the model is decently accurate To quantify the accuracy of the model, the following equation will be used to calculate the percentage error:

$$\% \, error \; = \; \left| \frac{Experimental\ value - actual\ value}{Actual\ value} \right| \times 100\%$$

Where the experimental value corresponds to the value from the simulation model and the actual value corresponds to the value from the data collection. The model is deemed accurate if the percentage error for the minimum and maximum temperature does not exceed 15%. The reason why such a lenient number is picked is because a small difference in temperature will cause a substantial error in the result. The calculated percentage error is shown in table 5.

Table 5: the error results of the model accuracy

Date/time	Minimum temperature % error	Maximum temperature % error
24/05, 10:00	5.38	8.67
24/05, 12:00	12.55	12.37
24/05, 14:00	12.11	4.07
25/05, 10:00	12.88	4.46
25/05, 12:00	9.18	9.78
25/05, 14:00	23.69	23.59
27/05, 10:00	6.79	9.81

27/05, 12:00	2.89	5.42
27/05, 14:00	15.3	4.08

As seen from table 5, there are three error percentages that exceed 15%, meaning 2 out of the first 9 simulation maps are inaccurate. This error is likely caused by a mistake in collecting data, where the thermal camera has not been calibrated before taking the reading. However, with the majority of the simulation maps being accurate, the model can be deemed accurate. This completes testing for model accuracy, and the model validation and sensitivity analysis can be carried out on this simulation model after the results of the data collection after the road maintenance has been revealed.

5.5 Stakeholder analysis - Interview with Strukton's Bosweg Project Manager

The demands of the municipality need to be taken into consideration as without its permission the road maintenance will not undergo realization. As such, the demands are revealed by interviewing Mr. Arnold ten Hove from Strukton, the project manager of the maintenance. Each question asked during the interview will contain the question itself, the motive for each question and the answer of the question. Furthermore, from this interview, the research student is able to obtain Strukton's plan of approach to maintain Bosweg, and this confidential document will be used to supplement the answers from Mr. ten Hove's interview.

>Why did the municipality decide to put Bosweg under maintenance?
Formulating this question will reveal the municipality of Enschede's purpose to put Bosweg under maintenance which will help to gain insight to their intentions. Mr. ten Hove answered by stating that the asphalt in Bosweg's road was due for a replacement, citing the old age of the asphalt as the main purpose. He added that asphalt needs to be replaced every 16 years, and with today's research done to asphalt, the use phase can be extended to 25 years which can cut costs of the municipality and promote sustainability.

>Who proposed the idea of using the SMA 8G+ mix for the Bosweg maintenance? What was the intention of using such a mix, compared to a traditional asphalt mix?
This question was designed to investigate the motivation behind using the SMA 8G+ mix on the asphalt layer. Mr ten Hove admitted that Strukton came up with the idea of using the mix in question, and there are few reasons to use such a mix, listed below:

- Improve durability: Mr. ten Hove mentioned increasing the durability of the new asphalt road by extending its use phase from 16 to 25 years. Using the SMA 8G+ mix accomplishes this by introducing an unknown modified bitumen (Strukton, 2024). They also added that the light-colored property is able to reflect up to 30% more of incoming light, leading to a reduction of heat stress and thus longer use phase. A benefit with improving the durability and use phase of the asphalt is the decreased need for maintenance to replace the road.

- Reduce CO_2 emissions: Because of its 30% more light reflection, less lighting is required to maintain the visibility of Bosweg's users. This means that less energy is required to power the lamp posts, and consequently, less carbon footprint from the area.
- Reduce material consumption: Another way to reduce CO_2 emissions is by using recycled asphalt, where Mr. ten Hove explained that the first two layers will be made out of 100% recycled asphalt sourced from Tiel, eliminating the need to produce new asphalt and thus reducing emissions. Furthermore, with no new bitumen added and a commitment by Strukton to lower production temperature from 165°C to 140°C (Strukton, 2024), a 32% reduction of CO_2 emissions during construction will be achieved. The last layer of the road will be made from recycled asphalt, sourced from Amsterdam, which will make up 65% of the asphalt needed to complete the layer.

From Mr. ten Hove answers, it is clear that the municipality is interested in improving the durability of the road, promoting sustainability and circularity by using recycled asphalt and reducing CO_2 emissions.

5.6 Stakeholder analysis - road user survey

Taking into consideration the demands of the road users is as important as the municipality's demands, as Bosweg supports the habits of Enschede's inhabitants including the students and staff of the UT. Revealing the demands of the road users will take the form of a survey that judges several criteria that will be defined below. Each criterion will be scored from 1 to 5, where a score of 1 shows that the criterion is not relevant at all and a score of 5 shows that the criterion is very relevant, thus with each increasing score having an increase of importance. The questionnaire of the survey is found in appendix 6.

- Road availability: This refers to the availability of Bosweg for public use. This is considered to be an important criterion as a road unavailable for public use is unable to keep up with the habits of its inhabitants. However, some people do have an alternative to Bosweg in case it becomes unavailable, and this criterion is asked to judge the responders perception about the importance of having an available Bosweg.
- Proper infrastructure: The Dutch habit to cycle for commuting is supported by two reasons, one of them being the proper infrastructure to facilitate such a habit. Hence, a proper infrastructure such as a functional road completed with traffic signs is considered a criterion.
- Road visibility: visibility meets the requirement to be an important criterion as it ensures the safety of the road users. Similar to the first two criteria, this is asked to judge the responders perception about the importance of a visible road.
- Comfortable thermal conditions: if the area becomes a nuisance to go through because of its thermal conditions affected by its built environment, users are more likely to find an

alternative to that area. This criterion is asked to judge the importance of an area having a similar or the same temperature compared to the local temperature.

During the survey, the research student has to explain what each criterion is, what it means and help with any confusions the responders have about the survey. The results of the survey can be seen in table 6.

Table 6: survey results

	Criteria	Answers
Respondent 1	Road availability Proper infrastructure Road visibility Comfortable thermal conditions	4 5 4 3
Respondent 2	Road availability Proper infrastructure Road visibility Comfortable thermal conditions	3 4 3 4
Respondent 3	Road availability Proper infrastructure Road visibility Comfortable thermal conditions	3 2 3 5
Respondent 4	Road availability Proper infrastructure Road visibility Comfortable thermal conditions	2 3 3 4
Respondent 5	Road availability Proper infrastructure Road visibility Comfortable thermal conditions	1 4 3 5
Respondent 6	Road availability Proper infrastructure Road visibility Comfortable thermal conditions	3 3 2 4

From these sets of answers, the importance of criteria can be ranked by calculating the average score for each criterion. The order from highest to lowest is comfortable thermal conditions (average of 4.17), proper infrastructure (average of 3.5), road visibility (average of 3) and road availability (average of 2.67). The ranking shows that the most important criterion is comfortable thermal condition, showing the importance of having vegetation and shade to cope with the UHI effect. This importance is also proven by road availability coming last, implying that while Bosweg is an important street, the responders do have an alternative if the road becomes unavailable.

5.7 Data collection after the road maintenance

A second data collection was held on the 18th, 19th and 21st of July to give baseline temperature data for the initial impact of the SMA 8G+ mix to the air temperature data of Bosweg and for the validation of the simulation model. The result of the second data collection is presented in appendix 2. It should be noted that for the last day of the second data collection the weather was unconducive, resulting in the suspension of the last session (21st of July, 14:00). This was replaced on the 24th of July. Similar to the first data collection, the trends of the surface, greenery, and canopy temperature will be shown.

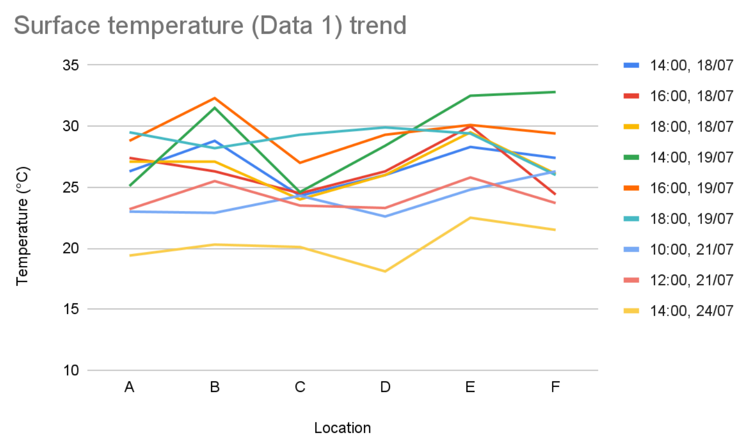


Figure 16: the trend of the surface temperature based on the second data collection

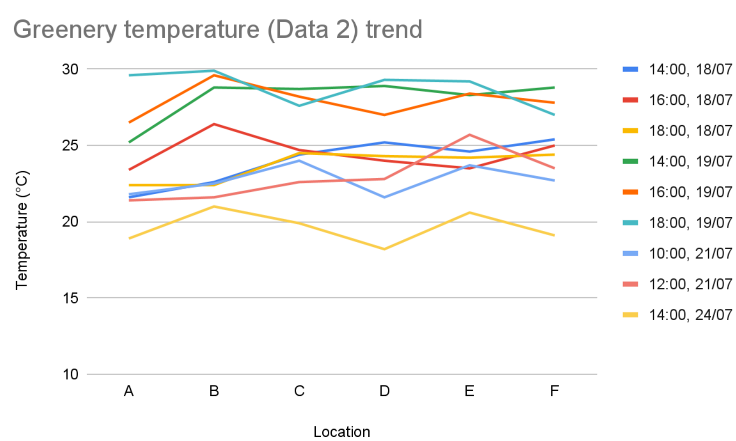


Figure 17: the trend of the greenery temperature due east based on the second data collection

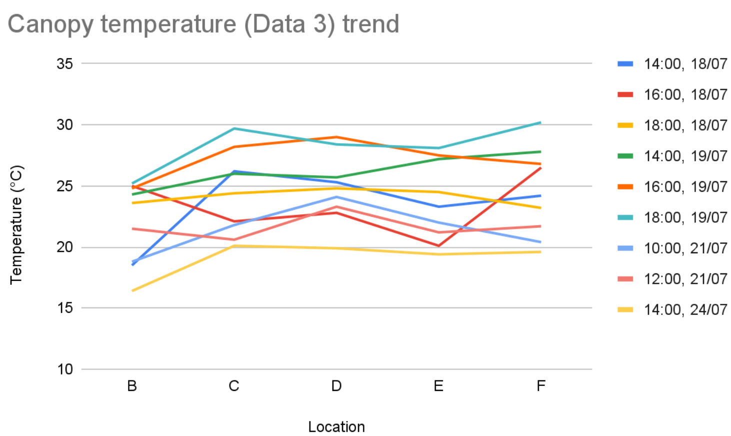


Figure 18: the trend of the greenery temperature due east based on the second data collection

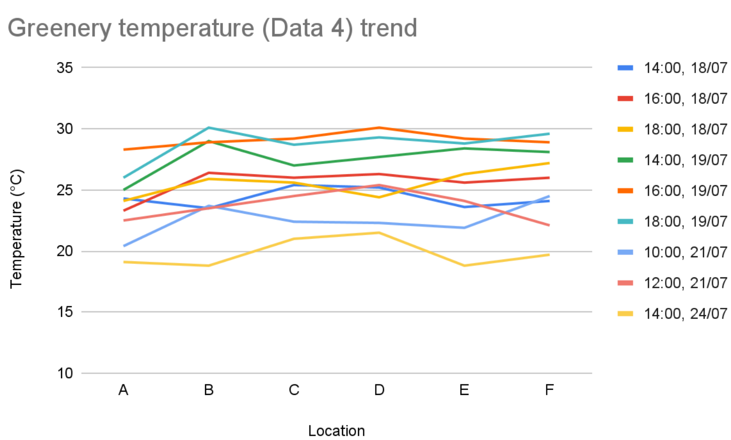


Figure 19: the trend of the canopy temperature based on the second data collection

5.8 Model validation

Model validation is performed to ensure that the model's accuracy will still hold when it is tested against a different data set. The procedures of model validation will be similar to testing for model accuracy, but it is tested against the temperatures obtained from the second data collection. The results of the simulation are shown in appendix 4, while table 7 shows the local temperature and relative humidity data used for the SIMX file.

Table 7: the temperature and relative humidity data used for model validation

Date/time	Temperature (°C)	Relative humidity (%)
18/07, 14:00	26	54.7

18/07, 16:00	27	58.17
18/07, 18:00	27	58.93
19/07, 14:00	28	50.53
19/07, 16:00	29	49.3
19/07, 18:00	29	50.23
21/07, 10:00	24	84.17
21/07, 12:00	26	84.6
24/07, 14:00	23	64.4

Table 8 shows the minimum and maximum temperature data from each simulation map and the location of the data. The corresponding temperature from the data collection is also shown in the same table.

Table 8: data needed to perform model validation

Date/time	Min temp (°C)	Location of data	Temp from DC (°C)	Max temp (°C)	Location of data	Temp from DC (°C)
18/07, 14:00	24.64	B, Data 2	22.6	25.17	A, Data 1	26.3
18/07, 16:00	25.44	B, Data 2	26.4	26.04	A, Data 1	27.4
18/07, 18:00	25.47	B, Data 2	22.4	26.07	C, Data 1	24
19/07, 14:00	25.95	B, Data 2	28.8	26.98	A, Data 1	25.1
19/07, 16:00	26.72	B, Data 2	29.6	27.87	A, Data 1	28.8
19/07, 18:00	26.79	B, Data 2	29.9	27.86	A, Data 1	29.5
21/07, 10:00	23.01	B, Data 2	22.5	23.43	A, Data 1	23
21/07, 12:00	24.48	B, Data 2	21.6	25.20	A, Data 1	23.2

24/07, 14:00	22.31	B, Data 2	21	22.68	C, Data 1	20.1

With this table completed, the process of validation can continue with calculating the percentage error. The calculated percentage error is shown in table 9.

Table 9: percentage error for model validation

Date/time	Minimum temperature % error	Maximum temperature % error
18/07, 14:00	9.03	4.30
18/07, 16:00	3.63	4.96
18/07, 18:00	13.71	8.63
19/07, 14:00	9.90	7.49
19/07, 16:00	9.73	3.23
19/07, 18:00	10.40	5.56
21/07, 10:00	2.23	1.87
21/07, 12:00	13.33	8.62
24/07, 14:00	6.24	12.84

From table 9, it can be seen that all of the error percentage is below 15%, which means that the model passes the validation test, and can simulate warmer temperatures (23-29°C) better than cooler temperatures (16-20°C) due to its lower overall error percentage. With the model deemed as valid, it can undergo sensitivity analysis where the albedo value is modified to analyze the change in maximum and minimum temperature.

5.9 Sensitivity analysis

Sensitivity analysis will be performed to assess the contribution of the SMA 8G+ mix to the air and surface temperature in Bosweg. This analysis will show the contribution of various albedo values to the area's air and surface temperature. To perform such an analysis, the albedo value of the asphalt will be increased by 10%, 20% and 30%, giving new albedo values of 0.22, 0.32, and 0.42 respectively. The cap of 30% increase is in line with Strukton's claim that the mix is able to reflect 30% more light (Strukton, 2024). This modification is done in the database, where a new material is created from the default asphalt surface provided in the software.

Unfortunately, after applying the changes described in the previous paragraph, the simulation results yield no changes in the maximum and minimum temperature and the resulting simulation map looks the same to the maps where the albedo value is set to be 0.12 in the ENVI-met database. In other words, the minimum and maximum temperature data depicted in tables 4 and 8, and the maps found in appendix 3 and 4 is also the result of the simulation after applying the changes in albedo value. This error will be assessed in the discussion section.

It should be noted, however, that the removal of vegetation does slightly change the minimum and maximum temperature data. The simulation maps that depict this change are shown in appendix 5, while table 10 shows the minimum and maximum temperature data from the simulation. In this hypothetical scenario, only the vegetation is removed, and the conditions from the second data collection is used, while the other parameters stay the same.

Table 10: the minimum and maximum temperature data when vegetation is removed

Date/time	Minimum temperature (°C)	Maximum temperature (°C)
18/07, 14:00	24.66	25.19
18/07, 16:00	25.19	26.08
18/07, 18:00	25.42	26.05
19/07, 14:00	25.92	27.00
19/07, 16:00	26.72	27.9
19/07, 18:00	26.78	27.89
21/07, 10:00	23.10	23.43
21/07, 12:00	24.47	25.21
27/05, 14:00	22.36	22.59

The results of the sensitivity analysis concludes this section and will be continued by the discussion chapter.

6. Discussion

The discussion section assesses the results achieved from the previous section, and aims to answer the sub-research questions defined earlier.

6.1 Sub-research question 1

In section 1.3, sub-research question 1 was defined as "What are the geographical factors affecting air and surface temperature in an urban area?" and this will be answered by using the results from the physical visitation of the study area.

From the results of the visitation, the research student is able to deduct that the listed geographical factors affect the air and surface temperature of an urban area:

- Presence of vegetation and greenery: The presence of vegetation and greenery surrounding Bosweg contributes to its cool temperatures even in the summer heat as the vegetation increases the rate of transpiration. This interaction is explained by the complex system of leaf cells where it retains more water. Furthermore, by surrounding the area with vegetation, the study area is covered by shade as a result of the overlapping leaves casting a layer of canopy. The forming canopy blocks in the incoming light and solar radiation, which disallows the asphalt from absorbing it and in turn, maintain temperatures similar to its surroundings and prevent the formation of UHI. The importance of having shade in an urban area cannot be understated as it gives low-albedo materials to not receive as much radiation to emit, especially at night times.
- Decreased use of material with low albedo and/or low thermal emittance: In their research (Faragallah & Ragheb, 2022), it has been observed that materials with high albedo and high thermal emittance are capable of lowering the minimum and maximum temperatures in an urban area. Similarly, an area with decreased use of materials with low albedo and low thermal emittance such as concrete and bricks is able to keep itself cool. This is the case with Bosweg, as there are significantly less housing and human activities in the study area.
- Decreased sources of anthropogenic heat: Anthropogenic heat sources, known as heat sources produced by human activities, as seen with less houses and business found in the area.
- Cultural reasons: While not considered as a geographical factor, the Dutch culture to cycle for commuting is deeply rooted to its society and is supported by its road infrastructure. This significantly decreases the vehicle users and in turn, the amount of emissions and anthropogenic heat produced from those vehicles.

With strategic urban planning, the aforementioned geographical factors keep an urban area cool and are the factors that affect the air and surface temperatures of an urban area. With these factors revealed, the first sub-research question is answered and the following sections are written to answer sub-research question 2.

6.2 Sub-research question 2

In section 1.3, sub-research question 2 was defined as “What is the desired situation in Bosweg, and how can SMA 8G+ asphalt mix help reach such a desired situation?” and this sub-research question will be answered by dividing it into three parts. First, the temperature conditions in Bosweg will be described with the data from appendix 1. Then, the desired situation will be described by summarizing the demands from the municipality of Enschede and Bosweg’s road users. The contribution of the SMA 8G+ mix will be assessed on how each demand is fulfilled by its properties.

Describing the current situation, which is the condition of Bosweg before the road maintenance is performed by completing a data collection, gathering the air and surface temperatures in the study area. With the procedures of the data collection and the types of data required described in the methodology section, the results of collecting temperature data before the road maintenance is shown in appendix 1.

From the results of the initial data collection, it can be seen that the surface and air temperatures have similar values to the local temperature. This is likely caused by the relatively cool temperatures in May, and also the vegetation in Bosweg keeping the UHI effect at a minimum. From this, it is unclear whether the asphalt in Bosweg exacerbates the UHI effect, but judging from the surface temperature data (data 1), the asphalt does display slightly higher average temperatures (19.54 °C) compared to the average local temperatures (17.83 °C) during the 9 sessions of data collection. This implies a less of heat island effect shown with warmer temperature from the data, but can also be caused by the fact that asphalt tends to absorb more solar radiation due its low albedo value.

In comparison, the average greenery (data 2 & 4) and canopy (data 3) temperatures reached 17.78 °C and 17.27 °C respectively which were below the average local temperature. From this information, it can be concluded that Bosweg is able to keep itself cool during temperatures of 16 to 21 °C, caused likely by its dense vegetation, less anthropogenic heat, and minimal human activities.

Aside from the temperature data, Bosweg has adequate lighting that provides visibility and thus safety to its users with the presence of lamp posts 17 m apart from each other. Using the SMA 8G+ mix presents an opportunity for improvement for visibility, as the lighter color of the asphalt mix will increase light reflection. This is important during the day time and winter season as the visibility of the users may be compromised by the shade blocking off light (at day time) and early sunsets during the winter time demanding visibility more than the summer season.

The condition of Bosweg before its maintenance is clear; it is an area dense with vegetation and adequate visibility, creating an area comfortable to cyclists and pedestrians. However, with warmer temperatures imminent due to the upcoming summer season forming the UHI effect, there is a demand for technologies to cope with this effect.

The summary of the demands of the stakeholder will be listed next, taken from the interview with Mr. ten Hove and the survey from the road users.

- Improve road durability and visibility: Improving road durability not only cuts costs for maintenance due to its longer use phase, but also ensures that proper infrastructure is maintained in Bosweg for its users. By replacing the road in the maintenance, the road durability is improved by extending its use phase from 16 to 25 years (Strukton, 2024). Also, the light-colored nature of the asphalt is capable of reflecting 30% more light, both improving the visibility of the road and also exerting less heat stress to the asphalt road.
- Reduce CO_2 emissions by recycling material: As mentioned in the interview, recycled asphalt is used to make up the layers of the road in Bosweg. This prevents the release of emissions from the manufacturing of new asphalt for the construction of the road. Furthermore, the commitment of reducing production temperatures from 165°C to 140°C will reduce CO_2 emissions by 32% (Strukton, 2024).
- Ensuring an available Bosweg for public use: While not as important as the other demands, it is important for Bosweg to remain available for public use to support the habits of its inhabitants. The road maintenance ensures the availability of Bosweg in the next 25 years, barring any natural disasters that may compromise the infrastructure in the study area.

One unanswered question however, is the impact of the SMA 8G+ mix to the air and surface temperature as the sensitivity analysis run on ENVI-met fails to show a difference when the albedo value is increased from 0.12 to 0.42. When comparing the simulation model to the model built by Faragallah and Ragheb (2022), the persistent maximum and minimum temperature data can be attributed to the absence of high-rise buildings forming urban canyons which contributes to the formation of heat islands in the urban canopy layer due to the transfer of heat from the atmosphere to the asphalt. This means that, if the study area was relocated to a busier area, for example, the city center, where high rise buildings are commonly found and less vegetation will be present, it is expected that the air and surface temperature will be more sensitive to the albedo of the area's surface. In the future, another data collection can be held to analyze the air and surface temperature when the color of the asphalt mix has fully settled, where the bitumen's dark color will fade due to wear and tear from vehicle use (Graniterock, n.d.).

6.3 Sub-research question 3

Answering the last sub-research question will conclude the discussion section. Sub-research question 3 is defined as "Can the SMA 8G+ asphalt mix be used as a recommendation in policies that plan to lower temperatures in urban areas and improve asphalt durability?", and it will be answered based on what has been noted in the results and earlier in the discussion sections.

Policy planning in civil engineering has developed from focusing on improving material quality due to the technological advancement from the industrial revolution (Sjøholt, n.d.) to an emphasis of sustainability and material circularity, leading to a paradigm shift of a sustainable civil engineering. Many frameworks have been formed to align and assess the progress for this paradigm shift, including the UN's SDGs. Specifically, goal 9 from the framework has promised to promote sustainable infrastructure development (United Nations Department of Economic and Social Affairs, n.d.), leading to much research on technologies that can help cope with the UHI effect. These technologies include the use of reflective coating, cool pavements and in the case of this research, light-colored asphalt mixes.

The use of light-colored asphalt mixes, specifically the SMA 8G+ mix, has brought many benefits in bringing environmental sustainability to an urban area. It can help improve asphalt durability and road durability by alleviating heat stress due to its higher light reflection, reduce 32% of CO_2 emissions by using recycled asphalt, save maintenance costs and improve road availability by extending its use phase from 16 to 25 years (Strukton, 2024). Due to its advantages, it can be recommended as a policy to lower the temperatures in an urban area, and can help cope with the UHI effect. However, these benefits are still to be proven, as the color of the asphalt mix has yet to appear and its effect thus cannot be fully analyzed for now. For future works, analyzing the surface and air temperatures can be performed through a data collection described in section 4.2. The new data can be compared with the data from the second collection, where the claims of this research can be proven or disproven.

7. Conclusion

Due to the increased demand for energy for cooling as a result of the ever-expanding urban areas, city planners have employed methods to cope with the UHI effect. The consequences of this effect is not to be underestimated - as higher temperatures in an urban area can compromise the habits, and more importantly, the health of its inhabitants.

While technologies such as reflective coating and cool pavements have been explored by past research, a method that has yet to be explored is the use of the SMA 8G+ mix, a stone mastic asphalt mix that utilizes 8 mm sized light stone aggregates to reflect more solar radiation, thereby alleviating heat stress and the UHI effect. According to the report from Strukton (2022), the use of the mix results in a 32% reduction of CO_2 emissions with the use of recycled asphalt, and a 30% more light reflection, but it should be noted that these claims are still to be tested.

However, an assessment of the mix's contribution to the air and surface temperatures has yet to yield a result due to the conditions of Bosweg, as its built environment of dense vegetation and shade can also help to cope with the UHI effect, highlighting the importance of urban planning to include plants and trees in area to keep temperatures cool.

In conclusion, vegetation, shade, the albedo and emissivity values of material are geographical factors that affect the air and surface temperature of an urban area. The SMA 8G+ mix can contribute to coping with the UHI effect due to its higher light reflection and the reduction of CO_2 emissions, and for this reason, this mix can be recommended as a policy to help urban planners to cope with the UHI effect.

In future works, the author wishes to conduct a data collection where the color of this mix has settled to gauge the difference of air and surface temperatures from using the SMA 8G+ mix. If an opportunity arises, using the mix in areas with more anthropogenic activities is more relevant, as these areas are filled with higher use of low-albedo materials and less vegetation compared to Bosweg, and as seen from table 1, these factors result to warmer temperatures and implies the presence of UHI.

8. Appendix

This section mainly contains the simulation results from applying the SIMX file to the model. It also contains the results of the data collection.

Appendix 1: the results of the initial data collection

Time/date	Location	Weather condition	Data 1 (°C)	Data 2 (°C)	Data 3 (°C)	Data 4 (°C)	Data 5 (°C)	Data 6 (°C)	Data 7 (°C)	Data 8 (°C)	Data 9 (%)
10:00/24/05	1	Drizzle/16-17 °C	20.5	19.5	-	18.6	19.1	19.4	18.6	20.7	71.1
	2		18.4	18.5	18.7	19	18.8	19.2	16.8	20	66.6
	3		17.5	18.7	18.9	18.9	18.7	19.2	15.3	18.9	72.2
	4		17.9	18.7	19.3	18.9	18.8	19.8	15.1	20.4	64.6
	5		18.5	19.3	18.4	18.8	19.1	19.6	15.7	19.5	68.9
	6		17.8	19	19.2	19	19.7	19.5	16.5	21.2	63.9
12:00/24/05	1	Light rain/16-17 °C	23.1	19.9	-	20.5	19.5	20.8	20.2	21.7	60.7
	2		20	19.5	19.4	19.7	19.8	20.3	17.6	20.6	59.7
	3		18.5	19.6	20.1	20.6	19.7	20	16.4	21.9	56.6
	4		18.7	18.2	18.6	20.2	19.5	19.3	16.9	21.9	56.6
	5		18.8	19.5	17.7	19.6	19.4	20	17.3	21.9	56.6
	6		18.8	19.1	16	19.3	19.9	19.9	16.9	21.9	56.6
14:00/24/05	1	Light rain/16-17 °C	19.9	17.8	-	17.2	17.4	17.7	18.5	18.2	77.1
	2		18.7	17.8	12.9	17.5	17.4	17.4	17.1	18.1	81.8
	3		18	17.5	13.1	17.3	17.3	17.2	16.1	17.5	84.4
	4		18.3	17.5	15.3	17	18.5	17.2	16.5	18	84.6
	5		18.8	17.1	14.9	17.2	17.4	17.5	17	18	82.5
	6		18.3	17.2	16	17.2	17.3	17.4	16.7	17.7	83.9
10:00/25/05	1	Cloudy/19 °C	18.6	18.1	-	16.9	17	17.4	17.1	18.3	76.9
	2		17.3	17.2	16.4	17.2	16.3	17.6	15	17.1	85.1
	3		17	16.5	16.9	16.3	16.9	17.6	14.7	19	76.5
	4		17.3	15.9	15.9	16.3	16.5	17.6	15	17.1	86.4
	5		17.3	15.5	14.5	16	16.9	16.9	15.6	19.5	78
	6		17.5	16.9	14.5	16.5	17.8	17.6	15.5	18.4	85.1
12:00/25/05	1	Cloudy/20 °C	18.4	16.6	-	17.1	17.3	17	15.4	22	61.7
	2		17.9	18.3	16.5	18.6	17.9	18.5	14.2	19.7	67.4

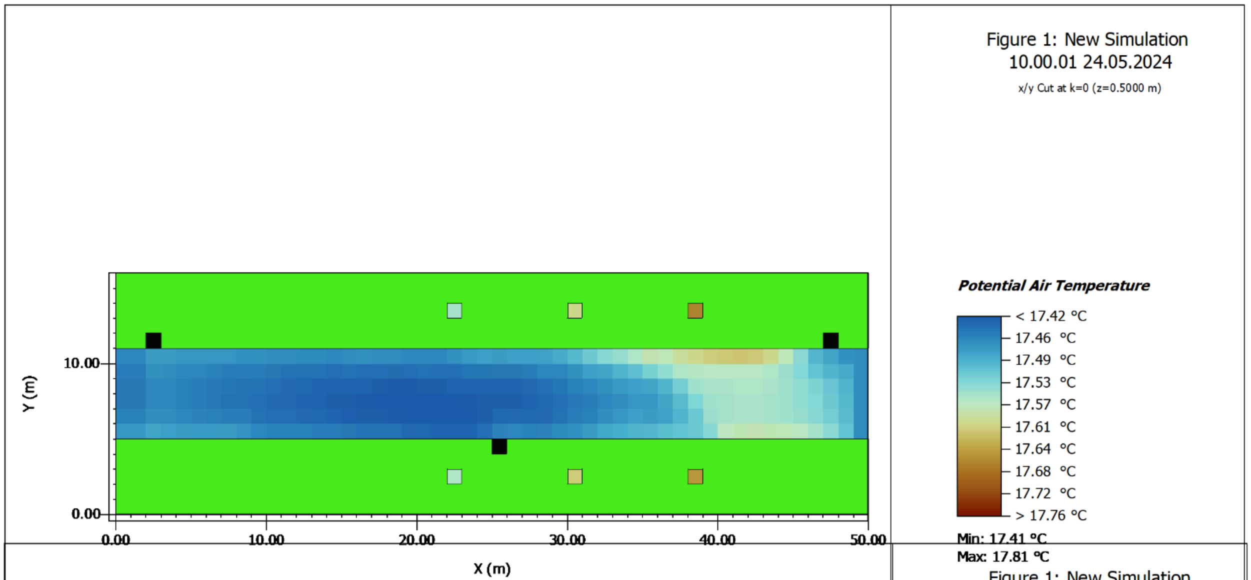
	3		17.4	17.3	18.4	18.2	18.5	18.8	14.9	20.6	65.8
	4		18.8	17.2	18.8	17.4	17.5	18.9	16.2	19.2	76.9
	5		18.4	17	17.2	17.6	18.8	19.7	16	18.6	76.2
	6		17.9	17.5	16.8	17.4	17.8	18.1	15.6	18.9	72.6
14:00/25/05	1	Cloudy/ 21 °C	18.8	16.7	-	16.8	15.8	16.9	18.2	17.4	79.1
	2		18	16.8	14.1	16.5	16.7	16.5	16.3	17.4	80.2
	3		17	16.7	16.5	16.2	16.9	16.9	15.8	17.5	80.9
	4		17.5	16.3	17.1	16.4	16.4	17.6	15.8	17.4	81.1
	5		18	16.1	15.9	16.8	16.8	17.5	16	17.6	78
	6		17.4	17	16.6	16.7	17.2	17.7	15.7	18.4	73
10:00/27/05	1	Cloudy/ 16 °C	16.6	15.9	-	15.9	15.3	16.4	15.5	17.5	68.4
	2		15.9	15.7	16.5	16.5	17	17.2	15	17	71.8
	3		15.9	15.7	16.7	15.5	16.6	17	14.6	17.1	71.1
	4		16.4	15.5	18	16.4	16.4	17.1	15.2	17.2	73.5
	5		17	15.1	15.2	15.8	17.5	16.5	15.1	17.2	75.4
	6		16.6	15.4	18.2	15.4	16.5	16.9	14.9	18.8	70.7
12:00/27/05	1	Partly sunny/ 17 °C	18.1	18.1	-	19.2	18.5	18.8	17.7	18.8	59.5
	2		18.3	23.4	18.3	19.3	18.4	19.1	17.4	18.4	60.2
	3		17	18.1	18.7	17.8	19	19.2	16.2	17.8	67.3
	4		19.7	17.7	18.6	18.2	18.7	17.8	18.1	18.4	67.5
	5		18	17	17.2	17.4	18.6	19	17	18.7	64
	6		17.1	18.4	18.8	17.8	17.4	19.1	16.3	20.1	59.6
14:00/27/05	1	Cloudy/ 18 °C	21.9	19.4	-	19.6	20.1	20.9	18.5	21	49.9
	2		23	19.7	19.9	19.4	20	22.6	26.7	20.1	50.4
	3		19.6	19.3	18.2	19.8	20.2	22.4	16.6	20.1	52.5
	4		19.8	18.5	20	19.7	19.6	21.6	16.3	19.8	57.1
	5		24.9	18.7	18.2	18.8	20.1	21.7	18.3	19.9	60.4
	6		18.8	18.6	20	18.3	20.9	21.3	16.8	20.1	58.2

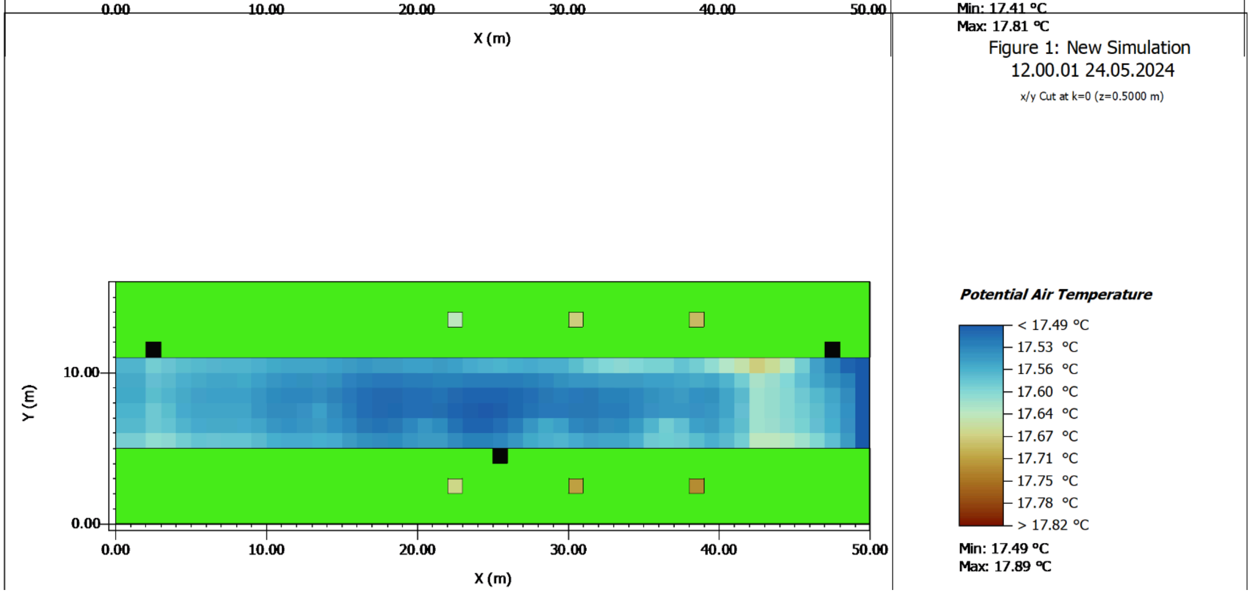
Appendix 2: the results of the second data collection

Time/date	Location	Weather condition	Data 1 (°C)	Data 2 (°C)	Data 3 (°C)	Data 4 (°C)	Data 5 (°C)	Data 6 (°C)	Data 7 (°C)	Data 8 (°C)	Relative Humidity (%)
14:00/18/07	1	Sunny/26 °C	26.3	21.6	-	24.3	23	25.4	23.4	20.1	53.4
	2		28.8	22.6	18.5	23.5	24.8	25.9	26.8	18.9	52
	3		24.3	24.4	26.2	25.4	24.1	24.1	18.1	20.2	58.7
	4		26	25.2	25.3	25.2	22.6	23.3	19.6	19.8	60.1
	5		28.3	24.6	23.3	23.6	27.8	26.8	23.5	20.1	60.6
	6		27.4	25.4	24.2	24.1	26.1	26.8	20.1	20.1	60.6
16:00/18/07	1	Sunny/27 °C	27.4	23.4	-	23.3	26.8	22.4	24.7	20.7	59
	2		26.3	26.4	25	26.4	27.1	26.2	24.6	20.2	58.9
	3		24.5	24.7	22.1	26	27.1	28.8	18.4	20	56.6
	4		26.3	24	22.8	26.3	27.2	28.1	18.5	19.6	59.1
	5		30	23.5	20.1	25.6	28.2	28.2	20.4	20.3	56.9
	6		24.4	25	26.5	26	27.2	26.8	18.9	20.2	61.5
20:00/18/07	1	Sunny/27 °C	27.1	22.4	-	24.1	22.7	24.2	22.8	20	56.5
	2		27.1	22.4	23.6	25.9	26	26.2	22.1	20.1	60.6
	3		24	24.5	24.4	25.6	26.2	25.7	19.4	19.9	59.7
	4		26	24.3	24.8	24.4	25.2	28.9	19	19.5	62.8
	5		29.5	24.2	24.5	26.3	28.2	28.9	22.5	20.3	61.3
	6		26.1	24.4	23.2	27.2	26.8	25.8	20.3	19.8	62.6
14:00/19/07	1	Sunny/28 °C	25.1	25.2	-	25	27.7	27.2	27	22.3	56.6
	2		31.5	28.8	24.3	29	29.3	30.6	29.7	20.6	45.6
	3		24.6	28.7	26	27	26.1	30.3	23.5	20.1	49.4
	4		28.4	28.9	25.7	27.7	27.2	27.5	24.4	20.4	53.7
	5		32.5	28.3	27.2	28.4	27.4	27.9	27.8	20.4	50.5
	6		32.8	28.8	27.8	28.1	29.1	27.8	25	20.5	50.1
16:00/19/07	1	Sunny/29 °C	28.8	26.5	-	28.3	27.7	26.3	26.9	20.7	50.1
	2		32.3	29.6	24.8	28.9	29.4	29.3	26.3	20.3	47.6
	3		27	28.2	28.2	29.2	28.9	27	22.2	20.1	50.2

	4		29.3	27	29	30.1	27.2	32.2	23.3	20.3	51
	5		30.1	28.4	27.5	29.2	29.7	30.4	26.1	20.3	54.2
	6		29.4	27.8	26.8	28.9	28.5	29.7	24.4	20.2	55.3
20:00/19/07	1	Sunny/29 °C	29.5	29.6	-	26	25.9	28.9	27	21	49.8
	2		28.2	29.9	25.2	30.1	28.3	27.4	24.5	20.3	52.6
	3		29.3	27.6	29.7	28.7	27.6	30.3	21	20.4	48.3
	4		29.9	29.3	28.4	29.3	29.3	28.3	21	19.8	50.7
	5		29.4	29.2	28.1	28.8	29.2	29.1	20.8	20.1	55.6
	6		26	27	30.2	29.6	28.5	28.1	20.3	20.3	54
10:00/21/07	1	Cloudy/ 24 °C	23	21.8	-	20.4	20.6	18.2	22.6	21.5	83.6
	2		22.9	22.5	18.8	23.7	21.6	22.3	22.3	21.1	85.7
	3		24.3	24	21.8	22.4	24.6	24.4	17.7	21.5	83.2
	4		22.6	21.6	24.1	22.3	23.7	23	17.3	21.1	87.8
	5		24.8	23.7	22	21.9	25.5	24	15.3	21.4	84.4
	6		26.3	22.7	20.4	24.5	22.9	24.6	14.4	21	88.2
12:00/21/07	1	Cloudy/ 26 °C	23.2	21.4	-	22.5	22.6	22.5	21.7	22.8	82.5
	2		25.5	21.6	21.5	23.5	22.6	22.5	20.6	22.4	85.9
	3		23.5	22.6	20.6	24.5	21.2	22.8	21.1	22.6	85.4
	4		23.3	22.8	23.3	25.4	25.1	23.7	21.3	22.2	90.1
	5		25.8	25.7	21.2	24.1	23.8	24.4	22.1	22.5	86.8
	6		23.7	23.5	21.7	22.1	24.3	23.4	21.4	22.1	89.7
14:00/24/07	1	Sunny/23 °C	19.4	18.9	-	19.1	19.2	18.3	21.6	16.3	64.4
	2		20.3	21	16.4	18.8	19	18.7	22.6	16.3	64.4
	3		20.1	19.9	20.1	21	19.9	19.6	18.9	16.3	64.4
	4		18.1	18.2	19.9	21.5	20.7	18.9	21.2	16.3	64.4
	5		22.5	20.6	19.4	18.8	19.1	21.2	22.1	16.3	64.4
	6		21.5	19.1	19.6	19.7	21	20.8	21.1	16.3	64.4

Appendix 3: the simulation maps based on the conditions of Bosweg before the road maintenance





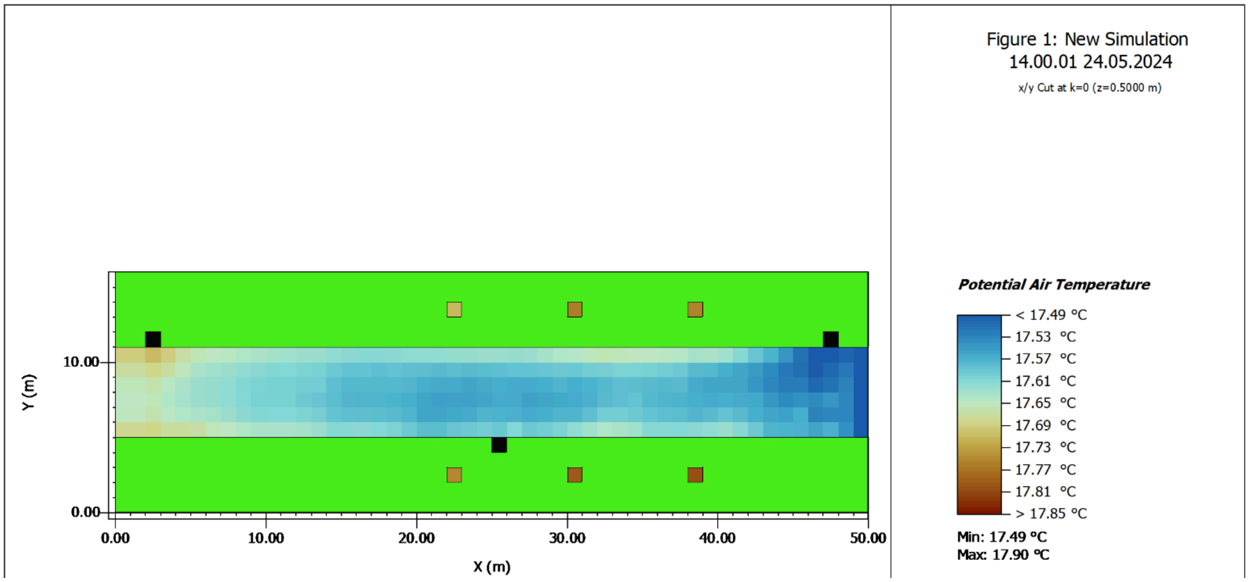


Figure 1: New Simulation
14.00.01 24.05.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 17.49 °C
17.53 °C
17.57 °C
17.61 °C
17.65 °C
17.69 °C
17.73 °C
17.77 °C
17.81 °C
> 17.85 °C
Min: 17.49 °C
Max: 17.90 °C
Y (m)
X (m)
0.00
10.00
20.00
30.00
40.00
50.00

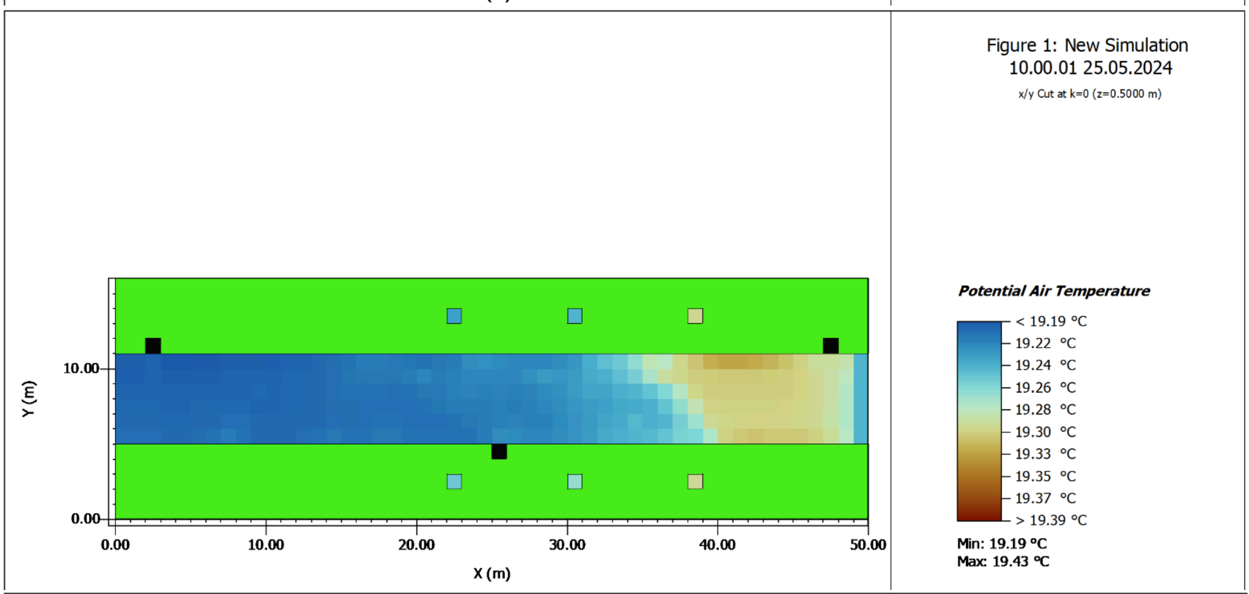


Figure 1: New Simulation
10.00.01 25.05.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 19.19 °C
19.22 °C
19.24 °C
19.26 °C
19.28 °C
19.30 °C
19.33 °C
19.35 °C
19.37 °C
> 19.39 °C
Min: 19.19 °C
Max: 19.43 °C
Y (m)
X (m)
0.00
10.00
20.00
30.00
40.00
50.00

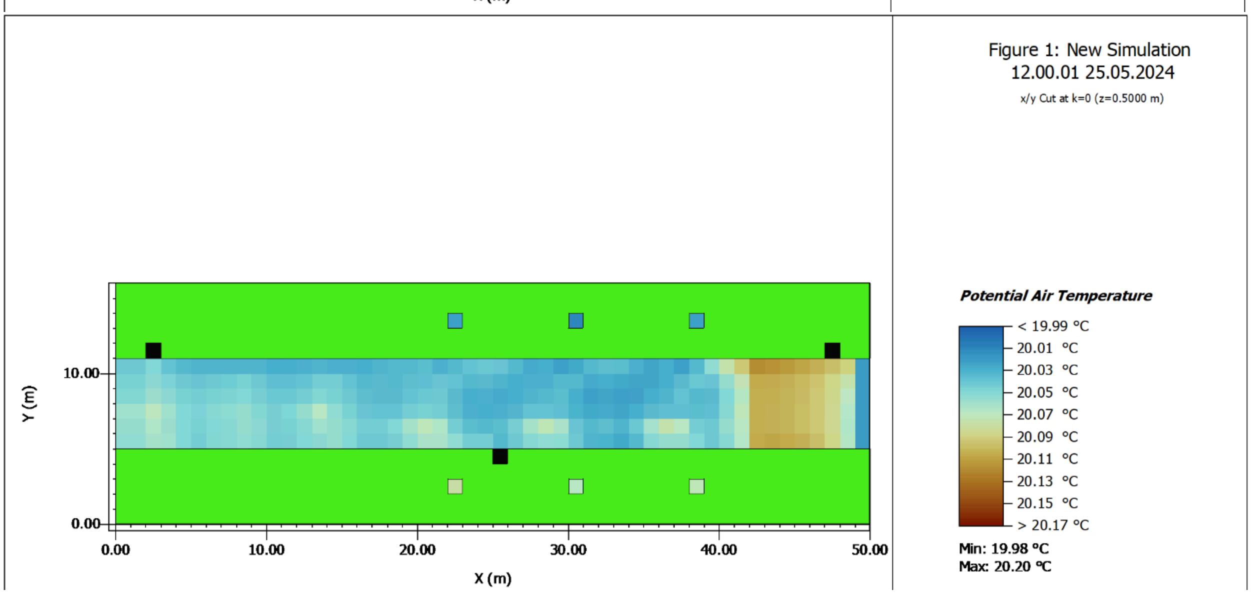


Figure 1: New Simulation
12.00.01 25.05.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 19.99 °C
20.01 °C
20.03 °C
20.05 °C
20.07 °C
20.09 °C
20.11 °C
20.13 °C
20.15 °C
> 20.17 °C
Min: 19.98 °C
Max: 20.20 °C
Y (m)
X (m)
0.00
10.00
20.00
30.00
40.00
50.00

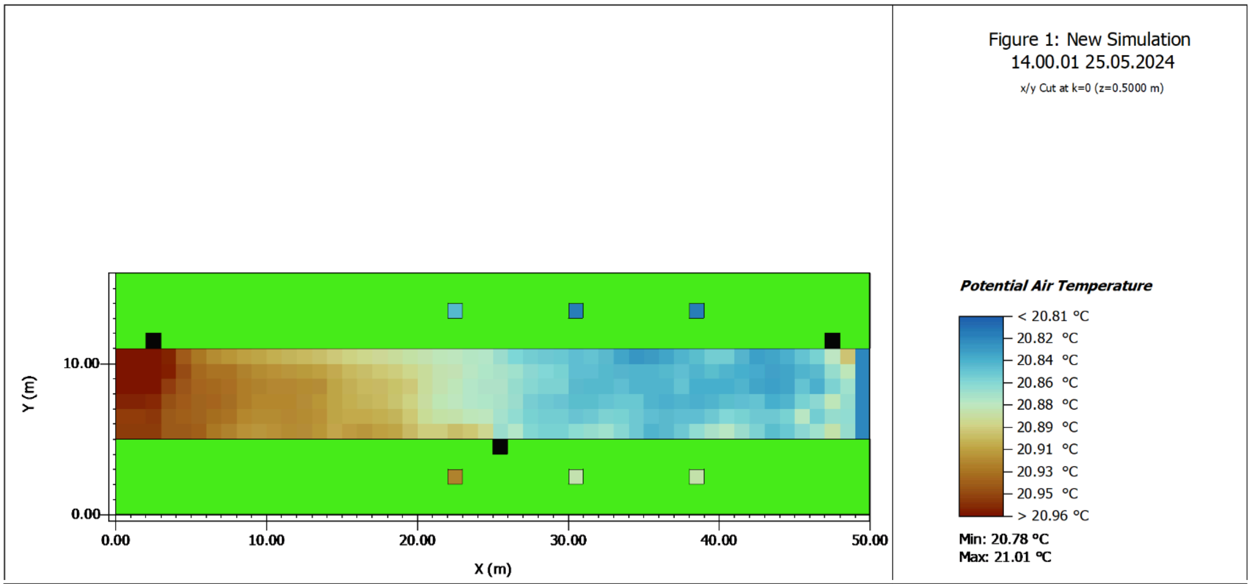


Figure 1: New Simulation
14.00.01 25.05.2024
x/y Cut at k=0 (z=0.5000 m)
Y (m)
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
X (m)
Potential Air Temperature
< 20.81 °C
20.82 °C
20.84 °C
20.86 °C
20.88 °C
20.89 °C
20.91 °C
20.93 °C
20.95 °C
> 20.96 °C
Min: 20.78 °C
Max: 21.01 °C

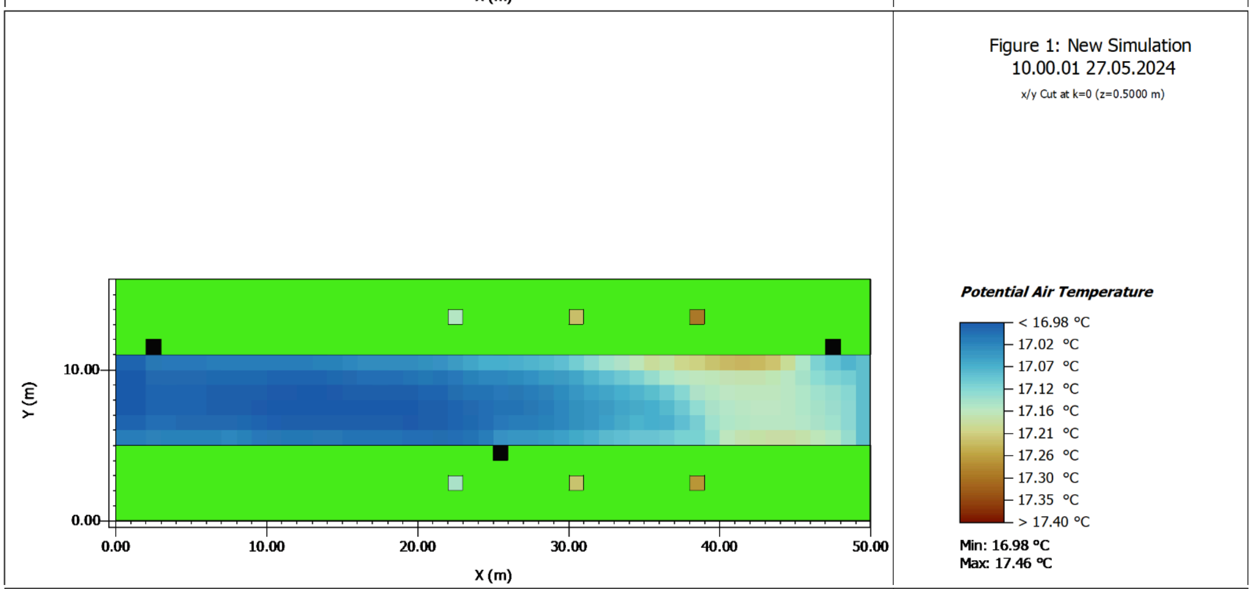


Figure 1: New Simulation
10.00.01 27.05.2024
x/y Cut at k=0 (z=0.5000 m)
Y (m)
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
X (m)
Potential Air Temperature
< 16.98 °C
17.02 °C
17.07 °C
17.12 °C
17.16 °C
17.21 °C
17.26 °C
17.30 °C
17.35 °C
> 17.40 °C
Min: 16.98 °C
Max: 17.46 °C

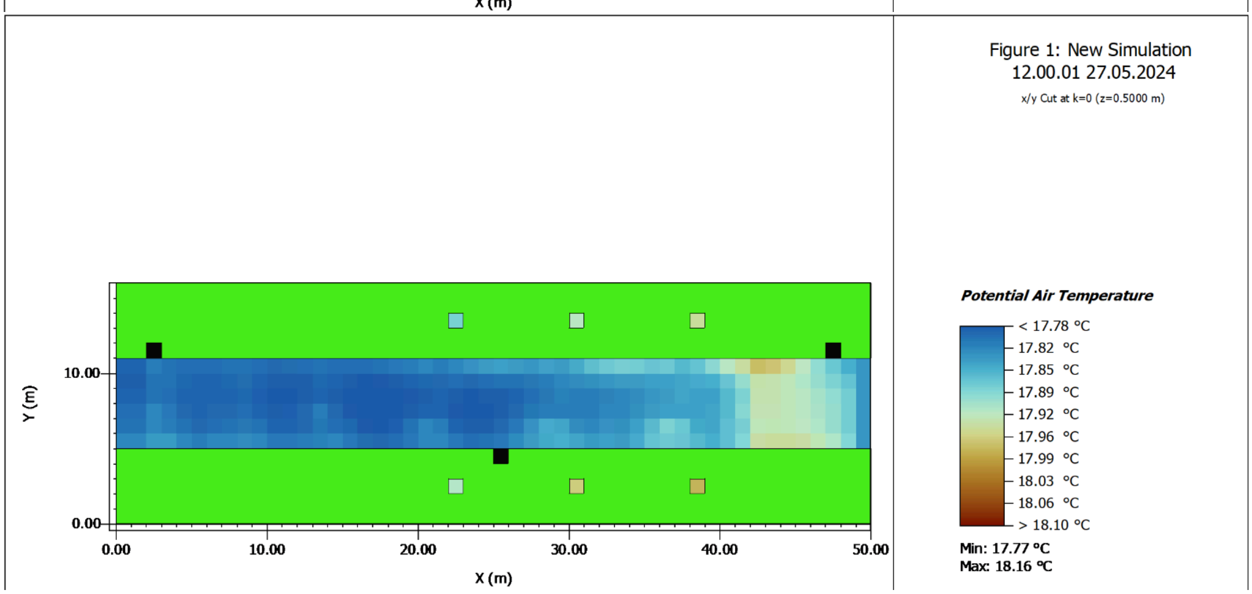
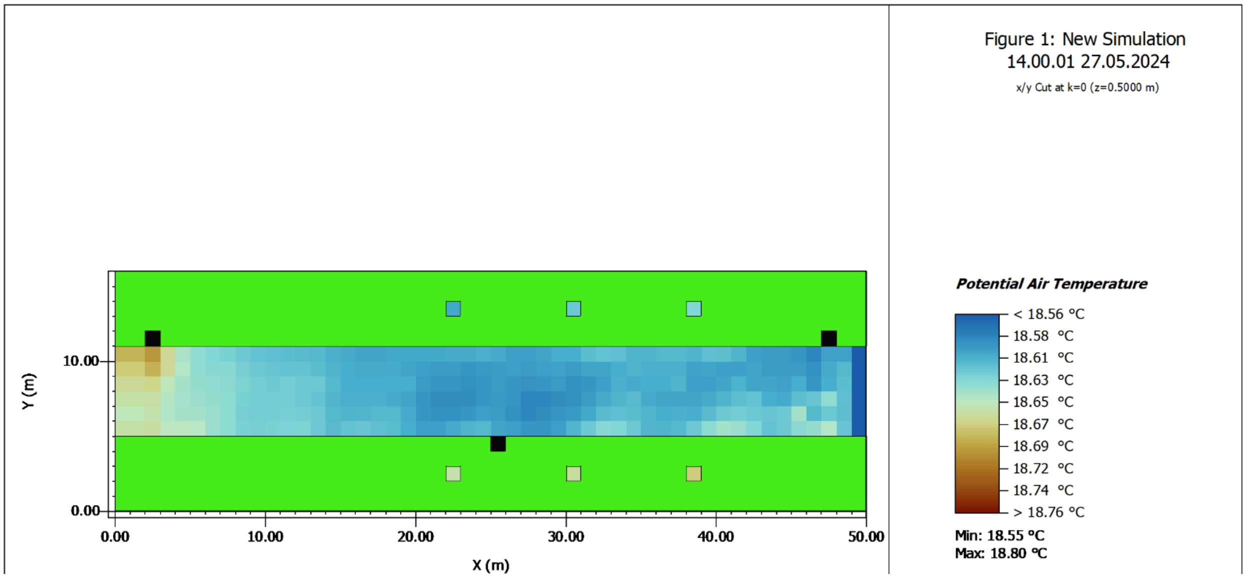
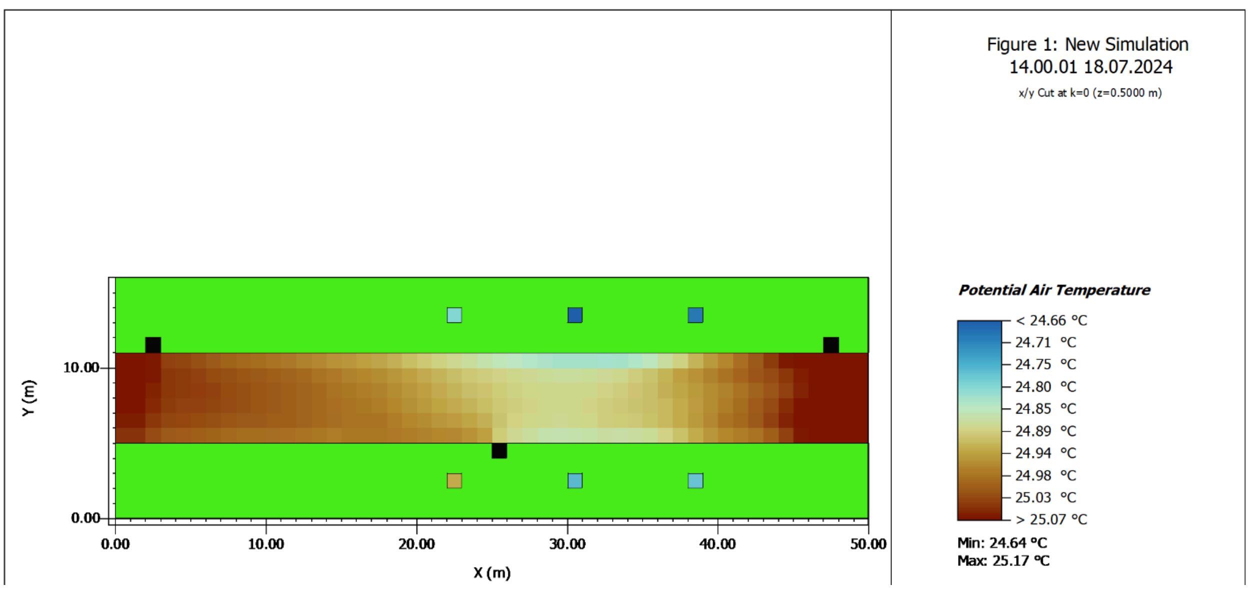


Figure 1: New Simulation
12.00.01 27.05.2024
x/y Cut at k=0 (z=0.5000 m)
Y (m)
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
X (m)
Potential Air Temperature
< 17.78 °C
17.82 °C
17.85 °C
17.89 °C
17.92 °C
17.96 °C
17.99 °C
18.03 °C
18.06 °C
> 18.10 °C
Min: 17.77 °C
Max: 18.16 °C



Appendix 4: The simulation results after the road maintenance



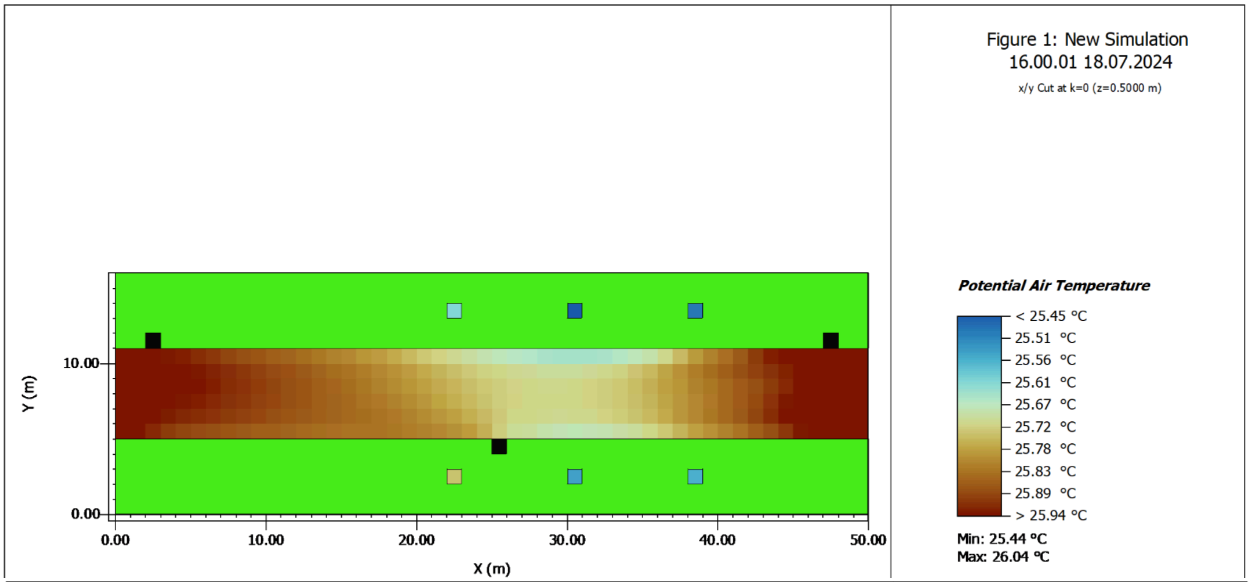


Figure 1: New Simulation
16.00.01 18.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 25.45 °C
25.51 °C
25.56 °C
25.61 °C
25.67 °C
25.72 °C
25.78 °C
25.83 °C
25.89 °C
> 25.94 °C
Min: 25.44 °C
Max: 26.04 °C
Y (m)
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
X (m)

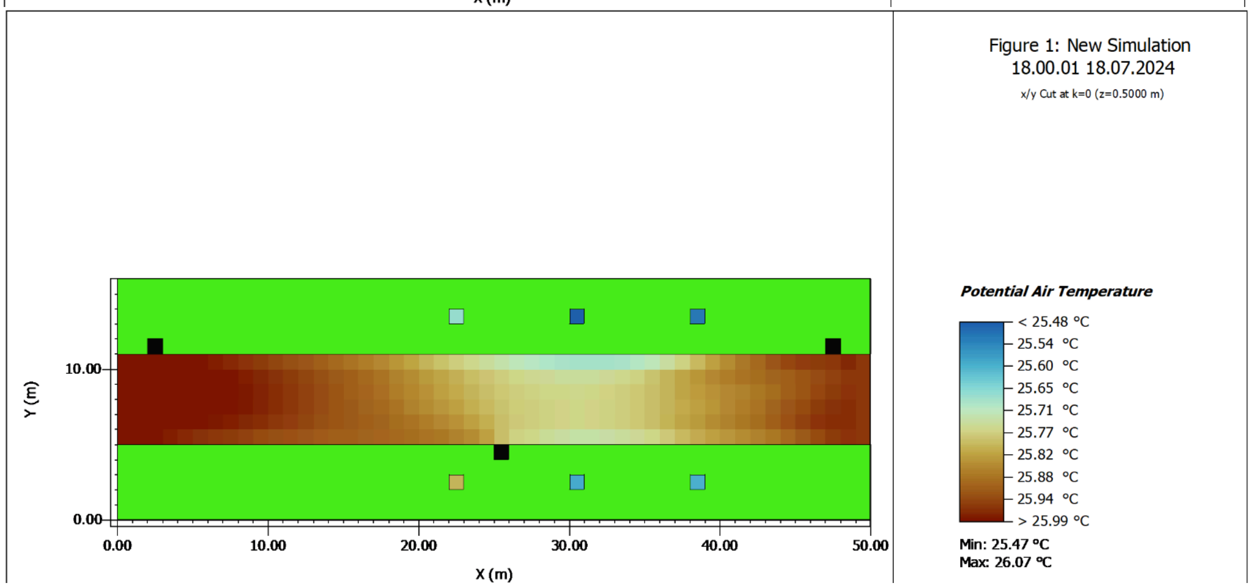


Figure 1: New Simulation
18.00.01 18.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 25.48 °C
25.54 °C
25.60 °C
25.65 °C
25.71 °C
25.77 °C
25.82 °C
25.88 °C
25.94 °C
> 25.99 °C
Min: 25.47 °C
Max: 26.07 °C
Y (m)
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
X (m)

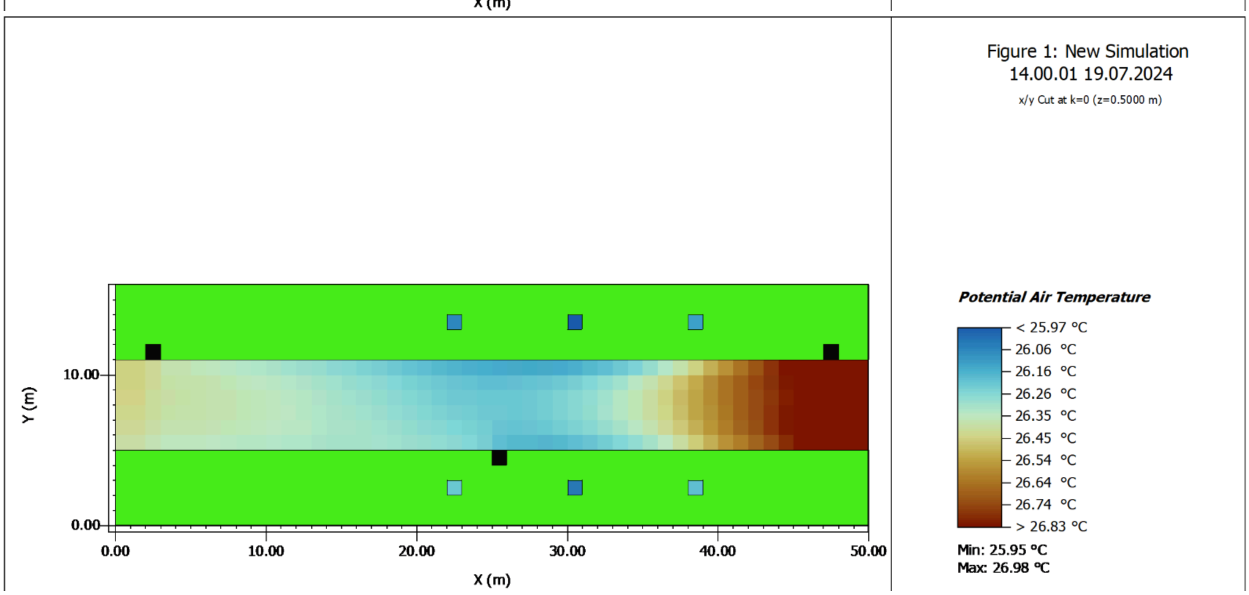


Figure 1: New Simulation
14.00.01 19.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 25.97 °C
26.06 °C
26.16 °C
26.26 °C
26.35 °C
26.45 °C
26.54 °C
26.64 °C
26.74 °C
> 26.83 °C
Min: 25.95 °C
Max: 26.98 °C
Y (m)
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
X (m)

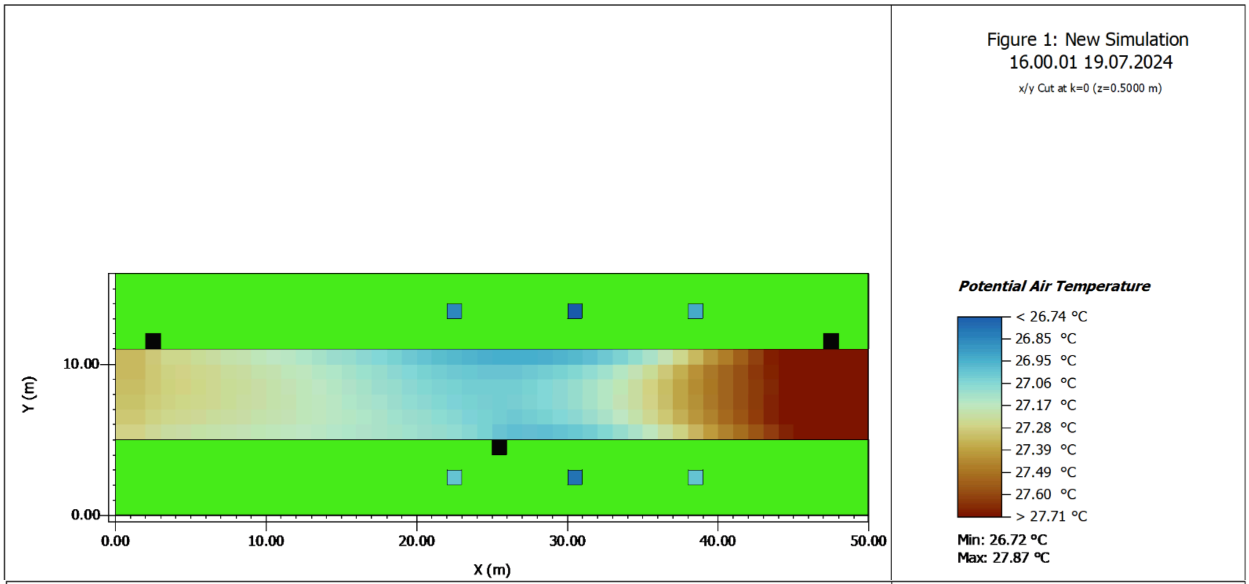


Figure 1: New Simulation
16.00.01 19.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 26.74 °C
26.85 °C
26.95 °C
27.06 °C
27.17 °C
27.28 °C
27.39 °C
27.49 °C
27.60 °C
> 27.71 °C
Min: 26.72 °C
Max: 27.87 °C
Y (m)
X (m)

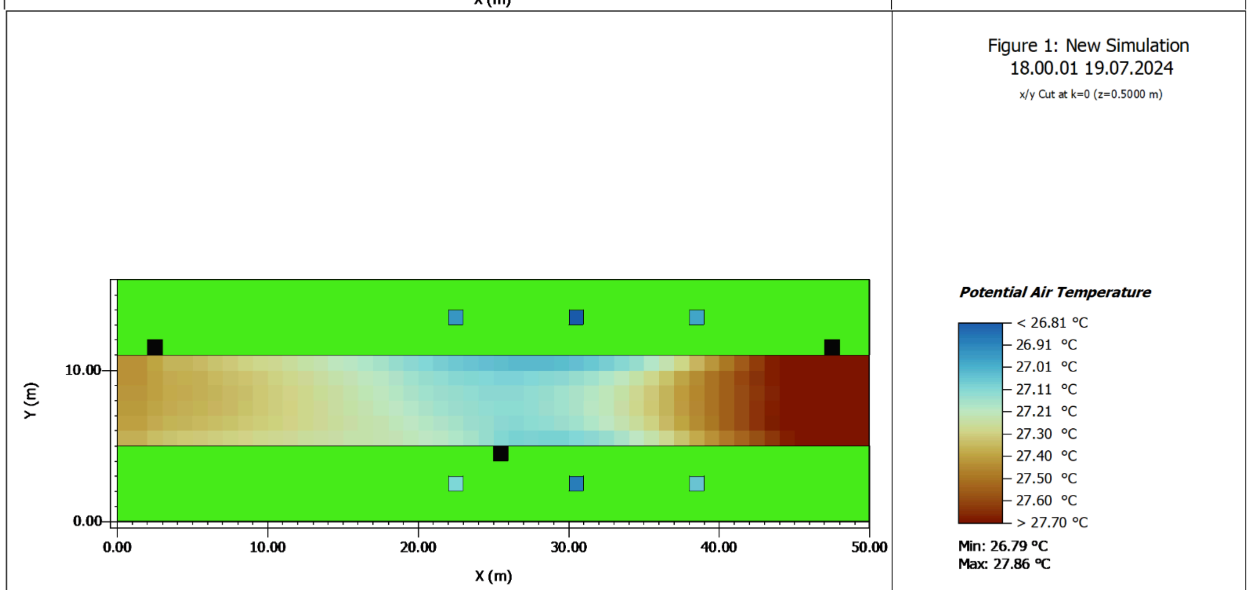


Figure 1: New Simulation
18.00.01 19.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 26.81 °C
26.91 °C
27.01 °C
27.11 °C
27.21 °C
27.30 °C
27.40 °C
27.50 °C
27.60 °C
> 27.70 °C
Min: 26.79 °C
Max: 27.86 °C
Y (m)
X (m)

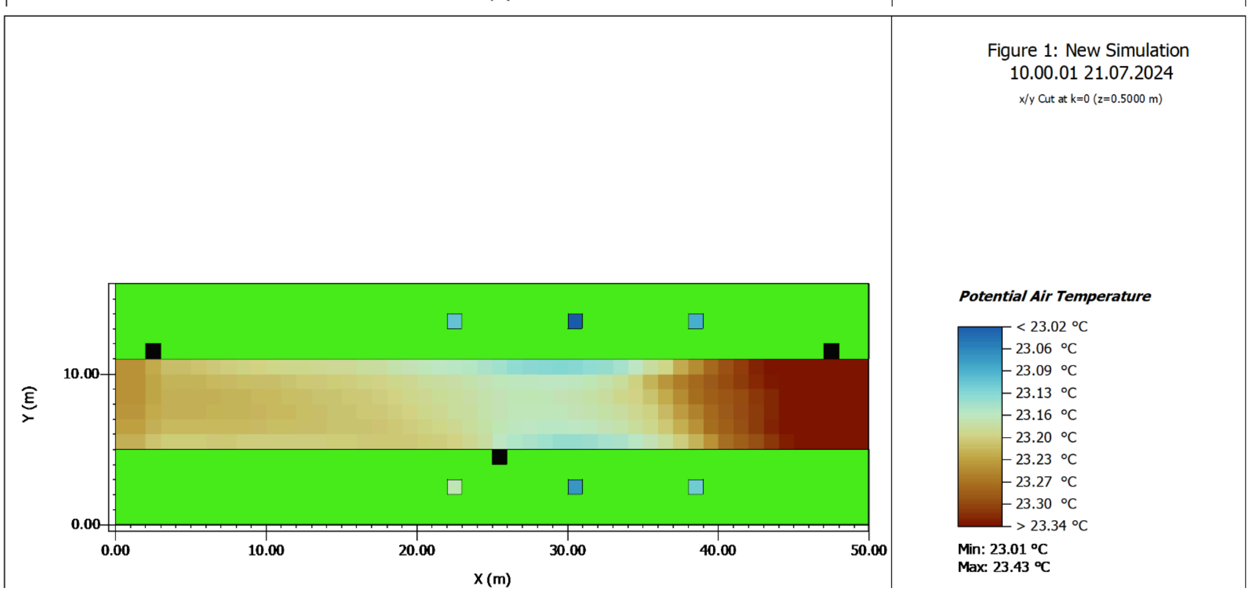


Figure 1: New Simulation
10.00.01 21.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 23.02 °C
23.06 °C
23.09 °C
23.13 °C
23.16 °C
23.20 °C
23.23 °C
23.27 °C
23.30 °C
> 23.34 °C
Min: 23.01 °C
Max: 23.43 °C
Y (m)
X (m)

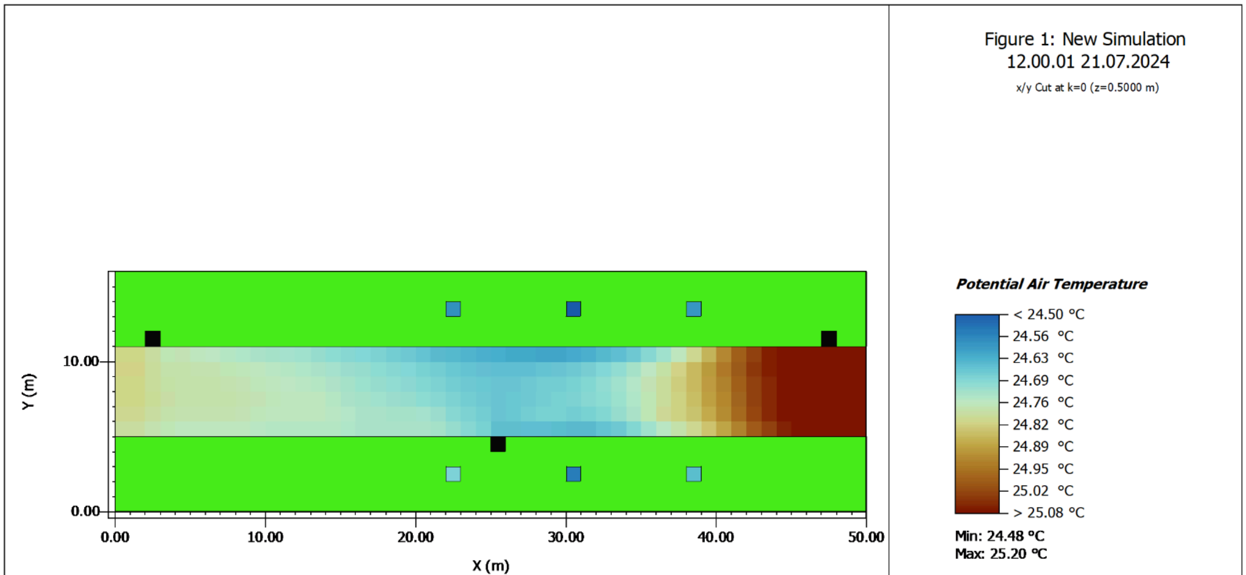


Figure 1: New Simulation
12.00.01 21.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 24.50 °C
24.56 °C
24.63 °C
24.69 °C
24.76 °C
24.82 °C
24.89 °C
24.95 °C
25.02 °C
> 25.08 °C
Min: 24.48 °C
Max: 25.20 °C
Y (m)
X (m)
0.00
10.00
20.00
30.00
40.00
50.00

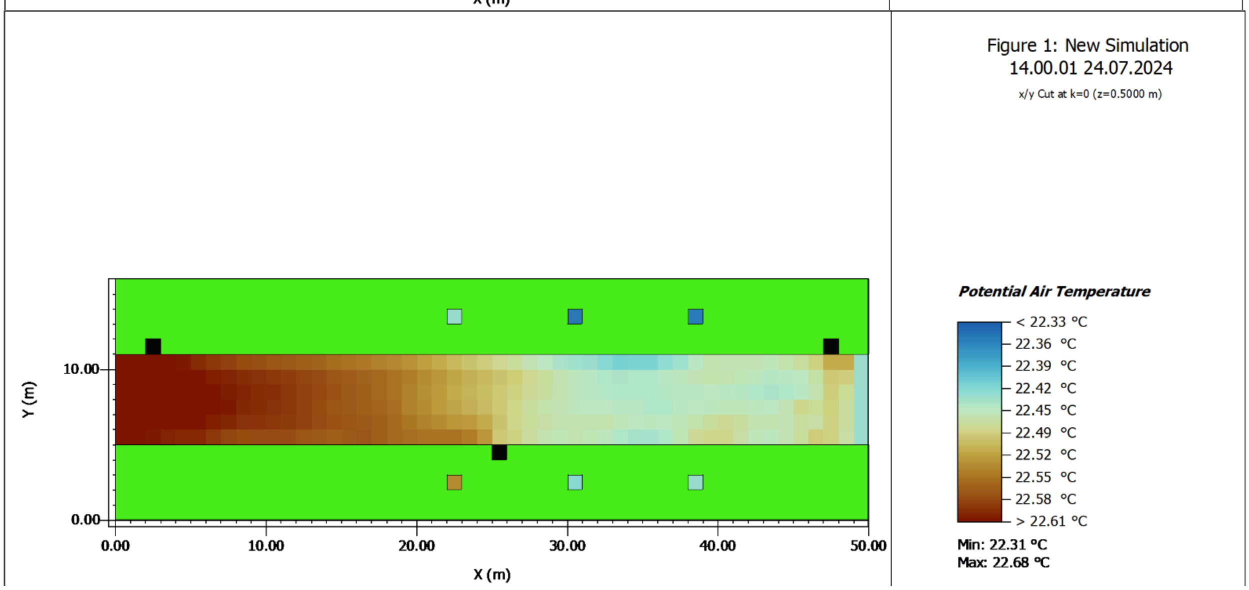
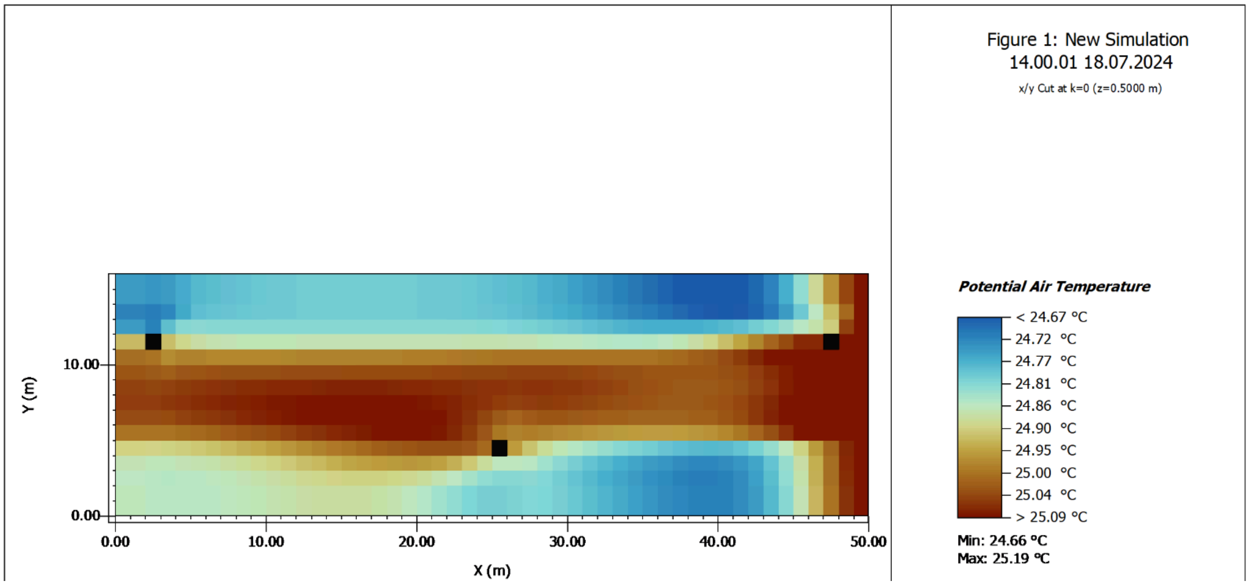
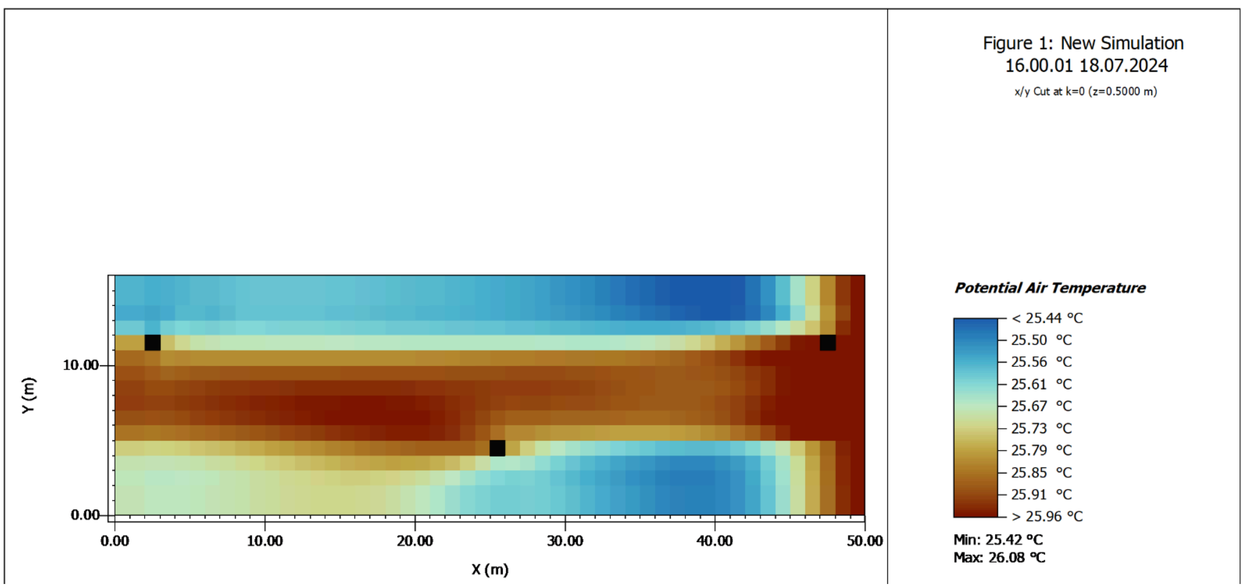


Figure 1: New Simulation
14.00.01 24.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 22.33 °C
22.36 °C
22.39 °C
22.42 °C
22.45 °C
22.49 °C
22.52 °C
22.55 °C
22.58 °C
> 22.61 °C
Min: 22.31 °C
Max: 22.68 °C
Y (m)
X (m)
0.00
10.00
20.00
30.00
40.00
50.00

Appendix 5: the simulation results without vegetation in the model





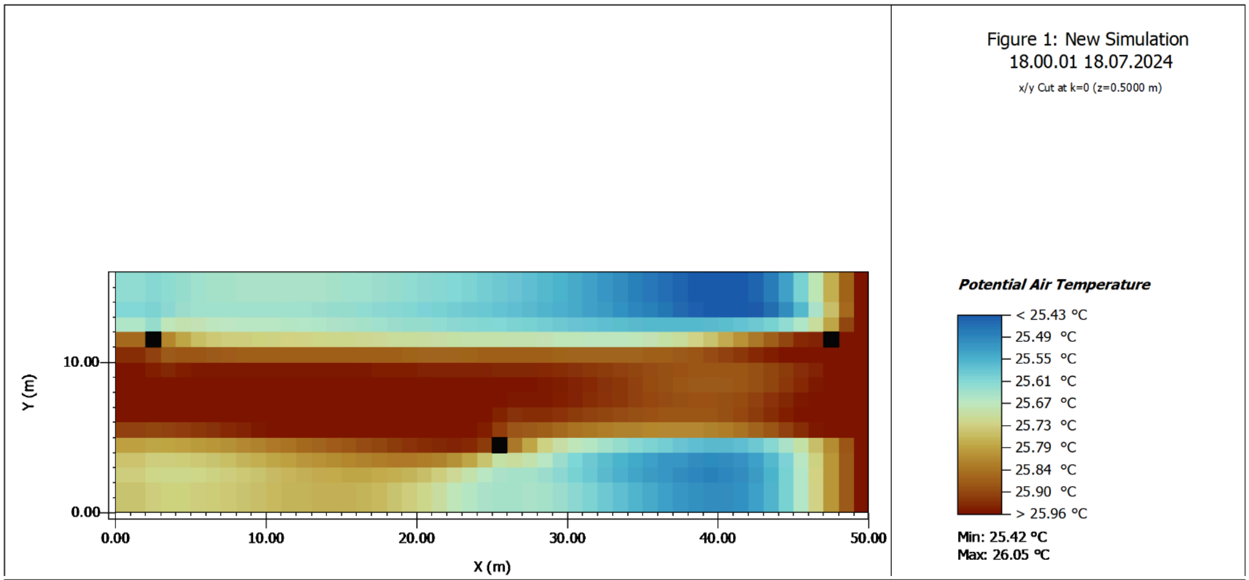


Figure 1: New Simulation
18.00.01 18.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 25.43 °C
25.49 °C
25.55 °C
25.61 °C
25.67 °C
25.73 °C
25.79 °C
25.84 °C
25.90 °C
> 25.96 °C
Min: 25.42 °C
Max: 26.05 °C
Y (m)
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
X (m)

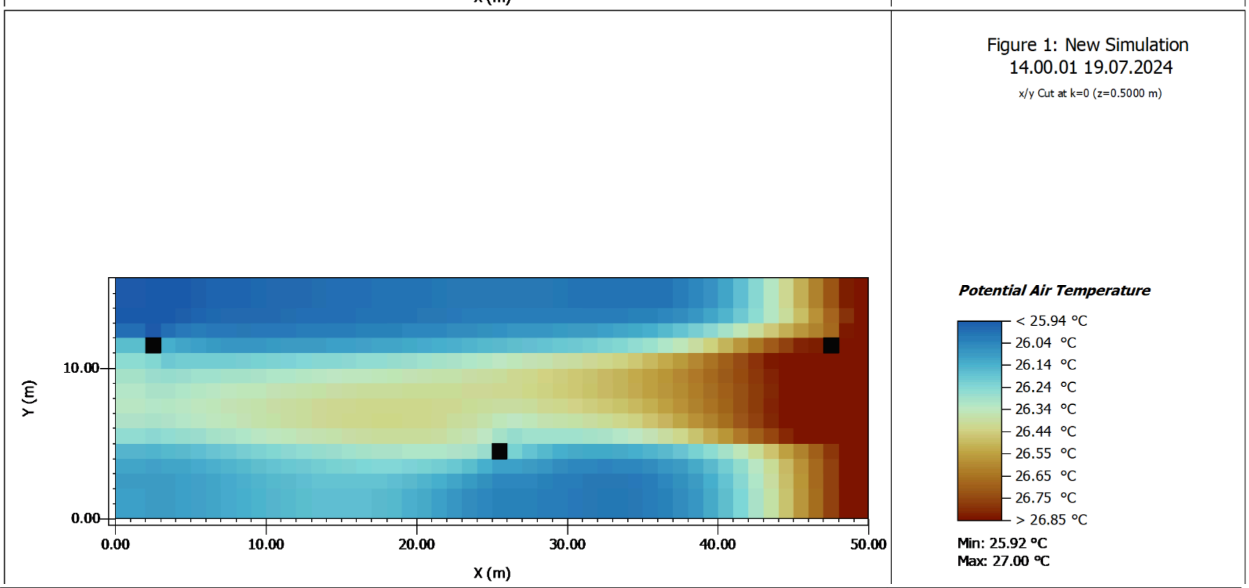


Figure 1: New Simulation
14.00.01 19.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 25.94 °C
26.04 °C
26.14 °C
26.24 °C
26.34 °C
26.44 °C
26.55 °C
26.65 °C
26.75 °C
> 26.85 °C
Min: 25.92 °C
Max: 27.00 °C
Y (m)
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
X (m)

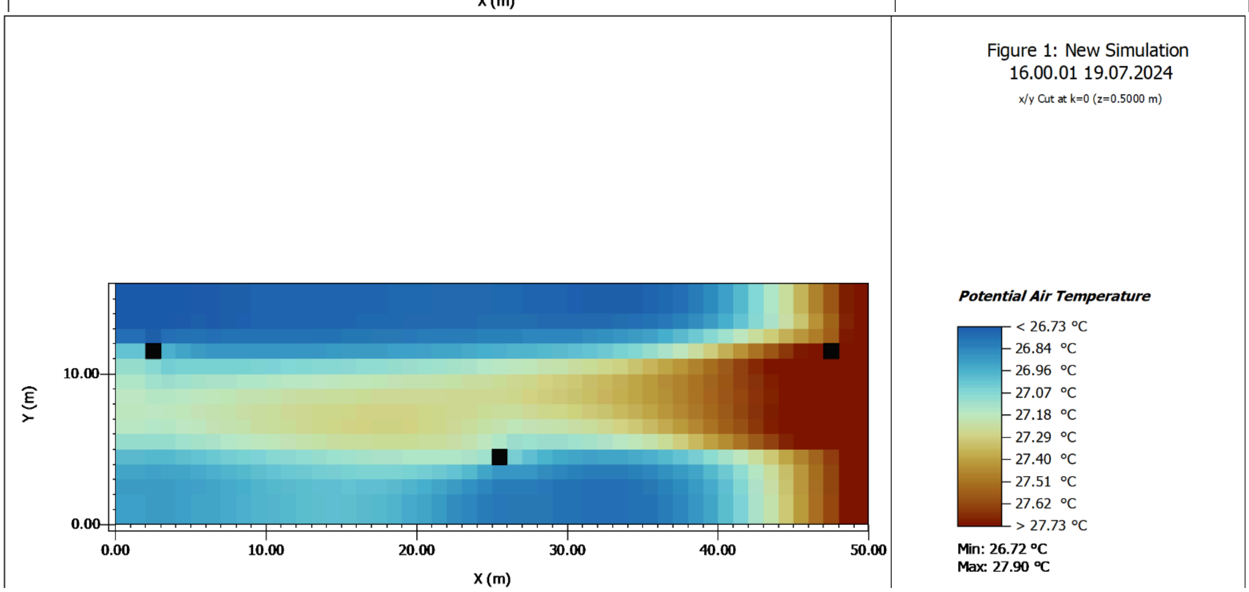


Figure 1: New Simulation
16.00.01 19.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 26.73 °C
26.84 °C
26.96 °C
27.07 °C
27.18 °C
27.29 °C
27.40 °C
27.51 °C
27.62 °C
> 27.73 °C
Min: 26.72 °C
Max: 27.90 °C
Y (m)
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
X (m)

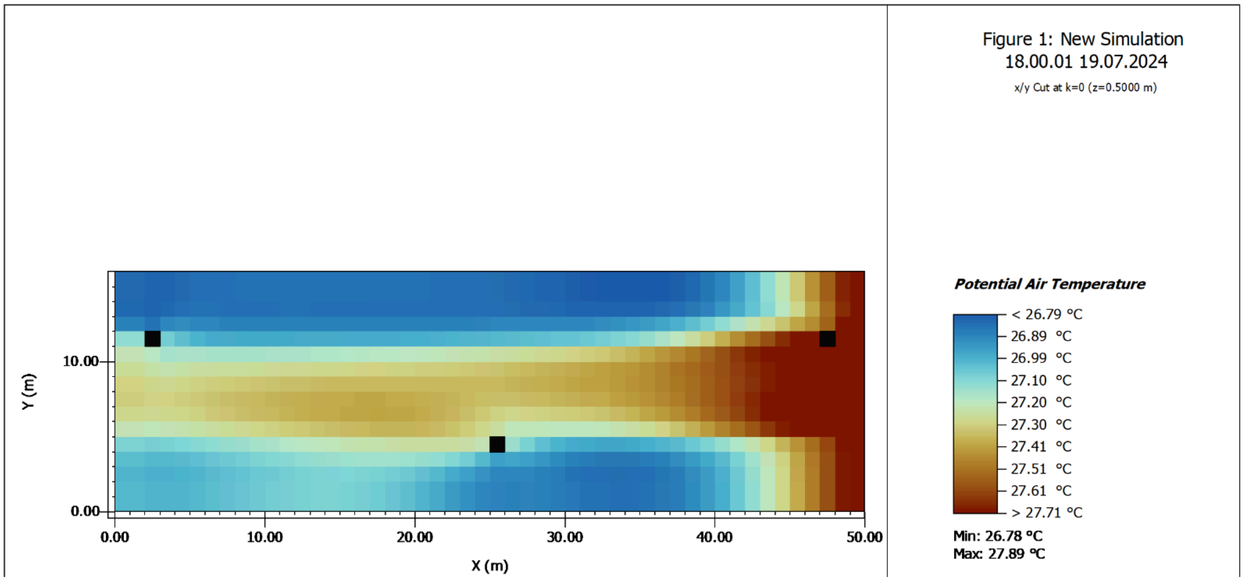


Figure 1: New Simulation
18.00.01 19.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 26.79 °C
26.89 °C
26.99 °C
27.10 °C
27.20 °C
27.30 °C
27.41 °C
27.51 °C
27.61 °C
> 27.71 °C
Min: 26.78 °C
Max: 27.89 °C
Y (m)
X (m)
0.00
10.00
20.00
30.00
40.00
50.00

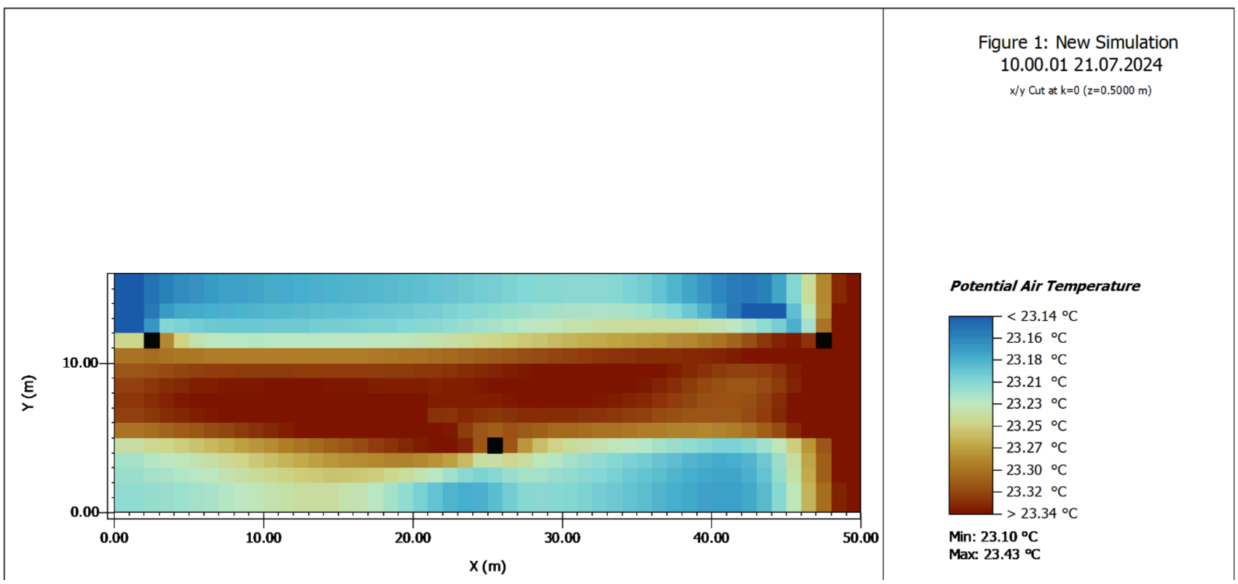
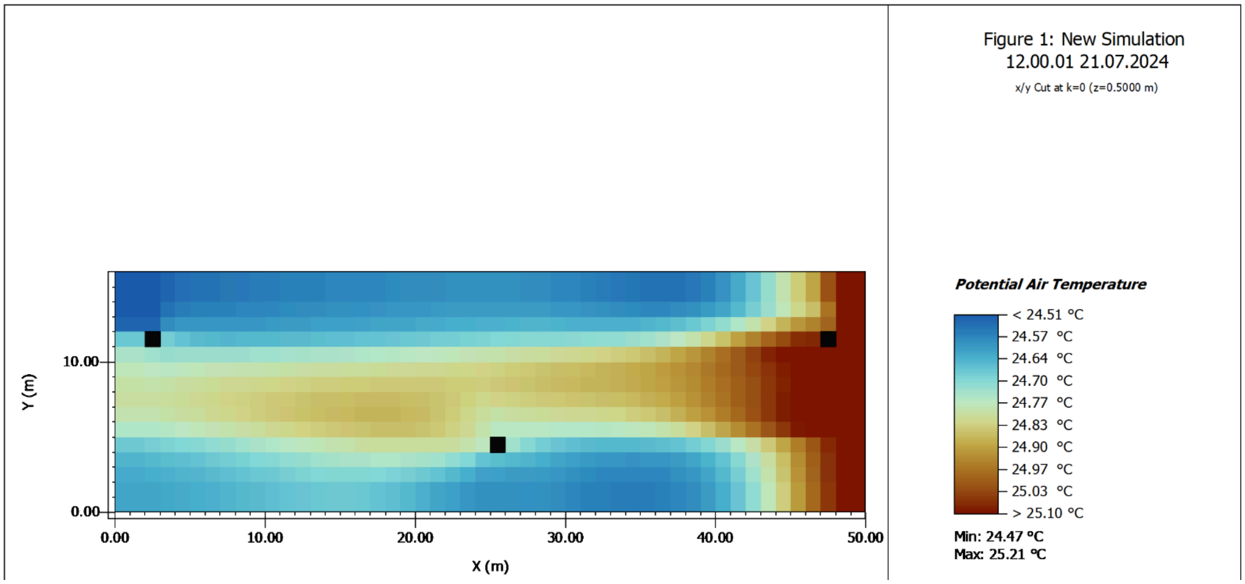


Figure 1: New Simulation
10.00.01 21.07.2024
x/y Cut at k=0 (z=0.5000 m)
Potential Air Temperature
< 23.14 °C
23.16 °C
23.18 °C
23.21 °C
23.23 °C
23.25 °C
23.27 °C
23.30 °C
23.32 °C
> 23.34 °C
Min: 23.10 °C
Max: 23.43 °C
Y (m)
X (m)
0.00
10.00
20.00
30.00
40.00
50.00



Appendix 6: The survey questionnaire

SURVEY	
Criteria	Answer
Road availability	O O O O O
-Refers to how often usable the road is for public use	1 2 3 4 5
Proper infrastructure	O O O O O
-Refers to the quality of the road and its surroundings	1 2 3 4 5
Road visibility	O O O O O
-Refers to the quality of road lighting, and therefore visibility	1 2 3 4 5
Comfortable thermal conditions	O O O O O
-Refers to the temperature conditions around the road	1 2 3 4 5
1 --> irrelevant	
5 --> relevant	

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