Ecole Polytechnique
Fédérale de Lausanne

Urban thermodynamics

Simulation Report: Urban Microclimate Analysis for EPFL Innovation Park

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1 Introduction

The EPFL Innovation Park faces typical urban environmental challenges, such as the urban heat island (UHI) effect and air quality issues. These problems are exacerbated by dense urbanization, high building morphology, and limited green infrastructure. This project investigates the impact of building geometry and vegetation on key urban microclimate parameters, including wind speed, radiation, urban canyon effects, surface temperature, and pollution dispersion. The aim of this report is to analyze these parameters using ENVI-met simulations and propose optimized solutions for mitigating urban overheating and improving environmental quality.

2 Site analysis

2.1 Site conditions

The case study site is the EPFL Innovation Park.The climate at EPFL is temperate continental, strongly influenced by Lake Geneva. Winter temperatures fall below 0 and summer temperatures range from 30 to 37 degrees. Relative humidity varies according to the season, but is generally between 60 and 80 percent. To analyse the site, we went out into the field to record a series of elements at seven strategic locations. The elements analysed were Natural elements , Ground cover material, Surrounding building material,Surrounding building height , Anthropogenic heat source ,Aspect ratio , Sky view factor, Shading sources. Most of the buildings are offices or study rooms. The buildings in this area vary in height from 16 to 8 metres and there are two roads on the edges of the study area. The aspect ratio varies between 0.5 and 1.2 depending on the location. The sky factor never falls below 0.7 We then received additional information about the ground cover, the type of building and the type of wall corresponding to each type of building.

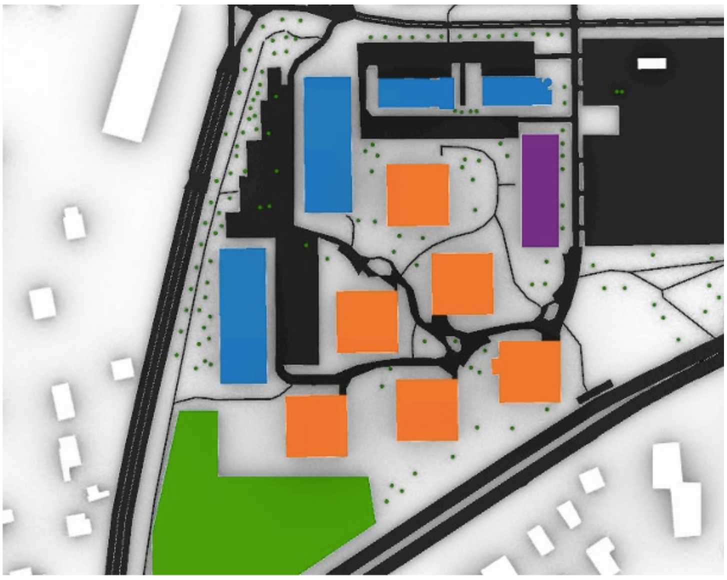


Figure 1: Details of the site.

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.

The ground cover is made up of cement which forms the grey area. The blue part are the buildings. The green part is greenery. The white areas are made up of loam soil. The yellow part is sandy soil and the black part is asphalt. During the field trip we analysed the sky factor in several places, which generally varies between 0.9 and 1, except in one place where it was only 0.7. The aspect ratio varies between around 0.53 and 1.25 depending on the buildings and their spacing.

Figure 3: Ground cover.

2.2 Overheating problem

We need to identify local microclimate problems. A good indicator of this is the urban heat island effect (UHI). We saw in class that urban areas have much higher temperatures than rural areas, and this difference is mainly due to human activity. This has many consequences. The temperature is higher in cities but this also increases the heat stress of residents in summer as well as disrupting biological rhythms and threatening the existence of plants and animals. The aim is to reduce UHI at our site. In the course we saw several causes of UHI: 1) Absorption of long-wave radiation due to air pollution. 2) Absoprtion of short wave radiation due to use of low-albedo materials 3) A lack of vegetation and water points leads to a decrease in evapotranspiration 4) A reduction in wind reduces convective heat transport.

2.3 Contributing factors of overheating

We then ran the basic simulation on ENVI-MET to see which of the above points could be improved on the site. The day on which the basic simulation was carried out is 18 August 2021. In this basic simulation, the temperature is highest at 14:00. We can see that the temperature between the buildings is over 39 degrees. It even reaches 43 degrees in areas containing asphalt, such as roads and car parks.

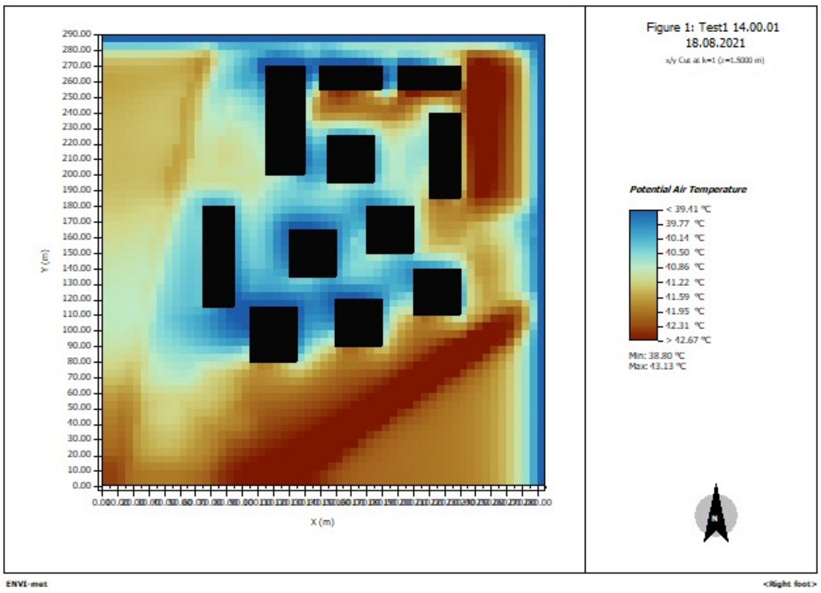


Figure 4: Temperature site.

We also compared the humidity at the same time. Humidity was highest between the buildings, at 51 per cent. On the asphalt areas it doesn't exceed 41 per cent. So between buildings, high heat and high humidity increase heat stress in residents. But humidity isn't highest at 14:00, it's at 8am where it reaches 95 per cent in some places. This is because the site is close to Lake Geneva and during the night the temperature drops, so the air no longer has the capacity to retain water vapour, which increases the relative humidity. The morning dew is strong near Lake Geneva, which also explains the high humidity at 8:00.

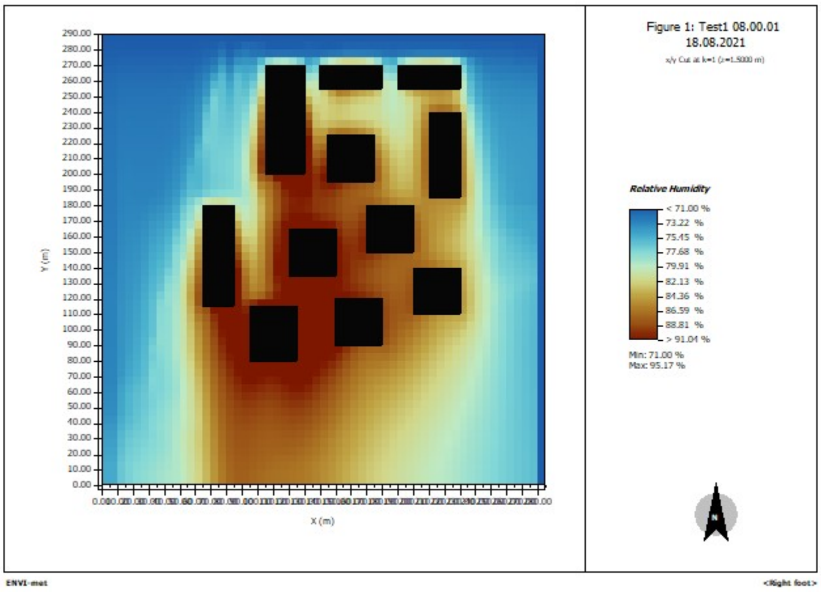


Figure 5: Humidity 8h00.

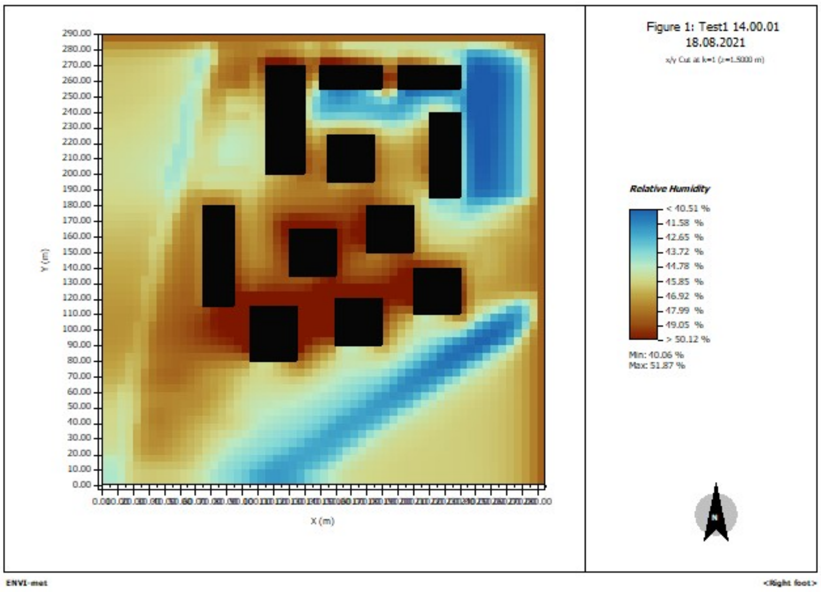


Figure 6: Humidity 14h00.

We then analysed direct radiation and reflected radiation. At 14:00 the direct radiation comes from the sun, so we can clearly see the shadows of the buildings on the image. In the shadow of the buildings the radiation is 0 W/m^3 whereas everywhere else the radiation reaches the value of 957.68 W/m^3.

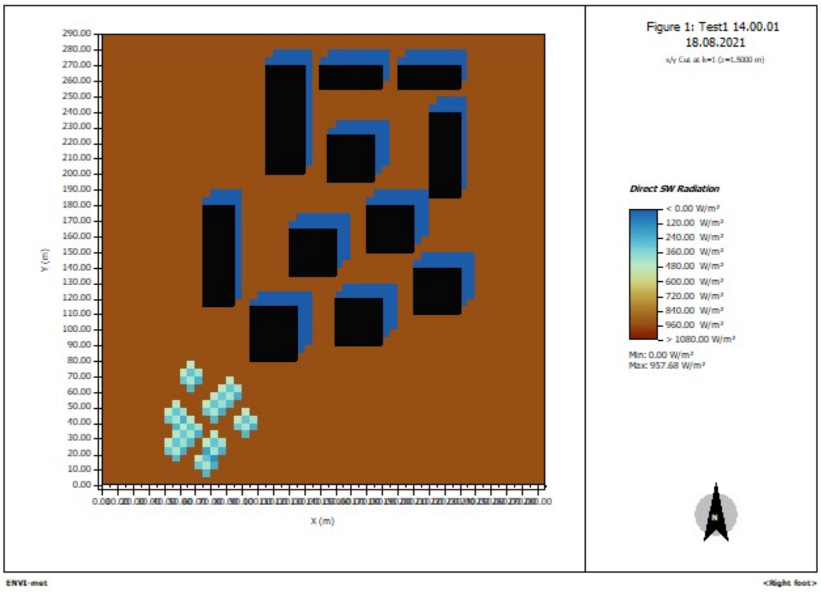


Figure 7: Direct radiation.

For reflected radiation in places where there was no direct radiation, the reflected is extremely low. Albedo plays a big role in this case. Places where reflected radiation is low are places where albedo is low, such as asphalt. The minimum is 16.36 W/m^3 and the maximum is 494.78 W/m^3.

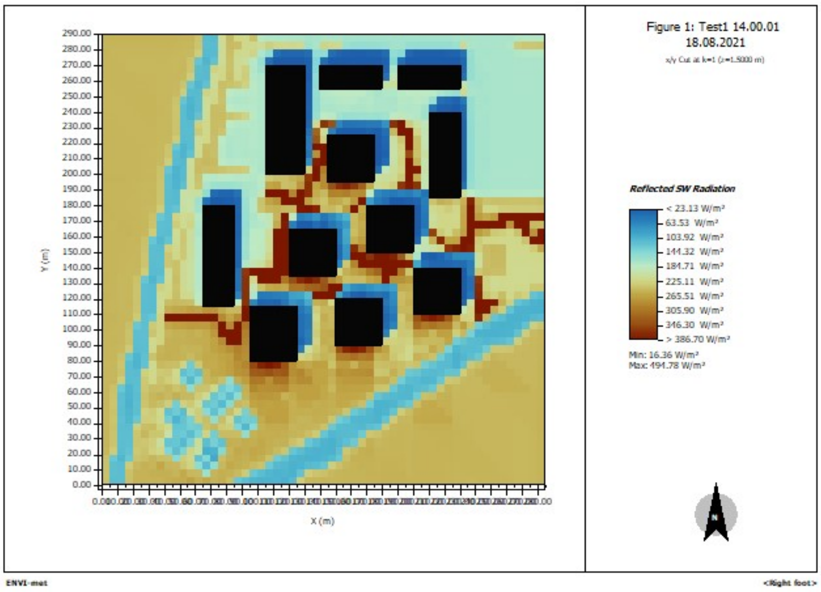


Figure 8: Reflected radiation.

One of the factors contributing to overheating is the wind, or rather its absence. In figure (9) at 14:00 we can see a strong absence of wind behind the buildings. With a value of 0.07 m/s. The maximum wind on this map is hardly more than 1.9 m/s. The absence of wind means that the heat stays between the buildings.

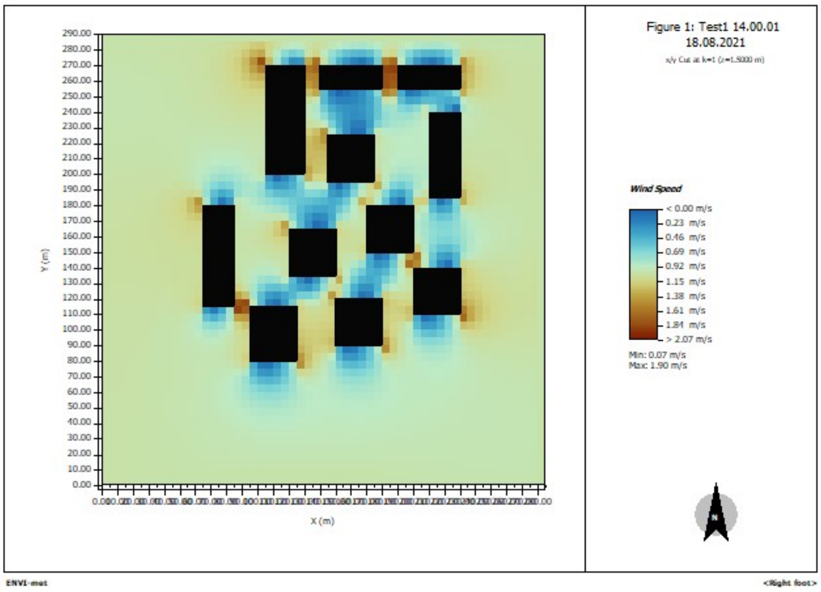


Figure 9: Wind 14h00.

Another example is at 22:00 you can visually see the differences between the areas where the wind is almost absent and where a sort of channeling wind could bring a little more coolness.

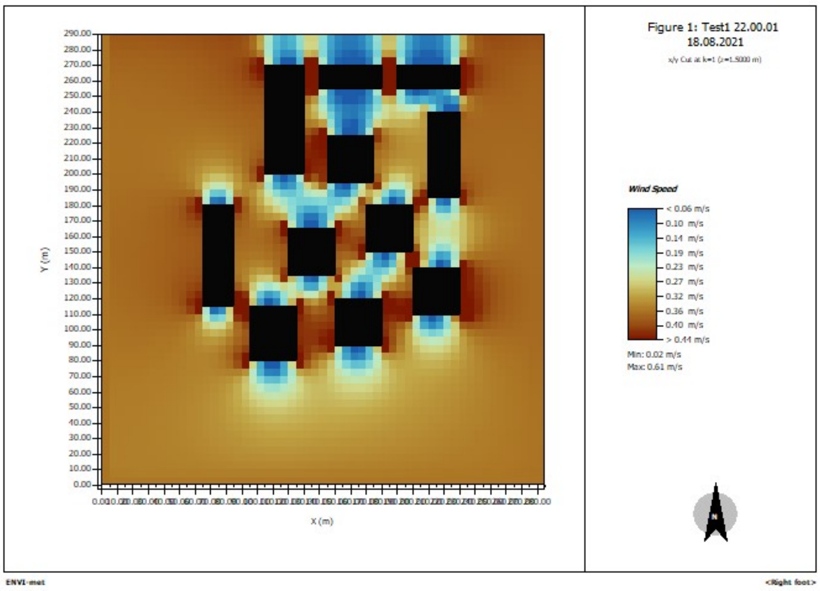


Figure 10: Wind 22h00.

Now that we've analysed the site and the basic simulation, we're going to try and improve it by changing the various parameters to find an optimal solution.

Analysis of outdoor thermal comfort indices will reveal integrated aspects of hotspots.

3 Thermodynamic principles

3.1 Building-environment interaction

The interaction between buildings and their environment significantly influences urban thermodynamics, affecting various aspects of energy and heat exchanges. Buildings interact with the atmosphere through the exchange of heat, moisture, and particles, while radiation exchange occurs with surrounding urban elements and directly with the sun. At the scale of a neighborhood, the positioning and shapes of buildings modify wind flow patterns, influencing both the movement of air and the transport of energy. Additionally, buildings interact directly with the ground, where heat and moisture are exchanged.

3.1.1 Surface Balance Energy

The Surface Energy Balance (SEB) is a crucial concept in understanding these interactions. For energy conservation, the SEB must always be in equilibrium. While the SEB equation focuses primarily on the net radiation flux (Q*), it is equally important to consider the control volume approach, which includes the mass balance of volumetric elements within the urban environment.

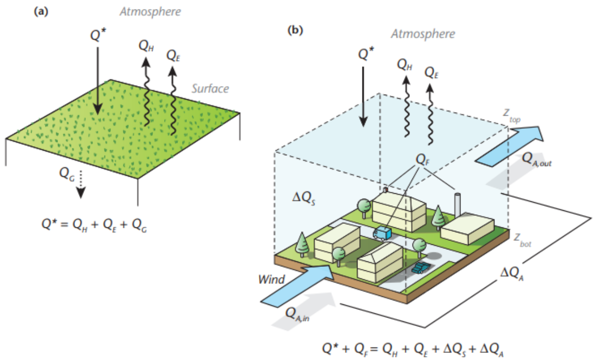


Figure 11: Schematic of the fluxes in the SEB

This balance is transient in nature, varying over daily and seasonal cycles. During the day, when Q* is greater than zero, energy is absorbed into the soil and atmosphere, predominantly as sensible heat. At night, when Q* becomes negative, the heat stored during the day is gradually released back into the environment.

The SEB of Basel is shown and we clearly see the difference during the day and the night.

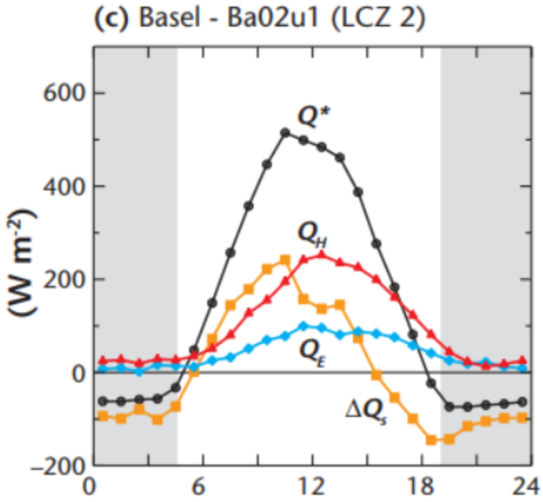


Figure 12: Different heat in a day at Basel, source: Oke, Urban Climates

If we sum all the SEB of the components of a city and their interaction between each other, we obtain the SEB of the city. By looking at the next graph, we can see how acts all the elements of the city in Basel center.

The roofs are excellent composure to the sun and sky. The surface materials used have a low albedo and high emissivity. It means that the surface absorbs the heat during the day and release it the night very well. In our case, we add some greenings on the roof to limitate the heat absorption.

Roads exhibit similar thermal properties to roofs, although their contribution is less intense; their temperature curves often parallel those of roofs, but with lower amplitude

The characteristics of the wall vary with their exposure and their orientation, their sky-view factor and the access to solare irradiance. As we can see on the graph, the north-wall temperature and the south-wall temperature arrive at their highest at different time of the day. In our case, we had greenings to the walls to lower the temperature

The lawn regroup a lot of different ground. It can be grass, but also moist soil. It's very important for the moisture. It influence the microclimate through the evapotranspiration and other thermal properties.

The canyon air temperature follows the curve of the north-wall temperature.

The building interior temperature varies differently during the day than the others temperature as it lowest temperature is at 2PM. It's explain by the fact that people wich are inside don't want the heat of the summer and if they come inside, it's to have fresh air.

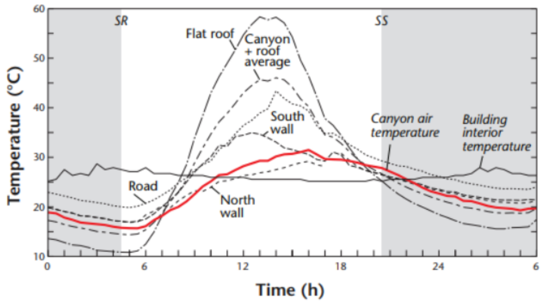


Figure 13: Different temperatures in a street canyon, source: Oke, Urban Climates

When temperatures are high, the heat is stored in the buildings and soils and then it release when during the night (Temperature exterior¡ Temperature building). To estimate the heat storage, we can use different equation as Energy Balance Residual Approach, the Thermal Mass Scheme or a Numerical Simulation. In our case, to reduce the heat stored, we modify the materials of the walls.

High-albedo materials reflect more solar radiation, reducing surface temperatures, while low-albedo materials, such as asphalt and dark roofs, absorb significant amounts of heat during the day and release it at night, exacerbating the urban heat island effect. Emissivity is another key property, determining a material's ability to emit absorbed heat as infrared radiation. Additionally, porous materials like concrete or brick can store moisture, influencing thermal conductivity and latent heat exchange.

What is your proposed intervention and how is the above-stated information inform the choice of intervention?

On our simulations we see than like expected the building with greening reflected more the direct radiation than the unmodified building. Without the modifications the building reflected between 20 and 46 W/m^2 while with the modification the global albedo increase and the reflected Radiation is between 20 and 85 W/m^2. The building are going to be cooler because they don't stock the heat and more appreciable to work/live inside.

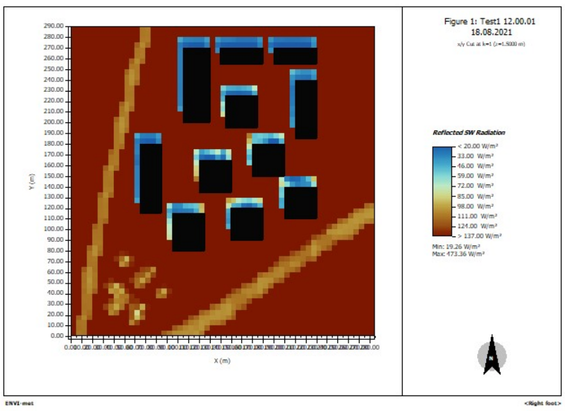


Figure 14: SW reflected without greening building

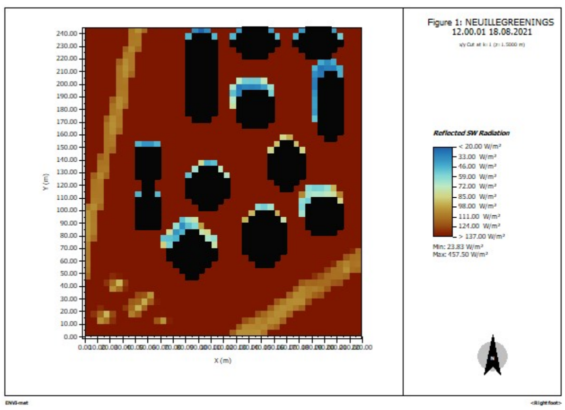


Figure 15: SW reflected with greening building

3.1.2 Urban Canyon

Thermodynamics are also influenced by the urban canyon, which is defined as the structure formed by the typical arrangement of a street flanked by buildings. This configuration affects both sensible heat and radiation exchanges.

For the walls and roads that form the canyon, thermal resistance can be calculated using the formula

$$R_{\text{tot}} = \sum_i R_i \quad \text{(for layers in series)} \tag{1}$$

$$\frac{1}{R_{\text{tot}}} = \sum_i \frac{1}{R_i} \quad \text{(for layers in parallel).} \tag{2}$$

These layers facilitate conductive heat transfer.

Sensible heat is exchanged differently during the day and night. During the day, the heat from the street is amplified within the canyon and tends to remain trapped because the canyon structure limits wind flow. At night, the temperature difference is smaller due to the release of stored heat. Urban canyons also create shade for the streets, impacting surface temperatures during the day by preventing direct solar radiation from reaching certain areas.

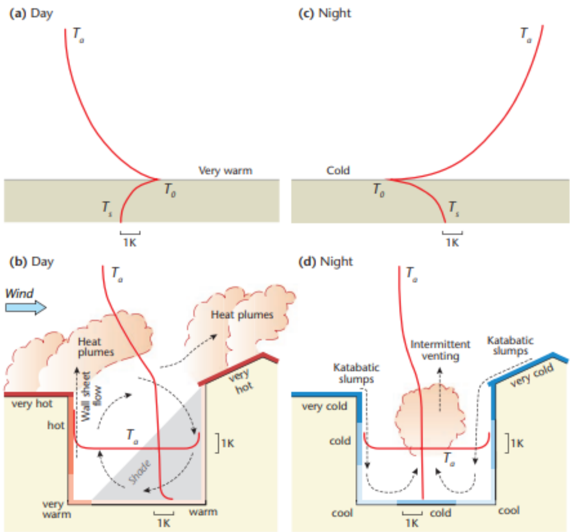


Figure 16: Schematic representation of typical diurnal sequence of vertical profiles of air temperature in the near-surface layer, source: Oke, Urban Climates, p.225

The canyon influences both shortwave and longwave radiation exchanges. The large number of surfaces within the canyon causes multiple reflection events, which intensify surface interactions. Diffuse irradiance is also redistributed within the canyon. To mitigate the effects of urban canyons, we modified building designs by rounding some structures and increasing the spacing between buildings. In deep and narrow canyons with a low sky-view factor, longwave radiation emitted by surfaces is largely trapped, as it is repeatedly absorbed and re-emitted by the surrounding walls and ground. This results in reduced radiative cooling at night, maintaining higher temperatures within the canyon. The trapped heat contributes to the overall thermal discomfort in urban areas, especially during warmer seasons.

If the urban canyon is narrower, the sky-view factor decreases. Consequently, shortwave radiation is more likely to be reflected and absorbed within the canyon, leading to an increase in the overall radiation budget. As shown in the diagram, longwave radiation tends to remain trapped within the street canyon, as it cannot escape easily due to the restricted sky-view factor. To reduce the impact of urban canyons, we implemented changes such as rounding building edges and enlarging the spacing between buildings.

We also reduced the building heights in our simulation, resulting in a lower canyon height-to-width ratio. This adjustment increased the sky-view factor, enhancing nocturnal cooling by allowing more longwave radiation to escape. It also improved airflow within the canyon, reducing heat stagnation and promoting better pollutant dispersion. However, the reduced height increased daytime solar exposure, leading to higher surface temperatures during peak hours.

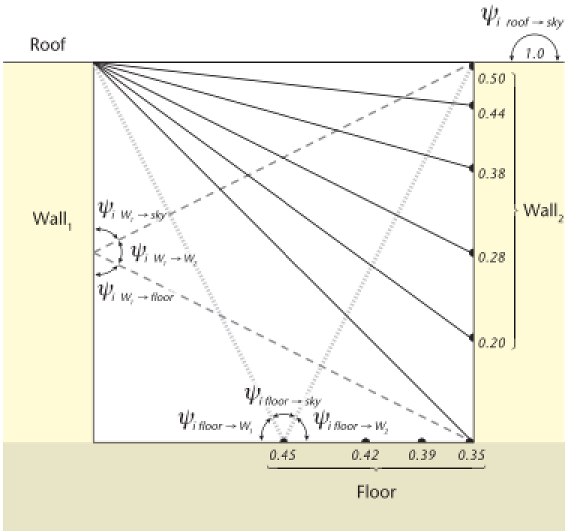


Figure 17: View factor in a canyon, source: Oke, Urban Climates p.136

To reduce the impact of the canyon street, we rounded the buildings and enlarge the distance between the buildings. On our simulation, we see that with no rectangular

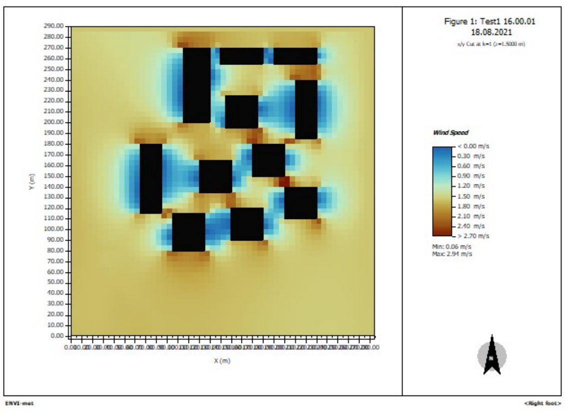


Figure 18: wind speed without greening building

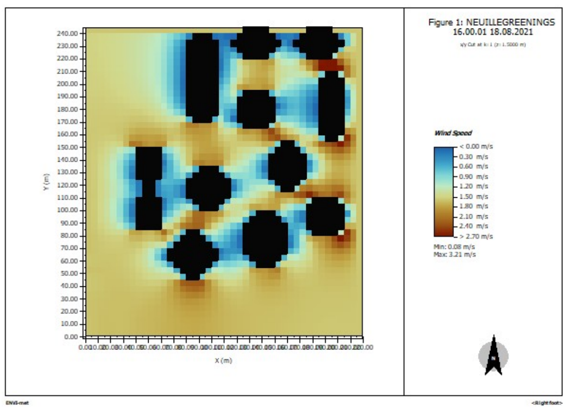


Figure 19: wind speed with greening building

building and more spaced building the wind can easier flow through the building. The air is more changed and avoid to heat because it stock at the same place. Wind can give the feeling that the temperature is less than in reality. It's more appreciable to have little bit wind.

3.1.3 Others interaction

Airflow around buildings plays a key role in heat dissipation. During the summer, as demonstrated in our simulations, elevated convection is preferred to enhance heat dissipation. This airflow also helps prevent the stagnation of pollution. To achieve these effects, we applied similar strategies as those used to mitigate urban canyon impacts, avoiding excessively complex building structures that could disrupt airflow. In cities, evaporation rates are generally lower, which reduces humidity levels. This results in an increase in sensible heat, as there is little latent heat being used for evaporation. By incorporating green walls and roofs, we can enhance evapotranspiration, which helps cool the environment and improve humidity balance.

Hydrodynamic interactions in cities primarily revolve around the movement and retention of water within urban materials and surfaces. Impermeable surfaces such as asphalt and concrete increase runoff, reducing the water available for evaporation and cooling. This lack of evaporation contributes to lower humidity levels and a greater proportion of sensible heat in the energy balance. In addition, building materials can absorb and store water through capillary action or condensation, affecting their thermal properties. Strategies like incorporating permeable materials, enhancing vegetation cover, and designing efficient drainage systems can improve water retention and mitigate hydrodynamic imbalances in urban environments.

3.2 Ground-environment interaction

Firstly, we recall from the course that urban artificial surfaces "are major contributors to the urban heat island (UHI) effect". Here the objective is in reality twofold: both to be able to offer a solution to reduce the absorption of heat but also to limit its storage in the ground. Two main parameters must therefore be taken into account : decreasing material absorption and heat storage. To reduce radiation absorption, the main idea is increasing albedo a (*i.e.* increasing reflectivity of shortwave radiation). In other words, it's the fraction of sunlight reflected by a surface. It therefore indirectly characterizes the capacity of a surface to absorb incident solar energy and surface with a low albedo absorbs a large part of solar radiation while surface with high albedo reflects much of this radiation and absorbs little heat.

A first suitable simple strategy that can be proposed consist in using a single continuous cover of light concrete pavement in place of dark concrete or asphalt particularly in northern part of case study. Indeed, we notice that even if the spaces inside the Innovation Park are often rather green spaces with sand/gravel paths as shown in Fig. 21 below, we also surprisingly find large asphalt spaces at the level of the access roads and parkings : for example close to G & H buildings and parkings between C building and PPH as we can see in Fig. 23 & 24.

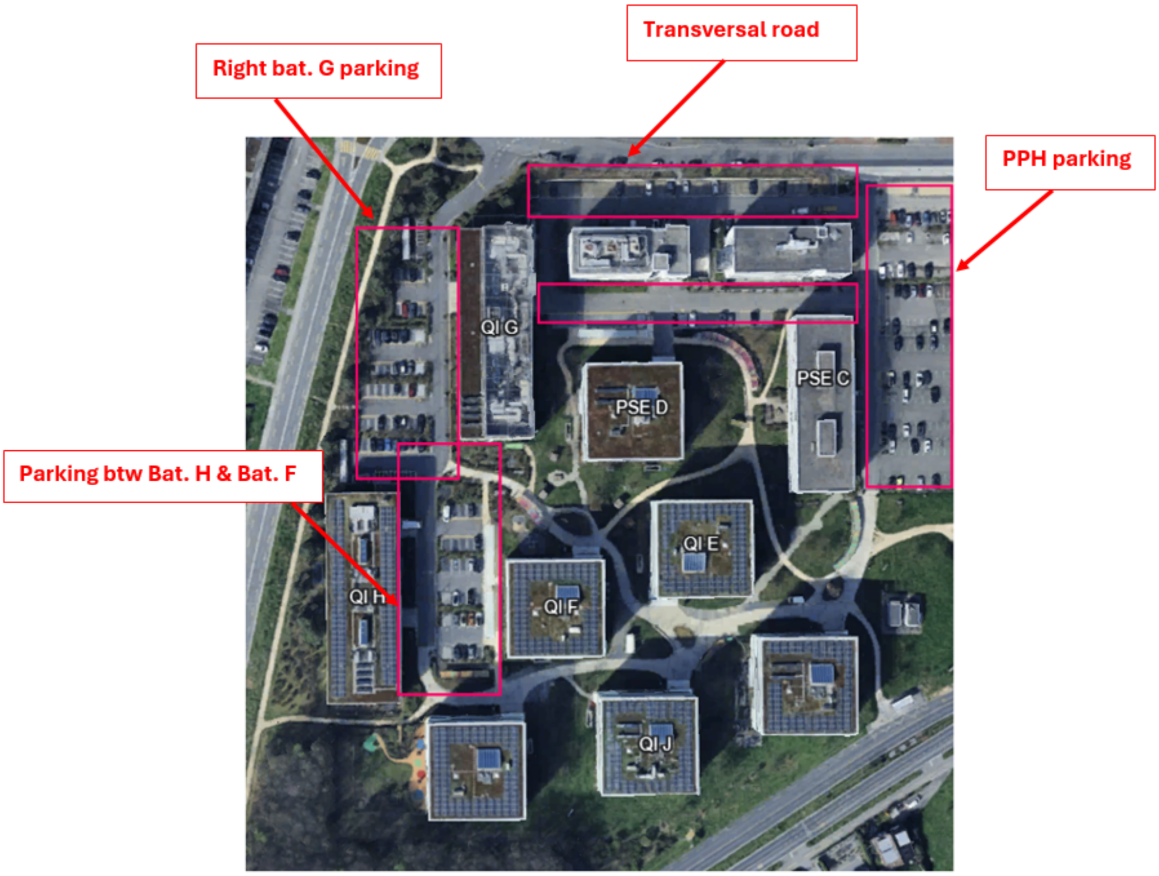


Figure 20: Study case map, *Google Earth*

Figure 21: stabilized sand paths

Figure 22: Light concrete pavement path

Figure 23: Parking between Innovation Park and PPH building

Figure 24: parking spot between G & H buildings

Light concrete implementation on *Spaces* interface is shown in Fig. 25 below :

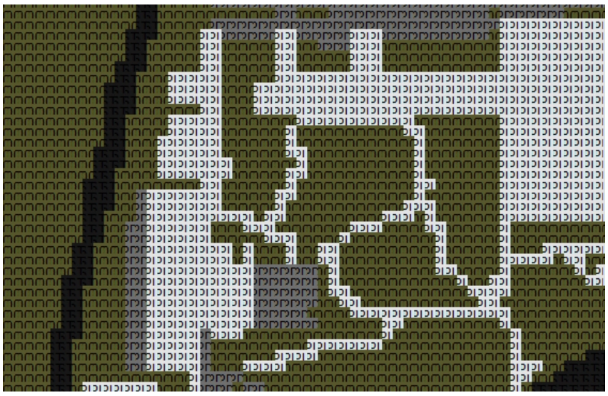


Figure 25: Soil & surfaces from *Spaces* interface with "light concrete pavement" soil profile

As expected, the simulation results (for illustrative purposes only, the results were taken arbitrarily at 2:00pm; the comparison would have to be made rigorously over the entire study day) show a clear reduction in both potential air temperature (denoted as PAT) in figures 26 & 27 and soil sub-surface temperature in figures 28 & 29 after replacing asphalt with light-coloured paving: the change is, as expected, more pronounced in the north-west (parking to the left of building G and one between H & F) and north-east (large parking lot in Fig.23) of study site.

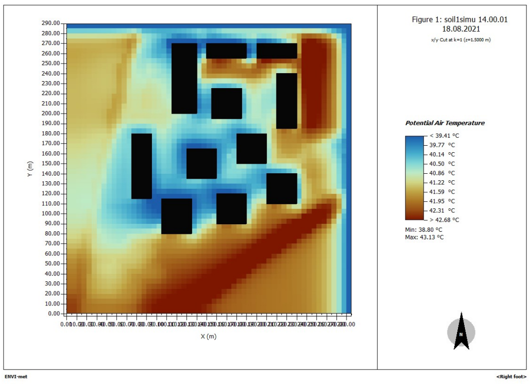


Figure 26: PAT, base case, 2:00pm

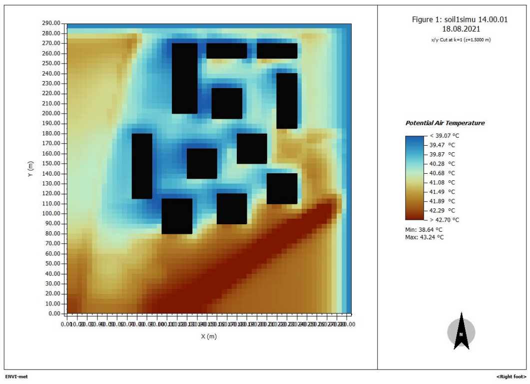


Figure 27: PAT, "light case", 2:00pm

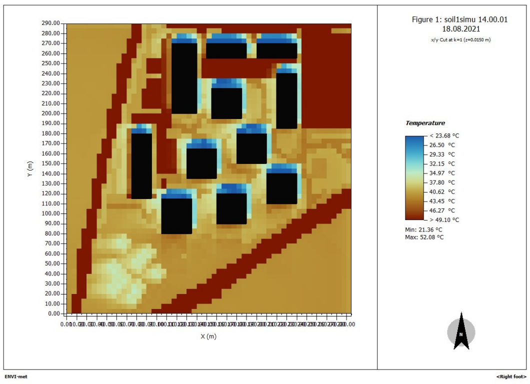


Figure 28: Soil temperature, base case, 2:00pm

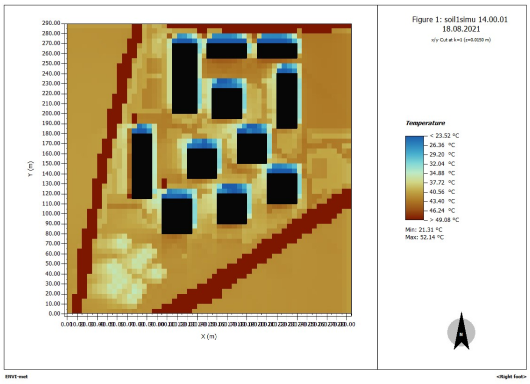


Figure 29: Soil temperature, "light case", 2:00pm

Using *Leonardo* we can also have a direct comparison map in PAT between our 2 cases (here we choose absolute differences with base case scenario as reference and not relative differences) as shown in Figure 30 below :

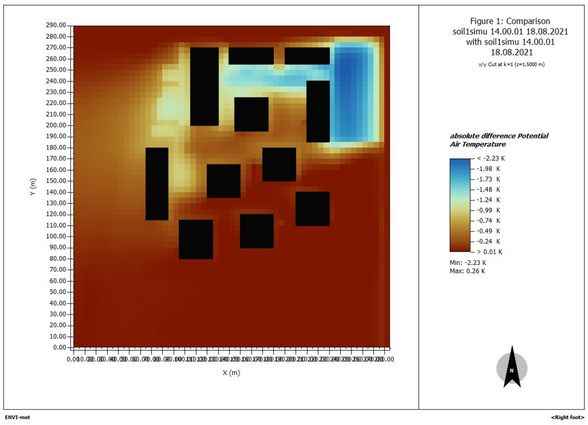


Figure 30: Absolute PAT differences between base case scenario and "light case" scenario, 2:00pm

The most visible difference is clearly located at the PPH parking lot on the right although there is a significant difference on the cross road ("transversal road") in the upper part.

We have :

$$\Delta_{PAT} := PAT_{observation} - PAT_{reference} = PAT_{basecase} - PAT_{lightcase} \qquad (3)$$

(We have negative differences in the figure above as expected)

As we have already said, all this only constitutes individual analyzes at fixed times, we give below the results in a more global way (no longer spatial at a given moment between the 2 scenarios but the average evolution depending on time). We export from *Leonardo* to Excel "atmosphere" files for the 2 scenarios independently "atmosphere" properties (we can do the same thing for "radiation" files for example) :

Figure 31: Entire study period

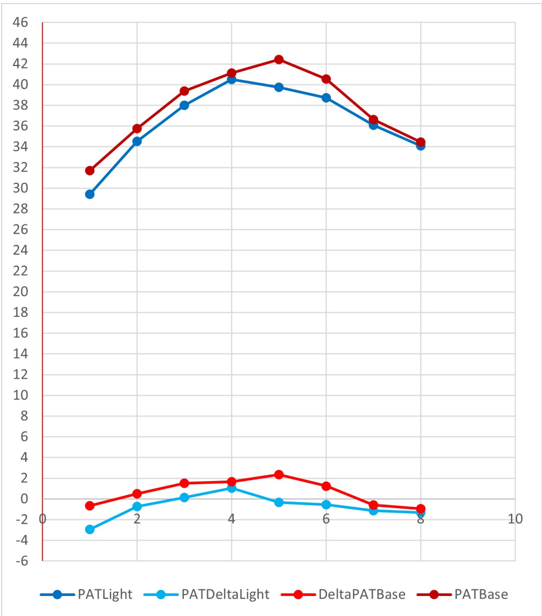


Figure 32: "Potential Air Temperature" and "Air Temperature Delta" in the 2 scenarios, 8:00am to 10:00pm

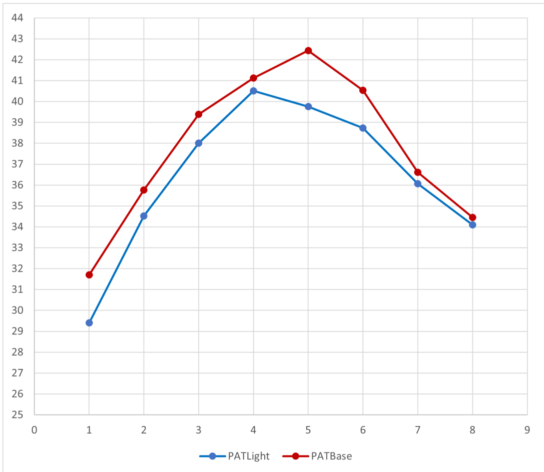


Figure 33: "Potential Air Temperature" in the 2 scenarios, 8:00am to 10:00pm

We conclude that in general, there is a significant reduction (of the order of 1 to 2 degrees) in the Potential Air Temperature over the entire study after replacement with lighter pavement.

We also give below the shortwave radiation reflected (we chose here "SW Reflected from the lower hemisphere") for the 2 scenarios :

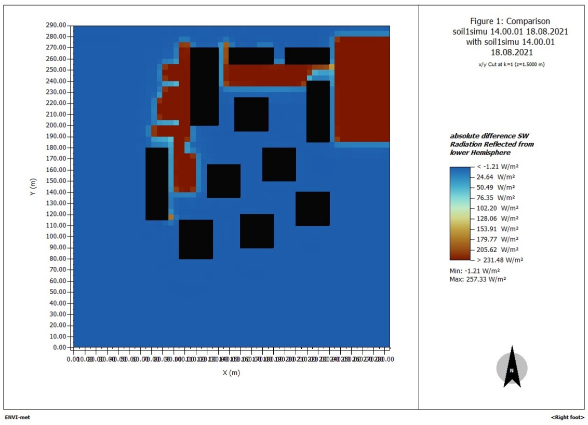


Figure 34: Absolute SW differences between base case scenario and "light case" scenario, 2:00pm

Here we have positive differences in the figure above as expected.

The advantage of using a continuous white concrete pavement is that it is suitable for vehicle traffic, but the disadvantage is that, apart from the color, the material is the same, so there's always a problem between the ground and its interaction with the hydraulic cycle for example (a completely impermeable coating means the ground can't breathe! in ground-vegetation interaction). As shown in Fig. 21, one alternative already present on site is stabilized sand pathways. Even though it would not be suitable for road or parking lot surfacing, it could nevertheless be used uniformly for all paths on site (as can be seen, some paths still have a white concrete pavement). Stabilized sand offers better cohesion than natural sand alone. This allows the creation of a surface resistant to erosion, foot traffic, and light loads, while remaining more flexible than rigid surfaces like concrete. Stabilization binds fine particles, preventing their dispersion due to wind or traffic. If stabilized sand is used with a non-hydraulic binder (e.g., polymers or natural stabilizers), it can retain sufficient permeability to promote water infiltration, essential for minimizing runoff and enhancing evaporation while if hydraulic binders (such as cement) are used, the permeability of the sand can be significantly reduced. This would limit water infiltration and could create a sealed surface effect.

However, with this strategy, we've really only modified the upper part of the ground: the coating. The idea now would be to not only modify the top layer, but also the soil part of the ground defined as "a mixture of organic matter, minerals, gases, liquids and organisms". For now, we actually only use predefined soil profiles in ENVI-met like : default sandy loam, dark concrete pavement, light concrete pavement and asphalt road. We show as an example the soil profile of the light pavement and the dark pavement .

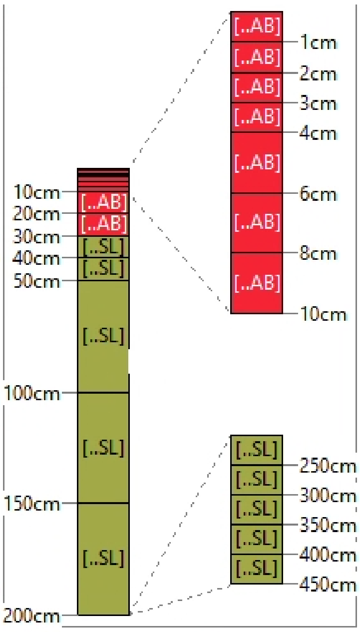
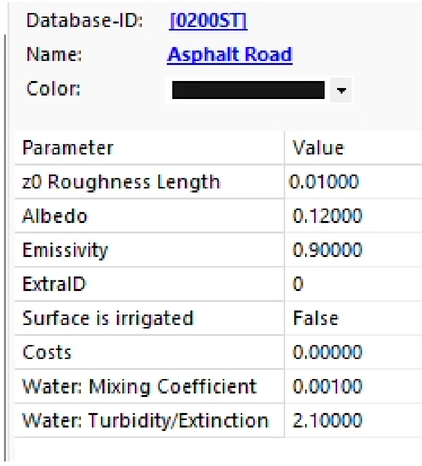


Figure 35: asphalt road soil profile layers



Parameter	Value
z0 Roughness Length	0.01000
Albedo	0.12000
Emissivity	0.90000
ExtraID	0
Surface is irrigated	False
Costs	0.00000
Water: Mixing Coefficient	0.00100
Water: Turbidity/Extinction	2.10000

Figure 36: asphalt road soil profile main properties

Now, the idea would be to be able to propose a virtual custom soil profile (still with default layers). We propose the theoretical model in Fig. 30 below :

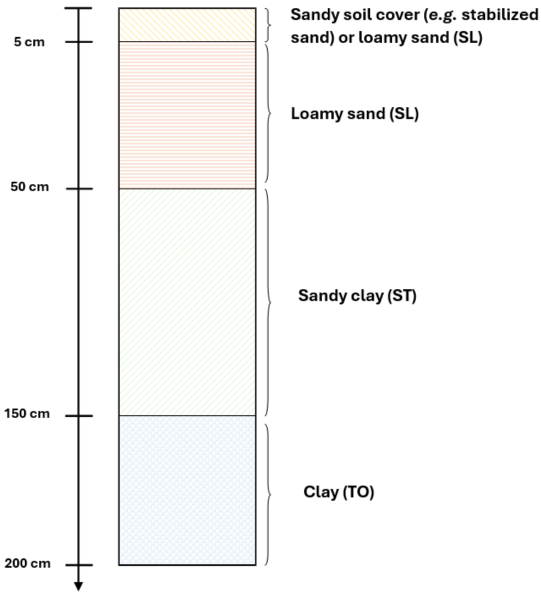


Figure 37: Virtual custom soil profile proposition

The customized stratified soil profile proposed is composed by a first layer made of stabilized sand or loamy sand (5 cm), providing high albedo and low thermal conductivity, enabling better reflection of solar radiation and limiting surface heat accumulation. The second layer (45 cm) composed of loamy sand, is characterized by moderate porosity but increased connectivity between voids, ensuring higher permeability compared to clay loam soil. This promotes water infiltration and reduces urban runoff. The third layer, consisting of sandy clay (100 cm), slows down drainage, preserving moisture in the upper layers for improved thermal and water regulation. Finally, the fourth layer (50 cm), made of clay, acts as a low-permeability material, crucial for limiting deep water losses. This soil profile ensures a balance between water management, thermal comfort, and environmental sustainability, making it adapted for urban areas affected by UHIs. Using soil profiles interface on *DB Manager*, we implement the artificial custom soil profile on *Envimet* as shown in Fig. 38 & 39

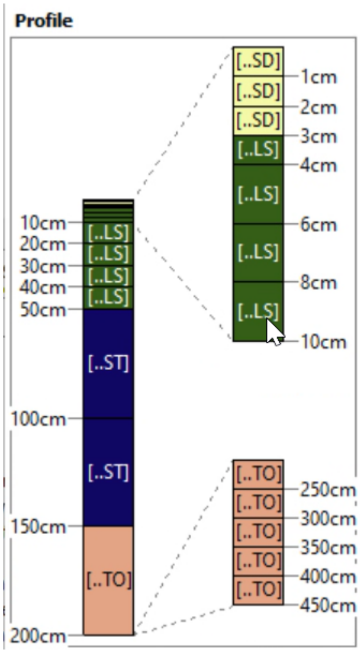


Figure 38: custom soil profile layers

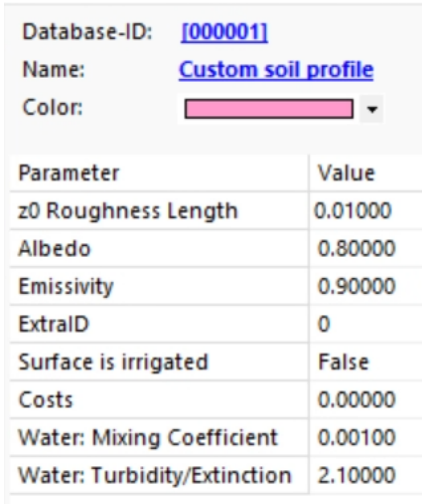


Figure 39: custom soil profile main properties

We resume below the effective albedo of soil profiles used (CP = concrete pavement/SP = soil profile) :

	Asphalt Road ■	Dark CP ■	Light CP ■	Default Sandy Loam ■	Custom SP ■
Albedo	0.12	0.2	0.5	0.2	0.8

Table 1: Albedo values for different soil profiles

We chose to distribute the ground profile in the following way as shown in Figure 40 (intentionally different from the distribution of the light case). We choose to replace the soil in places where the upper layer would be usable (paths inside the Innovation Park and at the parking spaces on the left (not suitable for large spaces of the PPH parking lot due to the risk of a large number of particles in the air, even with stabilized sand)

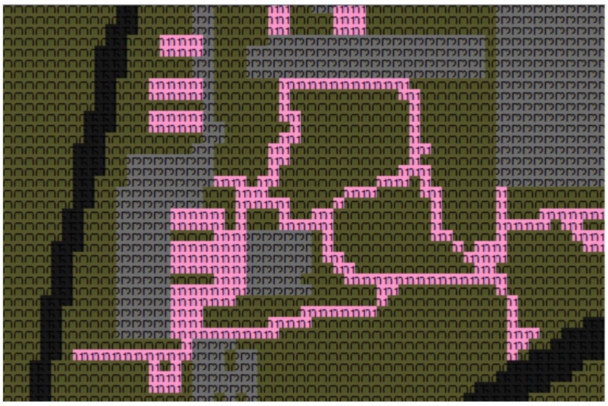


Figure 40: Soil & surfaces from *Spaces* interface with artificial custom soil

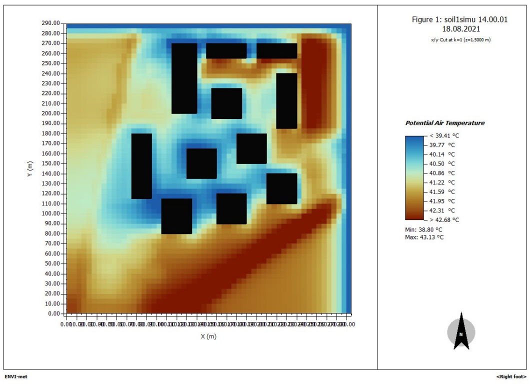


Figure 41: PAT, base case, 2:00pm

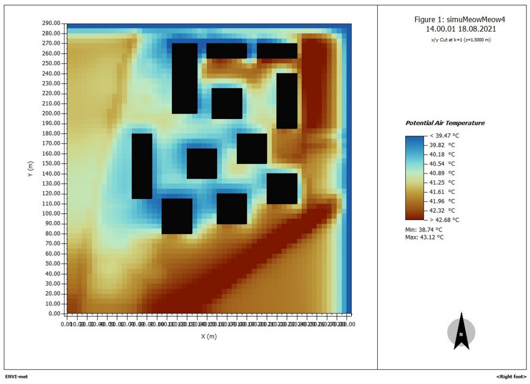


Figure 42: PAT, "custom case", 2:00pm

We notice that contrary to what we obtained after replacement with light concrete, we see almost no visible difference, even worse we notice in the figure below that the absolute differences in PAT are positive (always taking the base case as reference), in other words, the change of the ground by our profile has almost no influence and even gives very slightly higher temperatures even if the albedo of the replaced surfaces is higher (see Table 1). The result is more contrasted with regard to the reflected shortwave radiations, we find significant positive and negative differences compared to the base case (reference); there is a gain in reflectivity in certain places and a loss of reflectivity in other places.

An explanation could perhaps come from the weather conditions, our profile was created to avoid urban surface runoff and permit water retention in the first layers of the soil in order to maintain the cooling property of evaporation for hot days. If the "full forcing" file does not take into account previous events (initial saturation of the soil by rain in the past) we do not exploit this advantage. If we now consider the feasibility of such options, that is to say the possibility of implementing these strategies if EPFL would like to improve the fight against heat islands in the years to come; it is obvious that replacing the black paving with a light paving (light concrete or satbilized sand) with a thickness of 5 to 10cm is possible (even if this will generate significant financial costs, while replacing an entire soil profile over 2m is impossible It was a purely theoretical idea but absolutely not possible in reality!

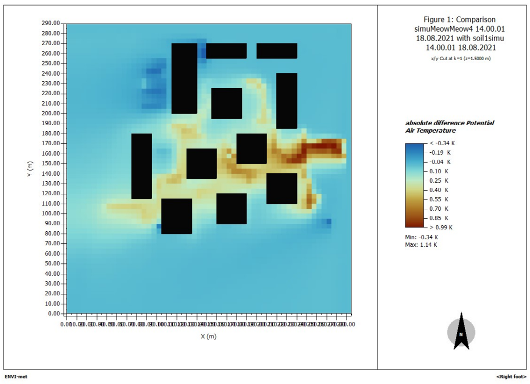


Figure 43: Absolute PAT differences between base case scenario and "light case" scenario, 2:00pm

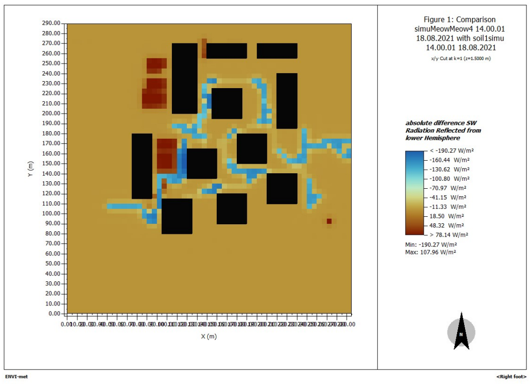


Figure 44: Absolute SW differences between base case scenario and "light case" scenario, 2:00pm

3.3 Water body-environment interaction

There are 2 types of water body depending on their scale. There is the urban scale and the local scale. The urban scale corresponds more to a river or a lake and the local scale to fountains or pools. In class we saw that the water body contributes to the mitigation of the UHI by the physical process of water evaporation. The athmosfere is tempered by the water body. In cities, the air is cooler when there are water bodies, but the streets must be wide and open, otherwise the effect is useless. Water bodies are referred to as Urban Cooling Islands (UCI). For our simulation for water body, we decide to add three fountains (in red on the next figure). Unfortunately, all our fountains are regular shape because we have lot of problem with simulation when the fountains have irregular shape.

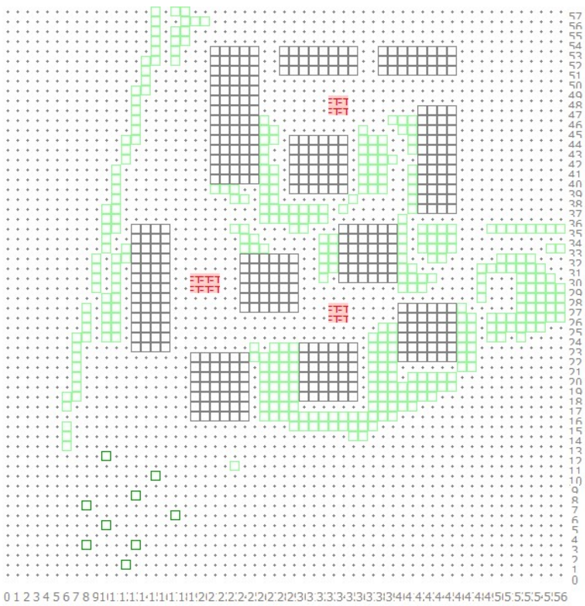


Figure 45: map with fountains

We know that the water acts on three parameters: humidity, temperature and wind speed. For humidity, we can see at the next figure that where the fountains are placed there are naturally a huge difference due the evaporation. With fountains, the humidity grow up of 0.75 g/kg. The biggest fountains (at the left) have bigger influence than others.

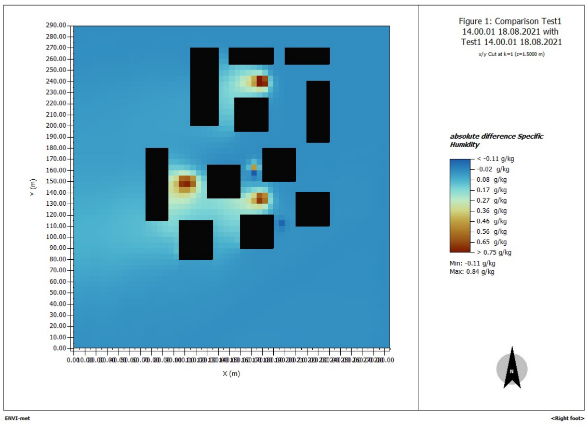


Figure 46: Different humidity with and without fountains

This humidity and evaporation is important to cool air and we see at the next figure that actually it works. Where the fountains are placed, the temperature loose between 0.8 and 3 K. We can observe too that the fountains on the top cool more than other. We can explain that because at this place the temperature are more higher than the others place. So the higher is the temperature, the more efficient is the fountains.
For the last element: the wind speed, we see on the next figure that there are no difference. We explain that because our water body are too small, the surface where the roughness change is too small.

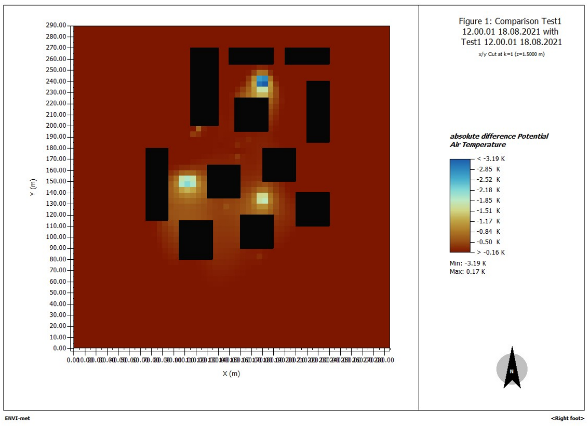


Figure 47: Different temperature with and without fountains

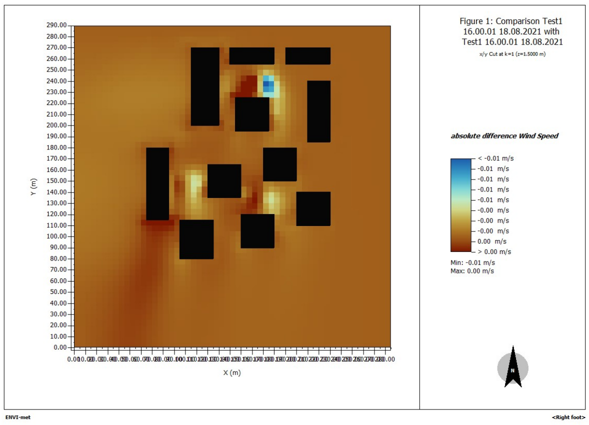


Figure 48: Different wind speed with and without fountains

3.4 Vegetation-environment interaction

The interaction between vegetation and the environment takes multiple forms in urban thermodynamics, involving exchanges with both the atmosphere and the ground. Vegetation plays an essential role in regulating the urban climate by providing shade, influencing wind flow, and contributing to moisture dynamics.

Vegetation helps mitigate urban heat islands (UHI), regulate microclimates, and support environmental functions such as oxygen production and carbon dioxide absorption. However, its effectiveness is influenced by seasonal variations, and not all vegetation types are well-suited for urban settings.

3.4.1 Mitigation with Vegetation

Green infrastructure contributes to temperature reduction in multiple ways. Trees, urban parks, green roofs, and green walls help by reducing reflected solar radiation, providing shade, enhancing cooling through evapotranspiration, and moderating wind speeds. To maximize their effectiveness, it is important to diversify and spatially distribute green structures, as their impacts vary in time and scale.

Greening buildings through the addition of green roofs and walls decreases heat transfer by reducing thermal inertia and increasing evapotranspiration. The choice of plant species is also critical; different species have varying effects based on their climatic suitability and functional properties. For example, pedunculate oaks provide excellent shade and are resilient to climatic variations. Maples are chosen for their high evapotranspiration capacity and ability to absorb CO2, while cherry trees and black pines are selected for their resistance to pollution and support for biodiversity. In our project, all chosen species are native to the region.

Although vegetation absorbs pollutants such as CO2, it also produces its own pollutants, such as pollen, which can contribute to air quality issues. Additionally, while vegetation reduces wind speeds, its porous structure allows airflow to continue, helping to disperse pollutants more effectively. The airflow is also impacted by the high of the trees. There is different way to implement vegetation in a city. We chose to put a lot of trees in the same place, to form a park. But we also put some trees alone between the buildings. Parks are more effective to improve the environment, but in a city, there isn't a lot of space so the trees alone are a good alternative as it provides shades, dispers air pollutants and makes evapotranspiration. The greenings and the grass have a key role in the humidity.

We try so to dispose the vegetation with the target to have a good co2 absorption and to have a good evapotranspiration. We choose Cherry trees and black pines for resistance to pollution and biodiversity. We finally find this disposition:

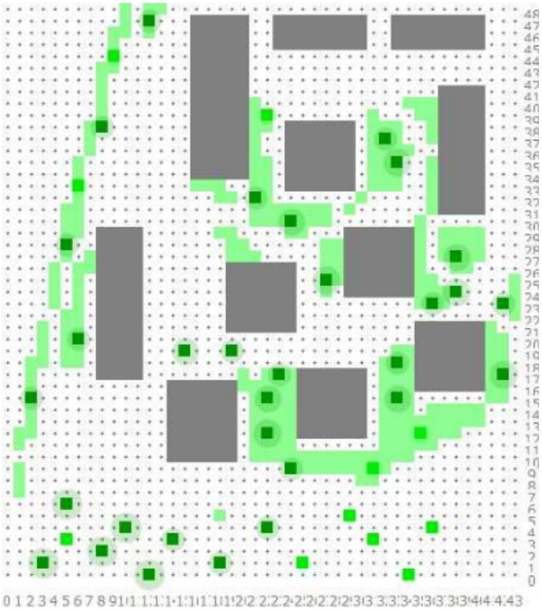


Figure 49: disposition Vegetation.

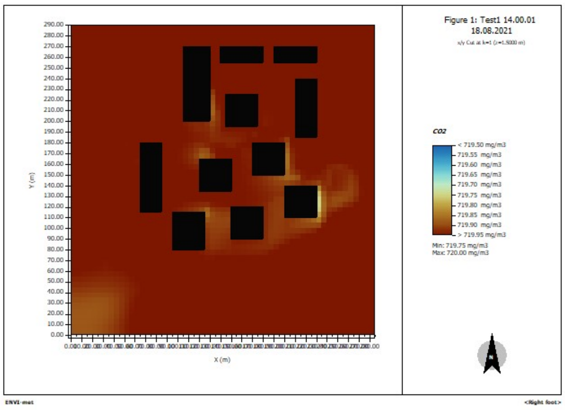


Figure 50: CO2 without add more vegetation

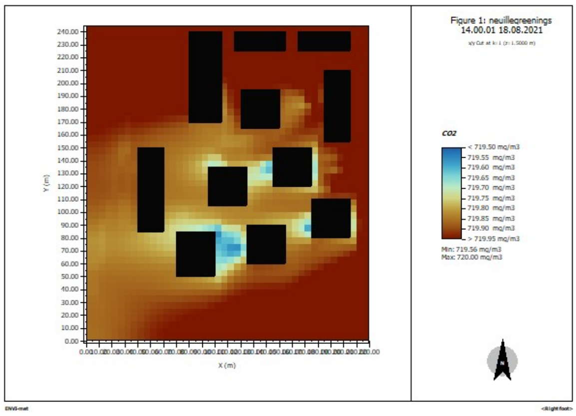


Figure 51: CO2 with add more vegetation

From our simulation, we see that plants help a lot to have less Co 2 on the atmosphere. Vegetation contributes to have a better air quality. At left the are no absortion of co2 and now the co2 decrease to less than 719.75 mg/m^3.

I don't think this analysis is meaningful, the range of CO2 is 719-720, which basically there is no variation. The Carbon Sequestration by a few trees in a day's time span can be very minor and not meaningful for cooling. You should rather analyse the cooling effect through shading and evapotranspiration.

3.4.2 Energy Balance

The energy balance of vegetation

$$Q* = QH + QE + QG + QS \quad (4)$$

varies among species and is primarily driven by incident solar radiation. Vegetation reflects shortwave solar radiation effectively, and leaves, with their high emissivity and absorptivity, reduce overheating by functioning as micro-sunshades. However, the albedo of a tree canopy is not equivalent to that of its individual leaves due to factors such as mutual shading, radiation trapping, and penetration depth within the canopy.

3.4.3 Evapotranspiration

Urban vegetation primarily reduces global temperatures through evapotranspiration and shading. The process of evapotranspiration increases latent heat, which cools the air, while shading reduces the impact of solar radiation on surfaces. Parks, in particular, have a localized cooling effect, often lowering temperatures within their immediate surroundings.

Evapotranspiration is a key process in latent heat exchange and comprises plant transpiration and the evaporation of soil moisture. It is governed by factors such as stomatal opening, moisture deficit, wind speed, and incoming radiation. In our case, maples were selected to enhance evapotranspiration due to their high transpiration rates.

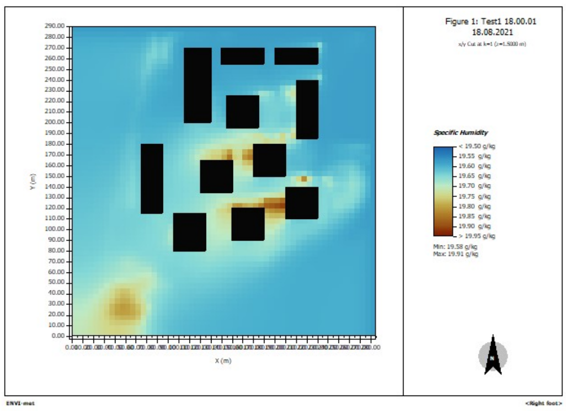


Figure 52: humidity without adding more vegetation

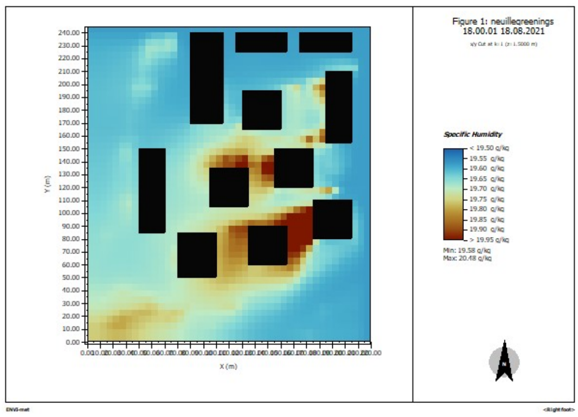


Figure 53: humidity adding more vegetation

From our simulation, to control that the plants do a good evapotranspiration, we choose the compare the humidity from plants with the humidity without plants. We see naturally than humidity increase between 19.5 and 19.75 g/Kg to more than 20 g/Kg. So plants increase the humidity and cool the temperature.

4 Integrated solution

4.1 Map of the integrated solution

For the integrated solution we decided to use all of the mitigations strategies together. So we replaced dark pavement and asphalt by light pavement, we rounded and spaced a bit buildings, we put greenings on the roof of building group A and on the walls and roofs of all the others, and made them different height. We also put more trees and 3 fontains at the spots where there is no dots.We also provided a 3D view of our solution.

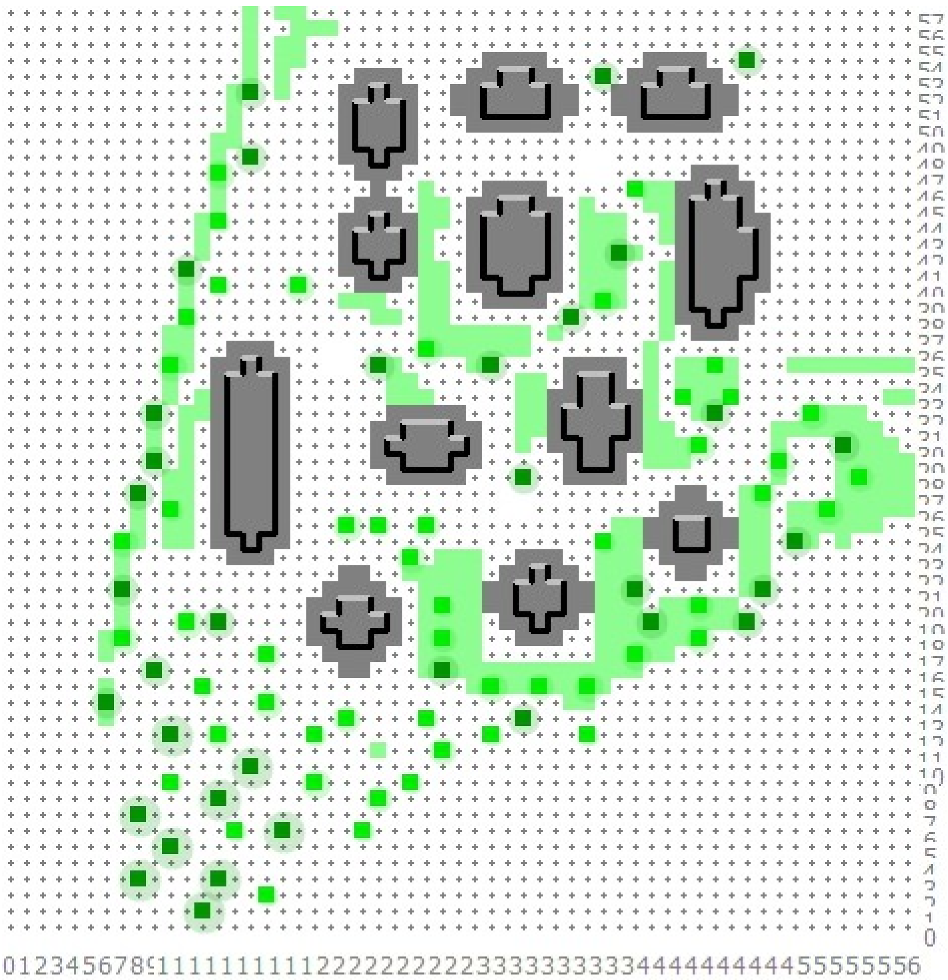


Figure 54: Map of integrated solution

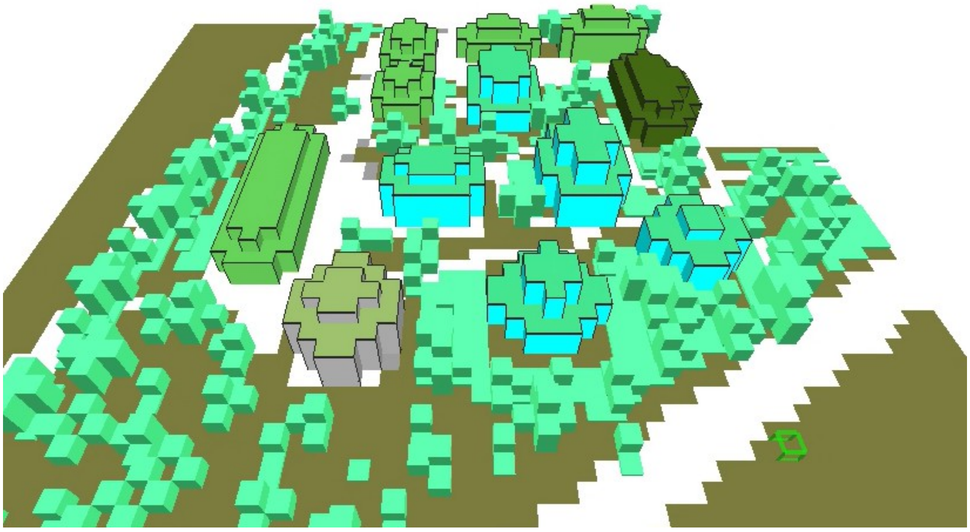


Figure 55: 3D Map of integrated solution

4.2 Thermal comfort

Rounded and spaced buildings :

- **Reduced Wind Tunnels and Heat Concentration**: Rounded building shapes soften the flow of wind, preventing harsh wind tunnels and turbulent hot air pockets, which are common around angular buildings.
- **Improved Air Circulation**: The smoother edges promote natural airflow across the neighborhood, enhancing ventilation and cooling during warm periods.
- **Optimized Solar Exposure**: Rounded buildings reduce excessive heat gain by avoiding large flat surfaces that face the sun directly for extended periods.

Vegetation :

- **Shade Provision**: Trees provide natural shade, reducing direct sunlight exposure on buildings, streets, and open spaces, lowering surface and air temperatures.
- **Evapotranspiration Cooling**: Through their leaves, trees release water into the atmosphere, cooling the surrounding air.
- **Reduced Urban Heat Island Effect**: Vegetation absorbs less heat compared to concrete or asphalt, contributing to a cooler overall microclimate.
- **Improved Air Quality**: Trees act as natural air filters, absorbing carbon dioxide and releasing oxygen.

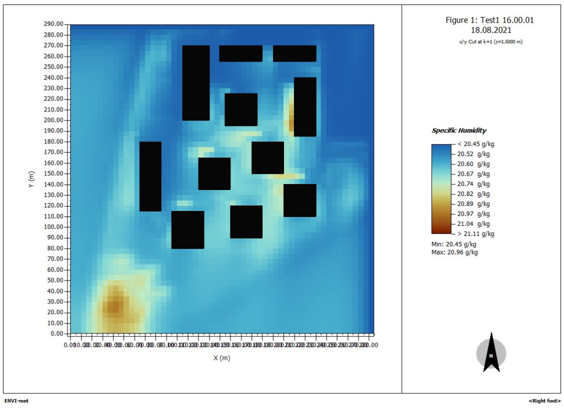


Figure 56: humidity in basic case

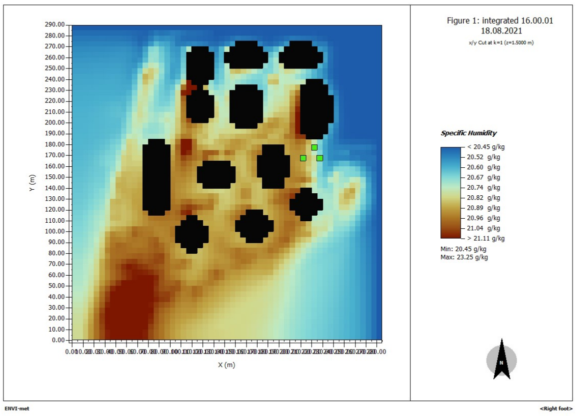


Figure 57: humidity in final case

Addition of fountains :

- **Evaporative Cooling**: Fountains and water features cool the air through evaporation, particularly effective during hot, dry conditions.
- **Psychological Comfort**: Water has a calming and refreshing effect, improving the perception of comfort even when temperatures are high.
- **Humidity Regulation**: Water features add moisture to the air, reducing discomfort in overly dry climates.

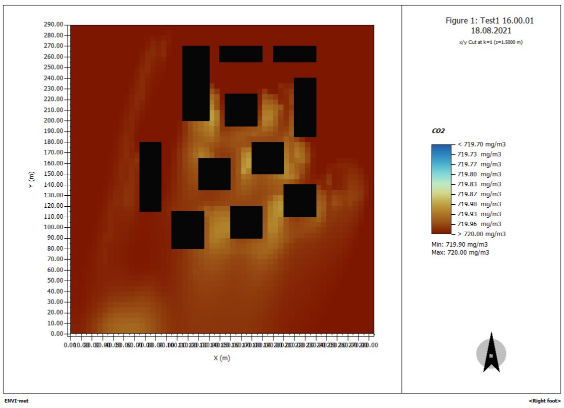


Figure 58: CO2 concentration in basic case

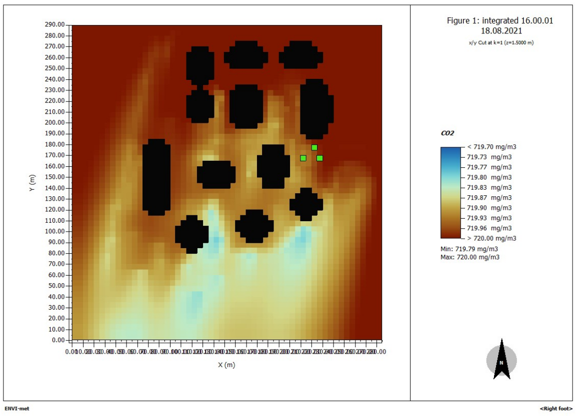


Figure 59: CO2 concentration in final case

Greenings :

- **Thermal Insulation**: Green roofs and vertical gardens provide natural insulation, reducing heat gain in summer and heat loss in winter.
- **Reduction of Surface Temperatures**: Vegetation on buildings prevents direct sunlight from heating building surfaces, lowering indoor and outdoor temperatures.
- **Evapotranspiration Cooling**: Similar to trees, greenings release moisture into the air, contributing to localized cooling.
- **Improved Air Quality and Aesthetics**: Green facades absorb pollutants and provide a visually appealing, natural aesthetic in urban areas.
- **Enhanced Biodiversity**: Green roofs and walls create habitats for birds, insects, and other small wildlife.

Light colored pavement :

- **Lower Heat Absorption**: Light-colored materials reflect more sunlight compared to dark materials, which absorb and store heat, resulting in cooler surfaces.
- **Reduced Surface Temperatures**: Streets, pavements, and walls with light finishes maintain lower temperatures, contributing to an overall cooler environment.
- **Improved Albedo Effect**: By increasing the reflectivity of the area, less solar energy is retained, helping to mitigate the urban heat island effect.

Overall benefits :

- **Enhanced Thermal Comfort for Residents**: Lower air and surface temperatures improve outdoor comfort, making the neighborhood more livable during hot weather.
- **Energy Efficiency**: Cooler surroundings reduce the need for air conditioning, leading to energy savings and lower greenhouse gas emissions.
- **Sustainability**: The combination of greenery, water, and reflective surfaces creates a more sustainable and environmentally friendly urban environment.
- **Health Benefits**: Improved air quality, reduced heat stress, and more pleasant outdoor spaces encourage physical activity and community engagement.

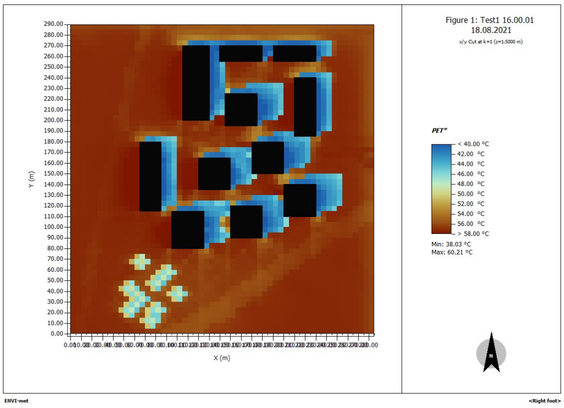


Figure 60: PET in basic case

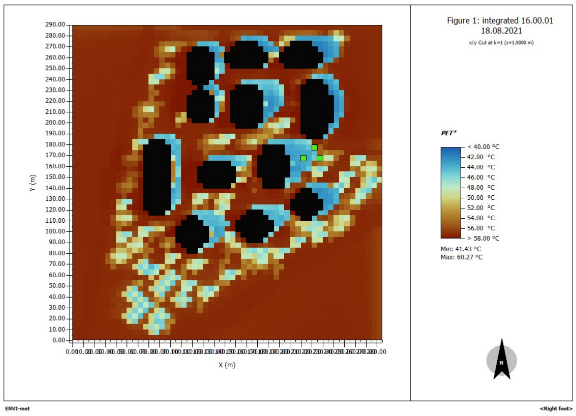


Figure 61: PET in final case

The PET beeing mostly related to the temperature, it appears that in this example at 16:00, PET is slightly higher in the solution than in the demo because the buildings are smaller so there is less shading. Our model could work well but, indeed, in the middle of afternoon during the hottest day of the year, having taller buildings could have been a better idea to add shading. But the trees we added are helping to shade.

What about air temperature and radiation for your final proposal? Are there any interactions between your proposed measures?

5 Some notes about running simulations

Our solution of rounding the buildings is not working so much in the simulations because of the size of the pixels of the grid, we could reduce the size of the pixels to make them more round and smooth to really see the difference but the simulations are taking too long when we increase the number of pixels.

6 Conclusion

This report has explored strategies aimed at improving thermal comfort in urban environments. By implementing solutions such as rounded building shapes, light-colored pavement, the integration of vegetation on the ground and buildings, as well as water infrastructure like fountains, we demonstrate that it is possible to significantly reduce the impact of urban heat islands. These interventions not only enhance residents' well-being but also reduce energy consumption associated with artificial cooling systems.

Moreover, the selection of vegetation adapted to the local climate, particularly in Switzerland, plays a crucial role in providing natural shade and effective thermal regulation. These measures, combined with thoughtful urban planning, promote a harmonious coexistence between urban development and environmental resource preservation.

In conclusion, to effectively address the challenges posed by climate change and increasing urbanization, it is essential to adopt an integrated and sustainable approach to urban planning. The solutions proposed in this report highlight the potential of multidimensional interventions to create more comfortable, sustainable, and resilient urban spaces in the face of future climate conditions.