Ecole Polytechnique Fédérale de Lausanne

Urban Thermodynamics

Course project
Microclimate Analysis : Case study of EPFL Innovation Park

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1 Introduction

Urban environments are undergoing rapid transformation, driven by increasing population density, intensified anthropogenic activities, and changes in urban morphology. These shifts bring significant environmental challenges, one of the most critical being the phenomenon of urban heat islands (UHI). UHI refers to the localized increase in temperature in urban areas compared to their surrounding suburban or rural regions, exacerbated by factors such as heat-retentive materials, reduced vegetation, and increased energy consumption. During heatwaves, this effect can become even more pronounced, leading to severe consequences, including thermal discomfort, elevated energy demands, and increased risks to human health through heat-related morbidity and mortality.

The urban microclimate, a complex interplay of environmental conditions shaped by elements such as building materials, ground surfaces, vegetation, and water bodies, plays a pivotal role in influencing thermal comfort and energy efficiency within cities. Understanding and mitigating urban overheating has therefore become a pressing objective for sustainable urban development. This is particularly relevant in the context of global warming, which amplifies the adverse effects of UHI. Addressing these challenges requires climate-sensitive urban planning and design interventions that integrate principles of urban thermodynamics.

This report investigates these issues through a case study of the EPFL Innovation Park, a mixed-use urban site in Lausanne, Switzerland. The project focuses on examining the current site conditions, identifying the factors contributing to its microclimate, and proposing targeted mitigation strategies to counteract urban overheating. Using ENVI-met microclimate simulation software, the project explores how urban elements interact thermodynamically and evaluates the effectiveness of potential interventions.

The report is structured as follows:

- **Site Analysis**: An overview of the existing site conditions, including its physical layout, material properties, and climatic characteristics.
- **Urban Microclimate Exploration**: An investigation of the effects of individual urban elements—buildings, vegetation, ground cover, and water bodies—on the microclimate of the site, supported by simulation results.
- **Mitigation Strategies**: Propositions for integrated urban interventions to alleviate overheating, combining all modifications.

2 Site analysis

2.1 General context

The EPFL Innovation Park serves as a hub for a dynamic community of start-ups, scale-ups, research units, and established technology firms. Situated in the southwestern part of the EPFL campus and near Lake Geneva to the south, the site is bordered by residential areas to the west and south. Spanning approximately 11 hectares, the site encompasses a mix of rectilinear office buildings, a parking lot, and an urban woodland, all surrounded by roads on three sides. The EPFL Innovation Park can be classified as LCZ5 (Open midrise).

Figure 1: Global view of the EPFL Innovation Park

The ground cover is composed of four main material types: asphalt road, sandy soil, cement concrete pavement, and loam soil. The facade and roof material have three to four layers of materials, including isolation for high thermal resistance, as shown in figure 2.

Category	Layer	Building Group A		Building Group B		Building Group C	
		Material	Thickness (m)	Material	Thickness (m)	Material	Thickness (m)
Façade	1	Prefabricated concrete wall	0.14	Plaster	0.01	Fiber cement board	0.008
	2	Insulation	0.1	EPS Expanded Polystyrene	0.18	Sandwich panel mineral wool	0.15
	3	Plaster	0.047	Plywood (heavyweight)	0.14	Aluminum	0.002
Roof	1	Gravel	0.05	Gravel	0.1	Gravel	0.04
	2	Insulation	0.2	XPS Extruded polystyrene CO2 blow	0.2	Mineral wool insulation	0.08
	3	Reinforced concrete slab	0.3	Concrete reinforced with 2% steel	0.3	Reinforced concrete slab	0.35
	4	--	--	EPS Expanded Polystyrene	0.065	--	--

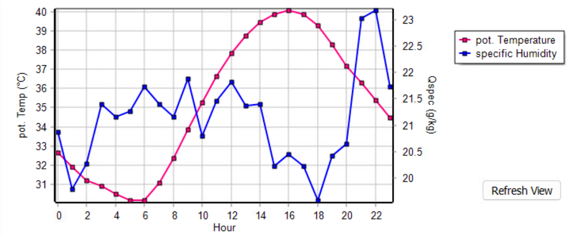
Figure 2: Building facade and roof materials (color code of building groups corresponds to Figure 1).

2.2 Climate analysis

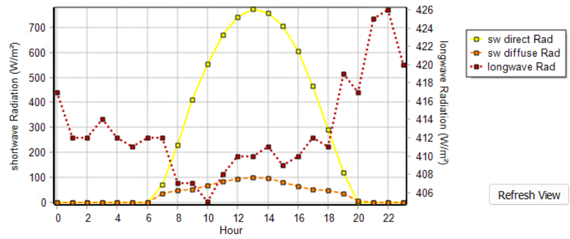
Since a weather file is provided, a short climate analysis can be done. Figure 3 highlights the main urban thermodynamic characteristics of the EPFL innovative park. The air temperature rises noticeably throughout the day, peaking at 40°C around 4:00 pm. In contrast, specific humidity moves in the opposite direction. This happens because warmer air can hold more moisture, as shown in the psychometric chart. Having a look at that document, we find that the relative humidity should be between 40% and 50%.

Moreover, air temperature follows the direct short wave radiation (i. e. sunlight, radiation from the sun) with a slight delay. As direct shortwave radiation decreases, longwave radiation increases, keeping temperatures high later in the day. Longwave radiation hits its peak around 10:00 pm, when materials that absorbed energy during the day release it back into the surroundings.

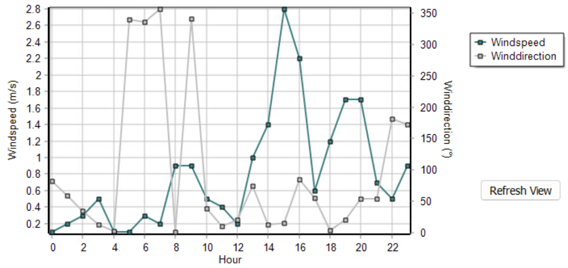
A last observation is that wind speed is very low. This is a problem to clear the air, bring fresh air and cool down the surroundings. Wind direction also shifts throughout the day, which we'll need to factor into our final design to ensure proper airflow, regardless of the wind direction.



(a) Temperature from weather file



(b) Radiation from weather file



(c) Wind from weather file

Figure 3: Temperature, radiation and wind from forcing manager file.

2.3 Characteristics of the neighborhood

An on-site tour of the EPFL innovation park has been carried out to collect information on neighbourhood characteristics: sky view factor, materials, ground cover, building layout, building height, aspect ratio, vegetation. The information reported is in figure 5.

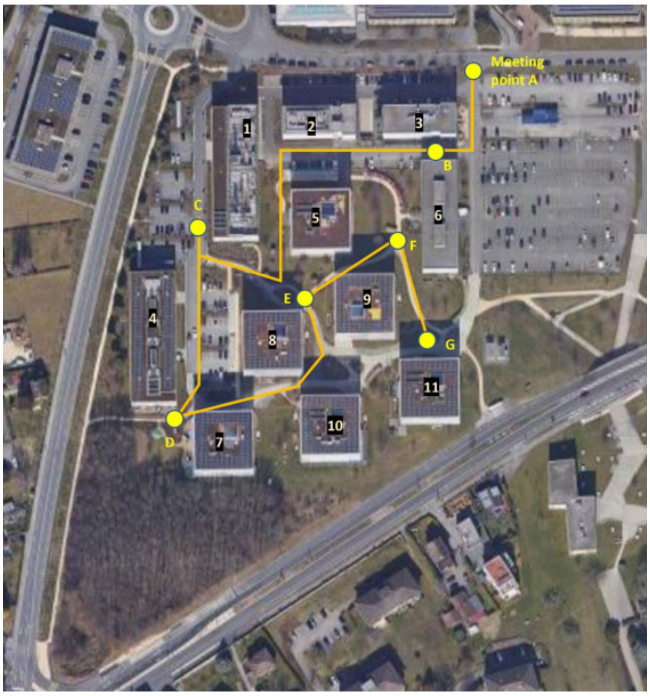


Figure 4: On site trajectory.

Let us review the definitions of anthropogenic heat source, the aspect ratio, and the sky view factor.

Anthropogenic heat refers to heat generated by human activities, such as the operation of vehicles, industrial processes, the heating and cooling systems of buildings, and other energy-consuming activities. This type of heat contributes to urban heat islands (UHIs), where urban areas exhibit higher temperatures compared to surrounding rural zones. In the given data, examples include cars and office buildings, which release heat into the environment, thereby increasing local temperatures.

Location	Natural Elements	Ground Cover Material	Surrounding Building Material	Building Height [m]
A	Bushes, Grass	Asphalt, Grass	Concrete, Glass	13
B	Grass	Asphalt, Grass	Concrete, Glass, Plastic	13
C	Bushes, Grass, Trees	Asphalt, Grass	Concrete, Glass, Plastic	14
D	Bushes, Grass, Trees, Soil	Grass, Gravel, Sand	Concrete, Glass, Plastic	14, 22
E	Bushes, Grass, Trees, Soil	Grass, Gravel, Sand	Concrete, Glass (a lot), Plastic	22
F	Bushes, Grass, Trees, Soil	Grass, Gravel, Sand	Concrete, Glass, Plastic	22, 13
G	Bushes, Grass, Trees, Soil	Asphalt, Grass	Concrete, Glass, Plastic	22

Location	Anthropogenic Heat Source	Aspect Ratio	Sky View Factor	Shading Sources
A	Cars, Office	N/A	1.00	Buildings
B	Cars, Office, Building	1.6	0.90	Buildings, Trees
C	Cars, Office, Building	N/A	0.95	Buildings, Trees
D	Office, Building, Kindergarten	1.25	0.80	Buildings, Trees
E	Building, Office	1.0	0.70–0.75	Buildings, Trees
F	Building, Office	0.5–0.6	0.95	Buildings, Trees, Bike Shelter
G	Building, Office	N/A	0.90	Buildings, Trees

Figure 5: On-site collected data following figure 4 trajectory.

The **aspect ratio** in urban environments describes the relationship between the height of buildings and the width of surrounding streets or spaces. It is a crucial factor in determining how air flows, heat is trapped, and sunlight reaches the ground in an area. High aspect ratios (tall buildings and narrow streets) can restrict airflow and reduce cooling at night, intensifying urban heat retention. In the data set, the values range from 0.5 to 1.6, suggesting a mix of environments, from relatively open spaces to denser areas. The not applicable aspect ratio refers to cases where the width between two buildings is high or the building is facing a parking lot, making it irrelevant to even consider an aspect ratio at that location.

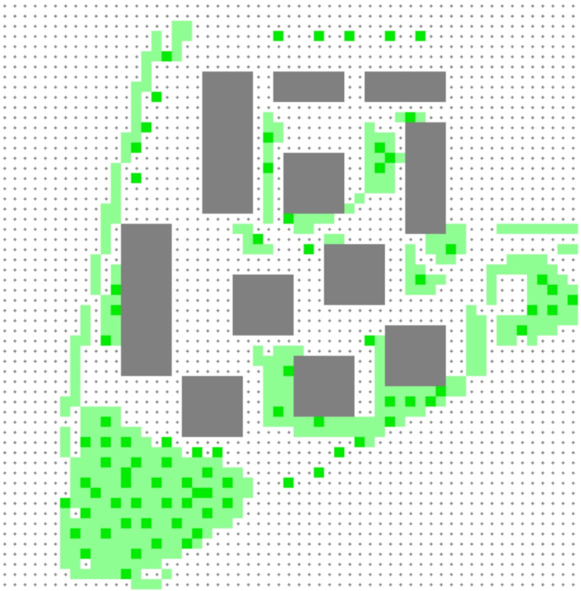
The **sky view factor (SVF)** is a measure of how much of the sky is visible from a specific point on the ground. Values closer to 1 indicate open areas where the entire sky is visible, while lower values suggest obstruction by surrounding structures or vegetation. SVF influences thermal comfort, as areas with a low SVF can retain heat longer due to reduced radiative cooling. The given data shows SVFs between 0.70 and 1.00, with lower values in areas with more shading elements, such as buildings and trees.

The dataset reflects a combination of dense urban zones and open spaces. The most dense area is location B. Location B has a high anthropogenic heat source and a high aspect ratio, which could make it prone to heat accumulation. The locations A, C, D, E, F, G are more open and shaded. Nonetheless, some of these locations are surrounded by less vegetation such as location C and A which are next to a large parking spot. They lack of vegetation coverage, which works as a natural air cooler. Locations D, E, F, and G, being in the center of the building complex can be victims of wind vertices and cavities enabling heat dissipation.

Results given by the ENVI-Met simulation of the current EPFL Innovation Park will give us more information on the site microclimate condition (air temperature, relative humidity, surface temperature, wind, and radiation). With this information a more precise analysis of the building complex can be done.

2.4 Simulation in the current conditions

In this part, we will analyze the simulation results of the base case simulation. Characteristics values of urban thermodynamics such as air temperature, soil temperature, relative humidity and wind speed will be studied. Figure 6a and 6b highlight the base case environment for our initial simulation.



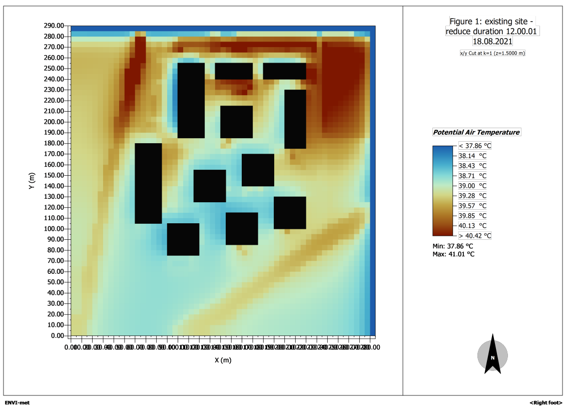
(a) Initial Space display

(b) Initial Ground Composition

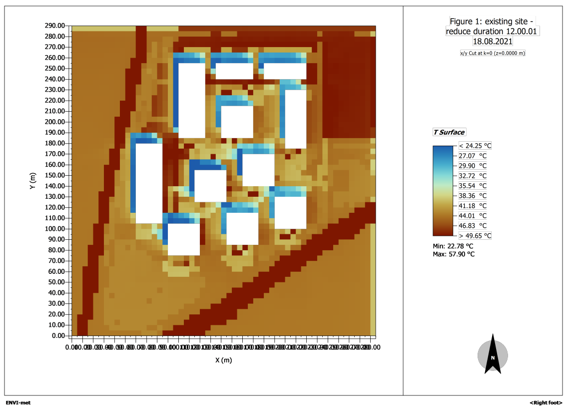
Figure 6: Base case environment

Those schemes were made as close as possible to the reality and with the tools available. In consequence of the squared mesh, elements such as trees and grass could not be implemented at their exact position. Similarly, ground composition (i.e pavements, roads) have approximate location. However, results should be accurate enough to draw insightful conclusions.

We will first analyze air and ground temperature as they are the most common variables. Temperature display is shown in Figure 7.



(a) Air temperature for the base case



(b) Ground temperature for the base case

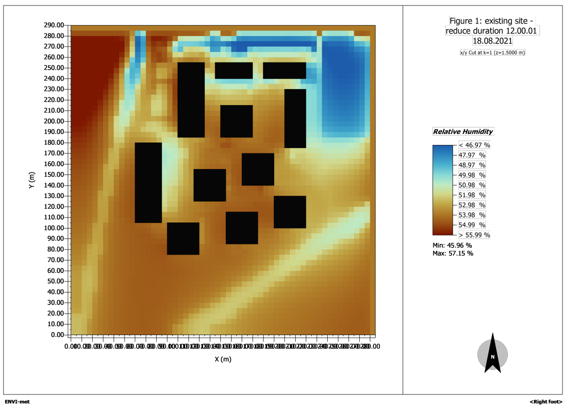
Figure 7: Ground and air temperature for the base case

We observe that the air temperature is higher above the parking lots and asphalt roads and reaches 41°C at noon. In fact, rural materials such as asphalt contribute to the urban sand effect by accumulating heat and absorbing solar radiation. On the other hand, air temperature is cooler in between buildings, but is still very high (37°C) and is not a pleasant environment for people working and leaving there or passing by. Indeed, tall buildings cast shade over the ground, preventing the surface below from absorbing as much solar radiation. In addition, the layout of buildings can enhance wind flow in certain areas (South-North axis between buildings since wind comes from North), increasing the rate of heat dissipation and cooling the air.

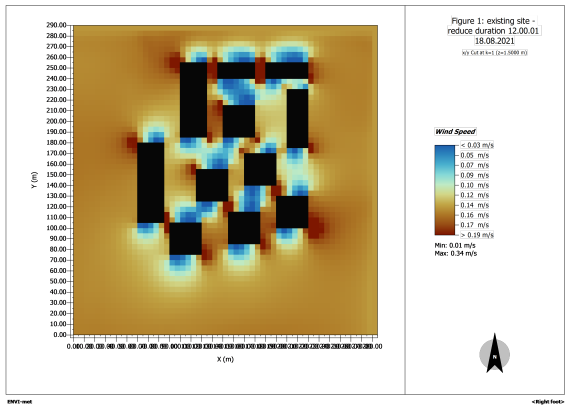
Similar comments are valid for ground temperature. But additional ones makes the amplitude of the maximum ground temperature difference much higher than for air temperature. Indeed, rural materials usually have a low albedo which means that it does not reflect sunlight and instead absorb it. Roads and parking lots reach a surface temperature of 58°C whereas location in the shade are between 24°C and 29°C.

Therefore, it is necessary to make improvements in order to have a better environment. Multiple changes to the initial case will be done in the next sections to come up at the end to a final proposition which will hopefully lead to great improvements in various domain of comfort and pleasure for the people of this area.

Finally, two more urban thermodynamics variables are to be discussed. Those are relative humidity and wind speed. Figure 8 highlight them.



(a) Relative humidity for the base case



(b) Wind speed for the base case

Figure 8: Other characteristic variables

We observe that relative humidity (RH) at noon stays within the comfort zone which is between 40% and 60%. Actually, natural soil and vegetation release obviously water drops which increase RH in between buildings and in the South part. On the other hand, RH is lower above parking lots and road. However, later in the afternoon and during the evening RH exceeds 60%. Unfortunately, RH is usually in conflict with temperature because solutions to decrease temperature will have a negative impact on RH. For example adding trees and water bodies will certainly decrease air and ground temperature but at the same time it will increase RH.

Finally we observe that the layout of the buildings does not allow speed to flow freely in between them. At noon, with a wind coming from the North only a small part receives the benefice of the wind whereas some places have a wind speed close to 0. A different layout should be implemented to allow more wind flowing.

3 Urban microclimate exploration

3.1 Building-environment interactions

In this part we will take interest on building-environment interactions and try to find an optimal modification of the EPFL Innovation Park. The basics environment-building interactions are quoted below:

- Buildings interact directly with their surrounding atmosphere by exchanging heat, moisture, and particles
- Radiation exchange happens with the surrounding urban elements in addition to the Sun
- Positioning and shapes of buildings affect the wind flow at the neighborhood scale
- Buildings also interact with the ground directly in contact by exchanging heat and moisture

The urban canopy aspect ratio, which is defined by $\lambda_s = \frac{H}{W}$ with H the height and W the width of an urban canyon, has a big impact on the climate. At first, the overall benefits of tall buildings, i.e. high λ_s, are that it cools down the neighboring area due to convection and that they have a potential to clean the air by substantial mixing. The height of buildings has an impact on the wind behavior too : the higher the buildings, the more intense the air flow between buildings. In addition, taller buildings increase heat absorption and retention, contributing to the urban heat island (UHI), where local temperatures are higher than in surrounding rural areas. Additionally, buildings have an impact on shading. Actually, taller buildings can reduce the amount of direct sunlight reaching the ground, affecting local temperature, humidity and vegetation. However, increase the height of buildings have negative effects too. Actually, tall buildings can trap pollution at ground level, leading to deterioration in air quality and increasing public health risks.

We decided to do a simulation by increasing the height of buildings, which were initially at 13 m, 14 m and 22 m, to 25 m. Additionally, we decided to change the disposition of the buildings in order to modify the canyon aspect ratio. Naturally, we added some vegetation to fill gaps left by buildings.

In this task, you are not supposed to add more trees

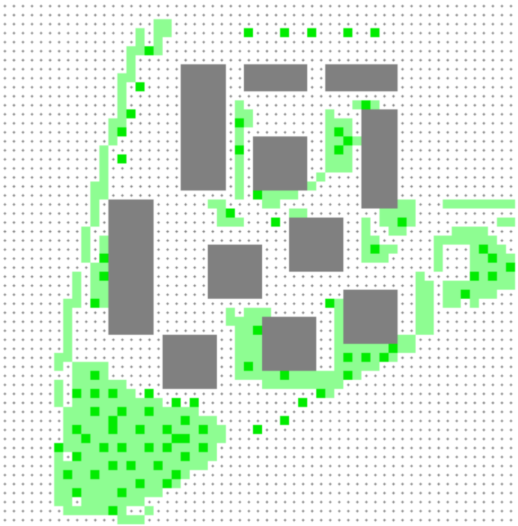


Figure 9: Initial configuration of the buildings

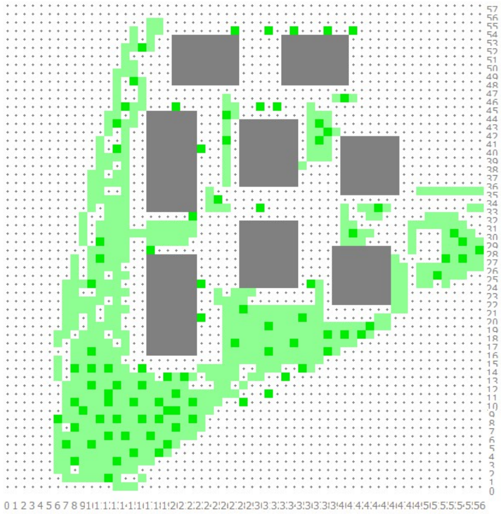


Figure 10: New configuration of the buildings

To analyze the effects of this simulation, we decided to focus on three aspects : the potential air temperature, the surface temperature and the wind. We will begin with the potential air temperature and the surface temperature shown on the graphs here :

These two graph are not informative, if you change building geometry, using 'comparison' in envi-met visualisation can be messy, better provide separate

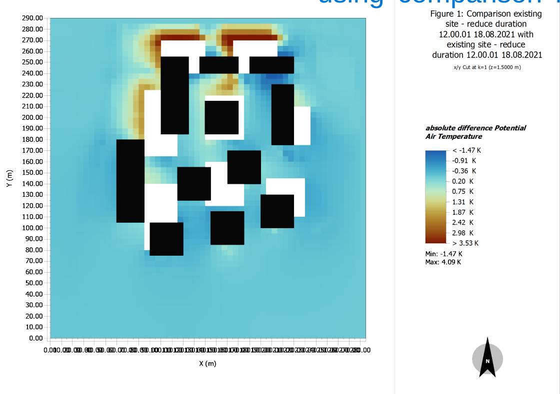


Figure 11: Potential air temperature difference

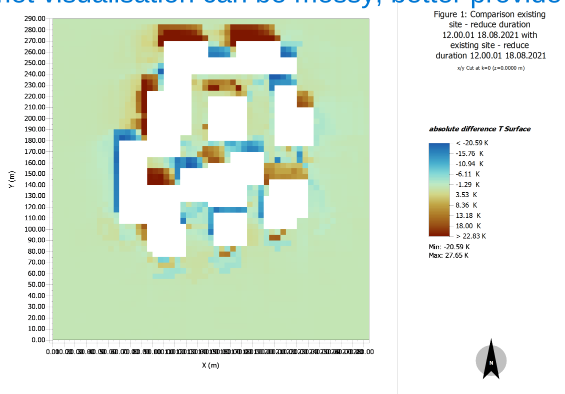


Figure 12: Surface temperature difference

At first, we can observe that the absolute difference potential air temperature varies between -1.47 K and 4.09 K. If we focus on the entire Innovation Park, we can see that increasing building size increases air temperature slightly, but by a relatively small amount (around 0 K). If we look at the south and east faces, the air temperature has risen slightly: this can perhaps be explained by the fact that the increase in building size has increased the UHI effect, and by the fact that the south faces of a building are the ones most exposed to the sun, and therefore potentially the most exposed to heat. On the contrary, we can observe that the northern faces, especially those of the building at the very top, see their air temperature drop to 3.53 K. This is mainly due to the increased shading caused by the greater height and concentration of the buildings.

Then, we can observe that the absolute difference surface temperature varies between -20.59 K and 27.65 K. Once again, the effects on surface temperature are only significant in the vicinity of buildings, and are close to 0 K away from buildings. If we look at surfaces close to buildings, we can see that they sometimes rise in temperature and sometimes fall. There are several possible explanations for this. Firstly, with sunshine: plots to the south of buildings are more exposed to the sun and will therefore heat up more, as is the case here. Conversely, plots to the north are less exposed to the sun and therefore tend to cool down more. Of course, sun exposure is also linked to the degree of shading created by the buildings. Surfaces can also cool through evaporation. Indeed, if urbanization reduces green spaces, some surfaces may cool down due to the absence of vegetation, while others, more exposed to heat and pollution, may increase in temperature. Finally, taller buildings modify air circulation, creating zones with less ventilation where heat is trapped (higher temperatures) and zones with more air circulation (lower temperatures).

Now, we can analyze the effect of the height of the buildings on the wind. Here is the result of our simulation on the wind :

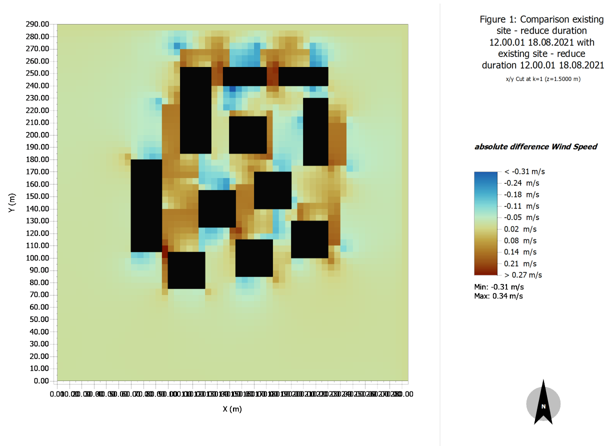


Figure 13: Absolute difference wind speed

Once again, the effects on wind speed are very local and almost non-existent far from the Innovation Park. Close to the buildings, we can observe that wind speeds can vary between -0.31 m/s and 0.34 m/s. The higher speeds are due to the channeling of the wind. Indeed, taller buildings can create channeling effects, where the wind is concentrated and accelerated between buildings (as in an “urban canyon”). This increases wind speed in certain narrow areas. Conversely, buildings can also block or disrupt air flows. In some areas, the wind is deflected or creates stagnation zones behind buildings, slowing wind speed. This explains why, in some places, wind speeds drop. Finally, taller structures generate turbulence, altering wind direction and speed. In some areas, this can speed up the wind, while in others, turbulence can make it more chaotic or slower.

With this simulation, we were able to observe that increasing the height of buildings has the effect of increasing shading, thus reducing the exposure of certain buildings to the sun and lowering their air and surface temperatures. Also, increasing the size of buildings has the effect of creating greater air flows and thus cooling temperatures.

3.2 Ground-environment interactions

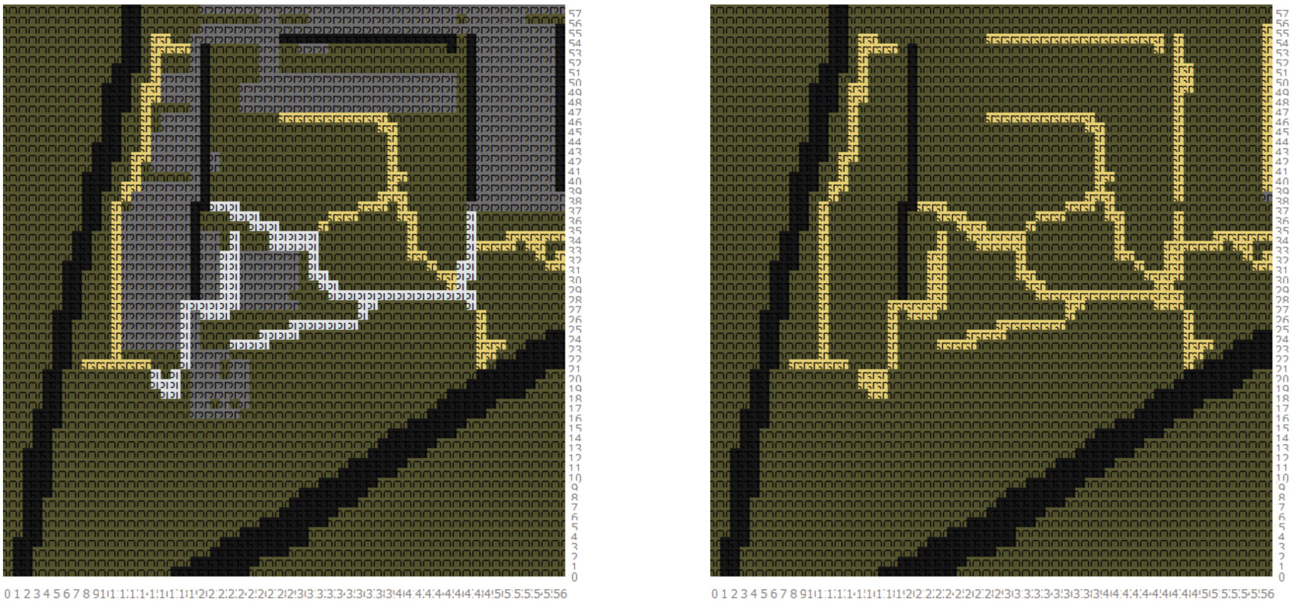
In this section, we will compare the initial ground composition of the site with an upgraded one, in order to understand the impact on different parameters such as the air temperature, the surface temperature and the relative humidity among the global site. To do so, we designed the upgraded ground composition using different materials, more permeable, more reflective and got rid of all the low albedo, impermeable and low reflectivity materials such as the concrete pavement dark and the asphalt.

To increase comprehension of the two schemes below, here is the link between the colors and the materials :

- Black : Asphalt Road
- Dark Green : Sandy Loam

- Beige : Sandy Soil
- White : Light Concrete Pavement
- Dark Grey : Dark Concrete Pavement

Here are the two composition of the ground :



(a) New Ground Composition

(b) Initial Ground Composition

Figure 14: The two ground compositions compared in this section

Our mitigation strategy is based on three different mechanisms.

- The first one is an improved permeability of the materials. Using sandy soil and sandy loam, instead of concrete pavement, allow for better water infiltration, thereby reducing surface runoff and enabling more moisture retention in the soil. This enhances evapotranspiration, which will cool the air temperature on the site.
- The second mechanism is to reduce thermal mass. Indeed, the materials used in the upgraded ground composition store way less heat than asphalt and dark concrete pavement. They also release heat more quickly, reducing nighttime warming effects.
- The last mechanism concerns an increase in reflectivity. We decide to replace all the low albedo materials as long as it was possible (for example not in the main road). High albedo materials allows a reduced heat absorption and a lower surface temperature.

More globally, these mechanisms collectively cool the air, stabilize the surface temperatures and maintain a higher relative humidity, mitigating the urban island effect.

Before the analysis of the results, it is important to briefly explain our hypothesis. We expected that the upgraded ground composition would result in lower surface and air temperature, higher relative humidity and an overall improvement in thermal comfort. Those enhancements would be due to the three mechanisms presented above. Let's now discuss the results obtained for the three parameters of interest (Air Temperature, Surface Temperature, Relative Humidity).

For the air temperature, we can observe two main phenomenons in the illustration below :

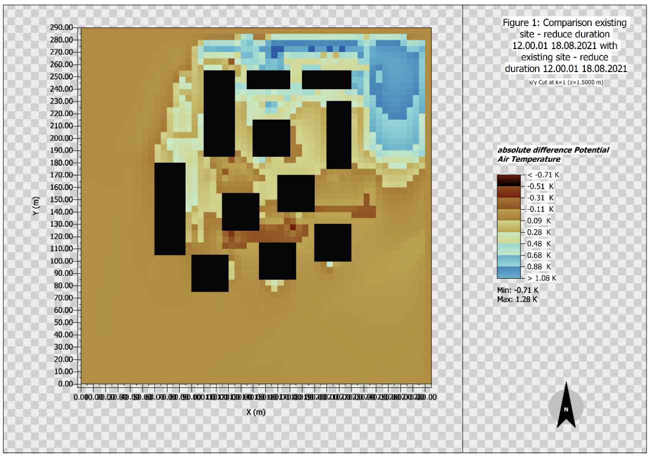


Figure 15: Air Temperature Difference between initial and upgraded ground composition

The first one is a decrease of air temperature in the top right corner (blue), which is the area where three small asphalt roads and a huge dark concrete pavement parking have been removed and replaced by sandy soil path in a sandy loam environment. This is mostly due to the cooling effect of evapotranspiration, which is increased by the higher permeability of the sandy soil and the sandy loam. The reduced heat storage and re-emission from the ground materials, due to a lower thermal mass, also limit nighttime warming.

The second phenomenon concerns the light concrete pavement paths that have been replaced by sandy soil paths. We observe a increase of air temperature near those replacements (red). This is due to the fact that the light concrete pavement has a really high albedo, allowing a better reflection of the heat. The replacement of the light concrete pavement by sandy soil appears as a pretty poor idea, which we will take into account in our final simulation.

Now concerning the surface temperature, the two phenomenons can still be observed in the illustration below :

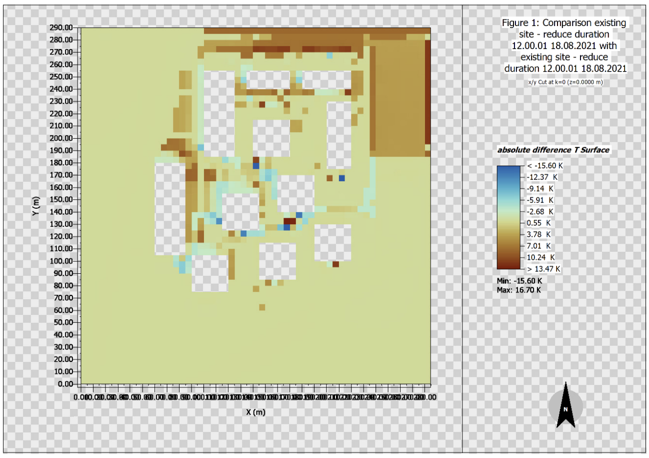


Figure 16: Surface Temperature Difference between initial and upgraded ground composition

There is a decrease in surface temperature in the top right corner (red). This is due to the replacement of the dark concrete pavement and the asphalt present initially in the area. Indeed, those two materials have low reflectivity and high thermal mass, which contribute to a high surface temperature in comparison to the sandy loam and soil which dissipate heat more effectively.

The small increase in surface temperature in the blue area is again due to the shift between light concrete pavement and sandy soil for some paths in the area. The really high albedo of the light concrete pavement maintained a lower surface temperature due to a better reflectivity. Again, this will be taken into consideration for our final simulation where we shall use light concrete pavement for most of the paths in the site.

Finally for the last parameters, the relative humidity, the results are as expected in our hypothesis, as it is depicted on the following illustration.

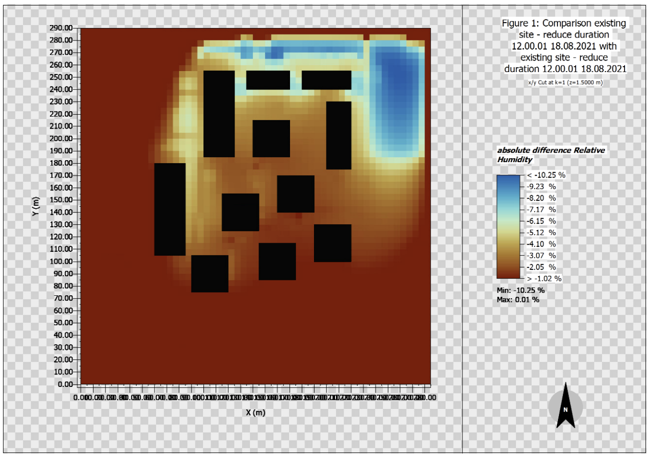


Figure 17: Relative Humidity Difference between initial and upgraded ground composition

Indeed, we can see that the relative humidity is globally higher everywhere on the site. The top right corner (blue zone) is once again the most impacted zone with the highest increase in relative humidity. This is due to the fact that the materials used in the upgraded soil composition of this area (sandy soil and sandy loam) have a higher permeability compared to the one used in the initial composition (dark concrete pavement and asphalt). This higher permeability allows for better soil moisture retention which supports evapotranspiration. This evaporative cooling process adds moisture to the air, which increases the relative humidity and stabilize the local microclimate.

To conclude, the simulation validates our hypothesis, demonstrating that the upgraded ground composition mitigates urban heat and improves thermal comfort. The inclusion of sandy loam and sandy soil creates zones of higher evapotranspiration. This natural cooling mechanism not only reduces surface and air temperatures but also increases relative humidity, which stabilizes the microclimate.

Asphalt's high thermal mass prolongs heat retention, leading to elevated temperatures even after sunset. The upgraded materials, with their lower thermal mass, cool down more rapidly, preventing nighttime warming and fostering a more balanced thermal profile. By allowing water infiltration, the upgraded composition reduces surface runoff and improves groundwater recharge. This hydrological balance supports vegetation and amplifies the cooling effects of evapotranspiration.

The results highlight the importance of material selection in urban design. Strategies prioritizing permeability and reflectivity are highly effective for mitigating urban heat. The only setback encountered in this section was the replacement of light concrete pavement. This materials should have been kept and even extended to all the paths as it has a higher albedo, which would have enhance the mitigation of the urban heat island effect.

Finally, here are the three main points that we should take from this section to improve the ground composition of our final simulation :

- A use of light concrete pavement for the paths to increase reflectivity
- A limited use of low albedo materials such that asphalt or dark concrete pavement to decrease thermal mass and heat storage
- A use of high permeability materials such that sandy soil and sandy loam to enhance evapotranspiration

3.3 Water body-environment interactions

Blue areas, such as water bodies, can play a pivotal role in mitigating the UHI effect by leveraging their unique thermal and radiative properties. The analysis presented here examines the interaction between water bodies and their environment, as simulated using ENVI-met for the EPFL Innovation Park. It highlights the thermodynamic characteristics of water, the mechanisms of heat and moisture exchange, and their impact on local microclimate.

The thermodynamic properties of water, which vary with temperature, are critical for understanding its thermal behavior. At 15°C, still water has a specific heat capacity (C) of approximately 4.18 MJ m^{-3} K^{-1}, a thermal conductivity (k) of 0.57 W m^{-1} K^{-1}, a thermal diffusivity (κ) of 0.14×10^{-6} m^2 s^{-1}, and a thermal admittance (μ_s) of 1.545 J m^{-2} $s^{-1/2}$ K^{-1}. These properties enable water to store and release heat effectively, impacting the thermal dynamics of the surrounding environment.

Water bodies interact with their surroundings through direct and indirect mechanisms. They receive solar radiation, which penetrates to considerable depths due to water's low reflectivity. Unlike solid urban surfaces, where radiation exchange occurs at the surface, water bodies exhibit volumetric absorption and exchange. The absorptivity of water depends on factors such as solar incident angle (α) and pond depth (H), with greater depths enabling more absorption. This characteristic reduces diffuse radiation perceived by urban objects, contributing to cooling effects.

During the day, water bodies absorb solar radiation and store heat owing to their high specific heat capacity. This heat is released gradually at night, moderating diurnal temperature fluctuations. Water's thermal inertia delays its peak temperature relative to peak air temperature, which can provide milder nocturnal temperatures in the vicinity. However, the effectiveness of this process depends on the water body's size, shape, and location.

Evaporation plays a central role in the cooling effects of water bodies, primarily through latent heat transfer. The rate of evaporation depends on two factors: the availability of energy (primarily radiative heat flux) and the transport of moisture away from the evaporative interface through convection or advection. High evaporation rates result in significant cooling, but these rates are constrained by local relative humidity (RH) and wind speed. High RH can inhibit further evaporation, reducing the cooling potential. Additionally, near-stagnant air limits moisture transport, further affecting evaporation efficiency.

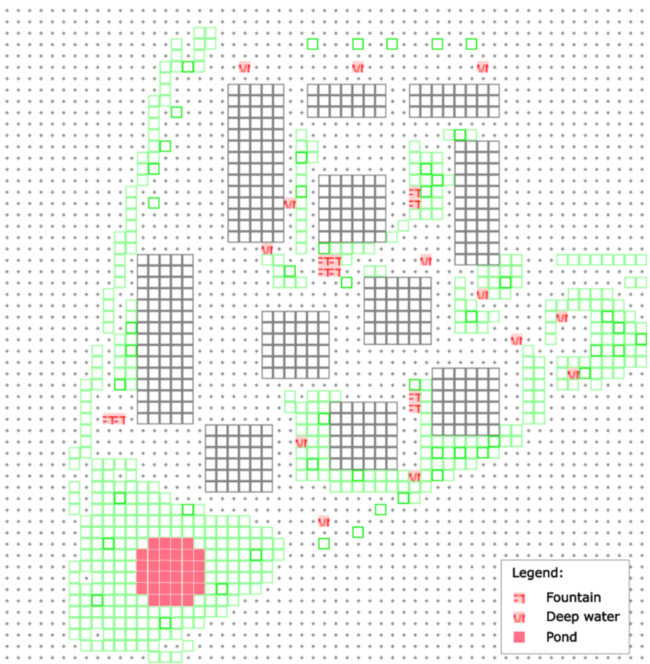
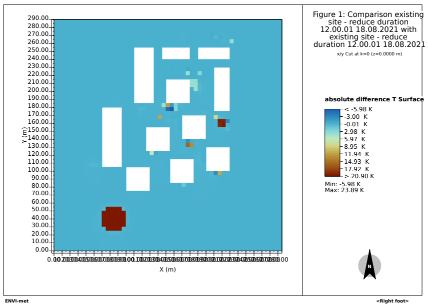
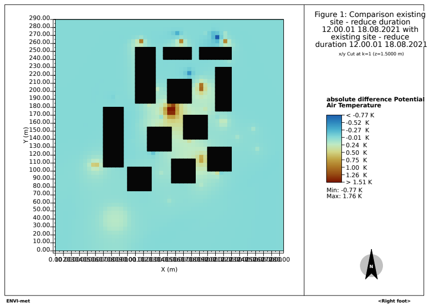


Figure 18: Water body layout

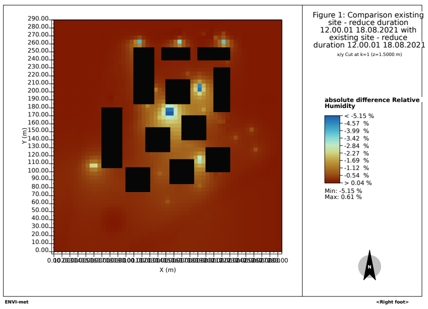
As shown on figure 18 we place several fountains and deep water inside as well as outside the building complex and a pond south-west of the building complex. The benefits of a deep water infrastructure is that it absorbs more radiation, and stores more heat; as for a pond, being a larger water body has higher cooling effects.



(a) Absolute difference T surface with the existing site after water body modifications



(b) Absolute difference Potential Air Temperature with the existing site after water body modifications



(c) Absolute difference Relative humidity with the existing site after water body modifications

Figure 19: Differences with the initial conditions

Let's analyze our ENVI-met simulation, the results are shown on the figure 19. Observations from the simulation highlight the cooling effects of water bodies. The surface temperature of water bodies was observed to be the same or cooler than the initial ground temperature, indicating their ability to mitigate heat buildup. Fountains and deep water structures had localized cooling effects. Inside the building complex, fountains reduced air temperatures by 0.2°C to 1°C, whereas deep water structures had a marginal impact on air temperature. The pond, located southwest of the complex, showed no measurable cooling effect on air temperatures within the building complex.

Relative humidity increased in areas near the largest fountains. While elevated RH can enhance human discomfort by hindering sweat evaporation, the RH levels observed near the largest fountain and between two buildings in the complex (going from 56 to 59%) remained within the acceptable comfort range of 30%–60% . The high relative humidity near these areas suggest localized moisture saturation. The wind speed around these areas was critical for maintaining a balance between evaporation and RH. A wind speed of 0.12 m/s near the fountain between two buildings ensured moderate air movement, enhancing evaporation. Near the largest fountain, the wind speed is of 0.03 m/s meaning the air is almost stagnant, which explains why the relative humidity is high in that area. This is not wanted; it slows down sweat evaporation because the air is already saturated with moisture, making it harder for the body to cool and leading to discomfort. It also makes the air feel warmer than it actually is. This is called the heat index, which combines temperature and RH to indicate how hot it feels.

However, some downsides emerged from the simulation regarding water body placement and design. The pond is situated in a suboptimal location, southwest of the building complex, where it is shielded by buildings and trees. This placement limits the pond's ability to influence the microclimate of the complex, as prevailing winds from the northeast do not carry cooled air into the interior spaces. To maximize the pond's cooling potential, it should be relocated to an area with unobstructed wind access and closer to high-traffic zones.

Fountains demonstrated greater effectiveness in localized cooling compared to deep water structures. To enhance human comfort, additional fountains should be placed strategically near pedestrian pathways and areas subject to high temperatures. This placement would ensure that cooling benefits are directly experienced by users of the space. Furthermore, fountains should be located in areas with sufficient air movement to facilitate continuous evaporation and avoid stagnant air conditions.

To optimize the overall cooling effect of water bodies, the pond and fountains should be positioned in locations where air movement ensures effective evaporation and moisture dispersion. Additional small fountains should be integrated into areas with significant pedestrian activity to directly improve thermal comfort.

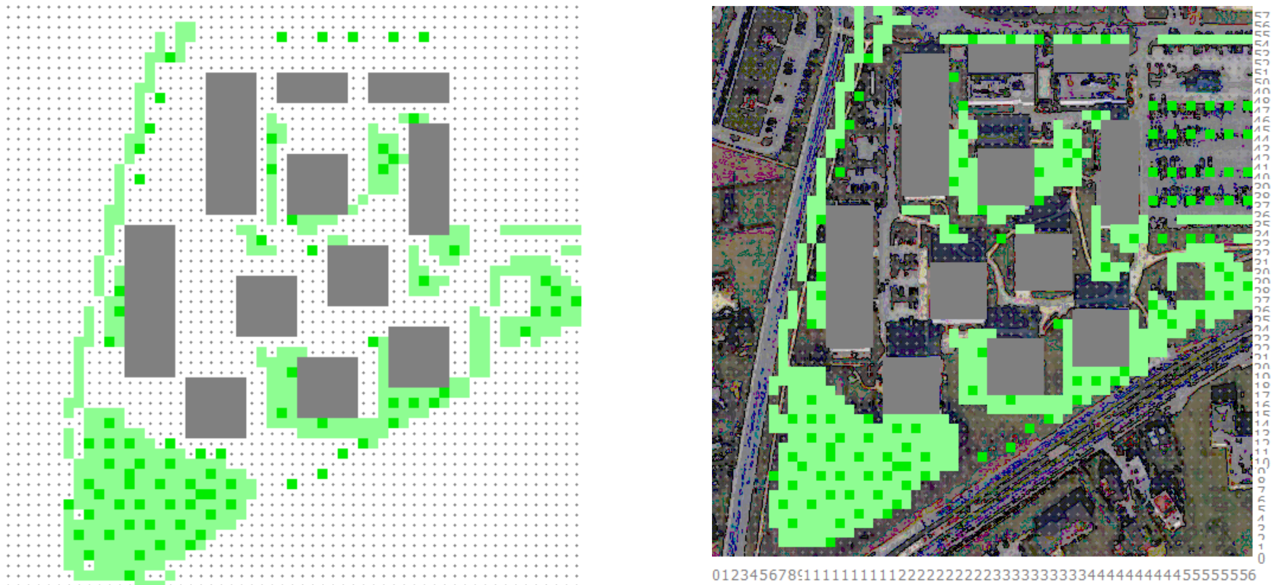
3.4 Vegetation-environment interactions

The last of our simulations concerns the interactions between vegetation and the environment. We wanted to know whether it was possible to improve outdoor thermal comfort by modifying the vegetation, i.e. the species and distribution of green spaces, on the site studied.

Indeed, vegetation is an extremely important aspect of a pleasant neighborhood. It is also a very powerful tool in the fight against the urban heat island. In fact, it plays a key role in two of the three UHI mitigation strategies.

- Firstly, trees reduce the sun's radiative absorption by providing shade. This leads to a reduction in radiative temperature.
- Secondly, like other plants, they contribute to increasing latent heat through the phenomenon of evapotranspiration.

Plants, in particular trees, also have other qualities that are important for outdoor thermal comfort, such as improving air quality, slowing down the flow of air without stopping it, regulating humidity levels, and so on. It is therefore important to include them in any project to improve outdoor thermal comfort.



(a) Initial...

(b) ...in the simulation

Figure 20: Disposition of trees (dark green) and grass (light green)

Figure 20 shows a comparison between the initial situation and the final situation. As you can see there has been a massive implementation of trees on the parking lot. Apart of this, there was an increase in the area that's covered with grass, both in the center of the site and on the borders of it. It is also important to note that deciduous trees were selected. They offer more shade in summer, when the foliage is at its peak. Conversely, in winter, the sun's rays can warm the ground and the facades of the buildings.

Our group's expectations in carrying out this simulation were therefore as follows:

- Improved shading, which should lead to a reduction in the absorption of solar energy by the ground and the walls of the buildings, and thus cause a reduction in their temperature;
- A reduction in wind speed, which in itself should improve thermal comfort;
- Improved air quality;
- An increase in humidity, as the existing site is particularly dry in certain areas.

Why would a reduction in wind speed lead to improvement in thermal comfort? What are looking at summer season.

The simulation results are shown in the figures 21, 22 and 23. Let's describe and analyze the results point by point.

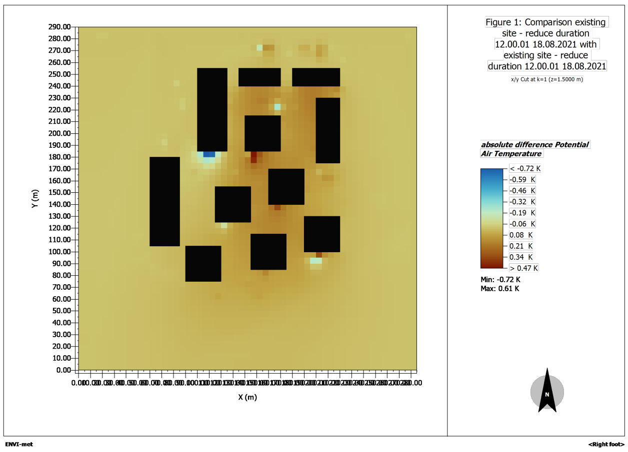


Figure 21: Difference in potential air temperature between initial situation and simulation.

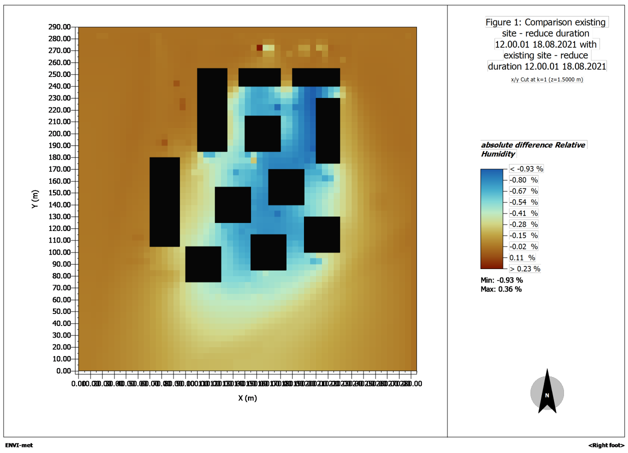


Figure 22: Difference in relative humidity between initial situation and simulation.

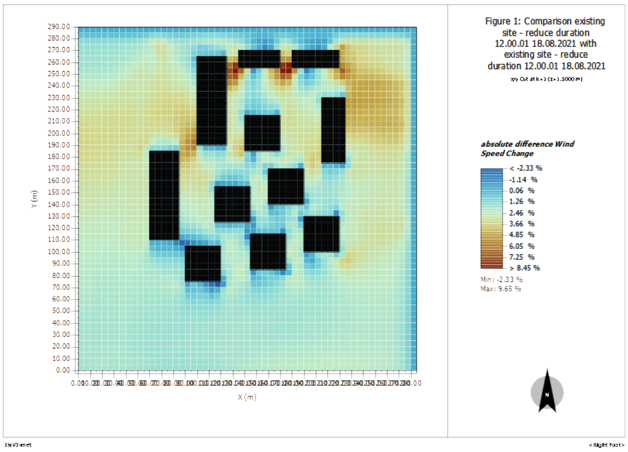


Figure 23: Difference in wind speed between initial situation and simulation.

Firstly, with regard to the potential air temperature, there is a very slight drop across the board between the buildings. We can see that this phenomenon is slightly more marked around the facades. The same applies to the parking. However, it should be noted that this reduction does not exceed the value of 0.67 K, which is not very significant. For the rest of the site, there is virtually no difference. These results are similar to those expected, but to a much lesser extent and with a much lower intensity than hoped for by our group.

Secondly, let's look at relative humidity. Here also, there was a drop between the different buildings on the site. Similarly, there has also been an improvement in the car park, concentrated around the trees that have been planted. Once again, this variation needs to be qualified, as it barely exceeds 1%, and remains almost negligible.

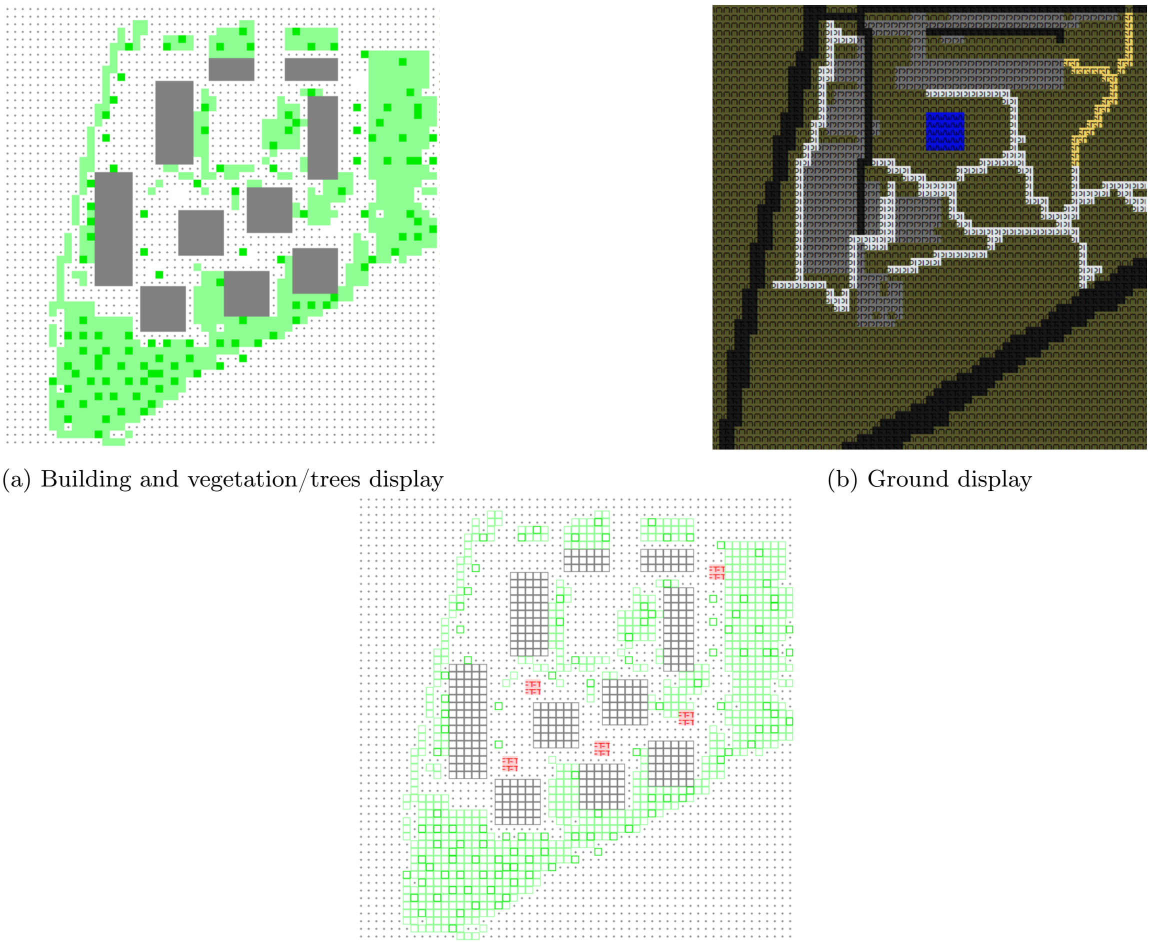
Thirdly, with regard to wind speed, the situation is somewhat different from the last two points. It decreases very slightly over the whole site. However, more significant reductions (up to 9%) can be seen in certain areas such as the car park and the gaps between the buildings to the north of the site. Conversely, there has been a slight increase (up to around 2%) in the corners of most of the buildings.

In the end, it can be said that in our simulation, trees and vegetation did not have as much effect as it was expected. While there are still positive results, they remain unfortunately less intense than our wishes.

However, it must be noticed that the main enhancements were located on the parking lot, which is the place with the most changes. Changes in other places were not very consequent. This teaches us therefore, that this path should not be given up. Rather, it should tested if more consequent changes, especially between the buildings, gives us more consequent changes.

4 Integrated microclimate solution

4.1 Our design's characteristics



(a) Building and vegetation/trees display

(b) Ground display

(c) Water display

Figure 24: Integrated microclimate solution

Let's now focus on our integrated solution, that combines all the advantages of the previous simulations.

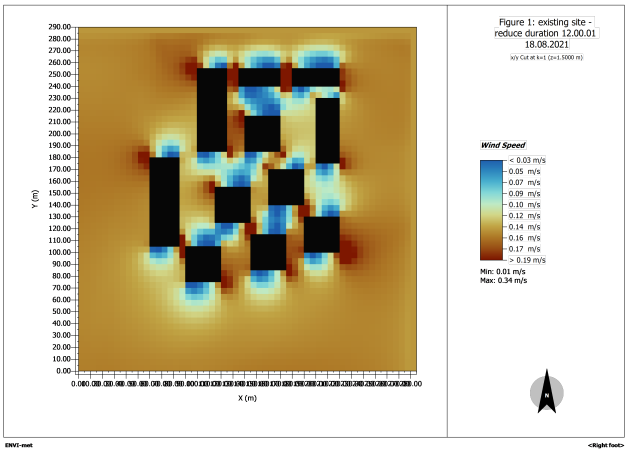
As for the layout of the buildings, as shown above, we decided to remove the central building, which we felt was not necessarily beneficial to the outdoor climate. In addition, we changed the location of some of them, particularly those furthest north, to maximize cooling effects. Finally, we increased the height of the buildings to the east to maximize shading. Indeed, as the sun rises in the east, it's preferable to have tall buildings on that side.

For the vegetation, the main change resides in the addition of grass on the parking lot, where there was only regularly spaced trees before. Apart of this, several grassy surfaces were added compared to both the initial situation and the simulation. Some additional trees were also spread around the site, especially on places that were free of trees, as for example, between some buildings.

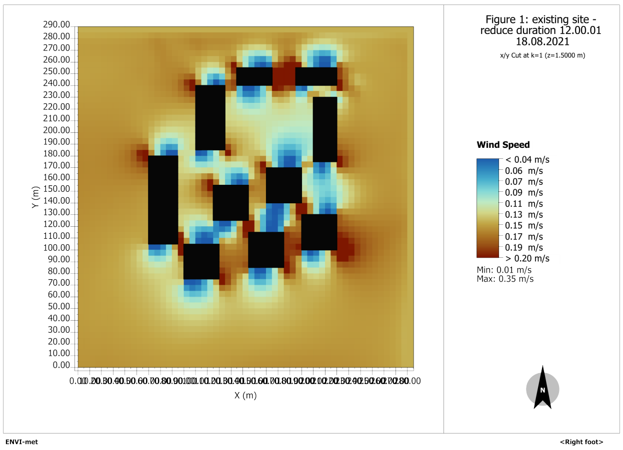
For the ground composition, we made two main changes. First of all, we decided that all the paths should be in light concrete pavement, to increase the albedo and the reflectivity. This change should decrease the thermal mass, store less heat and mitigate the urban island effect. The second choice is to replace the parking by a path in sandy soil and a environment in sandy loam. Thanks to there high permeability, those two materials will enable more water retention and reduce surface runoff: This will increase the evapotranspiration effect, which will cool the air temperature on the site.

Our objective here is to maximize the natural cooling effect and assure human comfort. As discussed earlier, larger water body surfaces enables higher evaporation, leading to a higher cooling effect. It should be checked if the wind speed with this new building display is optimal for equivalent propagation of the cooled air. The 5 fountains (see figure 24c) and the pond (see figure 24b) are placed in between buildings, where the heat island effect is the most critical and pedestrians often circulate.

4.2 Analysis



(a) Wind speed for the base case



(b) Wind speed for the final case

Figure 25: Wind speed comparison between Initial and final situation

The main achievements of the new layout of vegetation can be seen on the parking lot. As it can be seen on figures 26 and 27, this part stands out from the rest of the site. Surface, as well as air temperature, have largely been decreased. This can be partially explained by the addition of vegetation, although other changes took place in that area - see next paragraph. One can also see the impact of vegetation in between the buildings. By looking simultaneously at figures 24a and 29, one remarks that places that are located near forests or densely spread trees have potential air temperature close to 38°C while other remain near 40°C.

The new ground display's main improvement can be seen on the top right corner of the figures 26, 27 and 28. The replacement of the parking's asphalt by sandy soil and sandy loam decreased the surface temperature, the air temperature and increased the relative humidity. All those improvements are due to an increase in permeability, which allows a good evapotranspiration process in this area.

The change in the composition of the paths, which have been made in light concrete pavement, has also had a great impact on the surface temperature, as expected. We can see this improvement on the figure 26. The horizontal red lines, which correspond to a decrease of around 10 to 15 degrees Kelvin, match the paths positions. This is due to the very high albedo of the light concrete pavement, which enables a better reflectivity, reducing the heat storage of the paths, and by the same extend the nighttime warming effects as the heat is released.

Air temperatures are reduced by approximately 1°C around the fountains, creating a cooler pedestrian zone and enhancing human comfort within the building complex. However, wind speeds near the four fountains located at the bottom of the complex range from stagnant to slow, limiting their cooling effects to very localized areas.

The large pond situated at the top middle of the complex has a significantly greater impact compared to the fountains. This can be attributed to the wind speed in that area, measured at 0.11 m/s, and the pond's extensive surface area, which promotes evaporation and amplifies the natural cooling effect.

The fountain positioned at the top right of the complex does not influence temperatures within the complex but effectively creates a cool zone at its entry point. Lastly, the relative humidity does not exceed 60%, a level that is optimal for human comfort.

Let's now focus on the effects of the buildings layout. Like said before, the impacts are particularly high near the buildings, but there is fast no improvement far from the buildings. Furthermore, it is important to realize that implementing these changes would be very complicated; it is difficult to increase the height of the buildings, and fast impossible to move them. Thus, the effects of layouts would be difficult to implement in real life.

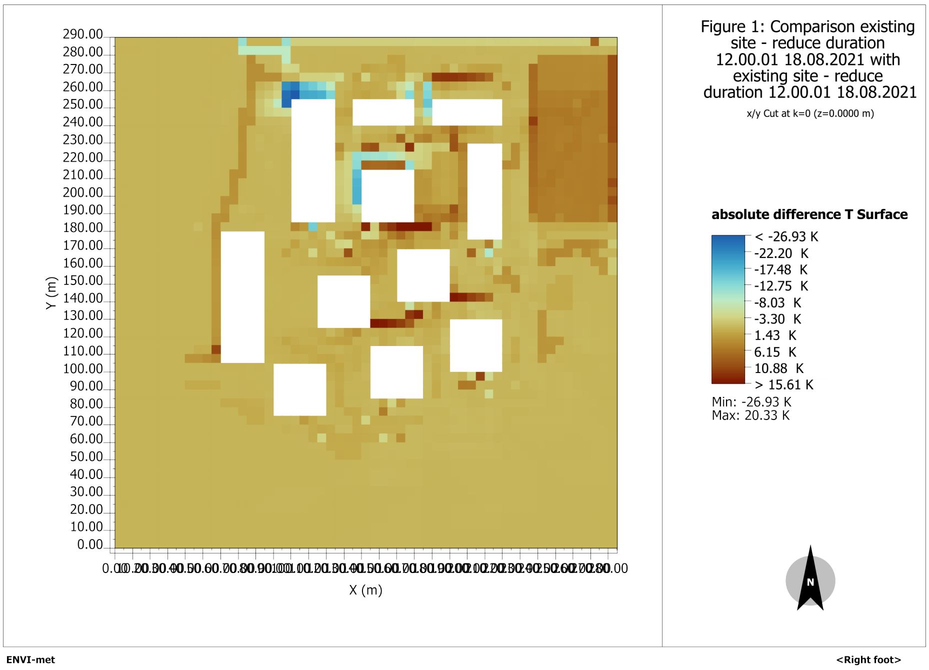


Figure 26: Absolute difference T surface with the existing site after final modifications

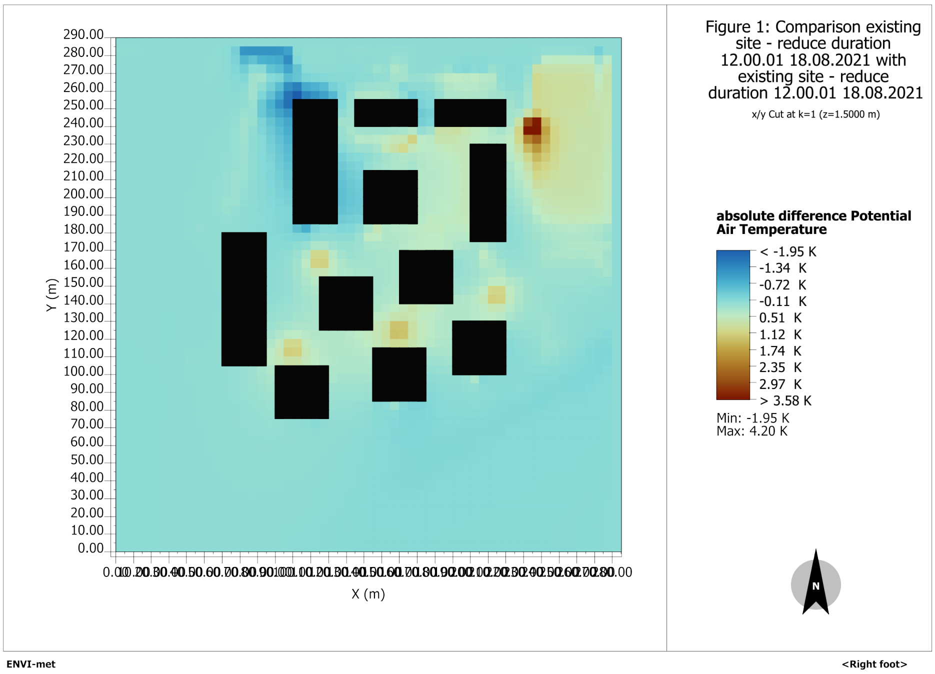


Figure 27: Absolute difference Potential Air Temperature with the existing site after final modifications

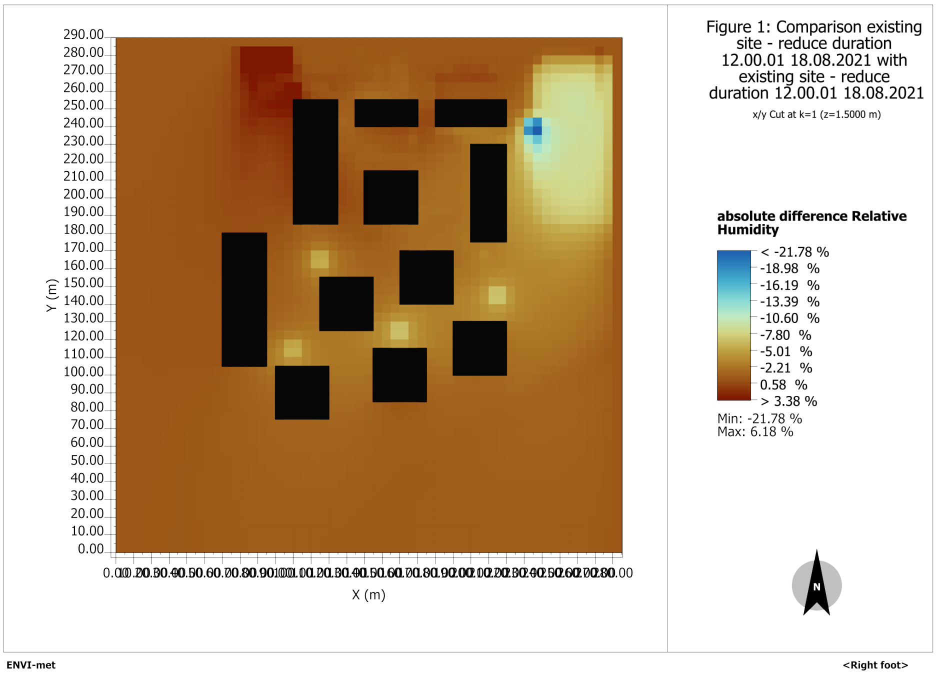


Figure 28: Absolute difference Relative humidity with the existing site after final modifications

4.3 Outcome

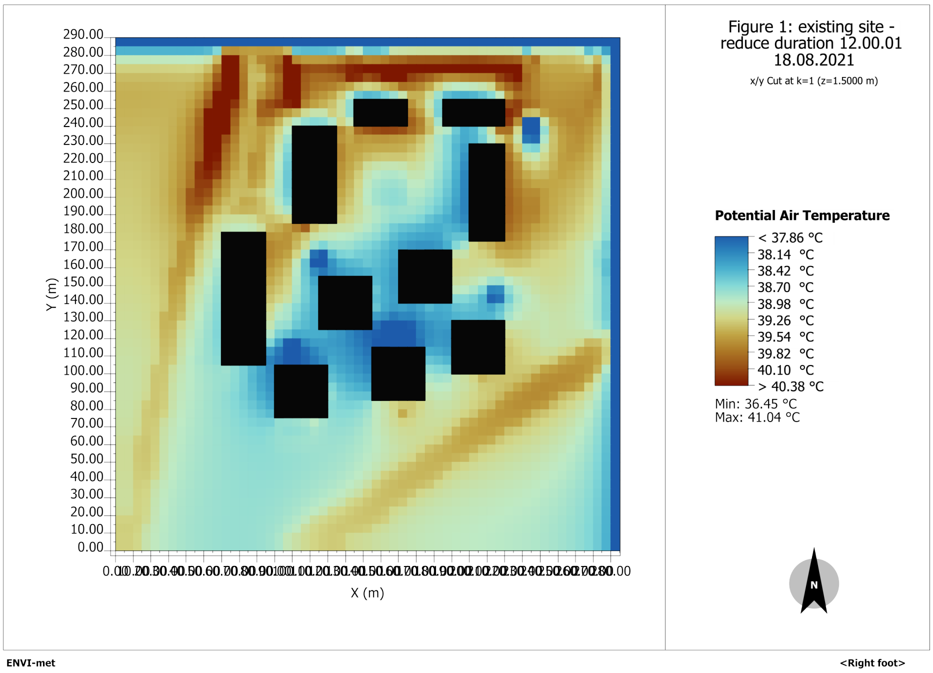


Figure 29: Final solution air temperature

In the final simulation, air temperatures range from 36.45°C to 41.04°C, compared to the initial simulation, where temperatures range from 37.86°C to 41.01°C. The maximum air temperature remains unchanged between the two simulations, as it originates from the two asphalt roads outside the building complex (located in the top left corner), which were not modified. Through our changes, we successfully reduced the minimum air temperature by 1.41°C. Notably, the area within the building complex exhibits the lowest temperatures overall, creating an ideal environment for pedestrians.

5 Conclusion

This report emphasizes the significant challenges associated with urban overheating and the urban heat island effect, especially in light of climate change. The case study of the EPFL Innovation Park illustrates how comprehensive site analysis, combined with simulation tools such as ENVI-met, can yield important insights into the thermal behavior of urban areas. The findings reveal the considerable influence of material characteristics, vegetation, and urban design on the microclimate. Proposed interventions, present viable strategies to alleviate overheating and improve thermal comfort.

Incorporating vegetation, such as trees and ground cover, has been shown to enhance shading and evapotranspiration, effectively lowering localized temperatures. Substituting asphalt with lighter concrete and permeable materials has increased reflectivity and water retention, resulting in significant cooling through enhanced albedo and decreased heat retention. The strategic placement of fountains and a central pond has further intensified natural cooling through evaporation, while optimal wind circulation has facilitated the effective distribution of cooled air. Additionally, the removal and repositioning of buildings to optimize airflow and shading, along with increasing the height of eastern structures, has minimized direct solar heating during critical times.

Overall, these strategies have led to substantial reductions in both surface and air temperatures, with localized cooling effects reaching up to 15 K. Our design illustrates how planning that is sensitive to microclimate considerations can effectively fight urban overheating while providing comfortable and sustainable urban environments.