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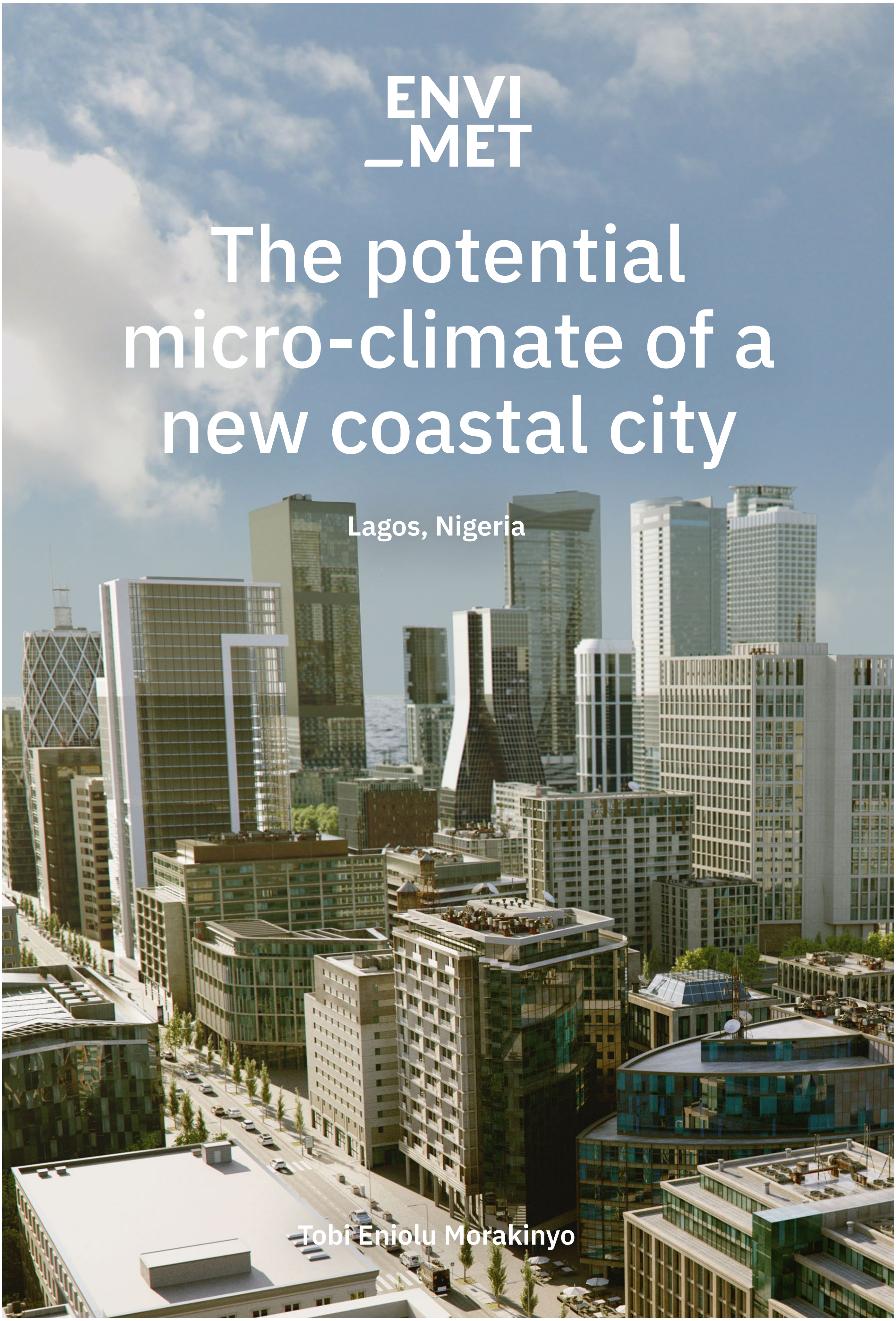
# The potential micro-climate of a new coastal city

Lagos, Nigeria



Tobi Eniolu Morakinyo

Introduction

# Why Lagos?

A new coastal city, of the size of Manhattan's skyscraper district, is emerging on an expanse of reclaimed land in Lagos, Nigeria - located in the hot-humid tropical climate.

This ENVI-met World Tour highlights some proven local temperature regulation and outdoor thermal comfort improvement strategies that could enhance the climate resiliency of the new city and nearby existing neighborhood.

Aside being the economic hub of the most populous country on the African continent, Lagos, Nigeria is one of Africa's fastest-growing cities and the second most populated mega-city in Africa. Like many other coastal cities, Lagos is highly vulnerable to flooding and coastal erosion owing to increasing mean sea level rise due to climate change.

Lagos is also susceptible to high urban heat risk in the current and future climate due to her tropical climate location. Thus, there is a clear need to better understand the urban heat and human comfort of cities like Lagos, to better inform their adaptation and mitigation needs.

To resolve both flood risk and housing deficits issues currently facing the city, the Eko Atlantic City (EAC) vision was conceived. EAC is new mixed-use development to be built on land reclaimed from the sea, with effective flood defences, and would house at least 250,000 residents upon completion".

However, there are key environment-related questions to be answered – e.g. What's the potential micro-climatic effect of the development on the existing adjacent neighbourhood? What will the inner-city micro-climate experience be? What proven strategies can help improve the micro-climatic condition of the new city? These questions were answered in this ENVI-met World tour to Lagos, Nigeria.



Design Concepts for Eko Atlantic
Source: https://www.ekoatlantic.com/media/image-gallery/

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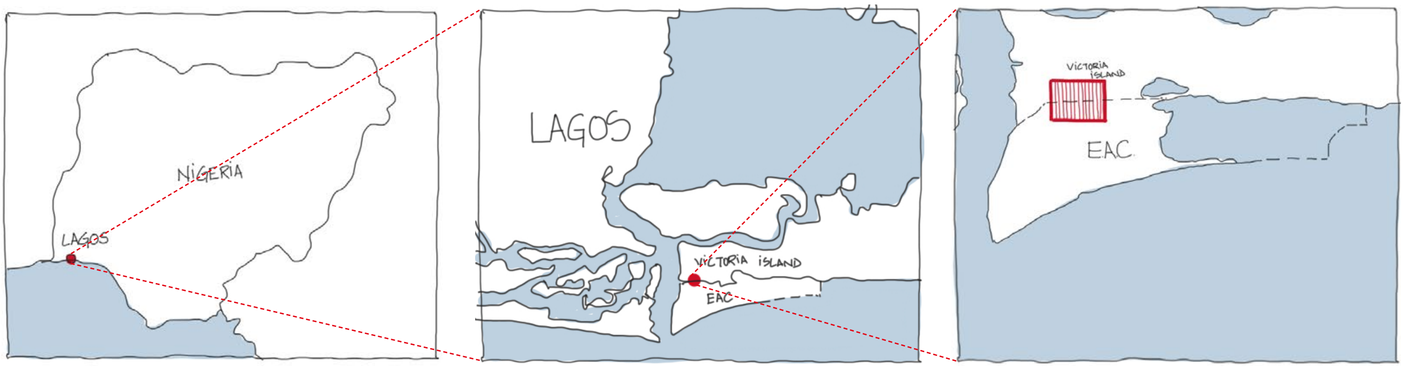
Urban Climatologist | GIS & Remote Sensing Analyst

# The motivation and description

## 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

Eko Atlantic City (hereafter, EAC) is a planned city in Lagos State, Nigeria, being constructed on 10 million square meters of land reclaimed from the Atlantic Ocean and protected by an 8.5-kilometre-long sea wall serving as flood defense both for the new city and the existing neighborhoods.

In perspective, EAC is of similar size to Manhattan's skyscraper district, being built to be self-sufficient and sustainable with state-of-the-art urban design, its power generation, clean water, advanced telecommunications, spacious roads, and tree-lined streets; and accommodating at least 250,000 residents upon completion.




Source: Sketches by Env-MET

The land reclamation of EAC commenced in 2008. To date, over 65% of the proposed 10,000,000 square metres of land have been recovered and some skyscrapers are already springing up or completed.

May 2016 site images
Source: https://www.ekoatlantic.com/media/image-gallery/

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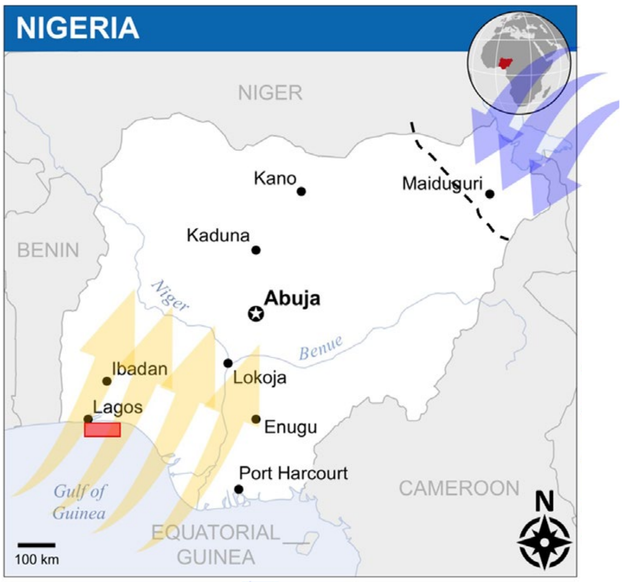
# Objectives and methodology

**Research objectives**

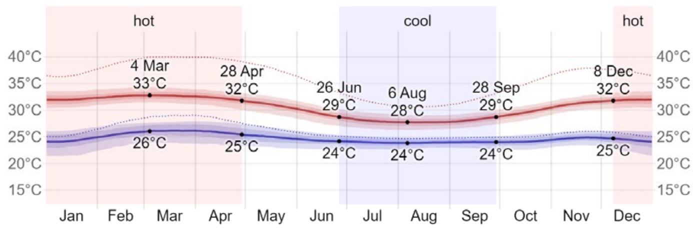
Lagos experiences a tropical savanna climate (Aw) and has a slight seasonal temperature variation with temperatures typically varying from 24°C to 33°C over the course of the year. This coupled with high humidity makes the heat-index to be high for most parts of the year in the city. In terms of wind, the city is dominantly affected by the moisture-laden maritime south-westerly trade winds.

Consequently, a built-up development on an expanse of reclaimed land on the Atlantic Ocean could potentially impact the local micro-climate/pedestrian comfort and downwind of the existing neighbourhood.

The present study, therefore, aims to evaluate the interaction between the new city and the existing neighbourhood's micro-climate and human comfort experience; and show with three different "post-reclamation" scenarios the effect of certain passive design interventions applied to the new city on the human comfort experience within the city and its environs. To achieve these objectives, the micro-climate model, ENVI-met was used




South West trade winds
North East trade winds
ITCZ
Major cities
EAC (Eko Atlantic City)




Lagos annual temperature variations (source: weatherspark.com)

# Objectives and methodology

**Methodology: scenario development**

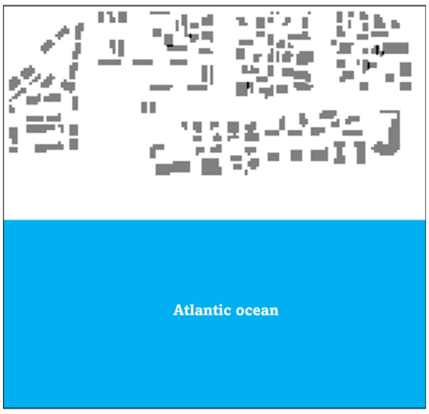
For the present demonstration study, a subsection of the study area was selected. The includes sections of the EAC's reclaimed land and existing neighbourhood of the Victoria Island area of the Lagos as shown in the figure below.  On the reclaimed land, idealized urban developments were imposed.

Existing old neighbourhood


Part of EAC's Reclaimed land

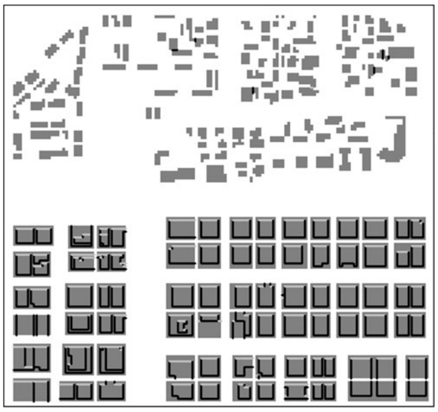
# Scenarios

Four scenarios have been developed based on the actual and idealized building/urban morphologies of the existing neighborhood and new city, respectively.



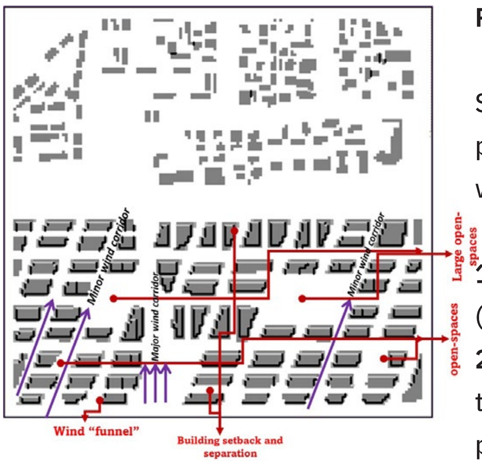

**Base Case: Pre-reclamation reference for comparison**

This scenario represents the reference or pre-reclamation scenario including the existing neighbourhood and the section of the Atlantic Ocean.



**Post reclamation Scenario A: High Density**

Compact- high-density high-rise development
This scenario represents a compact high density- high-rise development on the selected part of the reclaimed land and is assumed to be the status quo – high urban densification.



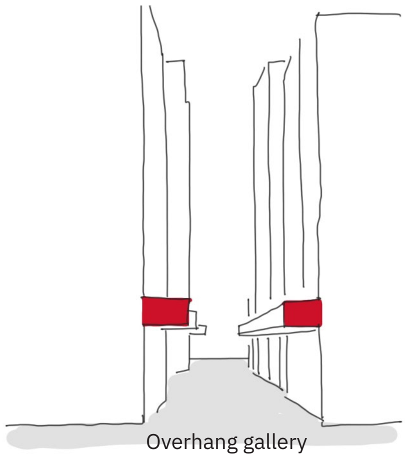

**Post reclamation Scenario B1: Optimised Density**

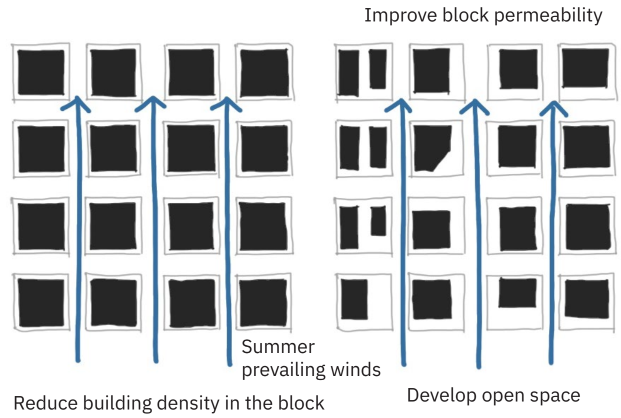
Since wind speed is an essential parameter for human thermal comfort, passive design strategies that support wind permeability were infused within the new city. These strategies are broadly two:

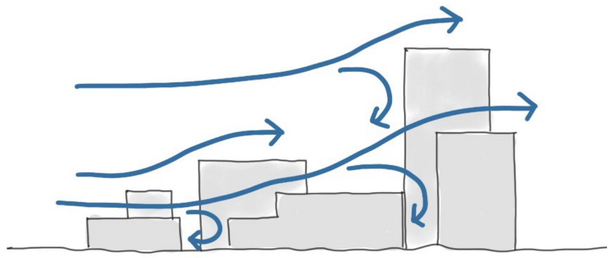
**1.** Alignment of buildings layout/streets with the prevailing wind direction (south-westerly) forming major and minor wind corridors.
**2.** Reduction of building block density and volume which can be achieved through several means as implemented such as (a) creation of large and pocket open spaces within the development; (b) design of overhanging gallery for building around the wind entering area – to create "wind funnel" effect; (c) use of podium tower typology; (d) widening street via building setback and separation and; (e) application  stepped building height design.

# Scenarios

In this scenario, all these “building/urban” (building) design interventions were implemented and spread across the new city subdomain.

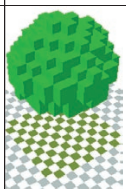
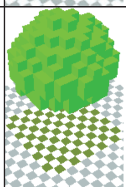
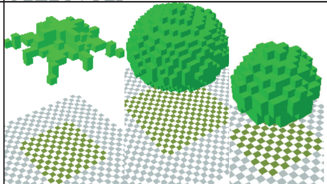
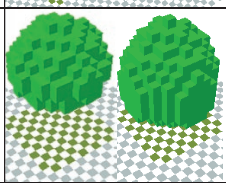


Stepped building height design

Sketches based on Yang, J., Fu, X. (2019). The centre of City: Wind Environment and Spatial Morphology. Springer Nature.

| Location | Coverage ratio | Suggested species form | |
|---|---|---|---|
| EW-oriented streets | Moderate to High |  | Large trunk, dense foliage, medium (~15m) height tree |
| NE-SW-oriented streets | Low to Moderate |  | Large trunk, sparse foliage, medium (~15m) height tree |
| Open area (wind corridor) | Moderate to High |  | A mix of large trunk, sparse/dense foliage, medium(~15m) /tall (~25m) height trees |
| Open area /High SVF, green spaces and pocket parks | Moderate to High |  | A mix of Small/Large trunk, dense foliage, medium (~15m) height tree |

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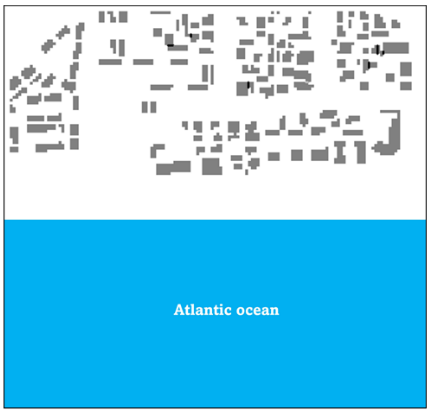
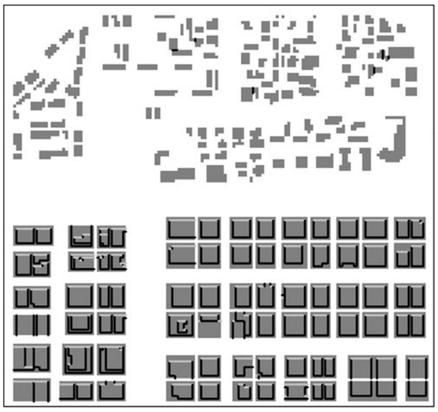
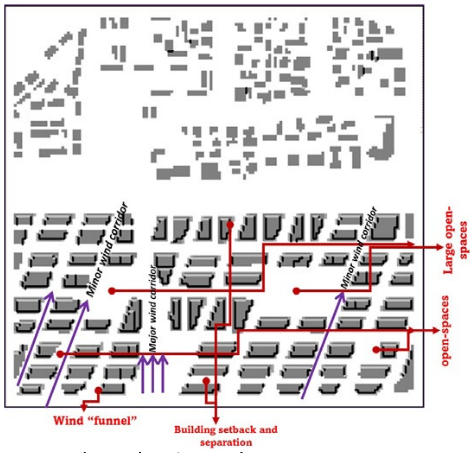
# Scenarios



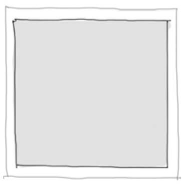

Base Case



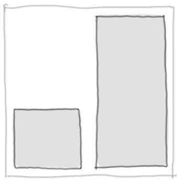
Post reclamation Scenario A
High Density



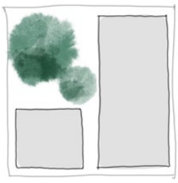

Post reclamation Scenario B1
Optimised Density



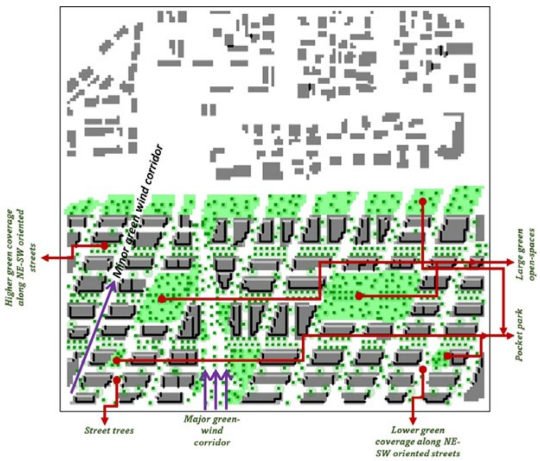
Scenario A



Scenario B1



Scenario B2




**Post reclamation Scenario B2: Optimised Density + Greening**

This scenario contains all the "building/urban" design interventions (Scenario B1) plus strategic greening. The strategic greening approach is the so-called right tree for the right place(location) in which trees of certain morphological characteristics correspond to definite urban morphology and orientation for optimized cooling benefits.

Thus, the following guidelines were adopted:

- Higher green coverage in the EW than NE-SW oriented streets. This is because the former has higher daily solar penetration and thus requires more shading, unlike the NE-SW streets that enjoy buildings' shadow-cast effect.
- In all streets, high trunk trees are implemented to minimize the vegetation's drag effect at the pedestrian level. Additionally, however, in EW and NE-SW oriented streets, trees with dense and sparse foliage are most effective, respectively.
- At high sky-view and open-areas (not wind corridor), dense foliage, and moderate height with a low trunk are imposed.
- Along the wind corridor, tall, dense foliage with a high trunk are recommended. This ensures a reduced drag effect at pedestrian height while assuring a significant solar shading effect.

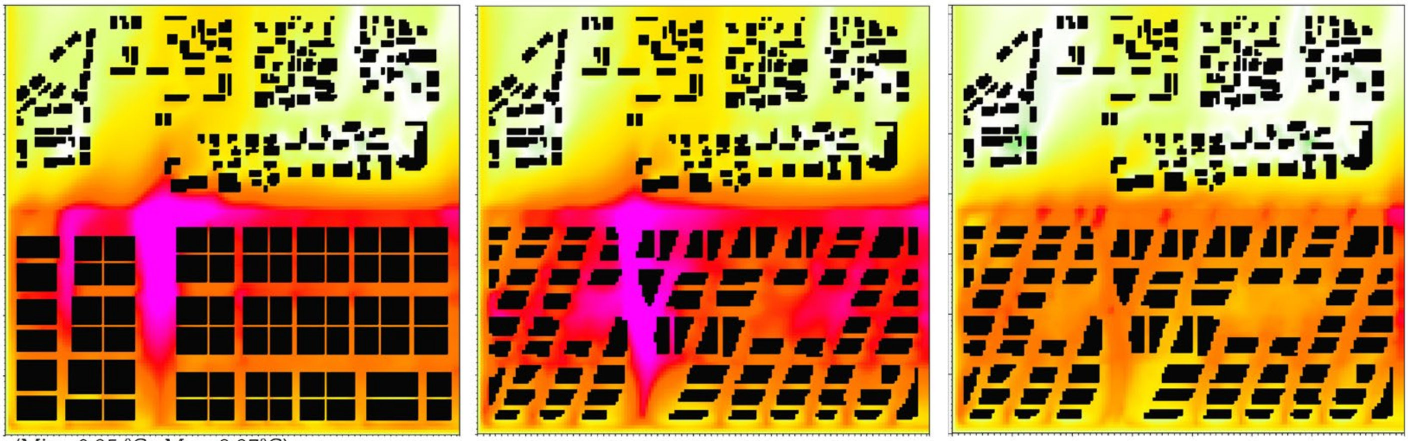
### Model and simulation conditions

- Model size: 151 x 143 x 45 Grid Cells
- Date:16.July
- Air Temperature: min.19°C; max. 28°C
- Relative humidity: min. 64%; max. 75%
- Wind speed: 4m/s. Wind direction: SW, 202.5º

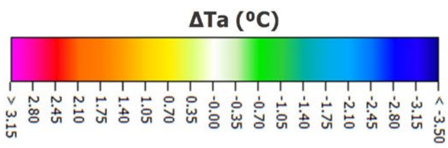
# Air temperature

## Impact of reclaimed built areas on insitu and downwind environmental performance

### Daytime air temperature difference (14:00 H)




(Min: -0.35 ºC , Max: 3.97ºC) (Min: -0.28 ºC , Max: 4.04ºC) (Min: -0.48 ºC , Max: 2.71ºC)


Creating a new area certainly has a lot of challenges – when replacing the ocean with built-up areas it will worsen the microclimate in situ but also downwind.

The air temperature difference between pre-reclamation and post-reclamation scenarios are summarised below.

The comparison of ambient air temperature "post-reclamation" (scenarios A, B1, and B2) versus "pre-reclamation" (reference/base case) revealed both the insitu and downwind areas became warmer both at day and night-time due to significant land cover change from water to a paved surface.

The land cover changes meant significantly higher daytime sensible heat release from the paved, unlike water surface to the atmosphere leading to higher ambient temperature during the daytime.

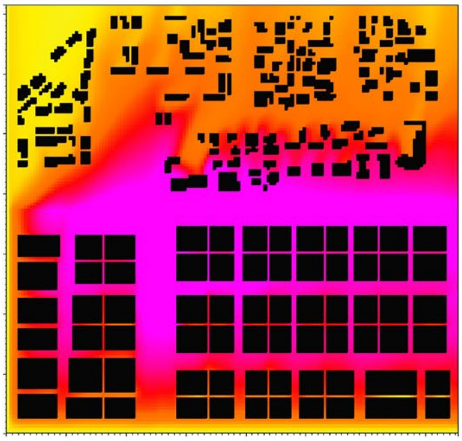
With larger energy absorption/storage during the daytime, paved surface releases more energy at night-time relative to water surface leading to warmer nocturnal ambient air temperature (i.e. urban heat island).

Depending on the urban structure/layout and design features imposed on the reclaimed area, the intensity of the consequent daytime and night-time warmth observed across the study domain varies but is more significant over the reclaimed area.

# Air temperature

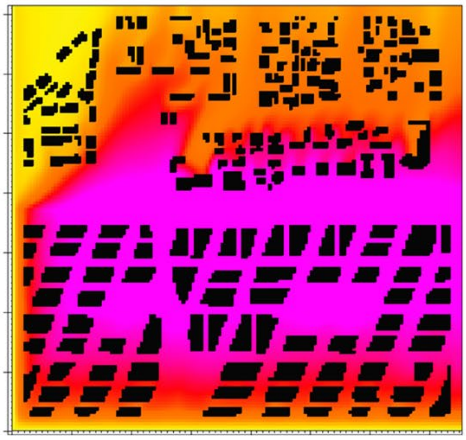
## Nighttime air temperature difference (22:00 H)

Scenario A – Reference



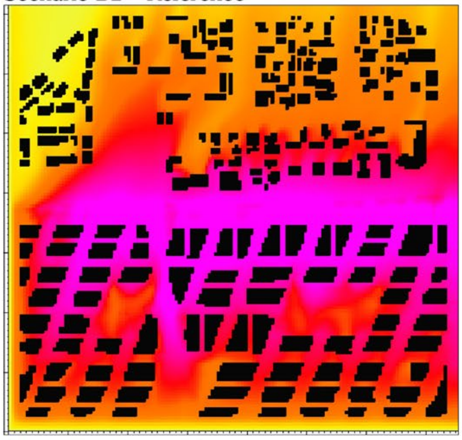
(Min: 0.25ºC , Max: 1.77ºC)

Scenario B1 – Reference

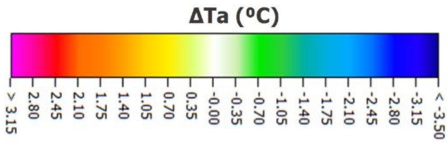


(Min: 0.25ºC , Max: 1.73ºC)

Scenario B2 – Reference



(Min: 0.21ºC , Max: 1.52ºC)

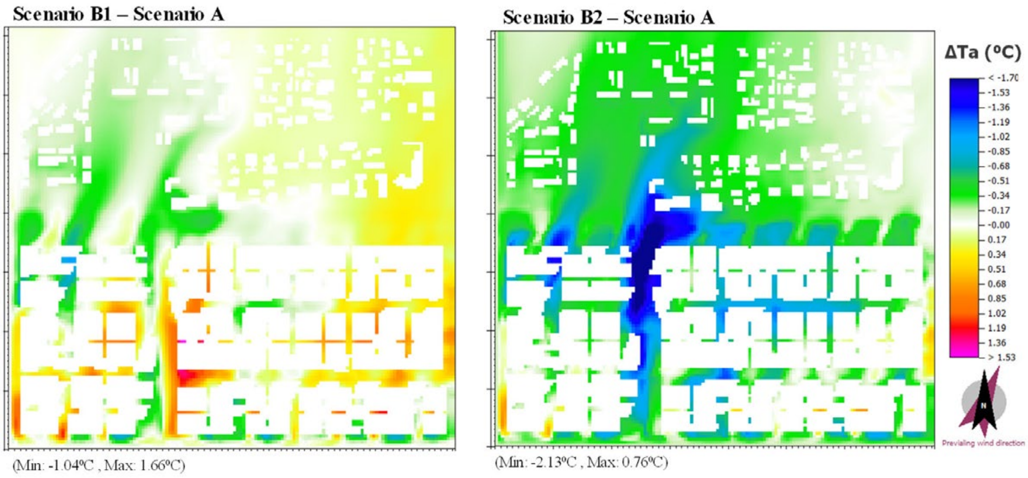

With a high densified urban structure (i.e., scenario A) imposed, the air temperature difference ranges between -0.35 - 3.97°C and 0.25 – 1.77°C at daytime and night-time, respectively.

With scenario B1 - building/urban strategies imposed, the air temperature difference ranges between -0.28 – 4.04°C and 0.25 – 1.73°C during daytime and night-time, respectively.

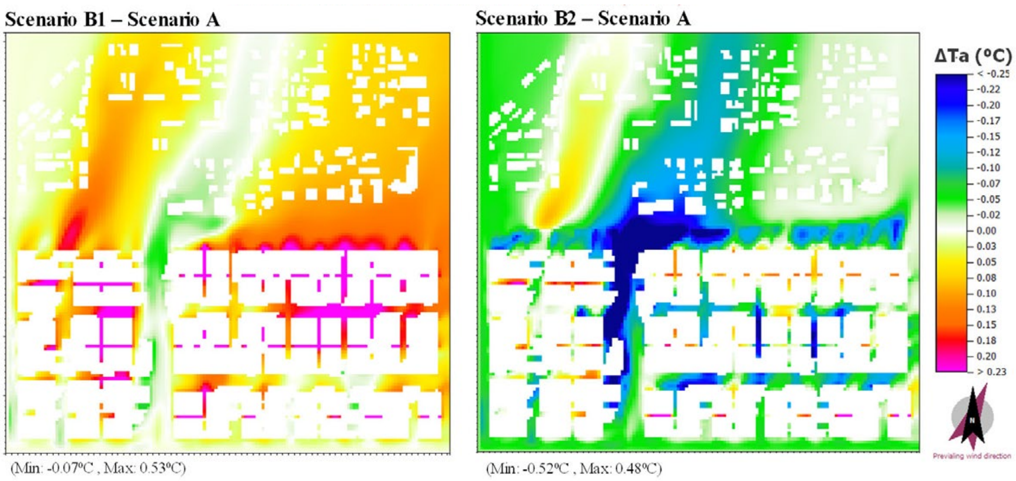
Scenario B2 shows the importance of complementing the building/urban design intervention. In this scenario, the intensity of warmer air was reduced to -0.48 - 2.71°C and 0.21 – 1.52°C during the daytime and night-time, respectively.

# Air temperature

## Daytime air temperature difference (14:00 H)




## Nighttime air temperature difference (22:00 H)




**Impact of passive design interventions: Inter-scenario comparison**

The buildings' layout and pattern imposed in the new development area matter, an alignment of the prevailing wind direction helps create major and minor wind corridors increasing breathability insitu and downwind. When greenery is fused along the wind path, a cooler air zone develops and advected downwind.

Scenarios B1 and B2 are slightly and significantly better than A, respectively. The urban layout aligning with the prevailing wind direction and de-densification play a major role here but also the latent heat flux in scenario B2 leads to (relative to scenario A) cool air being advected farther into the existing neighbourhood. The pattern follows suit at night-time but in a smaller magnitude.

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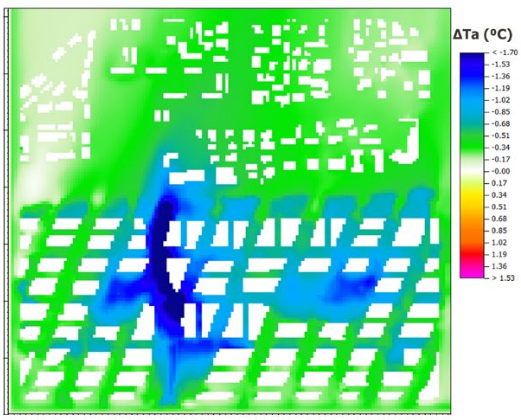
# Air temperature

The significant role of strategic urban greening for a climate-resilient city is quantified and shown in the figure below indicating the air temperature difference between scenarios B2 and B1 during the daytime and nighttime.

The result shows that in the daytime, the trees along the wind corridor show the most effect but at nighttime, the deep canyons and the green open-spaces show decreased air temperature in the green-building/urban scenario.

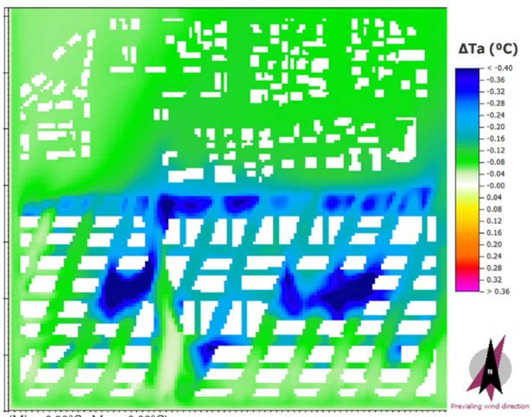
A wide extent of cooling was observed across the domain with the magnitude of reduction ranging between 0.02 – 2.11°C and 0.02 – 0.52°C during the daytime and nighttime, respectively. This highlights why the design decision on the new area would have an impact beyond the local, to downwind areas and thus worthy of consideration.

Scenario B2 – Scenario B1 / DAYTIME (14:00H)




(Min: -2.11ºC , Max: -0.02ºC)

Scenario B2 – Scenario B1 / NIGHTTIME (22:00H)




(Min: -0.52ºC , Max: -0.02ºC)

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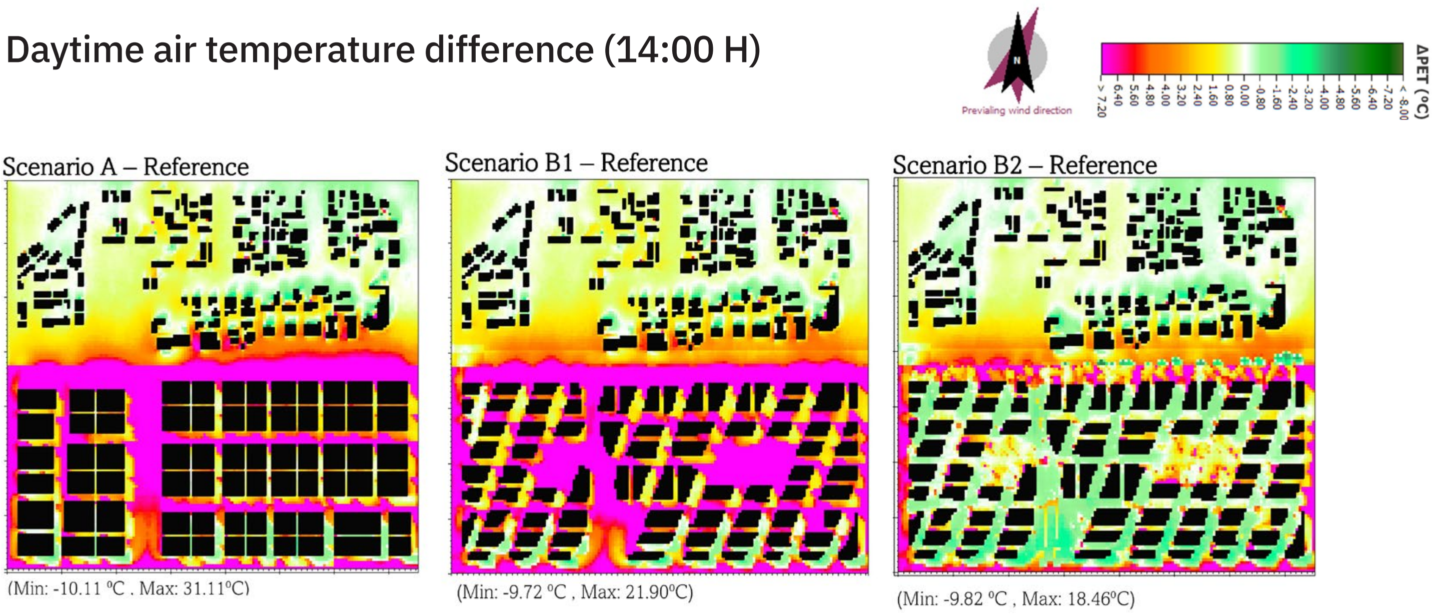
# Outdoor thermal comfort

## Daytime air temperature difference (14:00 H)




Physiologically Equivalent Temperature (PET) adopted in this study to provide a holistic understanding of the outdoor human thermal comfort at any point in the urban environment (i.e. study domain). PET difference between pre-reclamation and post-reclamation scenarios are summarised below.

Results show worsened outdoor comfort post-reclamation, especially at the previous waterfront area but also further down. This is a consequence of land-use changes leading to higher mean radiant temperature, warmer temperature, and weak wind speed as previously explained.

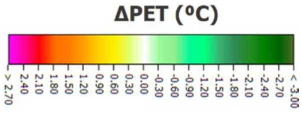
Relative to the “pre-reclamation” scenario, the daytime and nighttime ΔPET values were up to 31°C and 3.90°C higher, respectively within the highly densified scenario (A), this negative effect extended downwind into the existing neighbourhood.

With improved ventilation in scenario B1 due to implemented building/urban design strategies especially wind corridors, and urban de-densification, the positive ΔPET weakens indicating a more thermally comfortable environment insitu and downwind. Notice the reduced spatial extent of high ΔPET at the previous waterfront area. However, the reduction of the building density and volume with the building/urban design meant more open surfaces to solar penetration. Thus, the thermal comfort of some areas such as the open spaces and wide streets became worsened.

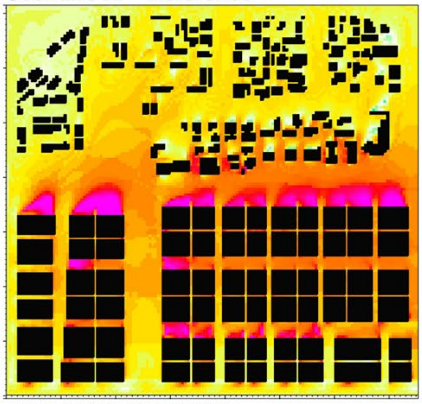
However, this can be moderated by appropriate tree planting in proportion, placement, and species selection. The implementation of strategic greening in the new city in Scenario B2 resulted in a significant reduction in radiant temperature in the area resulting in more comfortable thermal comfort levels. Here the max ΔPET was not more than 18.5°C compared to the 21.9°C and 31.1°C observed in scenarios B1 and A, respectively.

# Outdoor thermal comfort

## Nighttime air temperature difference (22:00 H)

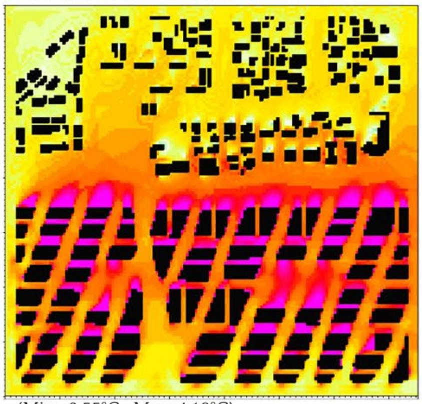



Scenario A – Reference



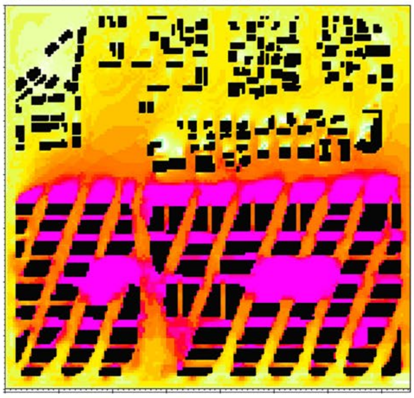
(Min: -0.85ºC , Max: 3.90ºC)

Scenario B1 – Reference



(Min: -0.55ºC , Max: 4.19ºC)

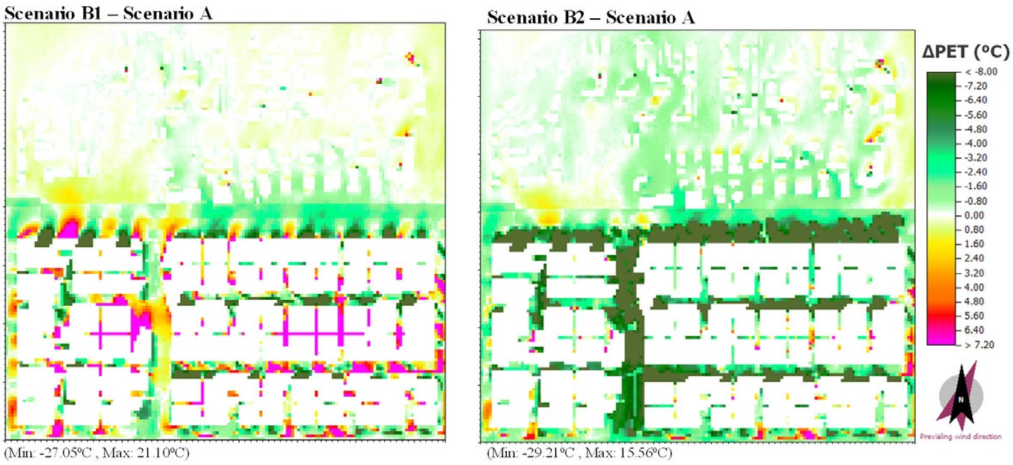
Scenario B2 – Reference



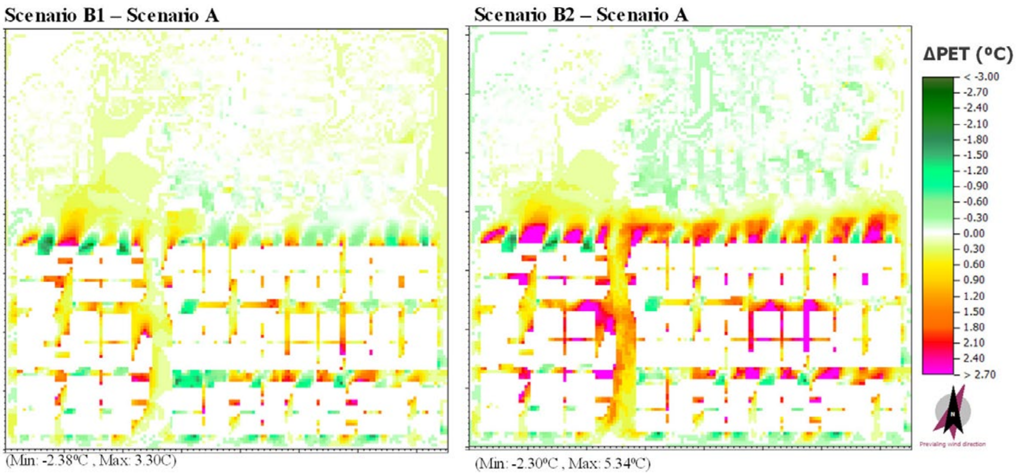
(Min: -0.48ºC , Max: 6.53ºC)

# Outdoor thermal comfort

## Daytime PET difference (14:00 H)




## Nighttime PET difference (22:00 H)




**Inter-scenario comparison: Scenarios A vs B1/B2**

By comparing scenarios, A and B1, the effect of urban structure/densification and building/urban design strategies can be deduced. Compared to scenario A, improved thermal comfort was observed in building shaded areas in B1. However, because of the reduced block density, the new area has a higher sky view factor, meaning more open to solar insolation. Thus, higher MRT/PET in those widened streets, and large open areas during the daytime and nighttime.

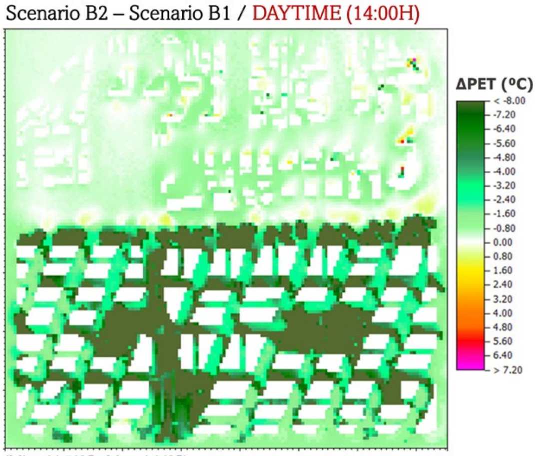
The key to countering higher radiation that comes with urban openness which supports wind permeability is to supplement this with a green strategy as seen with scenario B2. Here, a significant reduction in PET implies improved thermally comfortable to a greater extent in the new area and the positive effect was even observed downwind.

# Outdoor thermal comfort

The contribution of the green strategy beyond the building/urban design has been quantified and found to be up to 20K reduction during the daytime covering the entire domain, mainly observed in the new area but also visible in the existing area.

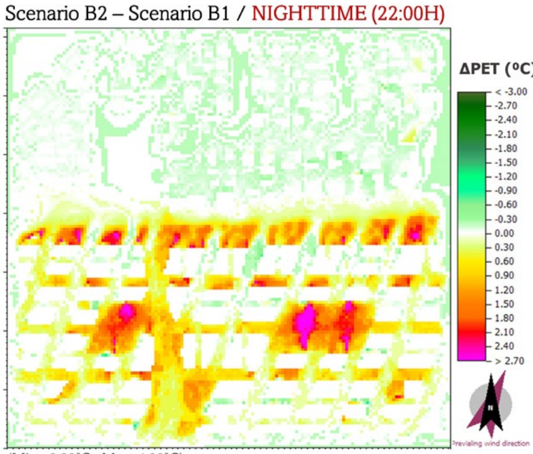
At night-time, however, the effect of downward longwave radiation by the trees becomes visible. Nevertheless, this so-called negative effect is minimal and underweights the significant daytime positive effects.

Scenario B2 – Scenario B1 / DAYTIME (14:00H)




(Min: -20.58ºC , Max: 6.96ºC)

Scenario B2 – Scenario B1 / NIGHTTIME (22:00H)




(Min: -0.98ºC , Max: 4.08ºC)

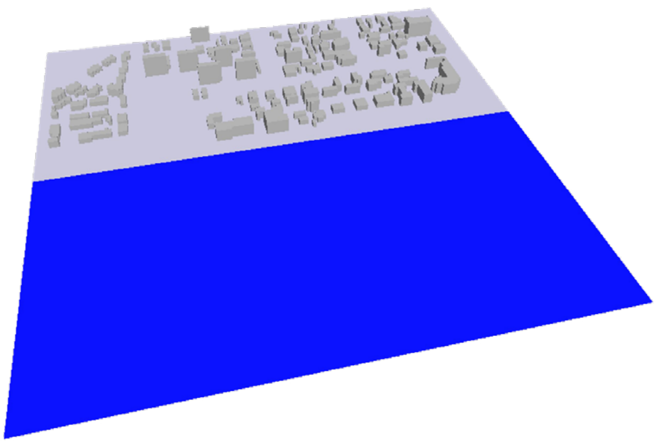
Conclusion

# Infusing climate-sensitive urban planning and design with urban renewal

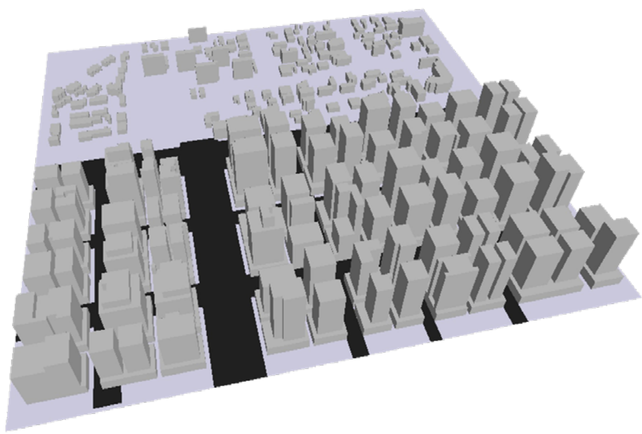
Climate-sensitive urban planning and development is the integration of climate-proofing strategies e.g., land use planning, inclusion of green-wind corridors, passive building/urban design implementation (e.g. urban geometry design, urban morphology optimization), and strategic urban greening into the urban development process to mitigate intense urban heat by reducing the thermal load and enhancing air ventilation in the urban environment.

The current urban renewal project of Lagos does not include such specific proven climate-informed strategies in the urban developmental framework or guidelines even though certain actions such as the LASPARK's projects are contributing to urban heat adaptation. However, there are several opportunities to scale up the urban heat mitigation strategies across the megacity.

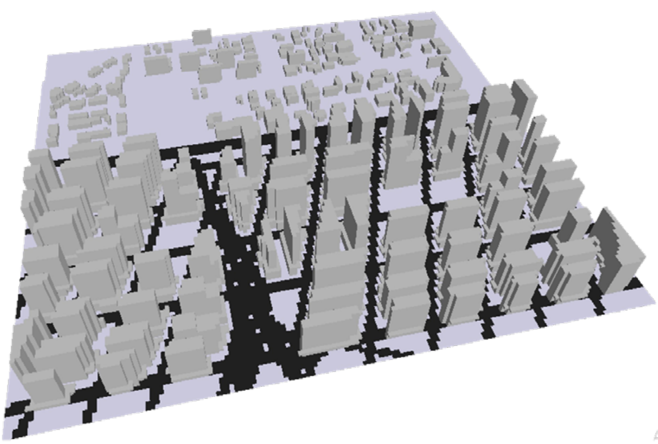
**Pre-reclamation - Reference**



**Post-reclamation - Scenario A | high densification**



**Post-reclamation - Scenario B1 | Grey design**



**Post-reclamation - Scenario B2 | Grey-Green**