ENVI_MET

Improving thermal comfort in the urban fabric of Lima

Carol Torres

Introduction

Why Lima ?

Like many other cites in the world, Lima, capital of Peru, is experiencing an evident increase in local temperature. Further, as a city close to the equator, it also experiences intense solar radiation.

Vegetation in urban areas has become a strategy to mitigate climate risk, enhance public health and create more liveable urban areas. However, simply increasing the vegetation cover can be unsustainable due to socio-economical and climatological reasons, in partcular the city's intense densification and aridity.

Lima is a megacity experiencing ongoing exponential growth and is currently home to over 10 million inhabitants. It is also one of the driest cites in the world, with low rainfall of around 9 mm per year, naturally constraining vegetation growth as well as scarce water supplies. Vegetation to mitigate urban heat thus needs to be planned strategically in order to provide beneficial effects on the urban climate while using minimal irrigation.

However, traditional approaches to urban vegetation in Lima have largely ignored the water scarcity. New approaches, such as xeriscape, are looking for resilience against water scarcity, but seem to lack consideration on their impact on urban temperature. This is particularly pertinent for informal settlements, as they are home to more than two million people, and are the centre for population growth and urban development.

The combination of rapid growth of informal settlements, water scarcity and climate change, raises the following key questions: How will thermal comfort in these neighborhoods evolve if they develop under the traditional approaches? What strategies could these still-developing neighborhoods use to improve this outlook in such water scarce and arid conditions?

This study analyzes the thermal comfort of an informal settlement in Lima, looking at the current environmental performance and how this could evolve under a business-as-usual development scenario. It also analyzes potential solutions which aim to improve urban thermal comfort in a way that is sensitive to the local context.

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Characterisation of the area of analysis

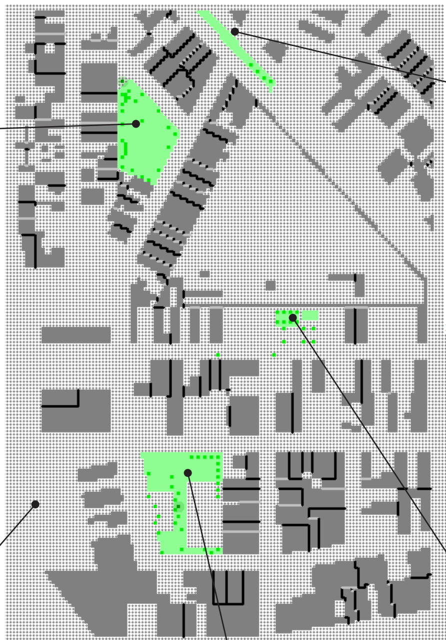
The area of interest is a neighborhood of an informal settlement in Lima, which has many typical aspects of a neighborhood in a relatvely early stage of development

In such areas, green and grey infrastructure are implemented a long time after land occupation. Therefore, many streets remain unsealed with a bare soil surface. The restricted access to water, in addition to natural aridity, limits the scope for urban vegetation in public areas. The neighborhood features a small artficial wetland located in one of the parks (Park-Wetland).

It was constructed to treat local domestc wastewater and produce water for irrigation. While this could facilitate vegetation growth, and could be replicated in similar neighborhoods, its current scope is limited to the park, and does not overcome the need for water sensitve solutions.

Park

- Small trees and shrubs with sparse foliage, resulting in low leaf area density (LAD)
- Large areas of grass
- Sealed surrounding streets/sidewalks with concrete and asphalt



Avenue 1

- Small trees and shrubs with sparse foliage (low LAD)
- Unsealed streets (bare soil)
- Adjacent private large vacant plot

Avenue 2

- Unsealed surface (bare soil) asphalt

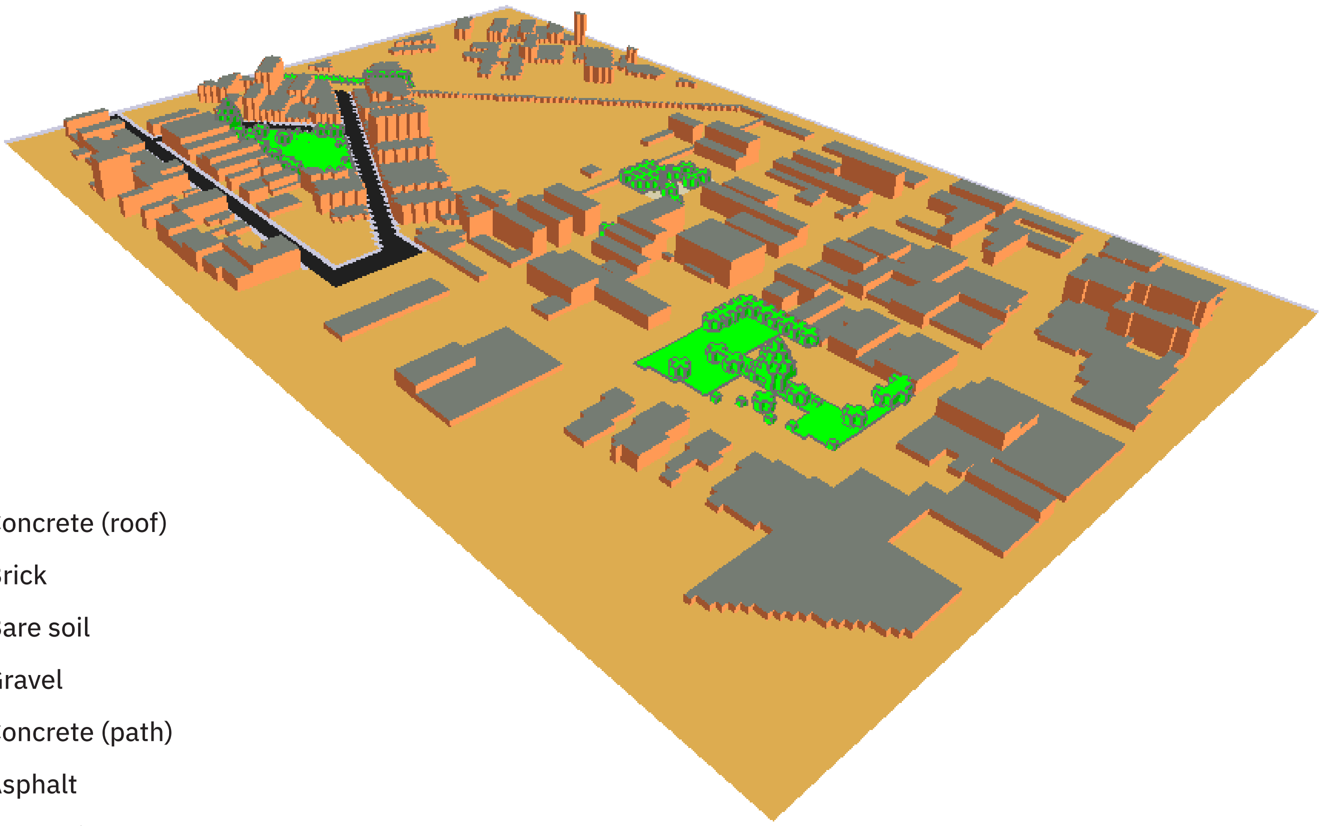
Park 2

- Tall trees with dense foliage (high-LAD) mixed with small trees with sparse foliage (low-LAD)
- Area mostly covered with grass
- Football field of bare soil

Park-Wetland

- Tall trees with dense foliage (high-LAD) mixed with small trees with sparse foliage (low-LAD)
- Area mostly covered with grass
- Football field of bare soil(bare soil)
- Planned school (plot reserved)

S1 As-is Scenario



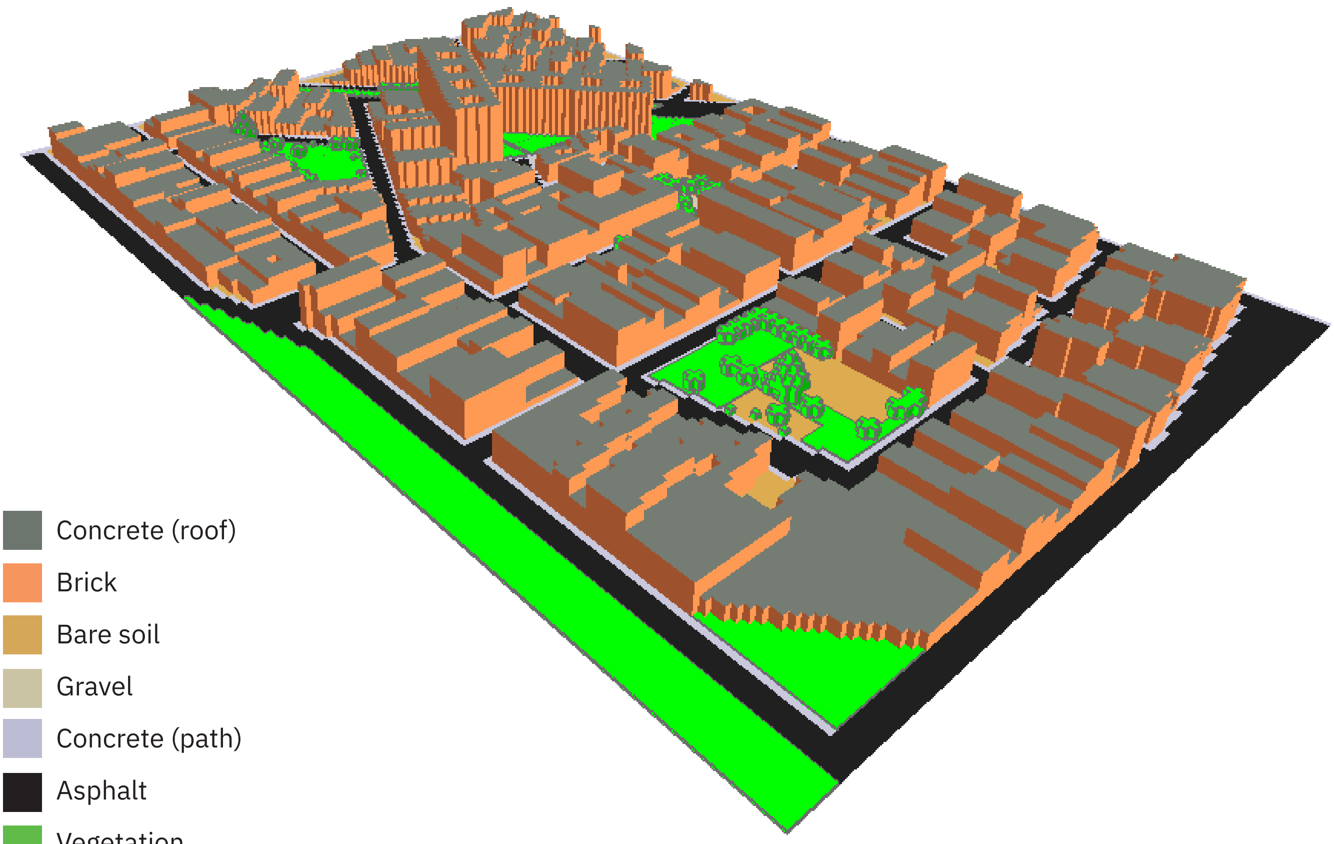
Concrete (roof)
Brick
Bare soil
Gravel
Concrete (path)
Asphalt
Vegetation

(S1) was modelled with ENVI-met, and simulated under conditions of a hot summer day.

Model and simulation conditions

Model size: 137 x 200 x 25 Grid Cells
Date: 22.02.2020
Air Temperature: min. 23°C; max. 32°C
Relative humidity: min. 79%; max. 88%
Wind direction: SW
Wind speed: 5 m/s

S2 Business as usual Scenario



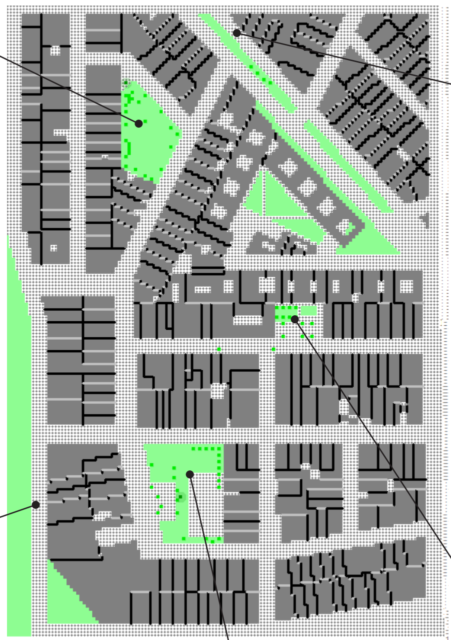
Concrete (roof)
Brick
Bare soil
Gravel
Concrete (path)
Asphalt
Vegetation

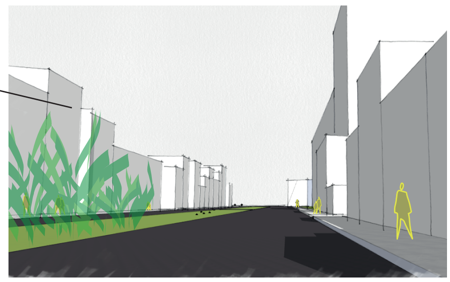
Exponential Densification

Like other areas of Lima, the neighborhood is expected to experience an exponential growth and intensive densification process. Building height may increase from 1 or 2 stories to 10 or more stories. Sidewalks and roads will progressively be sealed with concrete and asphalt, respectively. Despite the risk of demanding intense irrigation, public areas, particularly parks, road medians and verges, will be covered with large lawn. Tree and shrub planting will probably not follow a strategic approach with regards to placement or species selection. In order to assess and estimate potential changes in thermal comfort as the neighborhood develops, an additional future scenario under a business-as-usual basis - BAU (S2), and with a higher densification level.

Park

- Intense densification around perimeter





Avenue 1

- Extension of divided road with grass in the median
- Minimal tree-planting
- Adjacent new compact high-rise residential blocks (7 and 10 stories / 20m and 30m) with large private areas of grass

Avenue 2

- Road median definition with short grass
- No tree-planting

Park 2

- Football field paved with concrete

Park-Wetland

- Intense densification around perimeter
- School building (constructed)

Environmental Performance

A comparison of the two occupation stages shows a risk of higher temperatures derived from the intensive densification, as well as from planning decisions not accounting for vegetational demands, water scarcity and a warming climate.

Widespread use of impervious surfaces (concrete and asphalt), as well as bare soil, and gravel, with limited ventilation and shade, have a detrimental effect on thermal comfort. This can put people's health at risk and restrict outdoor activities due to extremely uncomfortable temperatures during the hottest times of the day (for instance at 13:00).

In S1, the temperature of non-shaded ground surfaces paved with concrete and asphalt are significantly warmer than those yet to be paved (bare soil). A similar effect is observed in S2, where all streets are paved. However, surfaces like gravel remain slightly cooler than concrete and asphalt.

Shaded surfaces remain cooler than non-shaded ones, regardless of material. In particular, the temperature of shaded asphalt is much cooler than exposed asphalt.

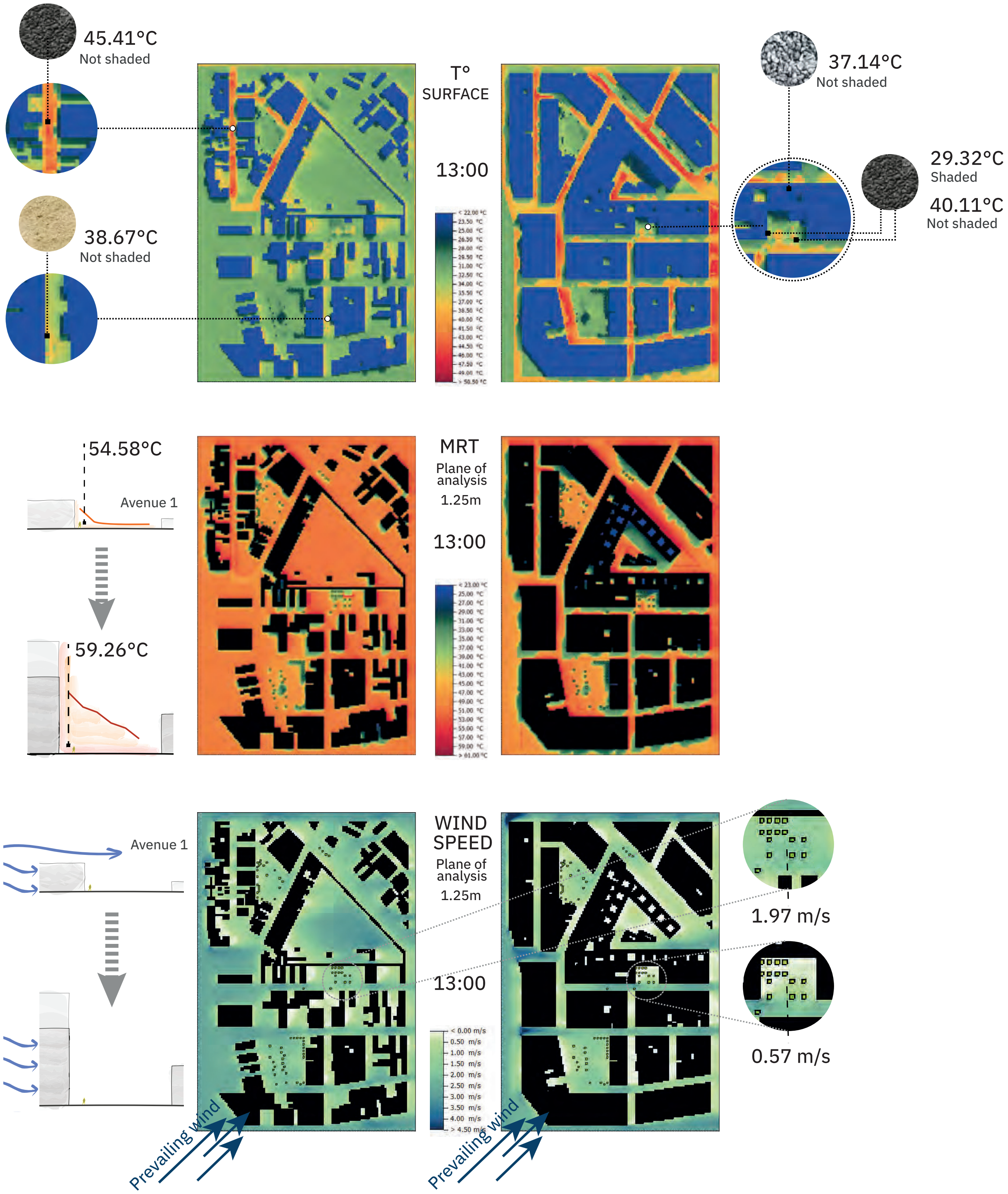
But building surfaces also have an impact on the radiant temperature perceived by pedestrians. The mean radiant temperature (MRT) accounts for radiation from these surfaces in addition to the radiation of other urban surrounding elements.

In both scenarios, the MRT close to buildings is hotter, but cooler further away, and especially in non vegetated or unshaded areas. This effect is more widespread in S2 given the higher proportion of building surfaces. However, overall in many areas of S2, the MRT is lower than in S1, due to the increased proportion of taller buildings shading street surfaces (average street width ~10m).

While reduced MRT is beneficial, the new morphology can nevertheless have a detrimental impact on thermal comfort due to reduced ventilation. In S2, the new and taller buildings block prevailing winds and trap heat, which can lead to experiencing warmer temperatures in the area and put the neighborhood at risk of becoming a so-called "urban heat island".

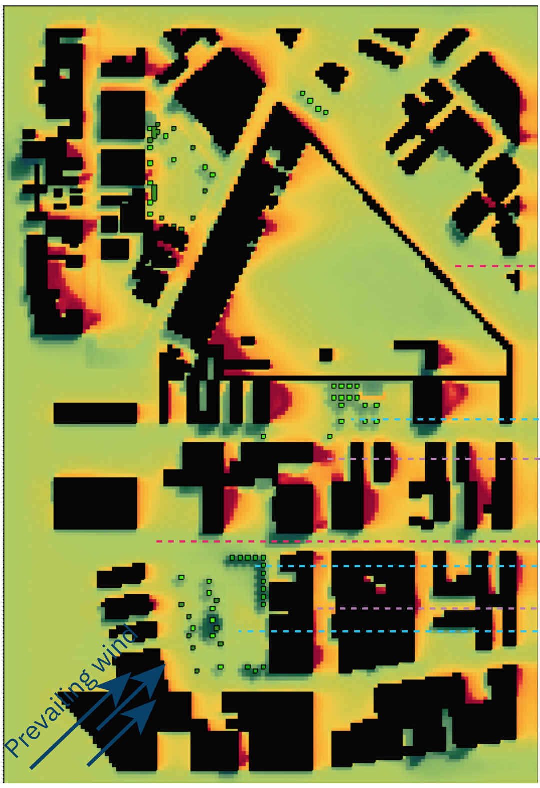
S1 As-is Scenario

S2 Business as usual Scenario



S1 As-is Scenario 13:00

A number of additional factors finally influence the actual temperature perceived by people. The Physiological Equivalent Temperature (PET) index was therefore used to understand the comfort provided by different areas of the neighborhood throughout the development process. The PET helps indicate the actual thermal sensation experienced by people within a certain urban geometry, considering meterological parameters: wind speed, MRT, air temperature and relative humidity. Aside from these, human characteristics, such body parameters, clothing insulation and the metabolic rate, are also considered.

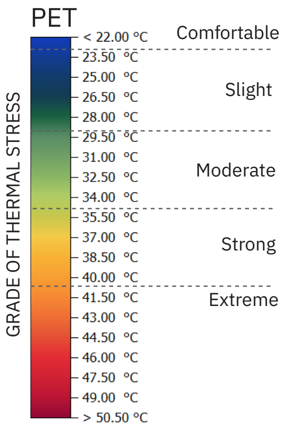


In S1, the PET analysis shows the coolest areas are generally the large open areas - particularly parks and shaded spots by trees.

Most streets show a moderate thermal comfort, especially those wide and well ventilated.

The hottest areas are those that are narrow and poorly ventilated.

Parameters considered
Clothing insulation: 0.57
Person height: 1.65 m
Analysis plane: 1.25 m



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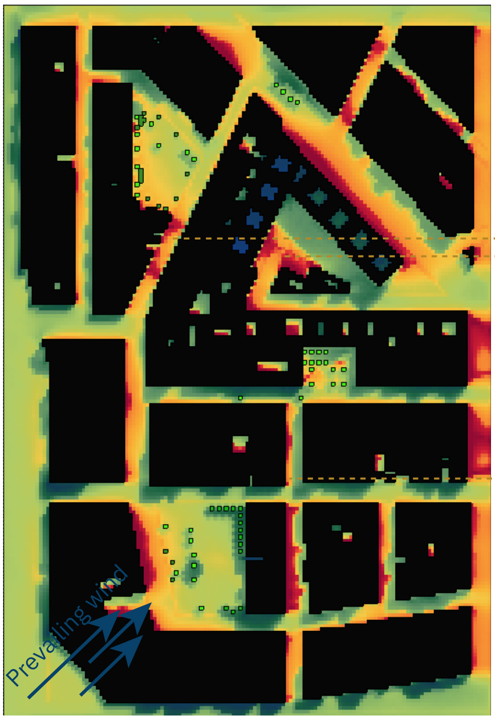
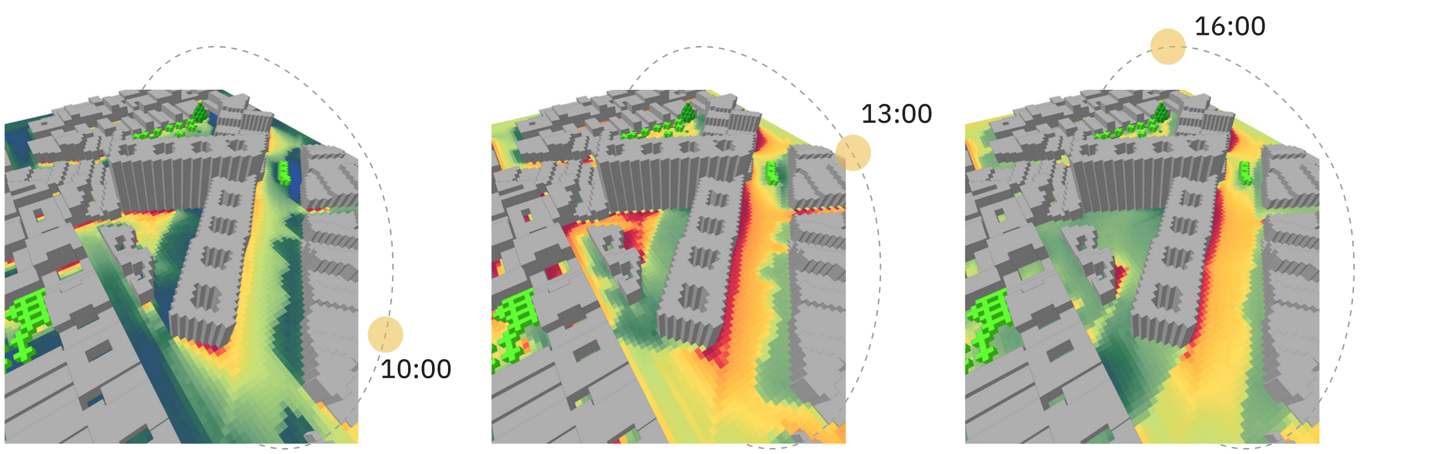
S2 Business as usual 13:00

For the Business as usual case, the densification of the area leads to significant changes in the patterns of sun lit and shaded areas. Moreover, the changes in the surface materials also modify the heat and vapour transfer from the ground and therefore have a direct impact on air temperature and humidity. Like in the case of the previous S1 case, these effects alter the thermal comfort level PET.



As the area densifies (S2), shaded areas and parks remain as the coolest areas. However, areas that become narrower and enclosed experience a dramatically reduced comfort level.

As the area densifies (S2), shaded areas and parks remain as the coolest areas. However, areas that become narrower and enclosed experience a dramatically reduced comfort level. One particularly critical location is the area of the tall residential blocks (20m and 30m), in the facade area and in almost half of the interior yard. Although the buildings shade part of the yard during the afternoon, and this includes a large vegetated area (also next to Avenue 1), the parking area, made of asphalt and concrete, remains unshaded leading to moderate/strong heat stress during the moments of strong radiation and due to poor ventilation.



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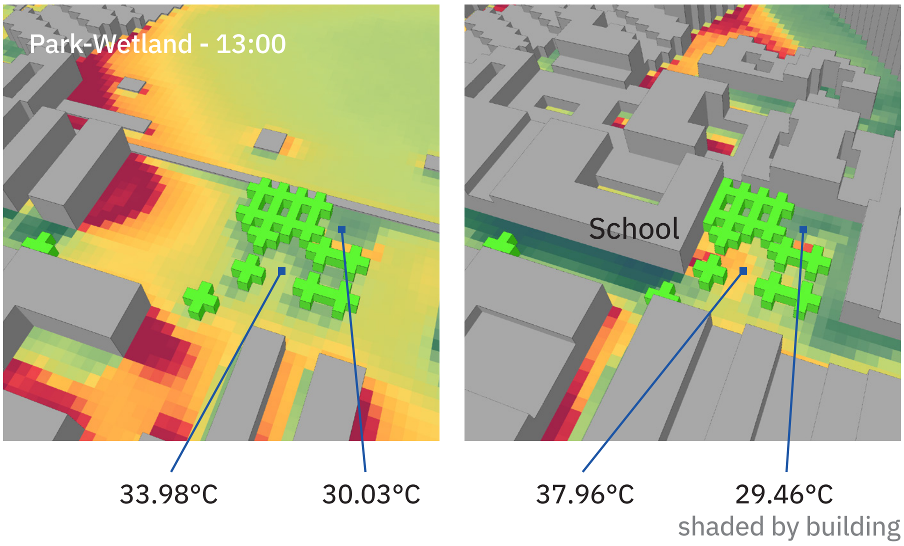
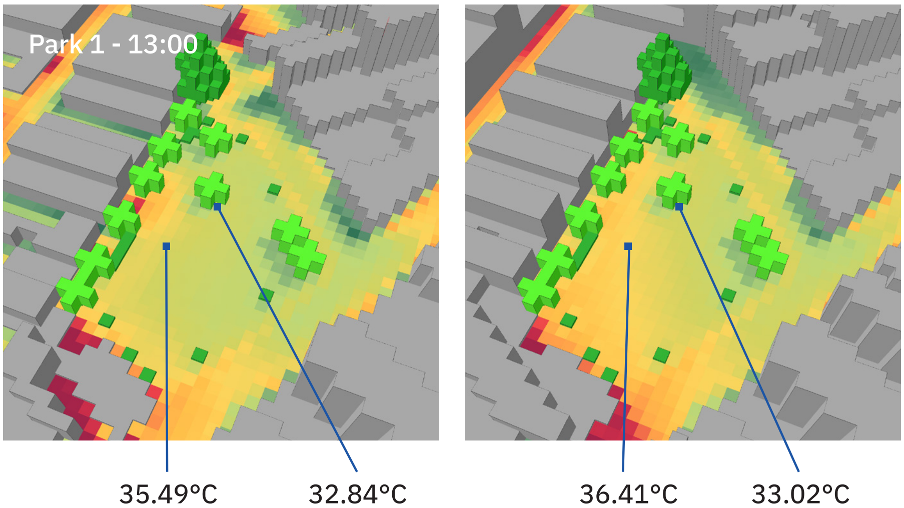
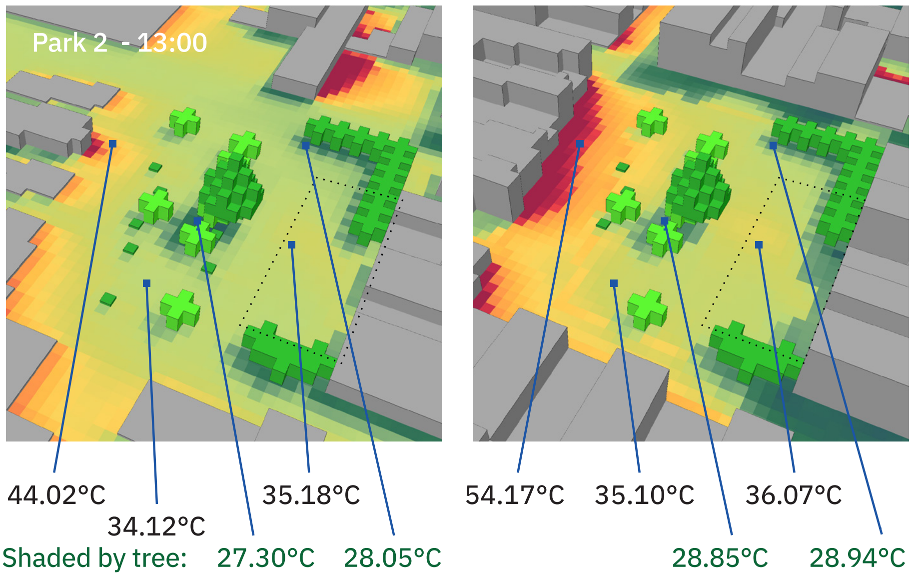
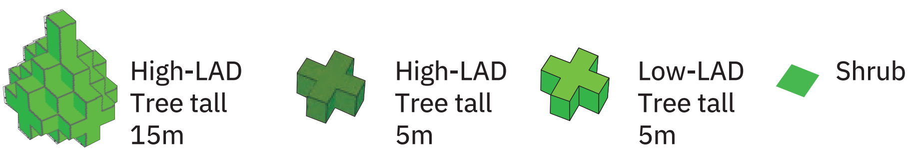


Similarly in Park-Wetland (S2), densification, including the construction of the school, has limited ventilation overall (wind flow) and enclosed a space that now has a worsened thermal comfort. New buildings help shade the perimeter, but mainly cover areas already shaded by some small low-LAD trees, which wastes their limited but still advantageous shading capacity.



By comparison, in Park 1 and Park 2, densification does not significantly affect the thermal comfort. Most areas of both parks show only a slight warming level compared to their situation before (S1). Still both scenarios show strong thermal stress and most of their areas lack shade, principally in pedestrian areas: in the east and west perimeter, particularly.





In Park 2, a critical area with high PET appears next to the new buildings due to increased reflection from their facades facing the sun. On the opposite side, there is a group of trees (mostly high-LAD) that are shaded by buildings, and therefore not providing an additional cooling effect. Considering that high-LAD trees (denser and with more foliage) show a higher positive impact on thermal comfort than low-LAD trees (sparse foliage), this is a missed opportunity to benefit from this existing group of trees and it represents an inefficient use of water in irrigation. Further, sealing the bare soil football field within the park with concrete does not significantly affect heat stress.

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Proposed Strategies

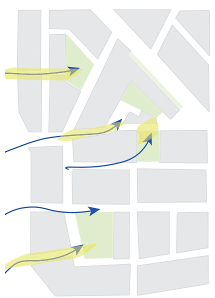
Minimal action, maximal impact

While the analysis shows the potential risks of proceeding under a business-as-usual development scenario, it also points to opportunities to intervene now.

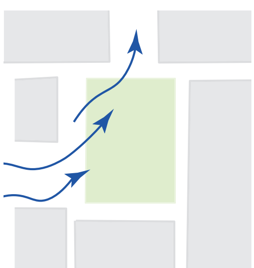
Intervention would ensure the neighbourhood develops with resilience to increasing temperatures and droughts, whilst improving thermal comfort, even when financial and spatial resources are constrained.

A number of passive strategies were included in a master plan scenario (S3) which was also analyzed with ENVI-met under the same climatic conditions as S1 and S2.

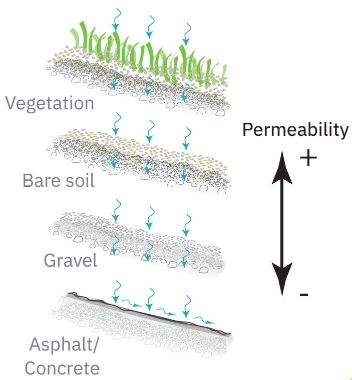
Ventilation corridors & strategic vegetation



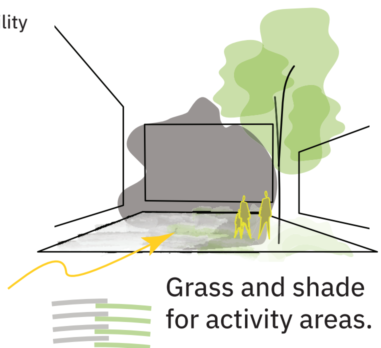
Identify potential ventilation corridors and prevent them from development

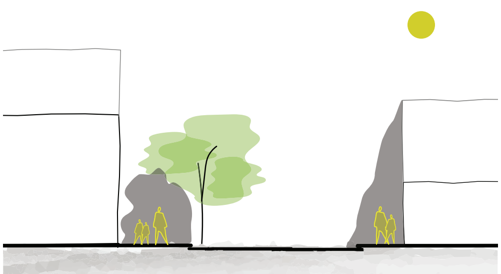


Ensure parks are well ventilated and remain as cool islands.

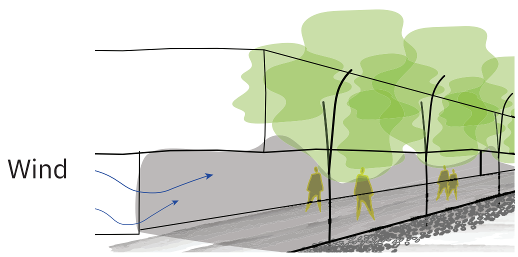


Reduce decorative grass for resilience to droughts, replace with shaded gravel or other permeable surface to assist rainfall infiltration in the area.





High-LAD tree species (dense foliage) with a wide shape and that require minimal irrigation in streets, positioned to shade to pedestrians at the hottest times of the day and not in areas already shaded by buildings.



Urban morphology to shade pedestrian areas and exposed surfaces, such as concrete, asphalt, gravel and bare soil. Tree-alleys in wide avenues with high-LAD and drought-tolerant species.

Park

- Replacement of small low-LAD trees by high-LAD drought-tolerant species or species requiring minimal irrigation, away from buildings and considering pedestrian shade
- Well ventilated xeriscape in shade to reduce neglected/dry grass and water consumption
- Vacant plot converted into street as ventilation corridor

Avenue 1

- No vegetated median between the lanes, instead high-LAD tree-planting on gravel for pedestrian shade
- High-rise residential blocks:
- Building morphology as ventilation corridor (towards Avenue 1 and Avenue 2)
- Yard: Addition of shade sail over parking area

Avenue 2

- Xeriscape in road median, but high-LAD tree-planting on gravel for pedestrian shade
- Vacant plot converted into street as ventilation corridor

Park 2

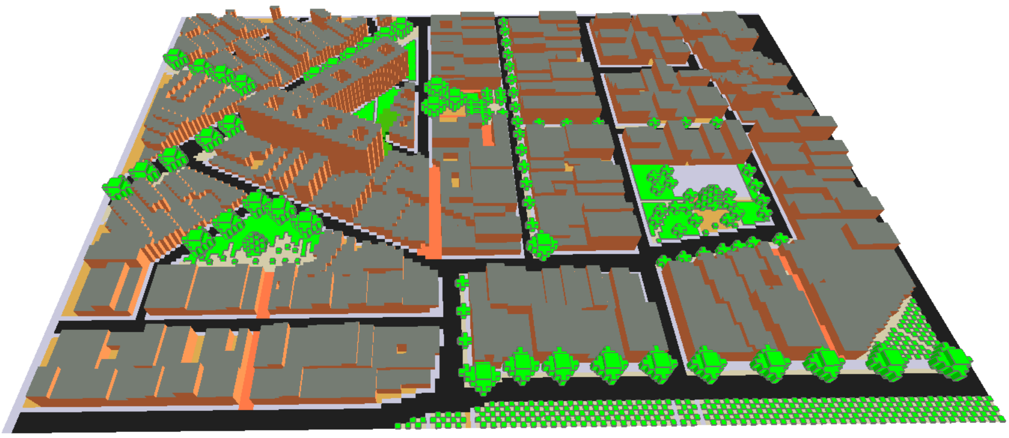
- Redistribution of existing trees to shade pedestrian areas and ventilate football field
- Strategic vegetation: grass for activity areas / decorative well ventilated xeriscape to reduce grass (and high water consumption)

Park-Wetland

- Expansion of the park and wetland (doubling its capacity)
- Addition of 3 high-LAD trees on bare soil for shade
- School: Building morphology to faciliate ventilation to Park-Wetland
- Additional small low-LAD trees in non-shaded areas of narrow streets

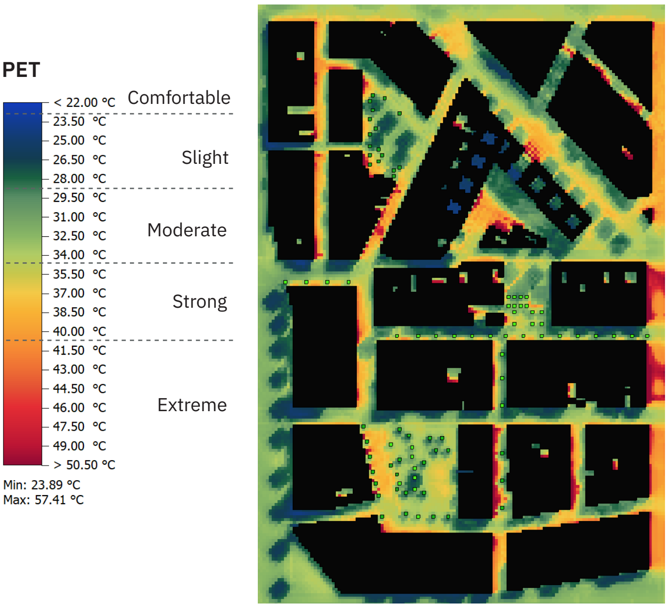
Ventilation corridors & strategic vegetation

The proposed interventions have a significant impact on the thermal comfort in the neighborhood. The analysis shows that the implementation of cool corridors and strategic vegetation can help despite the limitations of the context.

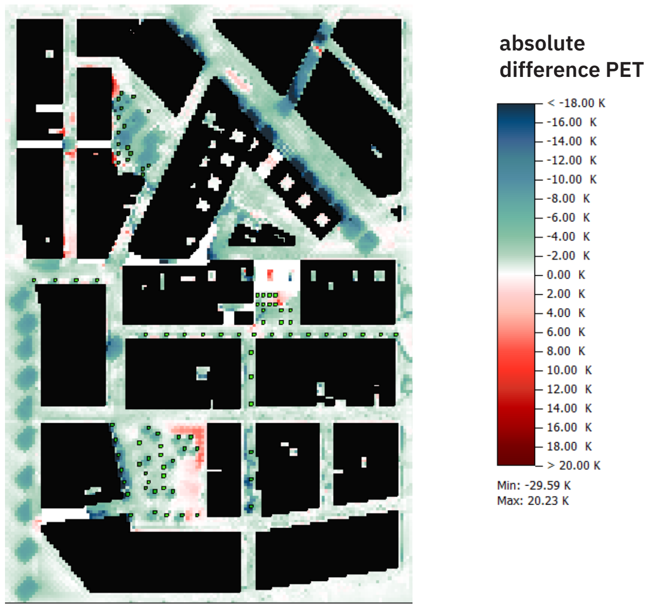


The PET is reduced in most areas of the neighborhood. High-LAD trees produce the biggest impact by reducing the PET, principally in Avenue 1 and Avenue 2, from extreme and strong thermal stress, to moderate and slight thermal stress respectively. Low-LAD trees in non-shaded areas of narrower streets around Park-Wetland are shown to be suffcient to improve thermal comfort in this case, given that the streets are mainly shaded by buildings. In Park 2, the area where the trees were originally located shows a small increase in PET because the area is no longer shaded. However, on average, the redistribution of existing trees generates more cooling spots around the football field area, and facilitates ventilation.

S3 PET - 13:00

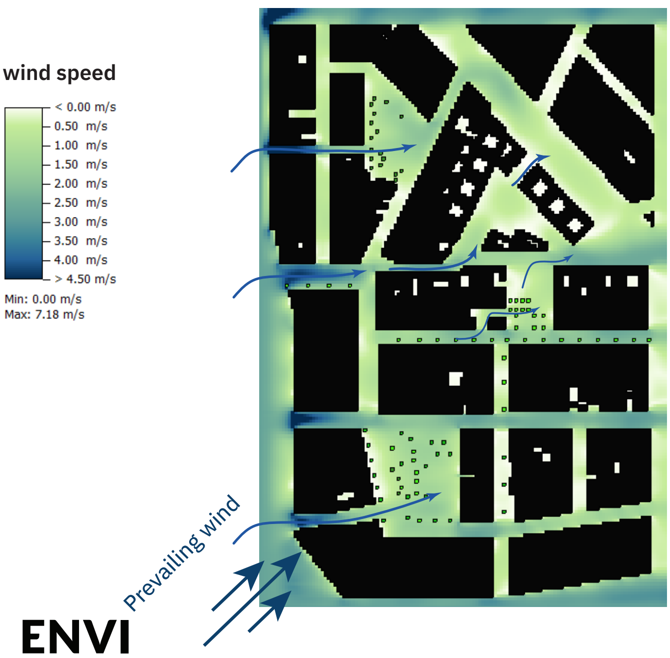


S3 PET comparison to S2

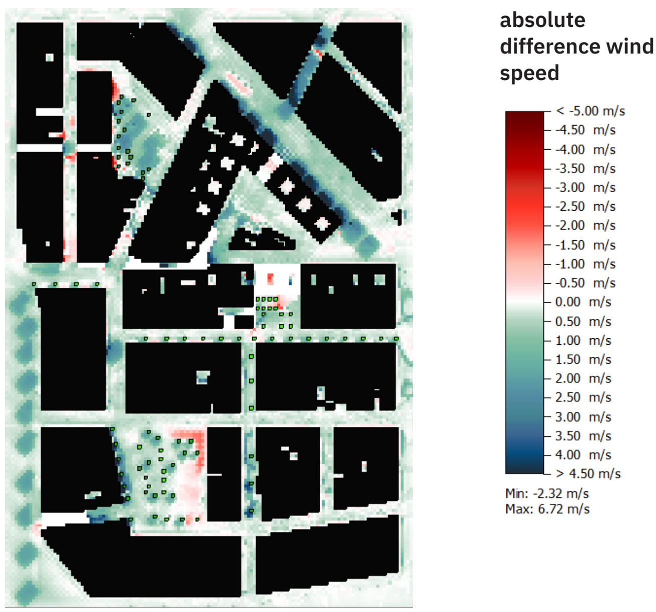


Strategic street openings in vacants spots help improve ventilation in most streets, principally in parks, thus lowering PET. New small low-LAD trees in the avenues near the Park-Wetland result in a slight decrease in ventilation; however, the PET is still lower due to their beneficial shading effect, particularly at this hot moment of the day.

S3 WIND SPEED - 13:00



S3 - WIND SPEED comparison to S2



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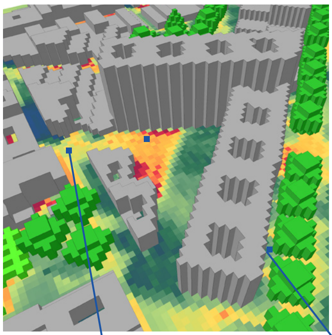
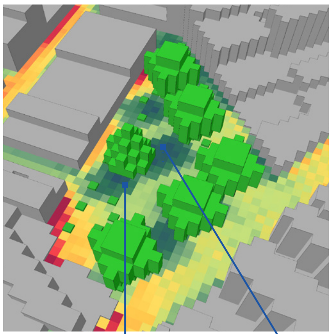


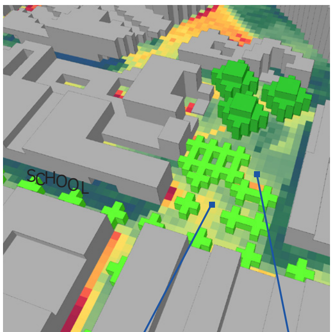
Avenue 1 - 13:00

The ventilation corridor leads to a notable cooling effect in the interior of the yard. The new shade sail, as well as the increased ventilation, creates a reduction in PET in the asphalt and gravel parking area.
In the avenue there is a large decrease in PET thanks to the changed street layout (tree-alley instead of grassed road median with low-LAD trees).



Park 1 - 13:00

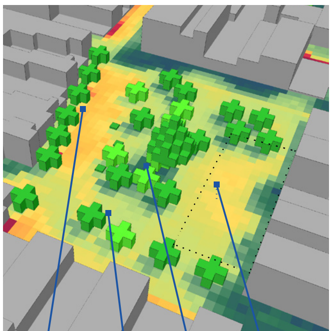
In Park 1, changing 10 low-LAD trees, to only 5 dense foliage (high-LAD) trees leads to a reduction in PET thoroughout the park, demonstrating the value of strategic species choice and location, particularly given there are fewer trees than before. This is achieved alongside a reduction of grassed area, which was replaced with gravel under a xeriscape approach.



Park-Wetland - 13:00

In Park-Wetland, expanding the park and altering the building morphology of the school at ground level increases ventilation, leading to a lower PET in general, including in unshaded areas. Three new high-LAD dense trees create a cool environment in the new section of the park, despite no grass being used at the ground surface in this area. The expanded wetland in itself does not create a noticeable cooling effect but allows for increased water treatment and irrigation capacity.

Park 2 - 13:00



Park 2 - 13:00

Overall the PET in Park 2 is reduced from, on average, strong thermal stress to moderate due to the redistributed high-LAD trees, and the addition of trees and the ventilation corridor on the left side.
At the center of the park, some of the trees provide shade and create a very cool area for spectators of the football field. However, in the playing area the PET increases by around 0.5°C. Further cooling strategies would be needed to achieve a better thermal comfort. Artificial shading or more high-LAD trees could help at this and later times of the day, since during the morning, the field is mostly shaded by buildings.

Informal settlements are at the centre of population growth and development that Lima is currently experiencing.

This analysis shows the impact of the intensive densification planning approach on urban microclimate and thermal comfort. It can be concluded that, if following this traditional city development strategy which is typical for other parts of the water-scarce and arid city of Lima, areas of extreme thermal stress will be generated outing the wellbeing of residents at risk. However, with some foresight and relatively straight-forward approaches, considering strategic vegetation placement and shade, this risk can be reduced. Shade - from both artificial structures and from vegetation - and ventilation need to be optimized through the design of the neighborhood. This includes shade on typical large areas of concrete, asphalt, gravel and bare soil, and the reservation of cool corridors to ensure airflow through the area. Vegetation, in particular trees, can also help improve thermal comfort, but they need to be carefully selected and planted to be sustainable and ensure positive effects are realised. Large open plots reserved for parks are key to deal with increased temperatures and show strong potential to become cooling islands within highly dense building agglomerations. These approaches have potential to be implemented at low cost and without significant water usage, particularly if they are done as the area is developed. Incorporating ENVI-met in the early stages of development of informal settlements presents an opportunity to analyse these approaches and to quantify and compare different planning scenarios. They create the opportunity to find optimized solutions for individual cases and thus allow to overcome existing planning deficiencies. This could then become an example for formal and informal settlements elsewhere in this megacity.