École Polytechnique Fédérale de Lausanne

CIVIL-309 Urban Thermodynamics

Case study - EPFL Innovation Park

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Summary

1 Introduction

Urbanization has significantly transformed natural environments, leading to pressing challenges such as the Urban Heat Island (UHI) effect, where urban areas experience higher temperatures compared to their rural surroundings. This temperature disparity, worsened during heatwaves, contributes to thermal discomfort, increased energy demands, and heightened risks to human health, especially under the intensifying effects of global warming. Addressing these challenges requires climate-sensitive urban design that mitigates the impacts of urban overheating while enhancing outdoor thermal comfort.

This course project focuses on evaluating urban microclimates, exploring the thermodynamic interactions between urban elements like buildings, vegetation, ground cover, and water bodies, and proposing effective mitigation strategies. The selected case study, the EPFL Innovation Park, offers a unique context with diverse ground materials, building morphologies, and its proximity to Lake Geneva. This project involves analyzing existing site conditions, simulating the impacts of various mitigation strategies using tools like *ENVI-met*, and proposing an integrated solution tailored to improve thermal comfort and reduce the UHI effect.

Through a comprehensive evaluation, the project seeks to provide actionable insights into sustainable urban design and contribute to a deeper understanding of urban thermodynamics.

2 Site analysis

Minimum site analysis. The analysis is very general and there is no quantitative analysis of the material, morphology, current site microclimate condition.

The EPFL Innovation Park is a hub for advanced research and technological progress, hosting companies engaged in research and development. Primary activities include commuting by car or bike, walking, working in office buildings, and enjoying outdoor recreational spaces. The site also includes designated parking areas and is bordered by relatively large roads with moderate traffic activity.

Our analysis focuses on projected climatic data for 2100, enabling predictions of critical environmental parameters at the Innovation Park. Key parameters include air temperature, relative humidity, global radiation, wind speed, and thermal indices, revealing clear seasonal trends. Summer months exhibit the highest temperatures and radiation levels, with the hottest day, August 18, 2100, reaching a maximum air temperature of approximatively 40°C, relative humidity of 45%, and global radiation of 800 Wh/m², accompanied by minimal wind speeds of 2.8 m/s. These conditions create significant thermal stress, exacerbated by stagnant air circulation.

The Innovation Park is located within the EPFL campus, bordered by residential neighborhoods to the south and west and surrounded by major roads. The site features rectangular office buildings with green spaces, parking areas, and pedestrian pathways interspersed throughout. The buildings average 18 meters in height and are primarily surrounded by asphalt roads, concrete pavements, and patches of urban woodland. Nearby residential areas contribute to moderate vehicular traffic, particularly during peak commuting hours, while the proximity to Lake Geneva potentially moderates temperatures through evaporative cooling effects.

The site's urban morphology creates semi-enclosed spaces that could restrict airflow, especially during low wind conditions, intensifying heat accumulation. The flat terrain and interconnected pathways enhance pedestrian access but also contribute to surface heating due to the predominance of materials that absorb a high proportion of radiation. This mix of features—urban density, green infrastructure, and climatic variability—makes the Innovation Park a critical case study for understanding urban heat island effects and developing climate-sensitive mitigation strategies. *

3 Urban microclimate exploration

In our analyses, we will primarily focus on the graphs between 12 :00 PM and 2 :00 PM, as this is the time when solar radiation is at its peak and temperatures are at their highest. However, for certain analyses, we also consider data from other times of the day when it is necessary to understand temperature variations across different periods.

Additionally, we use indicators such as PET (Physiological Equivalent Temperature) and UTCI (Universal Thermal Climate Index) as they encompass a range of critical factors, including air temperature, mean radiant temperature, humidity, and wind speed. These indicators provide a comprehensive assessment of outdoor thermal comfort, making them particularly relevant for evaluating the impact of vegetation and surface modifications on the microclimate.

3.1 Building environment interactions

3.1.1 Presentation

There is no specification provided for your intervention, such as building height, thermal properties of the altered facade.

We proposed and studied several strategies to optimize the interactions between buildings and their environment. These interventions, including increasing building height and compactness, using reflective materials, and adding green roofs, rely on thermodynamic principles to reduce urban temperatures, improve thermal comfort, and enhance energy efficiency.

Firstly, increasing the height of buildings, combined with a more compact organization, offers significant benefits for urban thermal comfort. From a radiative perspective, taller buildings create shadows on surrounding surfaces, reducing direct solar radiation and, consequently, surface temperatures. This reduction in absorbed energy also decreases the infrared radiation emitted into the atmosphere, contributing to a cooler urban environment. From an aerodynamic standpoint, taller buildings alter airflows, channeling longitudinal winds through streets. These air currents increase the convective dissipation of accumulated heat while capturing high-altitude winds to enhance natural ventilation. These combined phenomena improve heat evacuation and limit thermal stagnation zones. However, these modifications could not be implemented in our simulations due to software constraints, restricting the analysis of their practical impact.

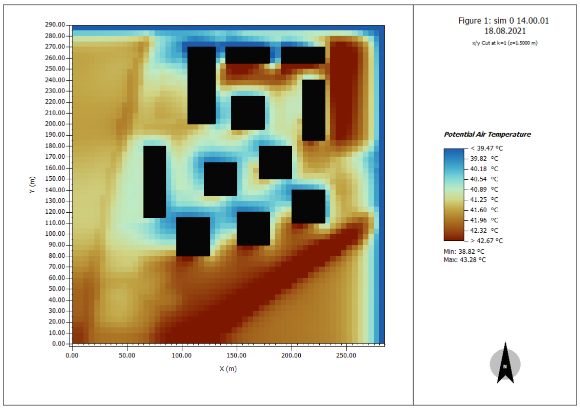
Furthermore, replacing traditional facades with aluminum panels is an effective intervention to reduce thermal fluxes. With their high albedo, these facades reflect a large portion of incident solar radiation, reducing the energy absorbed and stored in surfaces. This results in a decrease in sensible heat flux transferred to the surrounding atmosphere, mitigating the intensity of the urban heat island effect. Additionally, reflective facades alter radiative exchanges in dense urban environments, reducing the impact of multiple reflections between buildings. These facades also improve the thermal balance of structures by minimizing diurnal temperature variations, contributing to more stable energy regulation.

Finally, green roofs leverage the natural properties of plants and soil to regulate thermal fluxes. By promoting evapotranspiration, they convert a portion of thermal energy into latent flux, thereby reducing the proportion of sensible heat exchanged with the surrounding air. This limits the increase in ambient temperatures while improving the energy efficiency of buildings. Furthermore, green roofs provide effective thermal insulation, reducing heat loss in winter and heat gain in summer. In terms of water management, these roofs retain precipitation, decreasing runoff and increasing the availability of water for passive cooling, which optimizes overall thermal fluxes. These properties make them an ideal solution to mitigate urban heat island effects while enhancing the thermal comfort of occupants.

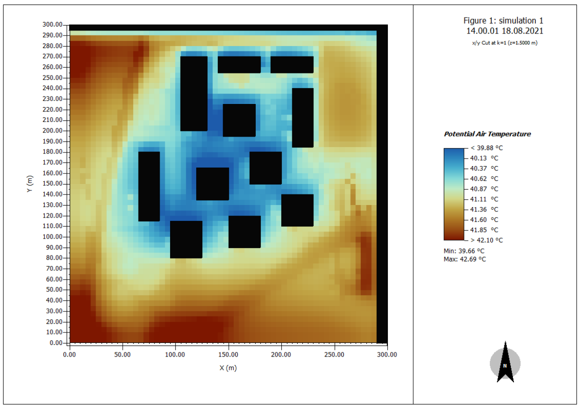
3.1.2 Results

The analysis of the simulations before and after modifications reveals significant impacts on the thermal parameters studied.

The colour scale used for your two plots are different, it is very difficult to compare the results between two.



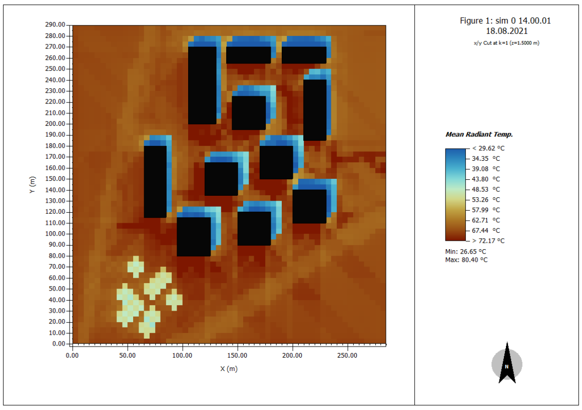
(a) PAT before modifications



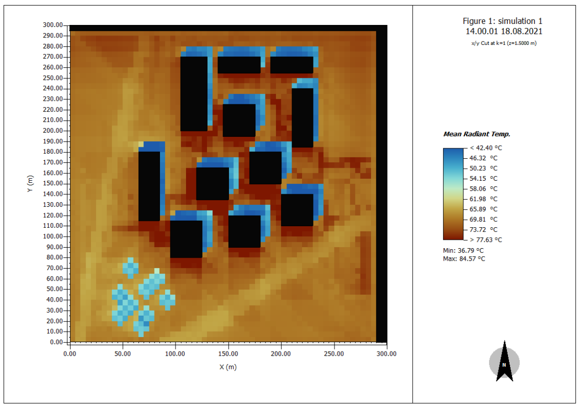
(b) PAT after modifications

FIGURE 1 – Comparison of results for PAT before and after modifications.

Potential Air Temperature (PAT) is a measure of temperature that reflects thermal conditions while avoiding the effects of pressure or altitude. The modifications reduced maximum temperatures, particularly around buildings, by better managing thermal fluxes. Areas near buildings benefit from more homogeneous temperatures and a local attenuation of urban heat island effects. However, a slight increase in minimum temperatures was observed, indicating a reduction in natural thermal contrasts.



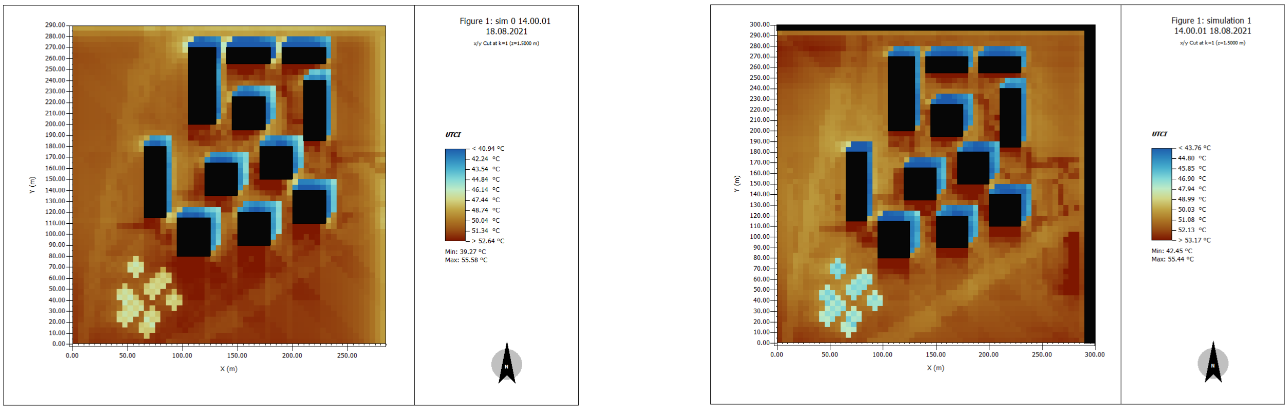
(a) MRT before modifications



(b) MRT after modifications

FIGURE 2 – Comparison of results for MRT before and after modifications.

The Mean Radiant Temperature MRT represents the heat felt due to radiation from surrounding surfaces. Radiant temperatures increased in open spaces after modifications, with intensified thermal radiation primarily due to reflective surfaces. However, areas near buildings showed local improvements due to shading created by the interventions. Despite these localized improvements, the overall effect remains negative for exposed spaces.



(a) UTCI before modifications

(b) UTCI after modifications

FIGURE 3 – Comparison of results for UTCI before and after modifications.

the Universal Thermal Climate Index (UTCI) estimates the sensation of heat or cold for a person, based on weather conditions (temperature, wind, sun, humidity). The UTCI results showed a notable increase in minimum values, indicating a global warming trend, while maximum values remained nearly unchanged. Although local thermal comfort improved near buildings, open spaces showed increased discomfort, particularly due to solar reflections.

The comparison of min and max is less meaningful than comparing the distribution of the relevant parameters.

3.1.3 Discussion

Discussion of thermodynamic principles in your interventions is not backed up with actual analysis of the simulation results.

The modifications, including the use of aluminum facades and the addition of green roofs, showed contrasting impacts on the studied parameters. Reflective facades reduced maximum temperatures near buildings, locally mitigating urban heat island effects, while green roofs improved thermal regulation through evapotranspiration and insulation, contributing to more homogeneous temperatures (PAT) and increased energy efficiency for buildings. However, for people, the effects were more negative, as intensified solar reflections in open spaces increased Mean Radiant Temperature (MRT) and Universal Thermal Climate Index (UTCI), resulting in overall thermal discomfort. To address these effects, additional modifications will be implemented, such as adding vegetation, fountains, and other cooling elements in open spaces to restore balance and improve thermal comfort for users. These new modifications will be particularly visible in the final simulation.

3.2 Ground-environment interactions

3.2.1 Presentation

As part of improving the microclimate of the EPFL Innovation Park site, two main interventions were implemented to address the interaction between the ground and the environment. These modifications aim to reduce urban heat islands, enhance outdoor thermal comfort, and integrate sustainable solutions aligned with the principles studied in the course.

Firstly, the roads, which were initially covered with black asphalt—a material known for its very low albedo (approximately 0.05 to 0.10) and its ability to absorb a significant amount of solar radiation—were replaced with asphalt featuring a red coating. This new material has a higher albedo (between 0.20 and 0.30). By increasing surface reflectivity, this modification limits heat accumulation at the surface and reduces local temperatures. This improvement directly mitigates the urban heat island effect, decreases re-emitted thermal radiation, and enhances comfort for road users, including pedestrians and cyclists.

Secondly, the parking area, which was previously made of standard low-albedo concrete (approximately 0.20), was transformed to incorporate light concrete and vegetated zones. The light concrete used has an albedo ranging from 0.30 to 0.50, enabling better reflection of solar radiation and reducing surface heat storage. This choice is particularly relevant for areas with high solar exposure, such as parking lots. Additionally, the integration of vegetated zones promotes evapotranspiration, which acts as an active cooling mechanism and locally improves relative humidity. The vegetated surfaces also enhance rainwater infiltration, reducing runoff and supporting water regulation.

These interventions align with the concepts of reducing sensible heat flux and increasing solar reflection through appropriate materials, two widely recognized strategies for mitigating the impacts of urban heat islands. Moreover, they are part of an integrated approach aimed at promoting more sustainable urban design while maximizing environmental benefits, such as reducing surface temperatures and improving outdoor thermal conditions.

3.2.2 Results

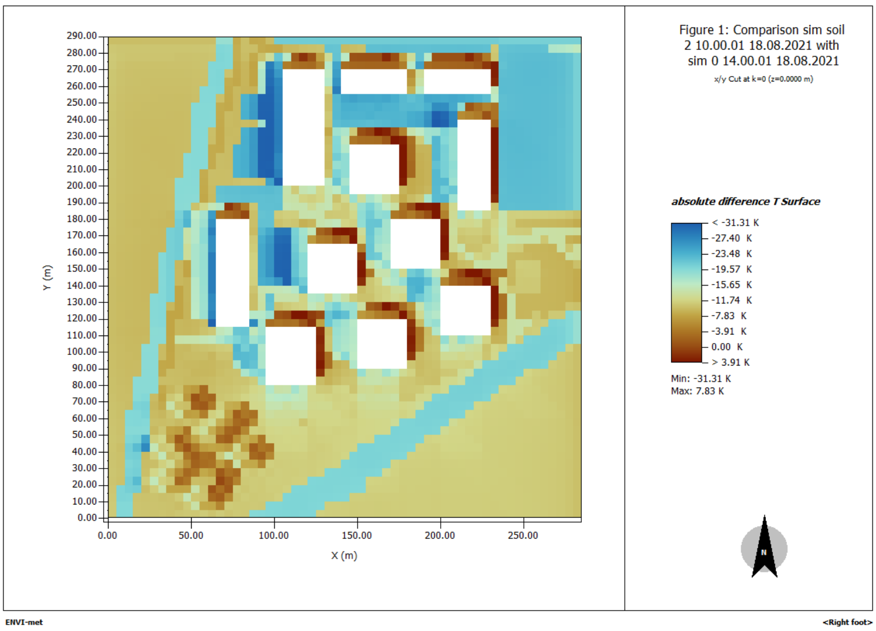


FIGURE 4 – difference of surface temperature

The modifications made to surface materials at the Innovation Park site have yielded significant results in terms of surface temperature reduction, particularly in areas where material changes were implemented. Specifically, the replacement of black asphalt on roads and parking lots with new materials, such as red asphalt and light concrete, has led to notable decreases in surface temperatures.

In the case of parking lots, where black asphalt was replaced with light concrete, surface temperatures decreased by up to 20°C. This remarkable reduction is attributed to the high albedo of light concrete

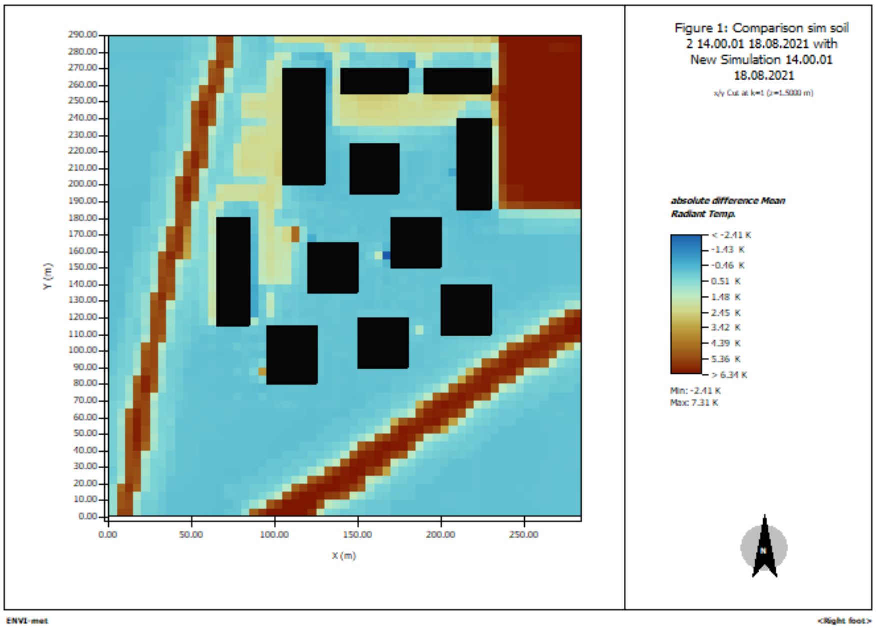


FIGURE 5 – difference of mean radiant temperature

Can you provide reference for red asphalt as measures for limiting UHI? It is not commonly used and albedo 0.2-0.3 is still quite low

(0.30–0.50), which reflects a significant portion of solar radiation rather than absorbing it, thereby limiting heat accumulation. Similarly, on roads, replacing black asphalt with red asphalt, which has an albedo between 0.20 and 0.30, also resulted in a substantial decrease in surface temperatures, albeit slightly less pronounced than in parking lots.

These results confirm the effectiveness of the new materials in combating urban heat islands. By significantly reducing surface temperatures, these modifications help limit heat transfer to the surrounding air, particularly during the hottest periods of the day.

However, it is important to note that reflective materials such as light concrete and red asphalt may have side effects, including an increase in the Mean Radiant Temperature (MRT) in directly exposed areas. This increase is due to the higher reflection of solar radiation by these materials. While they absorb less heat, they reflect a significant portion of radiation back into the immediate environment, thereby increasing the thermal load experienced by pedestrians and users in these spaces. This observation highlights the need to consider not only surface temperatures but also the broader thermal interactions within the environment.

If you want to demonstrate the point of increased reflection of radiation, you need to look at reflected radiative flux directly

Additionally, some areas show a reduction in MRT around buildings, which can be explained by several factors, including the shading effect of buildings or the dispersion of reflected radiation into the atmosphere. These positive effects could be further amplified with complementary interventions.

Moreover, a higher albedo for these materials significantly reduces their capacity to store heat during the day, thereby limiting nighttime thermal re-emission—a common issue with low-albedo materials like black asphalt. Consequently, these new materials not only lower daytime surface temperatures but also help mitigate urban heat island effects during the night, promoting a more stable and comfortable microclimate overall.(see Figure 18).

Why would high albedo limit heat storage capacity? They are separate mechanisms

3.2.3 Discussions

The results demonstrate that the modifications made to surface materials are particularly effective in reducing surface temperatures, thereby helping to mitigate urban heat island effects. By replacing black asphalt with higher albedo materials, such as red asphalt and light concrete, surface temperatures have significantly decreased, with reductions reaching up to 20°C in certain areas, particularly parking lots. These changes promote more sustainable thermal management and a more pleasant microclimate, especially during the hottest periods.

However, an increase in the Mean Radiant Temperature (MRT) has emerged as a notable side effect. This rise, caused by the increased reflection of solar radiation by the new materials, can compromise thermal comfort for users, especially in open spaces that lack natural or artificial shading. This observation underscores the need to complement these material modifications with additional strategies to maximize benefits while minimizing drawbacks.

To further enhance the effectiveness of these modifications, additional strategies have been considered in subsequent stages to counteract the secondary effects of these methods. The integration of vegetation, such as planting trees around parking lots and along roads, could mitigate the negative impacts of increased solar radiation reflection. Trees, by providing shade, would directly reduce MRT while improving thermal comfort for users. These approaches will be explored in greater detail in other sections.

3.3 Water body-environment interactions

3.3.1 Presentation

To address the Urban Heat Island (UHI) effect in the EPFL Innovation Park, we introduced water features, specifically fountains and nozzles, as part of our interventions. These elements were added to the ENVI-met model by creating custom materials in the database, carefully adjusting their parameters to accurately simulate their physical and thermal behavior. For fountains, this included configuring properties such as high evaporation rates to maximize latent heat flux, smooth surfaces for realistic wind interactions, and thermal parameters to reflect the heat exchange dynamics of water bodies. Similarly, nozzles were modeled with properties emphasizing rapid evaporation and localized cooling.

Fountains were strategically placed in locations where they could provide both thermal and social benefits. For instance, we added fountains to the green space in the bottom-left area of the Innovation Park, envisioning this as a future relaxation zone. This area is designed to be a shaded space where people can sit comfortably under trees and enjoy the cooling effect provided by the fountains. The combination of water features with surrounding vegetation enhances the cooling potential, creating localized areas of lower temperatures that improve thermal comfort.

Nozzles were introduced primarily along pedestrian walkways, targeting areas of high foot traffic where localized cooling could benefit individuals. By placing nozzles along these pathways, we aimed to reduce heat exposure for pedestrians, especially in transit. The fine mist produced by nozzles allows for rapid evaporation and immediate cooling, making them highly effective in narrow urban spaces and along walkways where direct solar exposure is significant.

In the upper-right area of the Innovation Park, we focused on adding both fountains and nozzles to utilize the wind's natural direction. As wind flows from this area, the inclusion of water features is intended to cool the air and allow the wind to disperse this cooler air across the park. This placement helps mitigate heat not only in the immediate vicinity of the water bodies but also in downwind areas, extending the cooling benefits.

Through these modifications, we sought to address specific UHI challenges by strategically integrating water features in a way that improves thermal comfort, enhances the usability of spaces, and maximizes the natural synergies between water, vegetation, and airflow within the Innovation Park.

3.3.2 Results

The simulation outputs reveal localized reductions in air temperature, particularly around the fountains and nozzles integrated into the design. As shown in Figure 6, the areas surrounding the fountains in the bottom-left green space experience temperature drops of up to 0.3 K, indicating effective evaporative cooling. Similarly, pathways equipped with nozzles display cooler air, suggesting that these features help mitigate heat along pedestrian routes.

However, the cooling effect remains concentrated near the water features, with limited influence beyond these areas. This highlights the localized nature of the intervention, suggesting that while fountains and nozzles create Urban Cooling Islands (UCI), their broader impact across the park is constrained.

Notably, slight temperature increases are observed near certain building facades and areas downwind from the fountains. This may result from heat displacement, where the cooling process redistributes warm air to adjacent zones. While the overall cooling effect is evident, this highlights the complex interaction between water features, airflow, and surface materials within the Innovation Park.

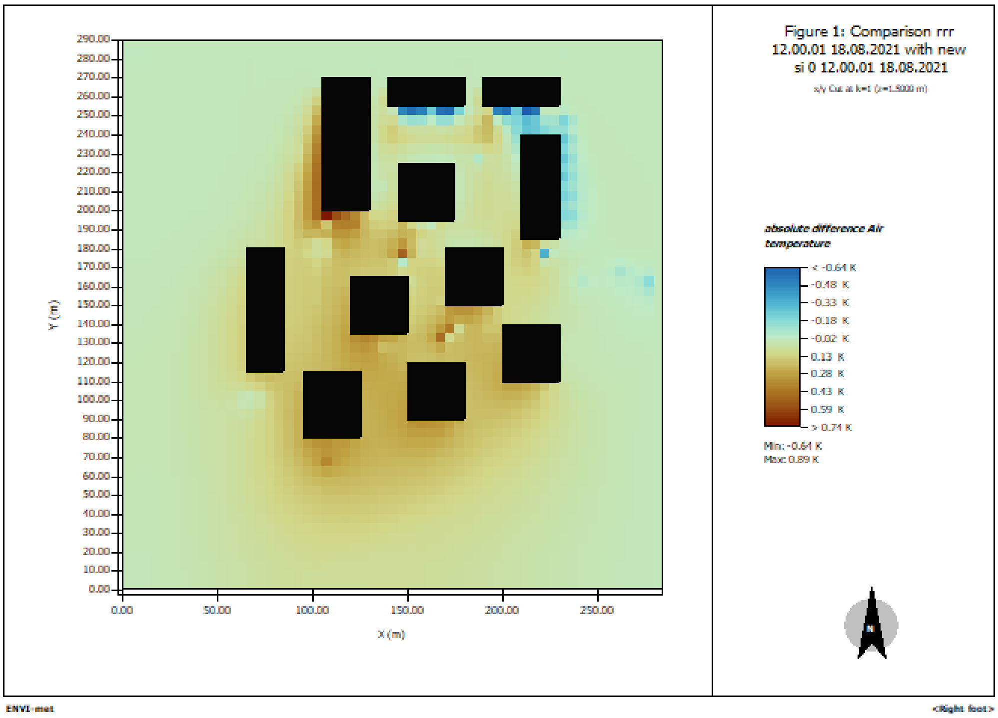


FIGURE 6 – Air temperature difference map showing localized cooling around fountains and nozzles.

Physiological Equivalent Temperature (PET) : The PET analysis highlights improvements in outdoor comfort during both daytime and evening conditions, driven by the placement of water features.

Figure 7 illustrates reductions in PET of up to 3.3 K during the day, particularly along pedestrian paths lined with nozzles. These areas show significant improvements in comfort, reinforcing the effectiveness of nozzles in reducing heat exposure along routes frequently used by pedestrians. In the evening, as shown in Figure 8, PET reductions persist around fountains, demonstrating the continued cooling effect of water bodies after sunset.

Despite these positive outcomes, the PET reductions associated with nozzles diminish in the evening, reflecting their transient nature. While nozzles provide immediate cooling during peak sun hours, their impact fades as solar radiation decreases. Conversely, fountains contribute to longer-lasting comfort, making them more suitable for stationary areas designed for social interaction and relaxation.

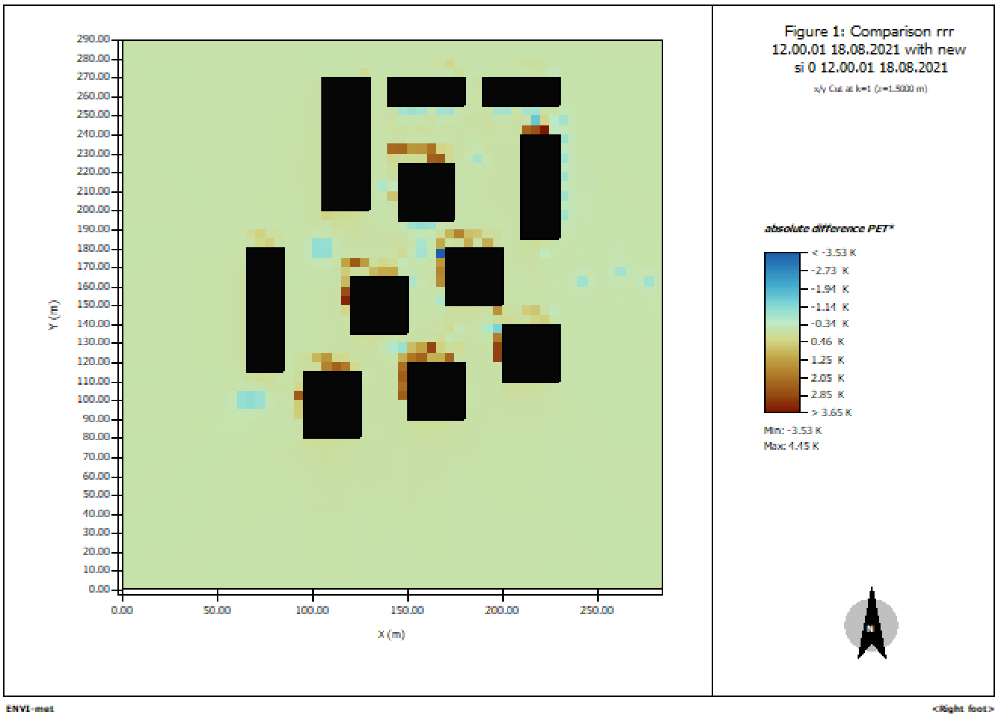


Figure 7 – Daytime PET map indicating reduced heat stress along pathways with nozzles.

The UTCI results reveal a significant overall reduction in thermal stress across most of the Innovation Park following the introduction of fountains and nozzles. As shown in Figure 9, temperature drops of up to 2.9 K are observed near fountains and along pathways lined with nozzles. The cooling effect is particularly noticeable in the upper-right area, where wind direction plays a role in dispersing cooled air further across the park. This reinforces the strategy of placing water features in wind-exposed zones to extend their influence and enhance comfort over a broader area.

Encouragingly, much of the park benefits from some degree of cooling, with fountains contributing to long-lasting reductions in thermal stress in social areas, while nozzles provide immediate relief along pedestrian walkways. The overall pattern indicates that even small-scale water features can generate measurable improvements in outdoor comfort when positioned strategically.

While the cooling effect is most pronounced near the water features, some areas experience less pronounced reductions beyond 10 to 15 meters. This reflects the inherently localized nature of evaporative cooling and suggests that integrating additional interventions, such as increased vegetation or shading, may further amplify the reach and longevity of the cooling effect. Despite this, the simulation highlights the potential of water bodies to create a more comfortable urban environment, demonstrating

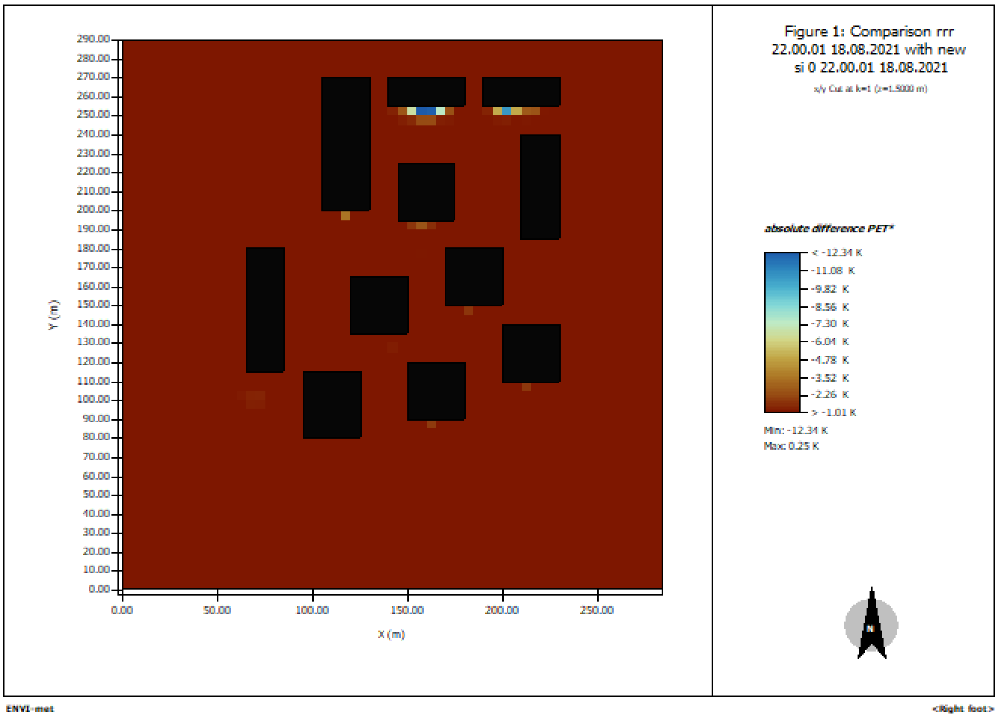


FIGURE 8 – Evening PET map showing continued cooling around fountains and green spaces.

meaningful progress in mitigating the UHI effect across the Innovation Park.

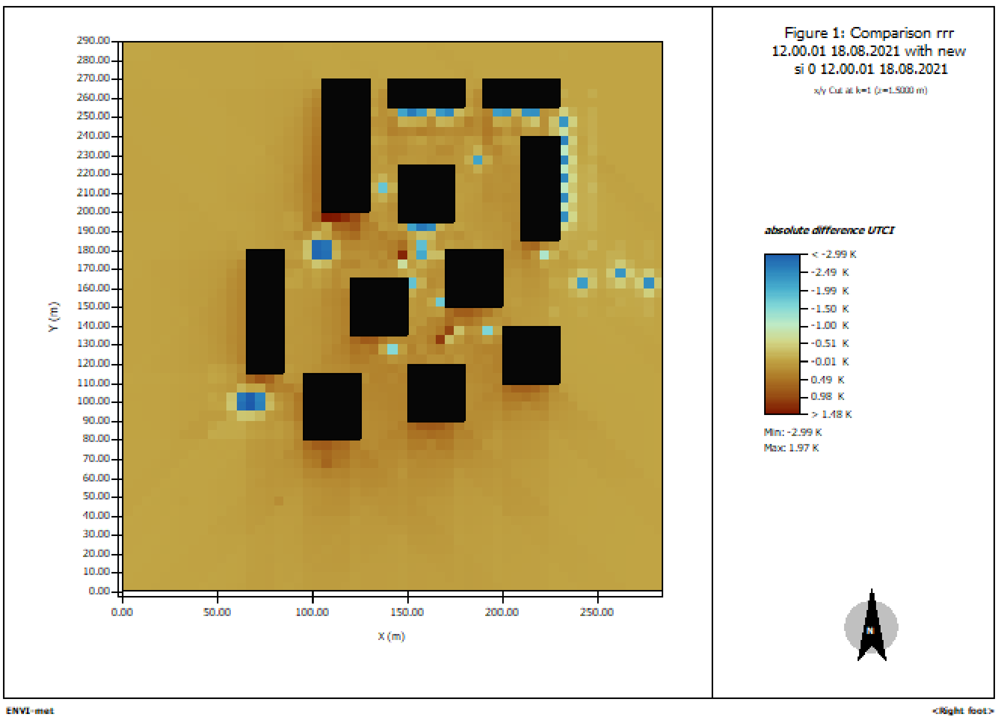


FIGURE 9 – UTCI difference map indicating reduced thermal stress around fountains and nozzles.

Mean Radiant Temperature (MRT) reductions, as shown in Figure 10, are most evident around fountains.

Along pathways with nozzles, MRT reductions are less pronounced. This is likely because nozzles primarily cool the air, with minimal direct effect on surface radiation. In some areas near building facades and paved surfaces, slight MRT increases are observed. While this may seem counterproductive, it likely reflects how MRT measures radiation from surrounding surfaces, where cooler air interacts with warmer materials.

These increases highlight the persistence of surface heat even as air temperatures drop, a common occurrence in urban areas with high thermal mass materials. Rather than indicating failure, this underscores the need for a holistic approach that combines evaporative cooling with vegetation, shading, or reflective material to further mitigate surface heat.

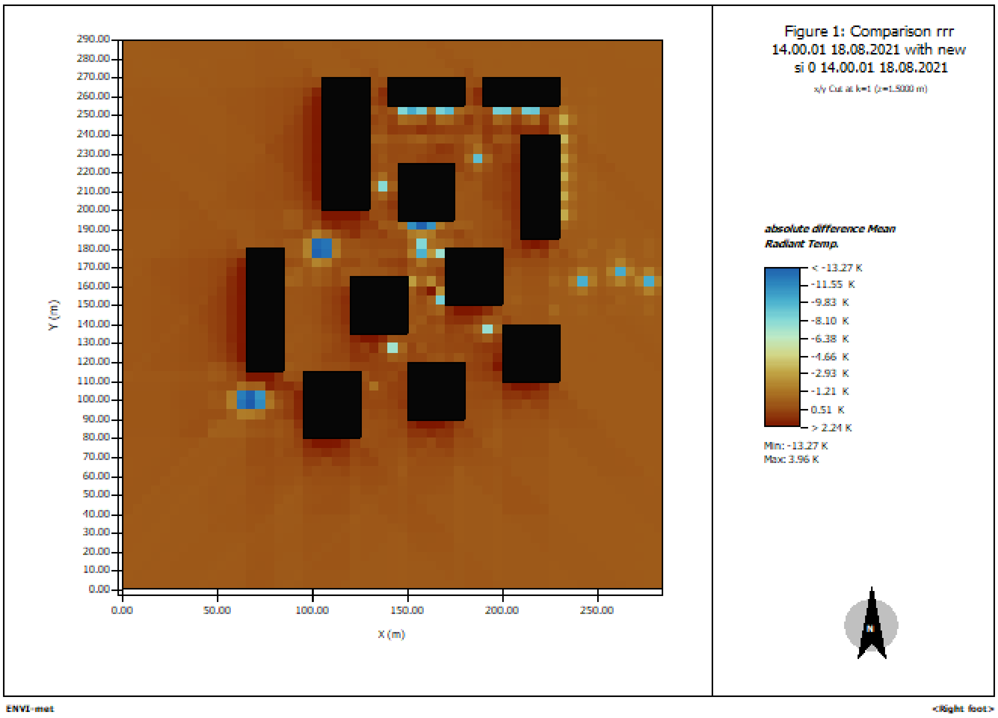


FIGURE 10 – MRT difference map showing localized reductions near fountains.

3.3.3 Discussions

The simulation results demonstrate that the addition of water features successfully reduces localized temperatures and enhances pedestrian comfort, particularly around fountains in social areas and nozzles along pedestrian pathways. However, the scale of cooling remains limited to their immediate surroundings, with the cooling effect diminishing beyond 10 to 15 meters from the water bodies.

To achieve broader Urban Heat Island (UHI) mitigation across the Innovation Park, water body interventions should be integrated with other modifications. Vegetation can amplify cooling by providing shade and contributing to evapotranspiration, while permeable and reflective soil surfaces reduce heat storage and support evaporative cooling. Similarly, modifying building materials and facades by incorporating green roofs, reflective coatings, or ventilated surfaces can lower heat retention and minimize re-radiation of heat to adjacent areas.

A holistic approach that combines water features with these strategies can create a more resilient urban environment, extending the benefits of localized cooling interventions and addressing heat accumulation across larger areas of the Innovation Park.

3.4 Vegetation-environment interactions

3.4.1 Presentation

The integration of vegetation into the Innovation Park project at EPFL represents a key solution for mitigating urban heat island (UHI) effects, improving outdoor thermal comfort, and promoting environmental sustainability. Several ideas have been implemented to achieve these objectives.

The first major intervention involves transforming the original parking lot into a green parking area. This approach combines zones of light concrete with vegetated parcels (grass). This type of design is inspired by projects in places like the Vauban district in Freiburg, Germany, where green parking lots are used to reduce heat islands and improve rainwater management (example shown in the figure below).

FIGURE 11 – difference of potentiel air temperature

As seen in the graphs, the current parking area is one of the main heat sinks on the site due to its ability to absorb large amounts of solar radiation, exacerbated by the low ventilation levels in this area. Partial replacement with light concrete, which has a high albedo (between 0.30 and 0.50), reduces heat absorption and significantly lowers surface temperatures. Additionally, the introduction of vegetated surfaces promotes evapotranspiration, acting as an active cooling mechanism by reducing ambient temperature and increasing rainwater infiltration.

A second major idea involved expanding lawn coverage across much of the site. Vegetated soils, such as grass, play a key role in natural thermal regulation by absorbing less solar heat than impermeable surfaces. Grass acts as a thermal buffer, limiting temperature increases during the day and reducing the emission of stored heat at night. Moreover, vegetation promotes increased rainwater infiltration, thereby reducing runoff. According to the principles studied in the course, this vegetative cover maximizes latent heat flux and reduces sensible heat flux, contributing to a generally cooler and more pleasant microclimate.

Another intervention involved planting trees, particularly species such as Tilia cordata (small-leaved lime) and Quercus robur (pedunculate oak), around heat sinks such as roads and paved areas. These trees were chosen for their ability to provide effective shading and improve air quality. In summer, their large canopies create dense shade, lowering surface temperatures and improving thermal comfort for pedestrians and drivers. These trees were also planted around and in front of buildings to reduce direct sun exposure, thereby lowering energy consumption for air conditioning. Additionally, trees were placed above pedestrian walkways to provide shade and enhance the comfort of passersby.

These deciduous species offer an added advantage in winter : they shed their leaves, allowing sunlight to penetrate and warm buildings and surrounding surfaces. Furthermore, their trunks and branches act as windbreaks, reducing the impact of cold winds on pedestrian areas and building facades. This dual seasonal role makes the selected trees an effective solution for improving year-round thermal comfort.

Finally, vegetation plays an essential role in CO sequestration and improving air quality. A mature tree can absorb up to 90 kg of CO per year while filtering fine particles and other atmospheric pollutants. By integrating harmoniously into the project, these plantations contribute to a healthier environment while reducing greenhouse gas emissions by decreasing reliance on artificial cooling systems.

The strategic integration of vegetation in the project is based on solid principles, such as those studied in the course, and draws inspiration from real-world examples of successful implementations. By combining grass, trees, and green parking areas, these interventions help reduce local temperatures, regulate the microclimate, and promote sustainable design. Simulation results will quantify these impacts and validate the effectiveness of the implemented solutions.

Two simulations were conducted for this section : one incorporating only the addition of grass throughout the space, and a second including both grass and the addition of plants and trees to compare the influence of each solution.

3.4.2 Results

In our analyses, parameters such as PET (Physiological Equivalent Temperature) and UTCI (Universal Thermal Climate Index) are used as they also account for humidity, a factor that can be crucial in evaluating the use of vegetation and its thermal impact.

The first simulation compares the city in its initial state, without vegetation, to a final simulation incorporating grass, plants, and trees. The results highlight a significant reduction in the temperatures experienced by users, with a decrease of approximately 20°C for PET and 10°C for UTCI. These notable reductions demonstrate the effectiveness of the proposed interventions in improving thermal comfort across the site.

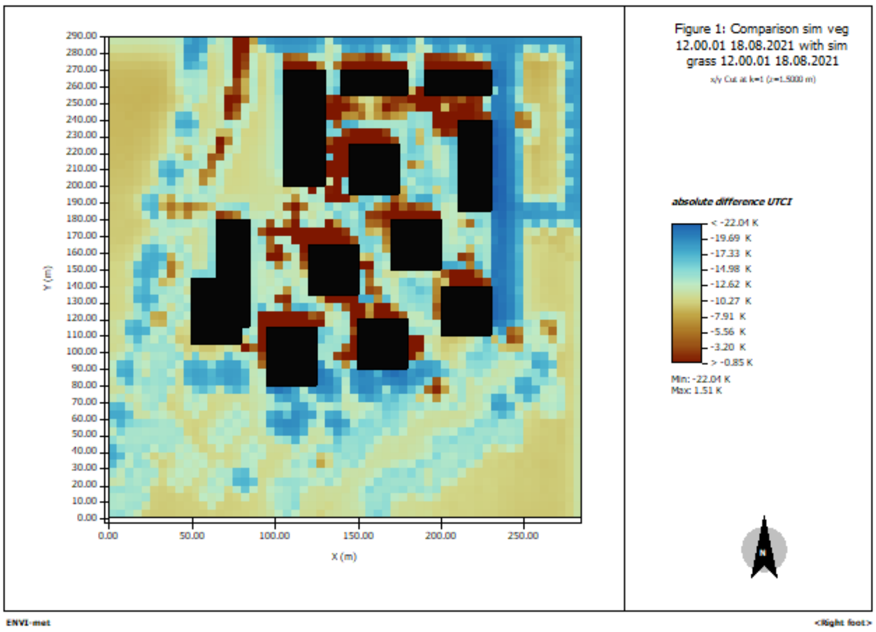


FIGURE 12 – comparaison of UTCI

The areas most impacted by this temperature reduction are primarily located between buildings, in pedestrian pathways. These spaces, initially exposed to significant direct solar radiation and characterized by low ventilation levels, now benefit from the shade provided by trees and the thermal regulation offered by grass-covered surfaces. This combination effectively reduces the thermal load experienced by users while making these spaces more inviting.

Furthermore, around the parking lot, the combination of vegetated surfaces and tree shading not only lowers localized temperatures but also improves air quality through evapotranspiration and CO sequestration. These observations demonstrate that the primary objective of the interventions—creating more comfortable and thermally adapted spaces—has been successfully achieved, particularly in strategically important areas with high user activity.

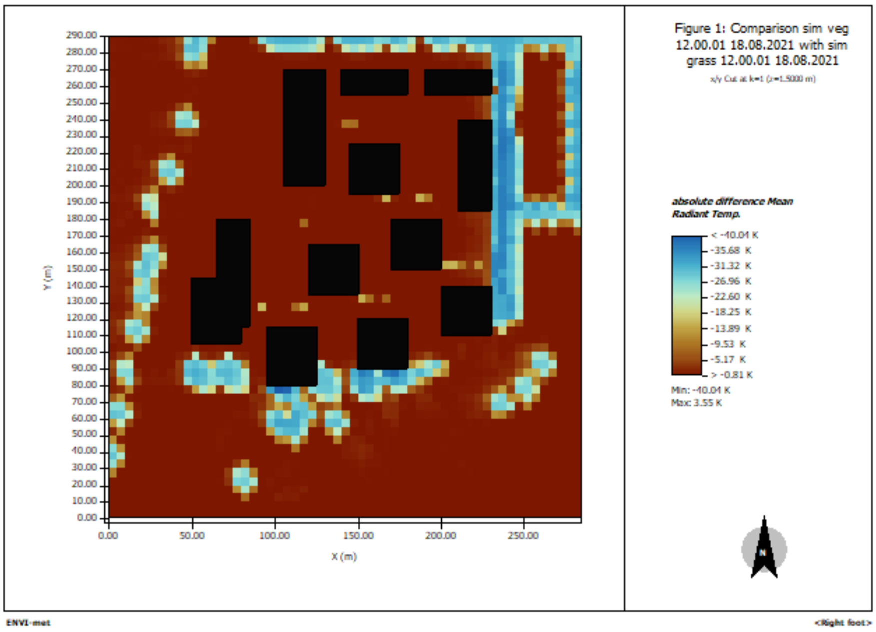


Figure 13 – difference of mean radiant temperature

The comparison between the simulation with grass alone and the one combining trees and grass highlights a significant reduction in the Mean Radiant Temperature (MRT) due to the shading provided by the trees (as shown in the graph above). The results indicate a decrease of over 40°C in areas directly beneath the tree canopies, particularly around pedestrian pathways, parking lots, and paved areas. This reduction is primarily attributed to the trees' ability to block direct solar radiation, thereby reducing the radiative load experienced in shaded areas, combined with the cooling effect of evapotranspiration.

Unlike grass alone, which primarily reduces surface temperatures and increases evapotranspiration, trees directly target the solar radiation received by users, significantly enhancing thermal comfort in strategic areas. These results confirm that integrating trees in sensitive zones effectively achieves the goal of creating a more pleasant and thermally suitable environment for daily use.

Another graphical analysis shows that the presence of trees in the simulation combining trees and grass results in a significant surface temperature reduction, reaching up to 20°C in areas directly shaded by the trees, particularly in parking lots. This temperature drop confirms the effectiveness of trees in mitigating the urban heat island effect by blocking solar radiation and reducing heat storage in exposed surfaces. These findings demonstrate that the initial objective of lowering temperatures in strategic areas like parking lots through tree planting has been fully achieved with this technique (see Figure 19 in the Annex).

The graphs also show a notable reduction in CO_2 concentrations in vegetated areas due to the integration of trees. At 12 PM, a decrease of up to -15 ppm is observed, primarily around trees and vegetated zones (see Figure 20 in the Annex for details on CO_2 levels at 12 PM). This phenomenon can be explained by the photosynthetic activity of the trees, which absorb carbon dioxide for growth while releasing oxygen. However, by 10 PM, this effect is no longer present; on the contrary, some areas show a slight increase in CO_2 levels, up to +2.9 ppm, due to the cessation of photosynthesis and the nighttime respiration of the trees, during which they emit CO_2 (see Figure 21 in the Annex for details on CO_2 levels at 10 PM).

These results indicate that, during the day, trees actively contribute to reducing local CO_2 levels, improving air quality, which is particularly relevant in urban environments where concentrations tend to be higher due to human activities. However, this impact remains relatively modest in magnitude, with a maximum reduction of 6 ppm, and is limited to daytime, reducing its significance in the broader context of microclimate improvement. While these findings provide evidence of environmental benefits, they should be seen as complementary to the more significant effects of trees on thermal regulation and user comfort.

It should also be noted that our simulation was conducted in the middle of a summer day when CO_2 levels related to human activities are much lower compared to a winter day, due to building heating systems. Conducting a simulation in winter would have been more insightful to better assess the impact of trees on CO_2 levels.

Do you have any graph showing the effect of evapotranspiration?

3.4.3 Discussions

he results confirm the effectiveness of the vegetative interventions in achieving the set objectives, particularly in terms of thermal regulation and improving outdoor comfort. The addition of grass, plants, and trees significantly reduces perceived temperatures (up to 20°C for PET) and surface temperatures (up to 20°C in shaded areas beneath trees), while also improving air quality through evapotranspiration and CO sequestration. These targeted interventions, especially around parking lots and pedestrian pathways, have shown a particularly positive impact in strategic areas.

However, certain limitations are observed. For instance, the reduction in CO levels remains limited in magnitude and does not extend into the night, when trees enter their respiration phase. Furthermore, the impact of these interventions on parameters such as relative humidity and airflows could be analyzed further for a more comprehensive evaluation.

These results highlight the relevance of the proposed solutions for thermal regulation and air quality in an urban context. Nonetheless, to maximize their effectiveness, complementary analyses—such as assessing energy fluxes, wind dynamics, and seasonal interactions—could be considered. This would strengthen the scientific validity of the solutions.

4 Integrated Microclimate Solution

4.1 Final solution plan

We have retained all the proposed solutions for vegetation, soil, and buildings, as they appeared both realistic and feasible. Regarding the buildings, we were initially hesitant to use aluminum cladding due to its high cost and the potential increase in solar reflection, which could elevate the Mean Radiant Temperature (MRT) in adjacent areas. As for water features, we ultimately decided to keep only the fountain located in the small park in the southwest of the site. This decision was based on the minor and highly localized effects of fountains on temperature, as already discussed in the section on water. While these structures take up considerable space and have a limited impact on the overall microclimate, the fountain remains relevant in this specific park, where optimizing available space is not a priority. Additionally, it can help maintain humidity and support vegetation in the area.

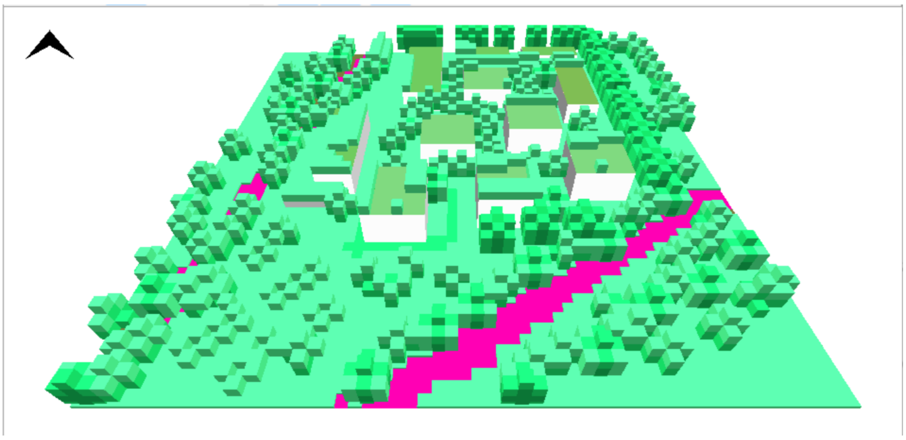


FIGURE 14 – 3D view

4.2 Final solution results

To compare our results, we will analyze the data obtained from the combination of the proposed solutions against those from the initial simulation without any modifications.

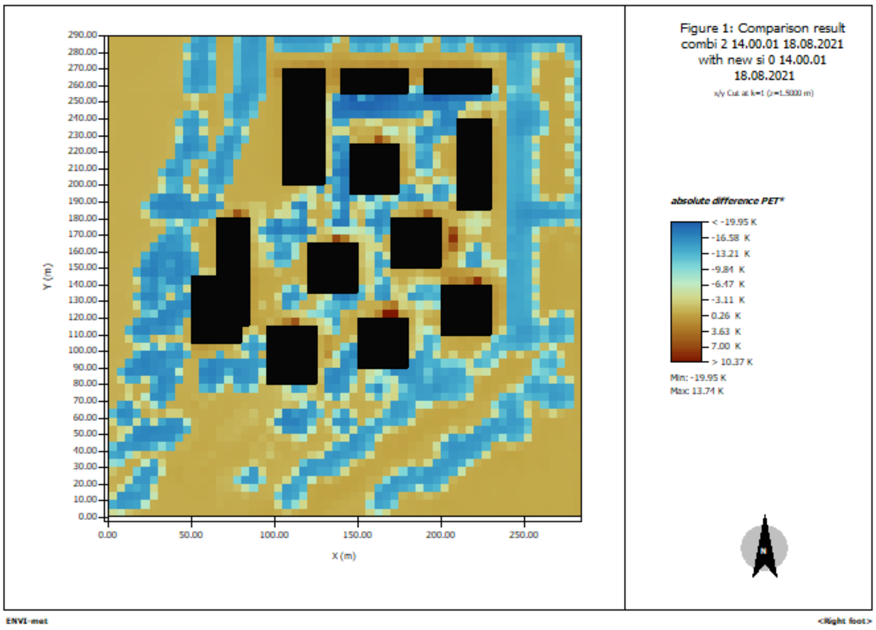


FIGURE 15 – difference of surface temperature

The analysis of the Physiological Equivalent Temperature (PET) reveals significant improvements in areas where the proposed solutions were implemented. The graph shows a reduction of up to 20°C in PET, particularly in strategic zones such as parking lots and pedestrian pathways, where greening and shading interventions were applied. This substantial decrease highlights the effectiveness of these solutions in mitigating urban heat island effects and enhancing outdoor thermal comfort for users.

However, certain localized areas show an increase in PET of up to 10°C. These areas are very small in size and represent a negligible portion of the site. This increase could be attributed to the reflection of solar radiation from high-albedo surfaces or the lack of shading in these specific locations. Despite this, these localized increases do not significantly impact the overall results.

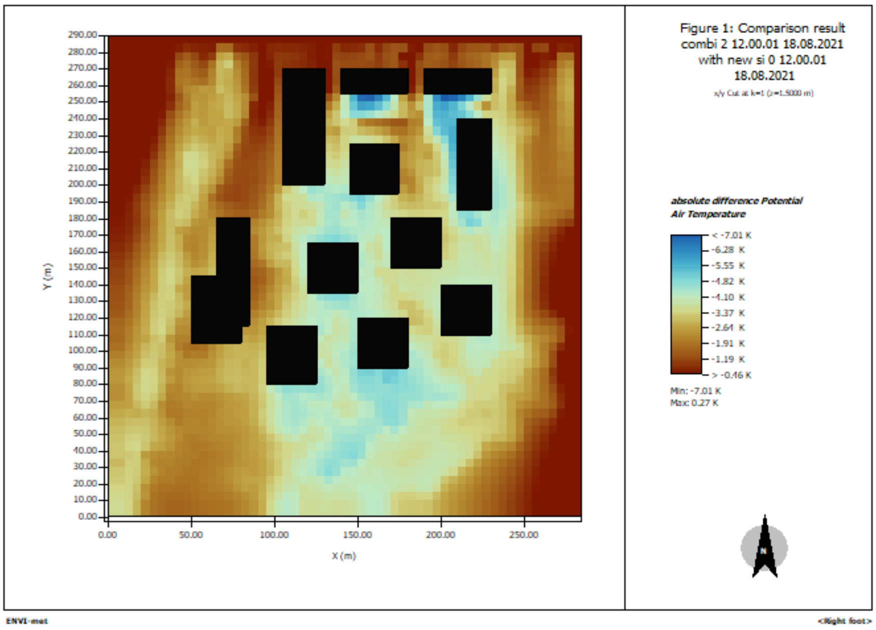


Figure 16 – difference of surface temperature

The graph shows a significant reduction in potential air temperature, reaching up to -7°C around the water fountains. This substantial decrease is a direct result of the cooling effects induced by evapotranspiration and the humidity generated by these water features.

Across the rest of the site, the reduction generally ranges between -3°C and -5°C, confirming the effectiveness of the implemented solutions, particularly the integration of vegetation and water elements. These temperature decreases are realistic and demonstrate the capacity of these measures to improve thermal conditions in urban environments.

For ground temperature, the graph shows a reduction reaching up to -27°C across all roads and in certain strategic areas. While this result may seem slightly unrealistic in magnitude, it remains consistent in indicating a notable decrease in surface temperature due to the measures implemented.

Nonetheless, this reduction is significant and highlights the effectiveness of the proposed solutions. The materials used, with a higher albedo, contribute to limiting solar radiation absorption, while tree shading plays a key role in lowering temperatures. Additionally, the combination of measures, including vegetated parking lots, modified roads, and tree plantations, not only reduces surface temperatures but also minimizes heat emitted into the atmosphere, thereby fostering an overall temperature reduction.

The analysis of the Mean Radiant Temperature (MRT) reveals a significant reduction of up to -40°C in some areas, particularly beneath tree canopies and in spaces equipped with reflective materials (see Figure 22 in Annex). This decrease is due to the interception of direct and diffuse solar radiation by the trees, which reduces the radiative thermal load received by the surfaces below. Furthermore, the

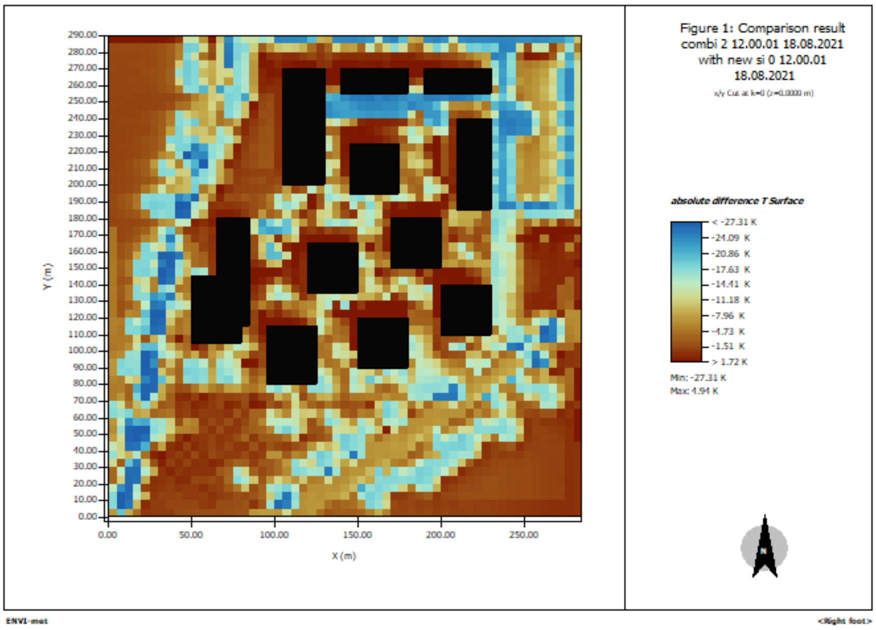


FIGURE 17 – difference of surface temperature

high-albedo materials limit heat absorption, while the shading combined with plant evapotranspiration enhances this cooling effect. However, a few zones show a slight increase in MRT, up to +11°C, likely due to increased solar radiation reflection or a lack of localized shading. Despite this, the overall results confirm the effectiveness of the implemented solutions in improving thermal comfort and reducing the impact of urban heat islands.

The analysis of the UTCI (Universal Thermal Climate Index) also shows a notable improvement, with a reduction of up to -13°C in strategic areas such as pedestrian pathways, parking lots, and vegetated spaces (see Figure 23 in Annex). This decrease is directly linked to the shading provided by the trees, which reduces exposure to solar radiation, and the cooling effect of evapotranspiration, which increases humidity and lowers perceived temperatures. Reflective materials also play an important role in limiting heat absorption by surfaces. A few isolated zones show a minor increase in UTCI, up to +1.6°C, attributable to local effects such as excessive reflection or the absence of shading. Nevertheless, these results confirm the overall effectiveness of the proposed solutions in enhancing thermal comfort for users.

5 Conclusion

The final proposal for the mitigation strategy at the EPFL Innovation Park integrates a comprehensive approach aimed at reducing the Urban Heat Island (UHI) effect, improving outdoor thermal comfort, and promoting environmental sustainability. High-albedo materials, such as red asphalt and light concrete, were implemented on roads and parking lots to reflect solar radiation and reduce surface temperatures, achieving reductions of up to 27°C in key areas like parking lots. Extensive vegetation, including grass, plants, and trees such as Tilia cordata and Quercus robur, was strategically placed to provide shade, lower the Mean Radiant Temperature (MRT) by up to 40°C in shaded zones, and improve air quality through CO sequestration and evapotranspiration. A single fountain in the southwest park was retained to provide localized cooling and support surrounding vegetation, offering functional and aesthetic benefits without compromising space optimization. The results demonstrate significant improvements in thermal comfort, with reductions of up to 20°C in the Physiological Equivalent Temperature (PET) and 13°C in the Universal Thermal Climate Index (UTCI) in pedestrian pathways and other high-traffic areas. While localized increases in MRT and PET were observed due to reflective surfaces, these effects remain minimal and highlight the importance of combining high-albedo materials with shading strategies like tree planting. The project confirms the effectiveness of these solutions in addressing microclimate challenges, offering a sustainable and replicable framework for urban environments. Future research could explore additional factors such as seasonal variations, wind dynamics, and energy fluxes to further enhance the proposed strategies.

6 References

[1] Mason Huges, *Introduction to Environmental Physics*.

[2] sncf connect, *Week-end de charme à Fribourg*

[3] Dolaana Khovalyg, *CIVIL-309 : Urban Thermodynamics*.

7 Annexes

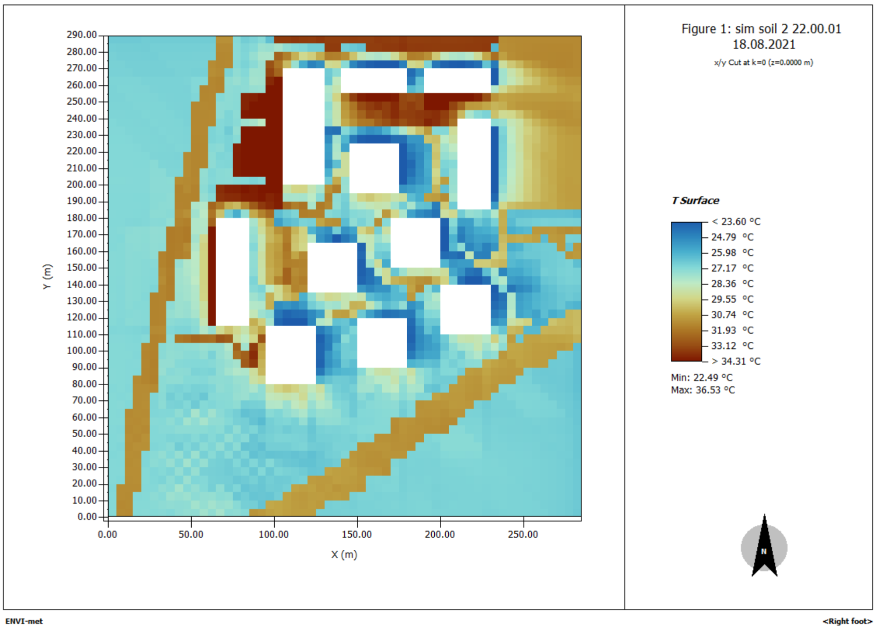


FIGURE 18 – soil temperature during the night

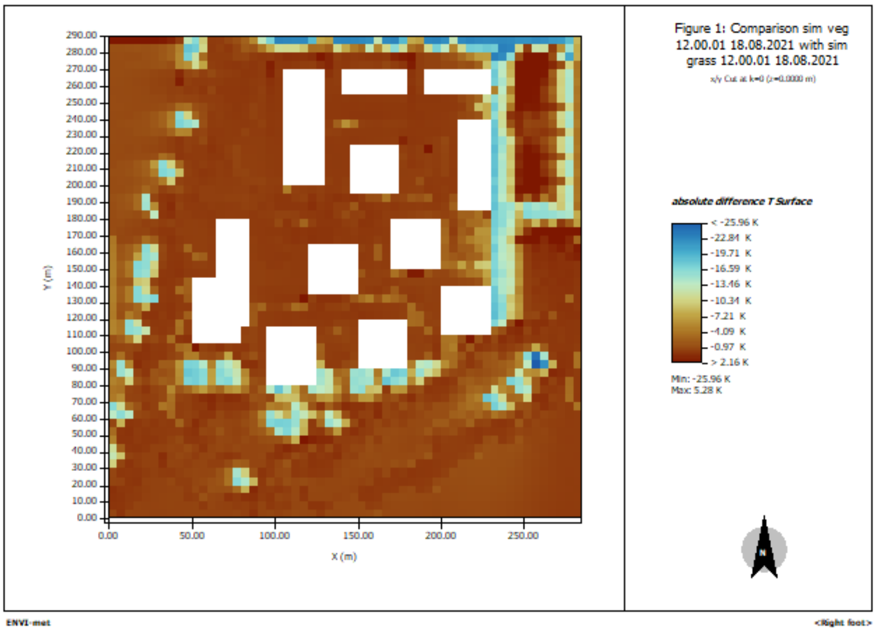


FIGURE 19 – difference of mean radiant temperature

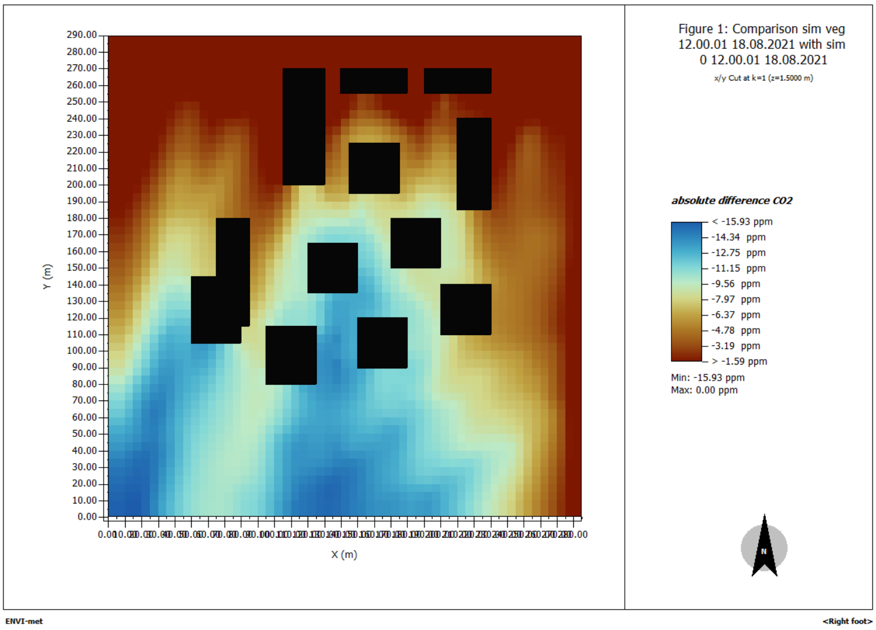


Figure 20 – difference of co2 level at 12 pm (in ppm)

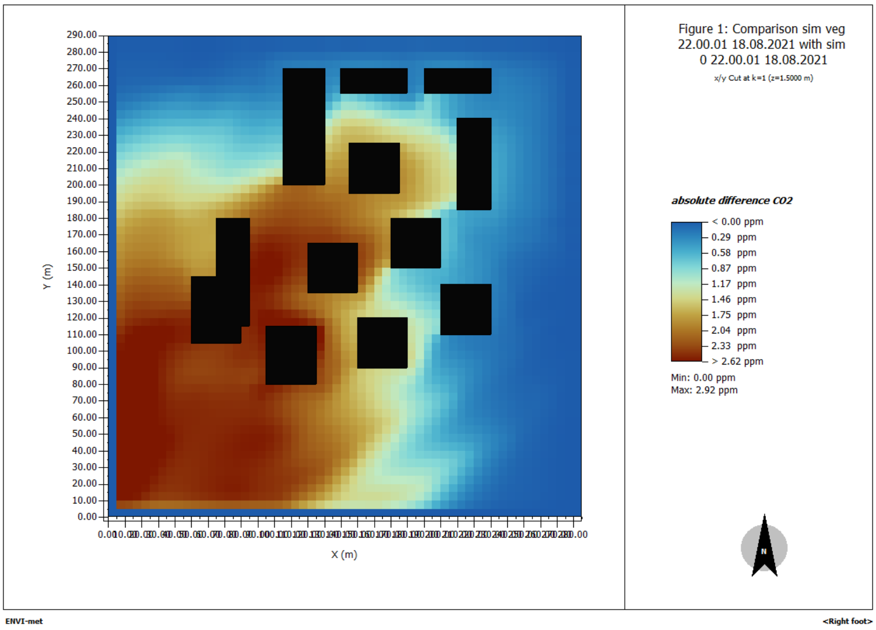


Figure 21 – difference of co2 level at 12 pm (in ppm)

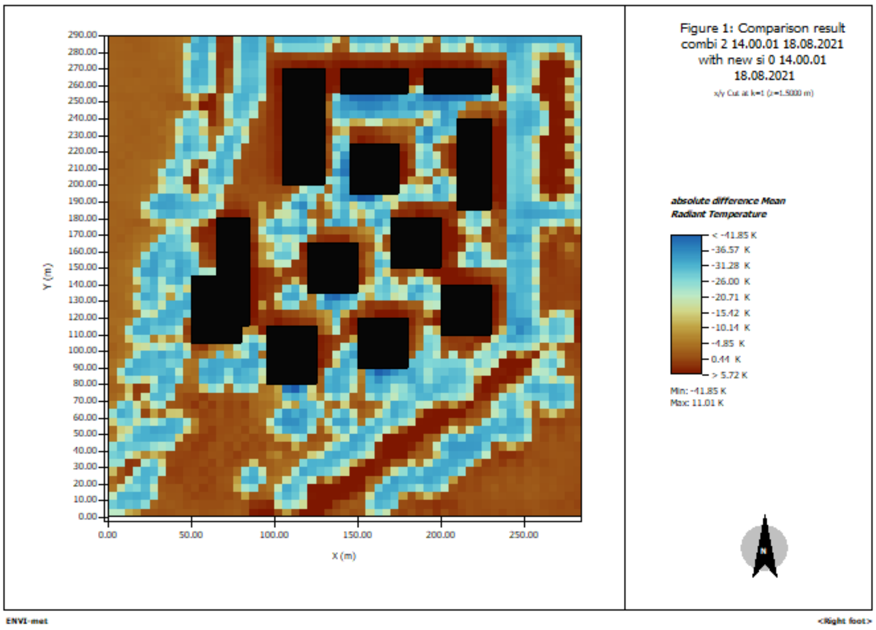


FIGURE 22 – difference of mean radiant

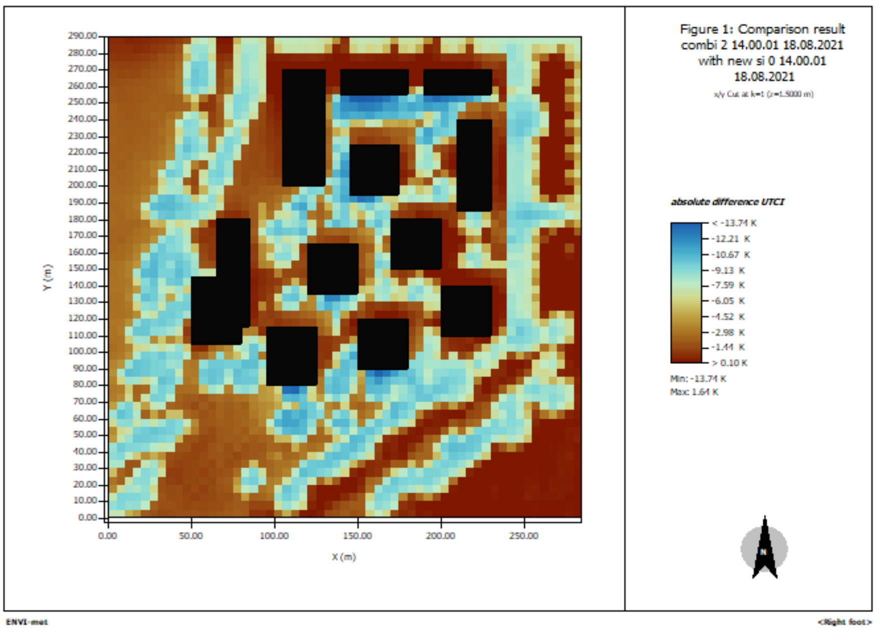


FIGURE 23 – difference of compar UTCI