

ROTTERDAM,
THE NETHERLANDS

THERMAL INTELLIGENCE

AI-DRIVEN STRATEGIES FOR THERMAL
COMFORT UNDER URBAN DENSIFICATION



THERMAL
COMFORT



NATURAL
VENTILATION



SOLAR
RADIATION



URBAN
FORM

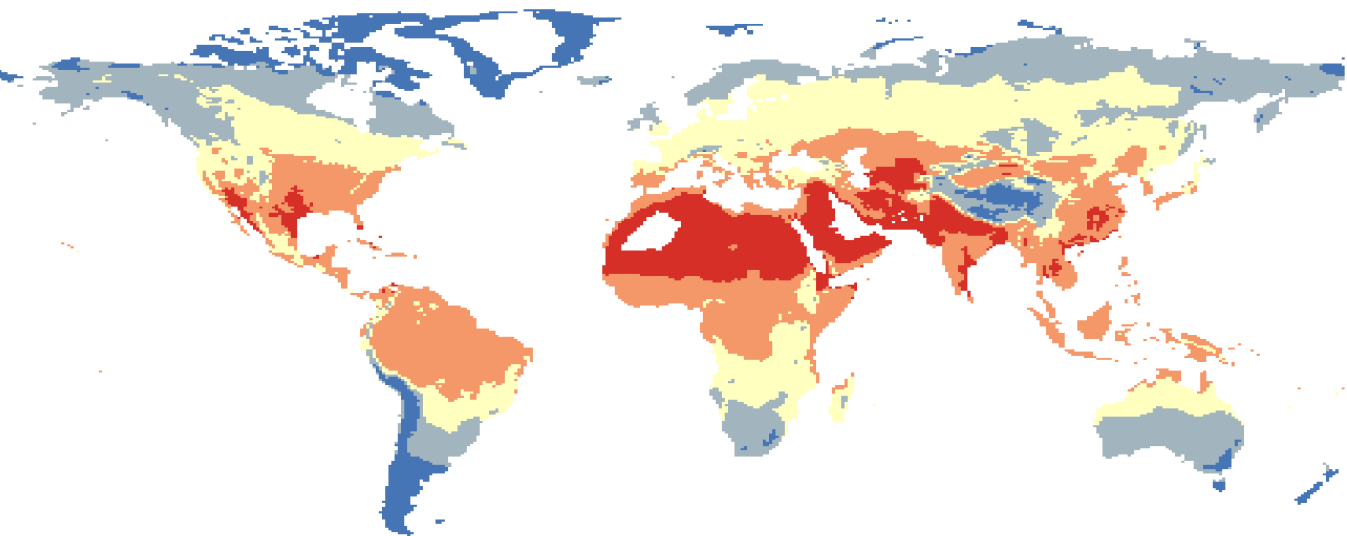
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Delft University of Technology

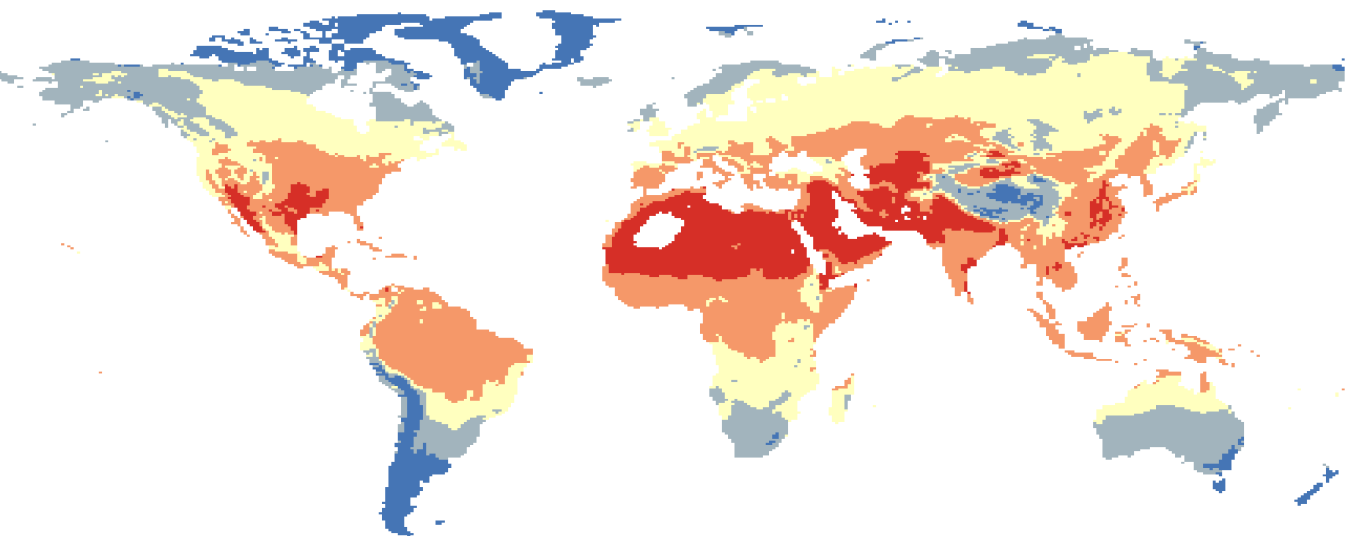


WHY IS IT IMPORTANT

BACKGROUND: GLOBAL WARMING



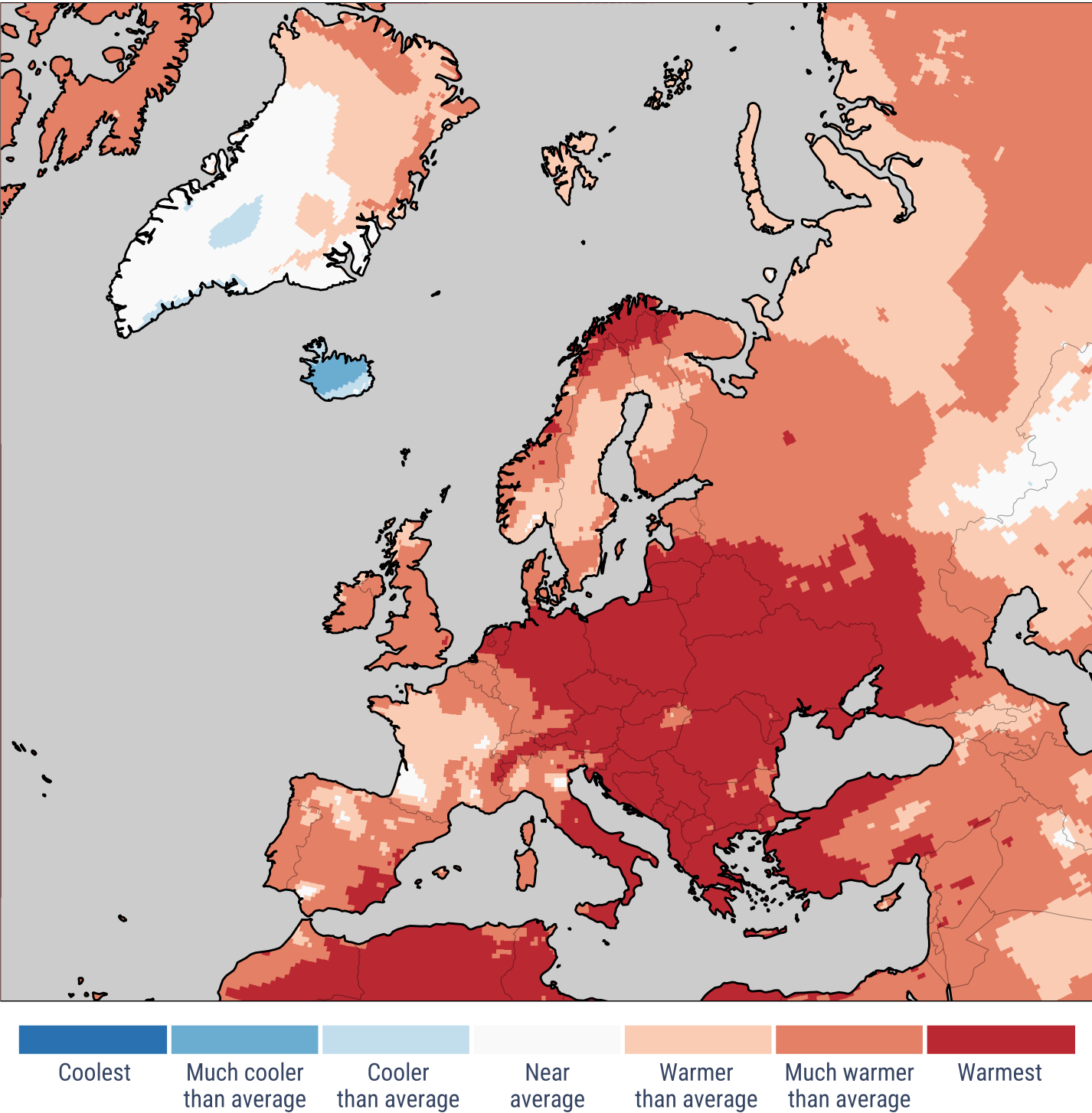
Extreme average air temperature from 1981-2000



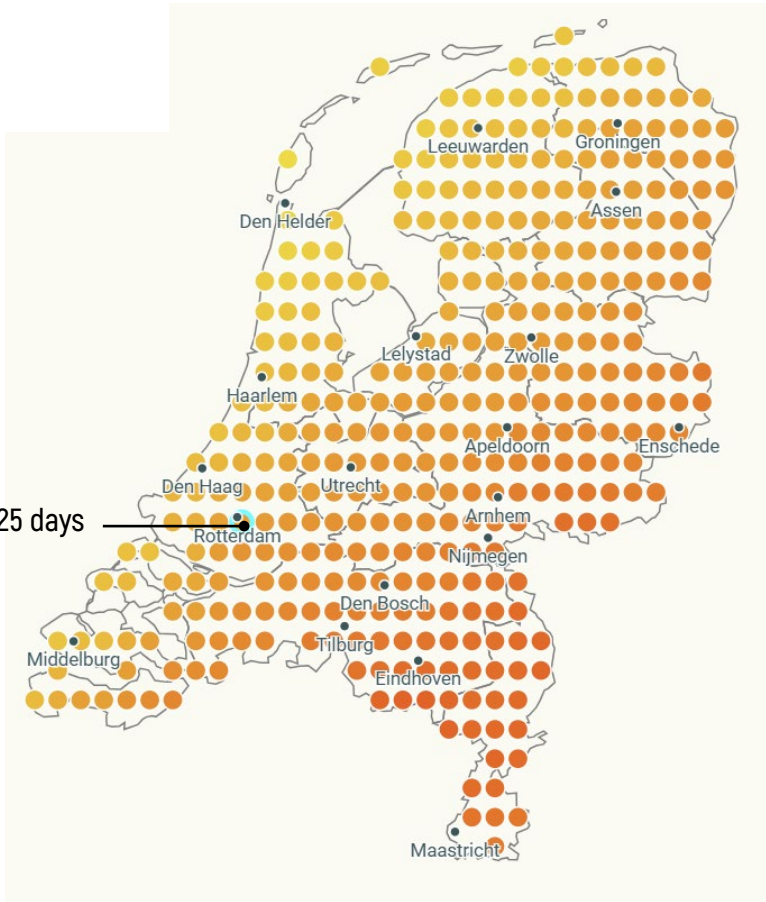
Extreme average air temperature from 2000-2025

Anomalies and extremes in surface air temperature in 2024

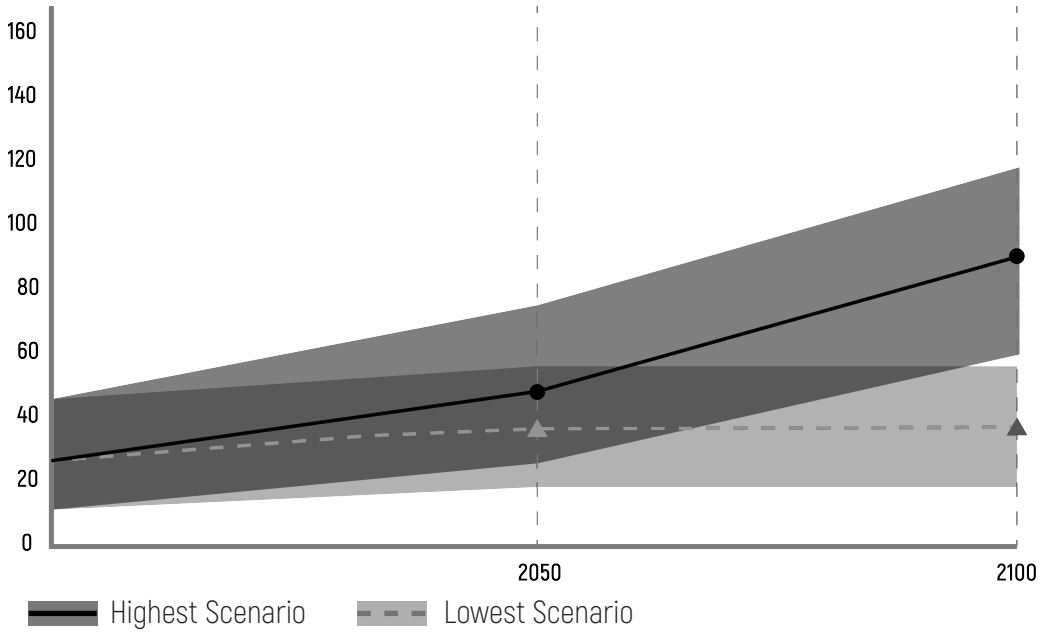
Data: ERA5 (1979–2024) • Reference period: 1991–2020 • Credit: C3S/ECMWF



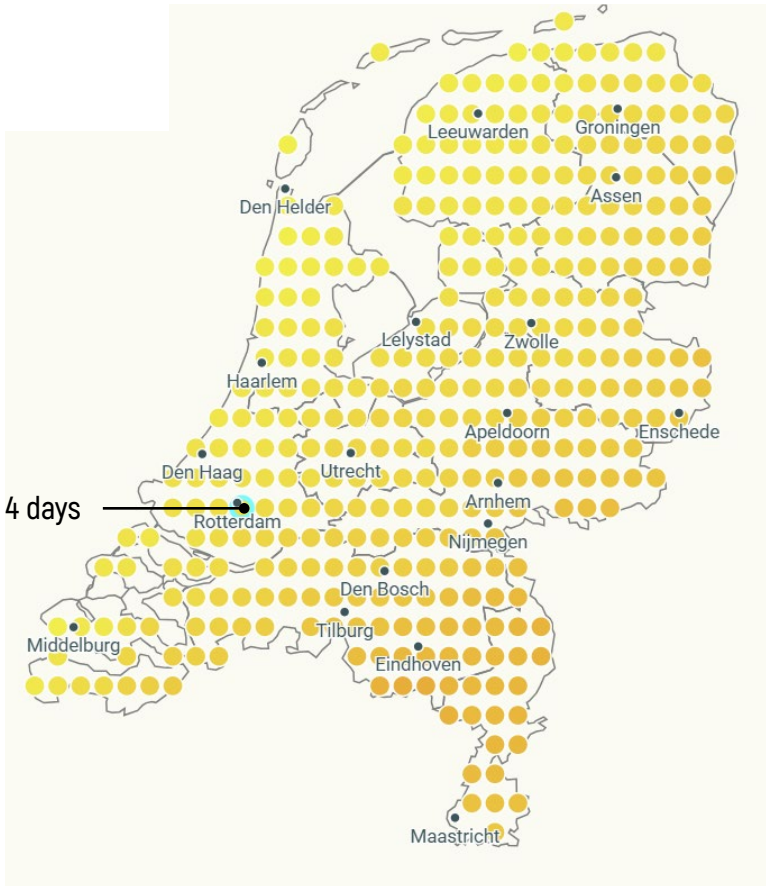
ROTTERDAM IS GETTING HOTTER



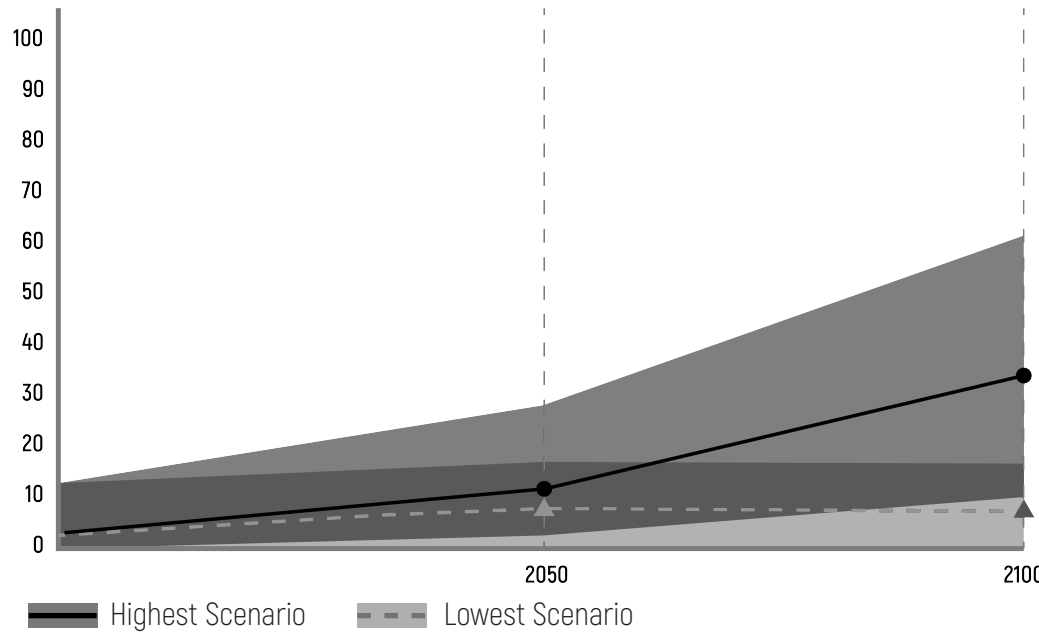
Number of Summer days in Rotterdam



Prediction of Summer days in Rotterdam

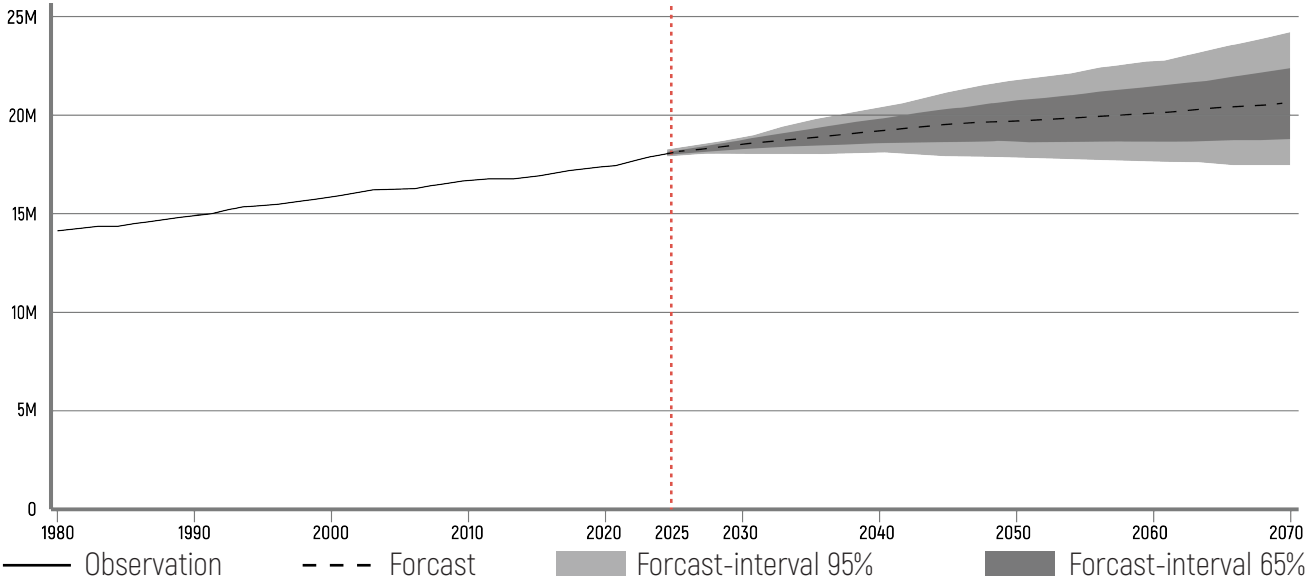


Number of days in Heat Wave in Rotterdam
[Source: <https://www.klimaateffectatlas.nl>]

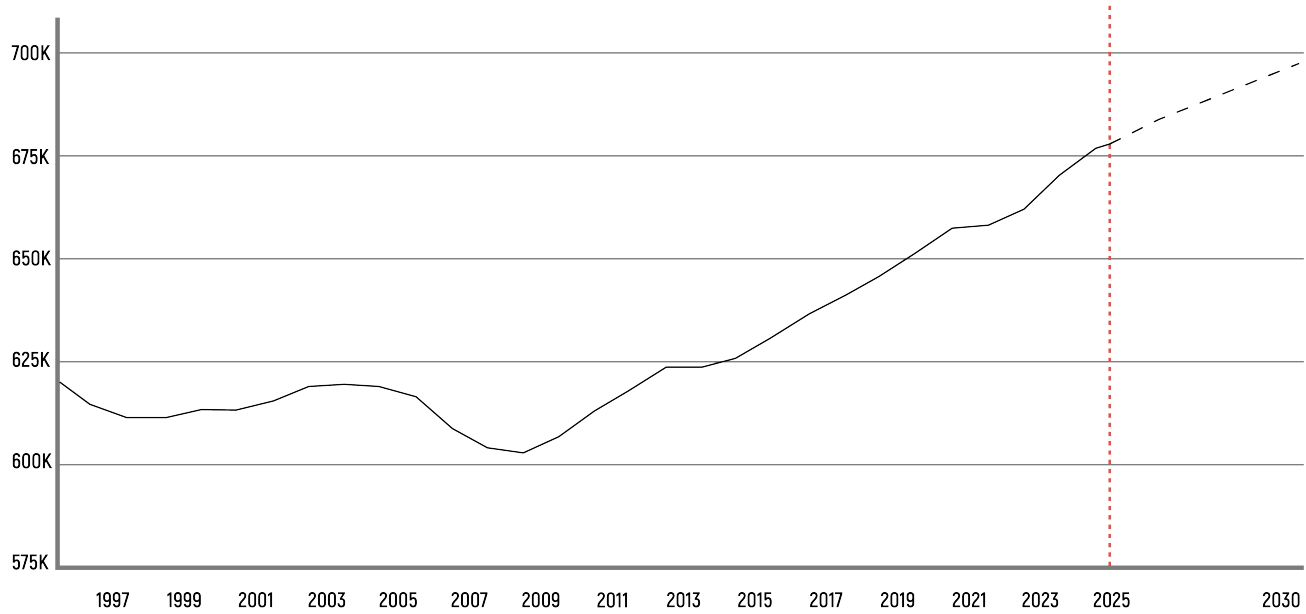


Prediction of days in Heat Wave in Rotterdam

DENSIFICATION MAKES IT WORSE

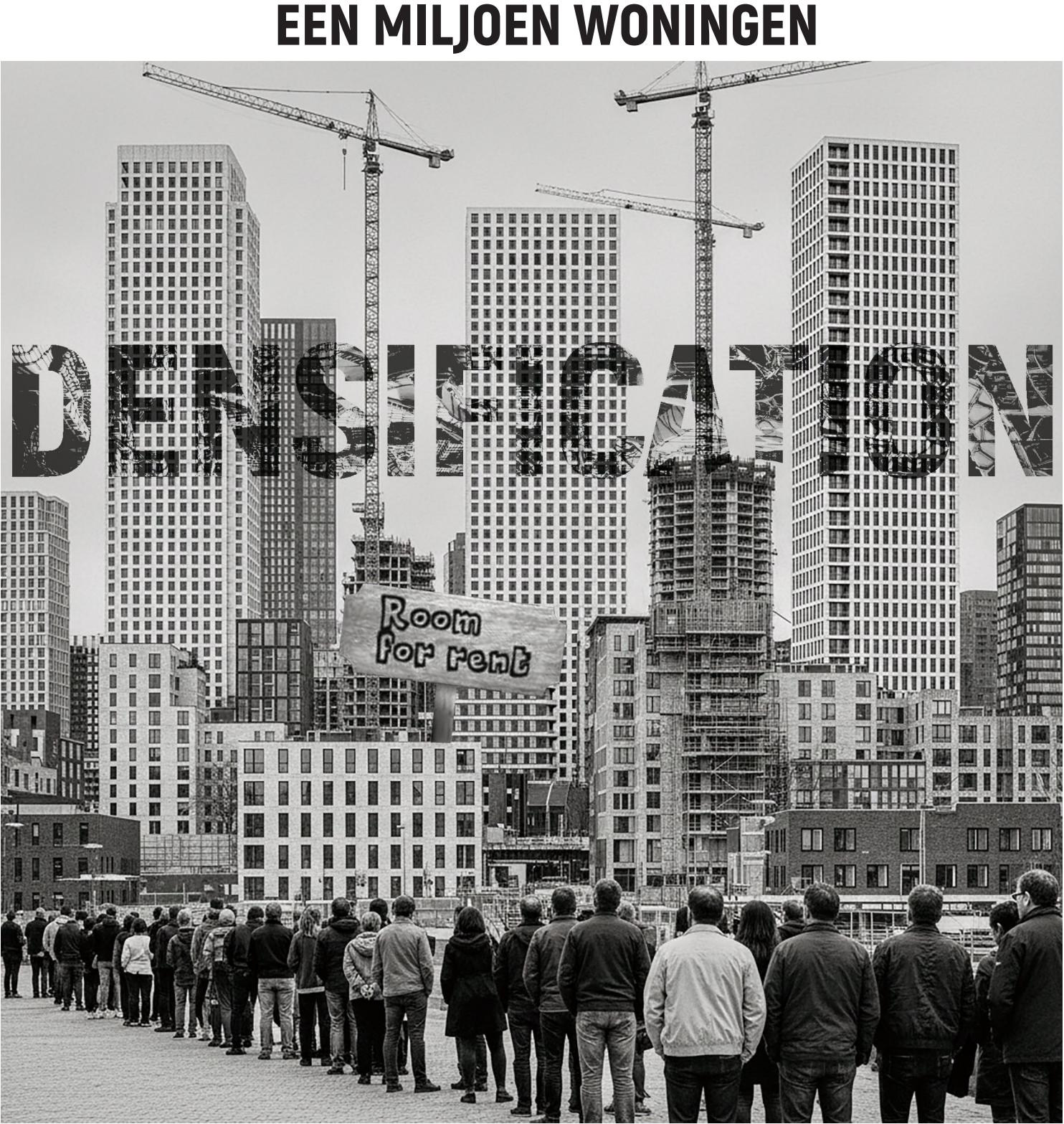


Prediction of Population Growth in Netherlands



Population of Rotterdam in 2025 and Prediction in 2030

[Source: Based on <https://allcharts.info/the-netherlands/municipality-rotterdam>]

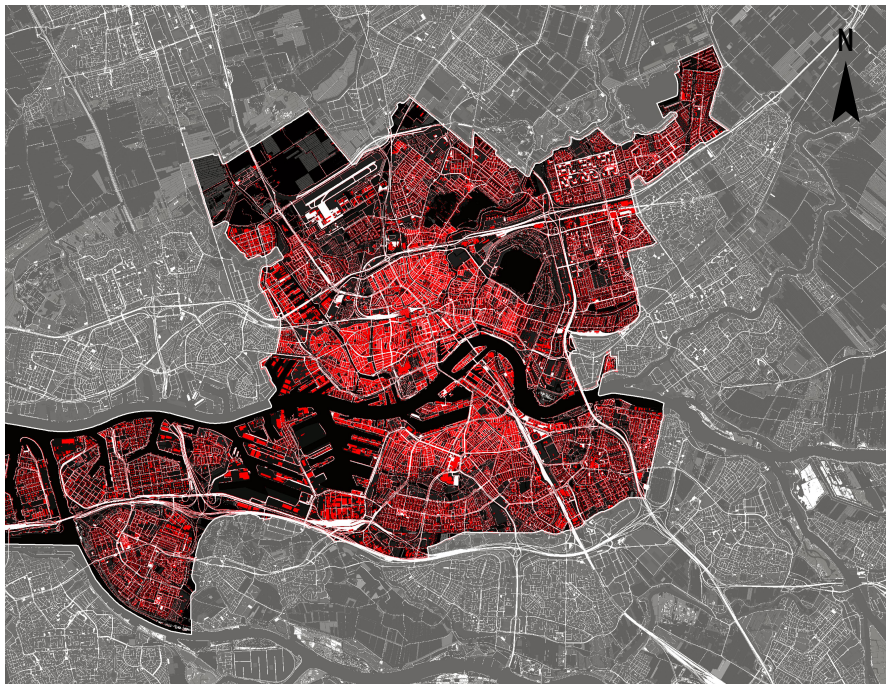


CURRENT SITUATION



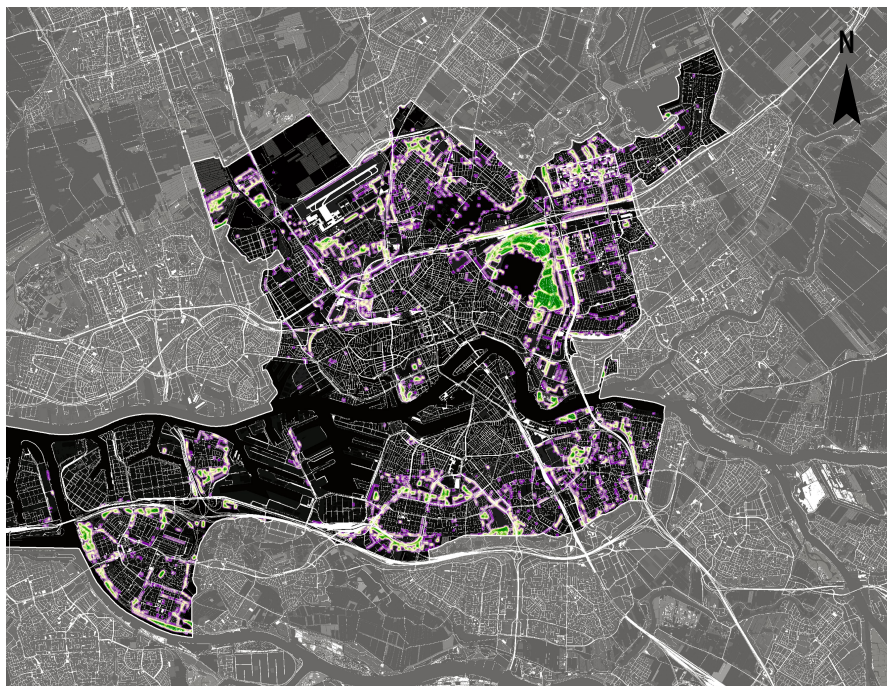
Green spaces in Rotterdam

Green Spaces



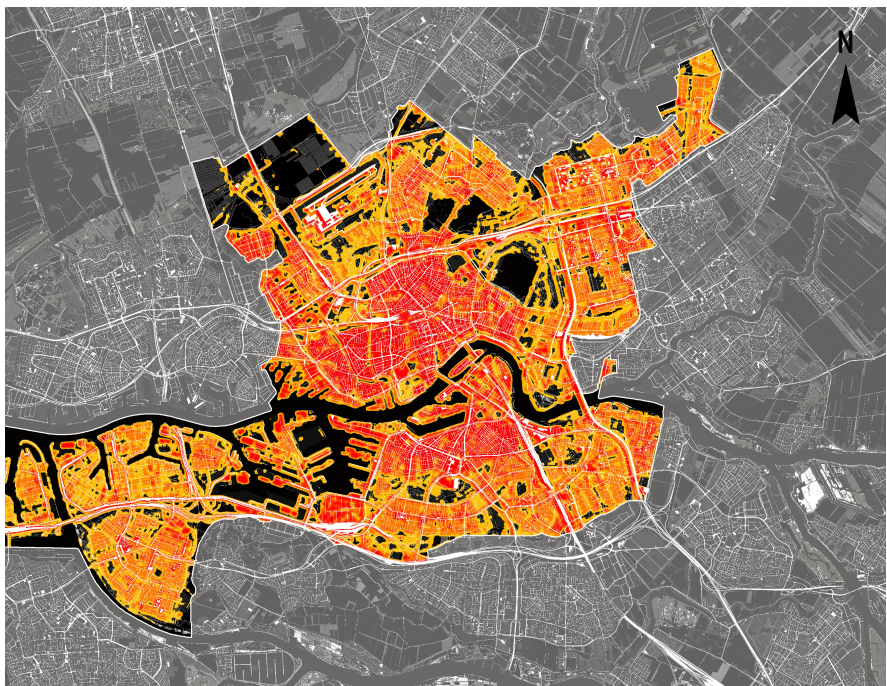
Constructed Areas in Rotterdam

Constructed



Green Space Density

Low High



Constructed Areas Density

Low High

ROTTERDAM

HOTTERDAM



Figure 2.14: Rotterdam and Hotterdam [Source: By Author and AI]

ACADEMIC GAP

- Limited systematic research on urban densification, morphology and thermal environment.
 - A few studies compare different heat-related factor together.
- Limited application of deep learning in practical urban climate design and planning.

KNOWLEDGE GAP

- Limited thermal-environment knowledge in current urban planning practices.
- Lack of heat-sensitive densification guidelines for high-density urban development.

PROBLEM STATEMENT

Rotterdam's densification is going to be conducted without effective standards or easy-to-use tools to assess the heat impacts of new buildings, which will likely result in an negative effect on ourdoor thermal temperature, elevated heat-related healthrisks, and reduced environmental livability for vulnerable communities.

RESEARCH QUESTIONS

Main Research Question

How could Rotterdam develop heat-sensitive densification strategies with the support of deep-learning technologies?

SQ 1

What kinds of urban, environmental and morphological factors contribute to urban outdoor temperature?

SQ 2

How can technology helps simplify and strengthen the prediction of urban outdoor temperature?

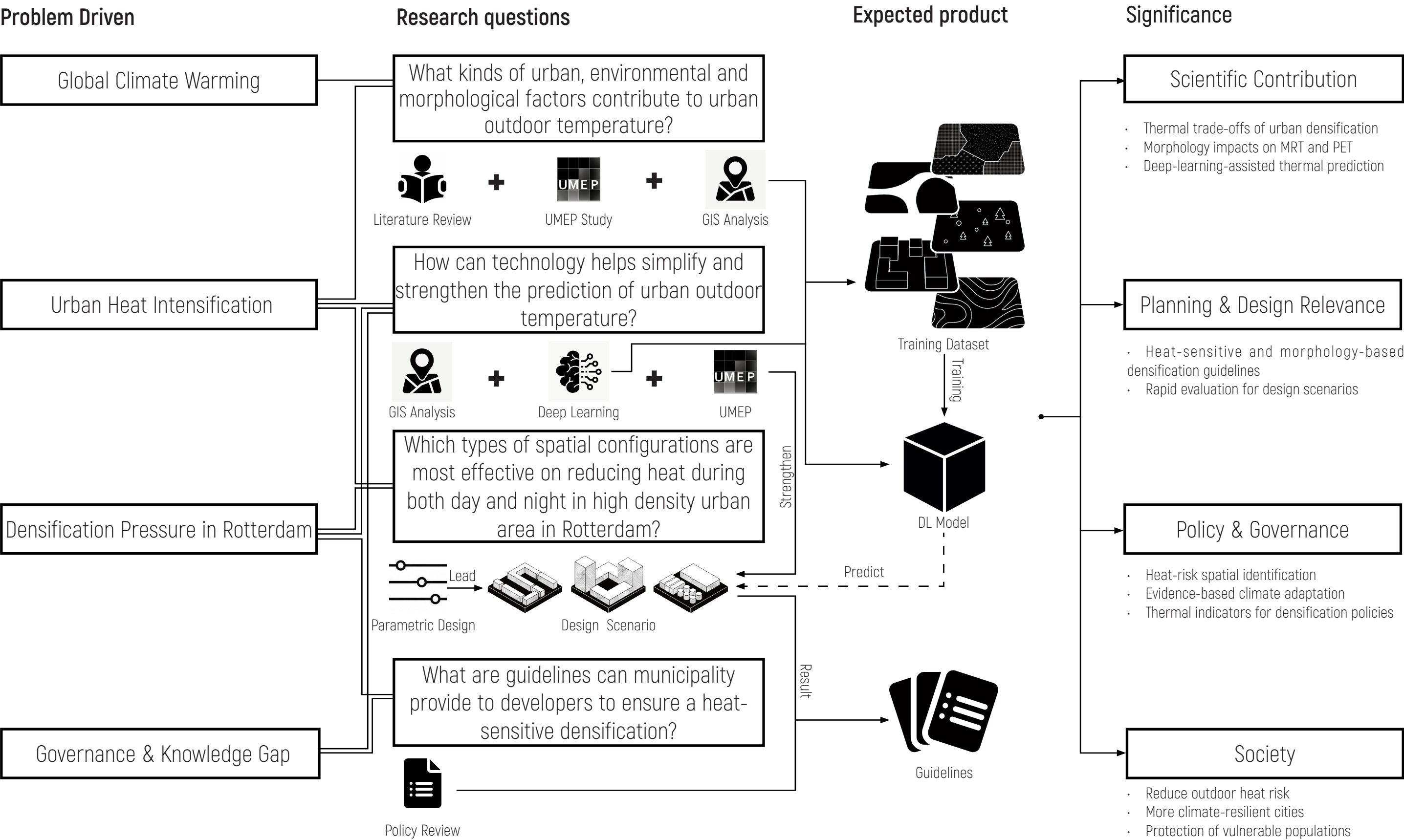
SQ 3

Which types of spatial configurations are most effective on reducing heat during both day and night in high density urban area in Rotterdam?

SQ 4

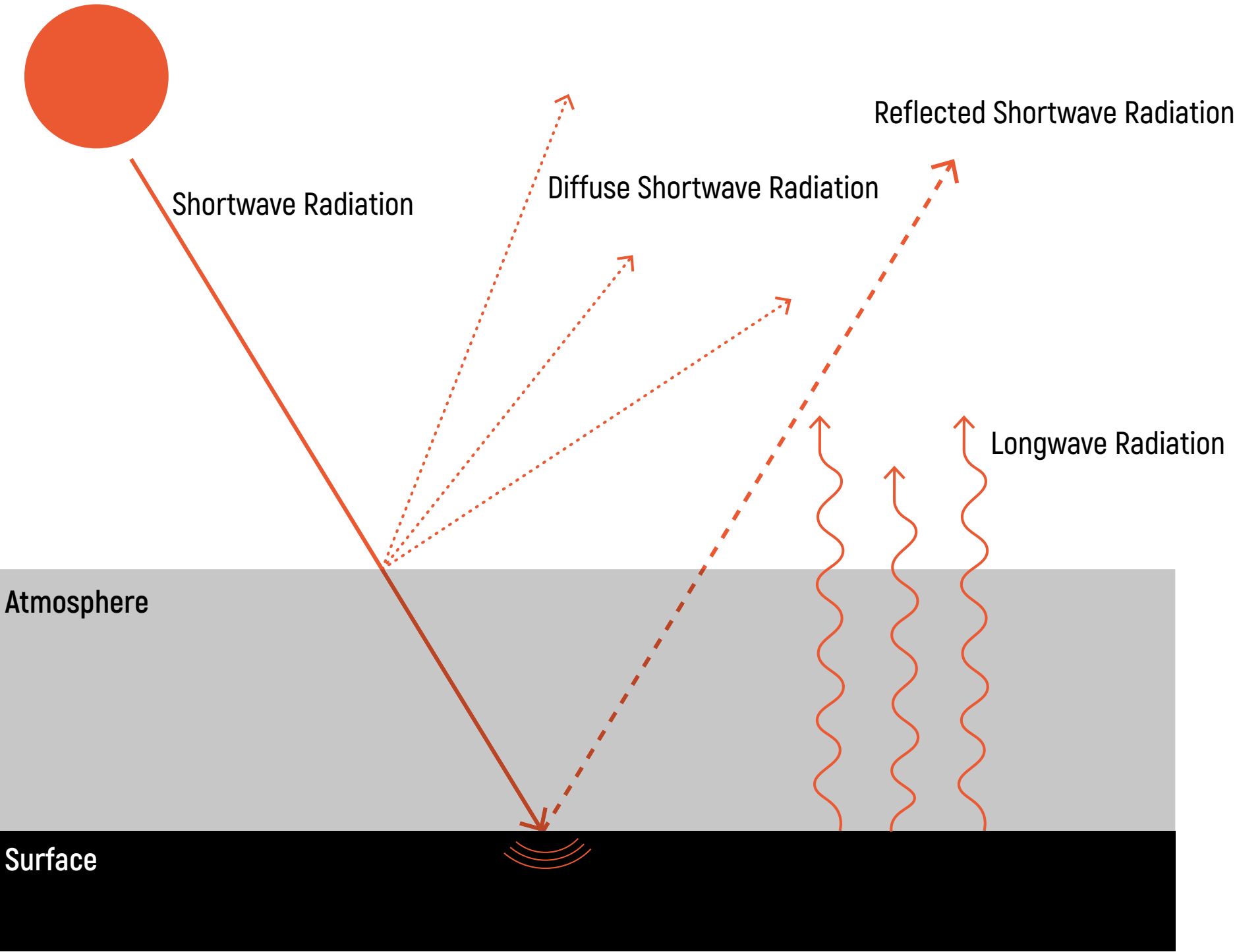
What guidelines can the municipality provide to developers to ensure a heat-sensitive densification?

METHODOLOGY FRAMEWORK



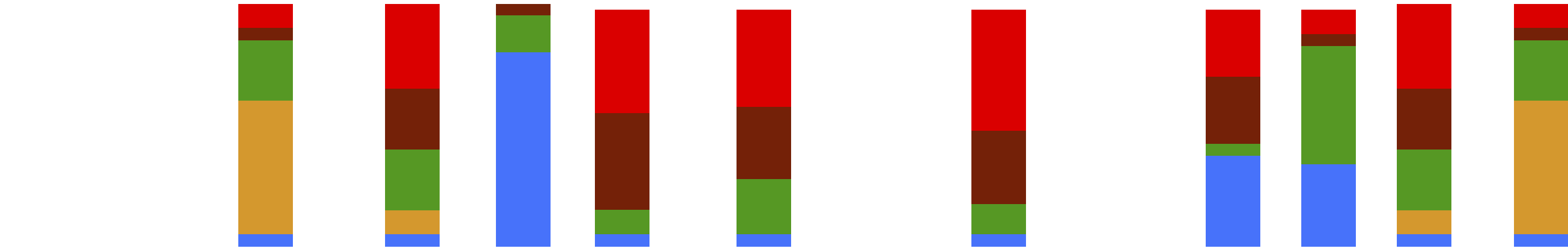
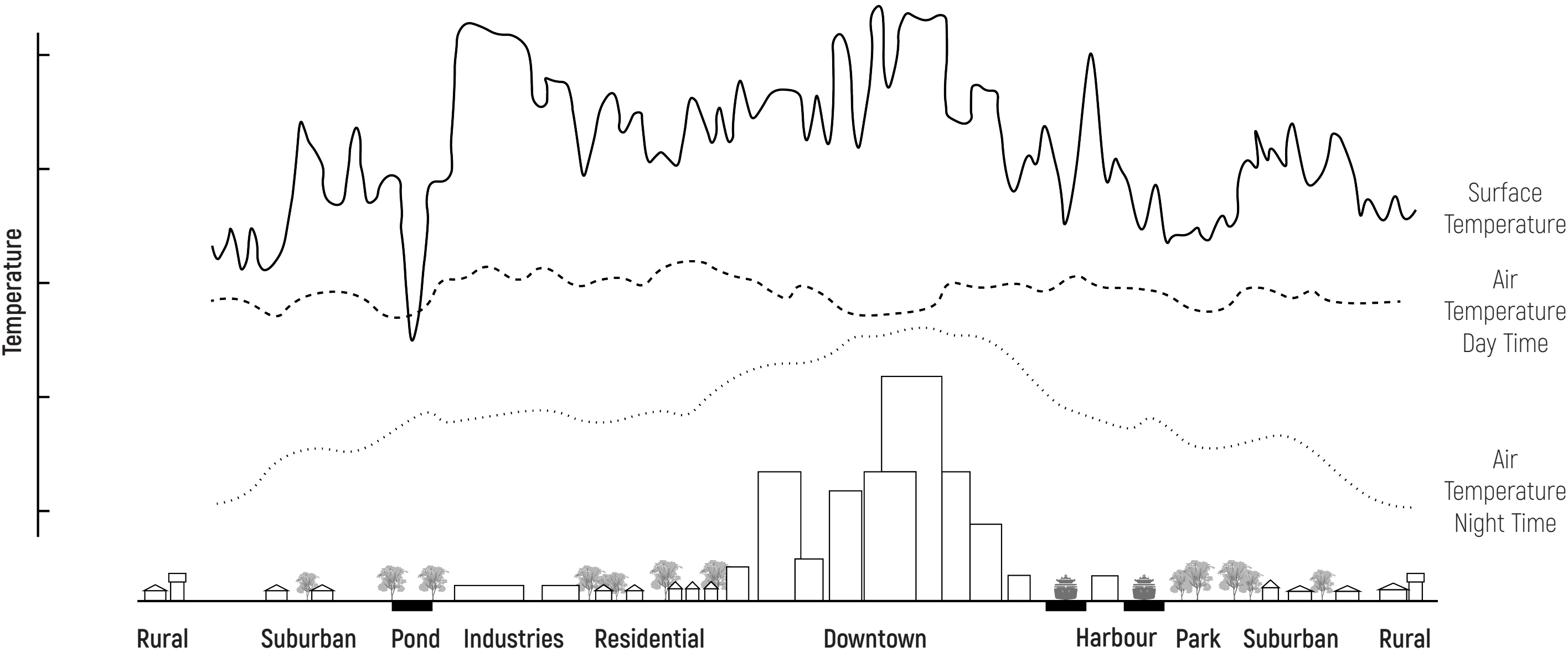
HEAT RESEARCH

RADIATION AND TEMPERATURE

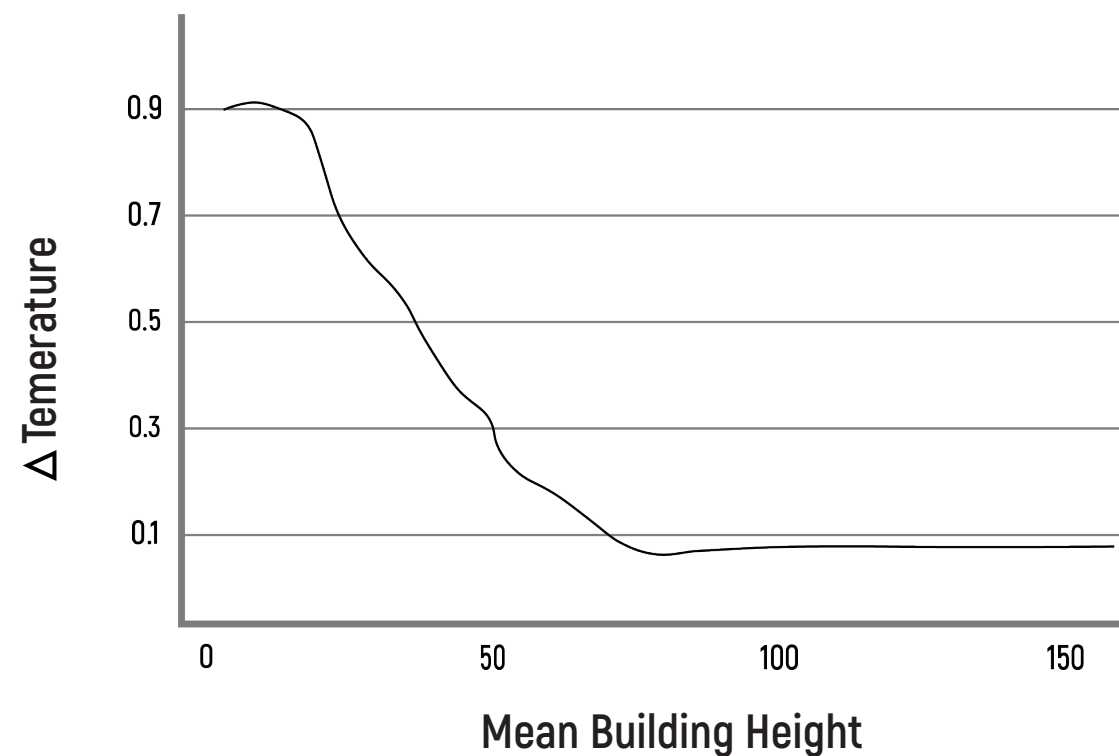
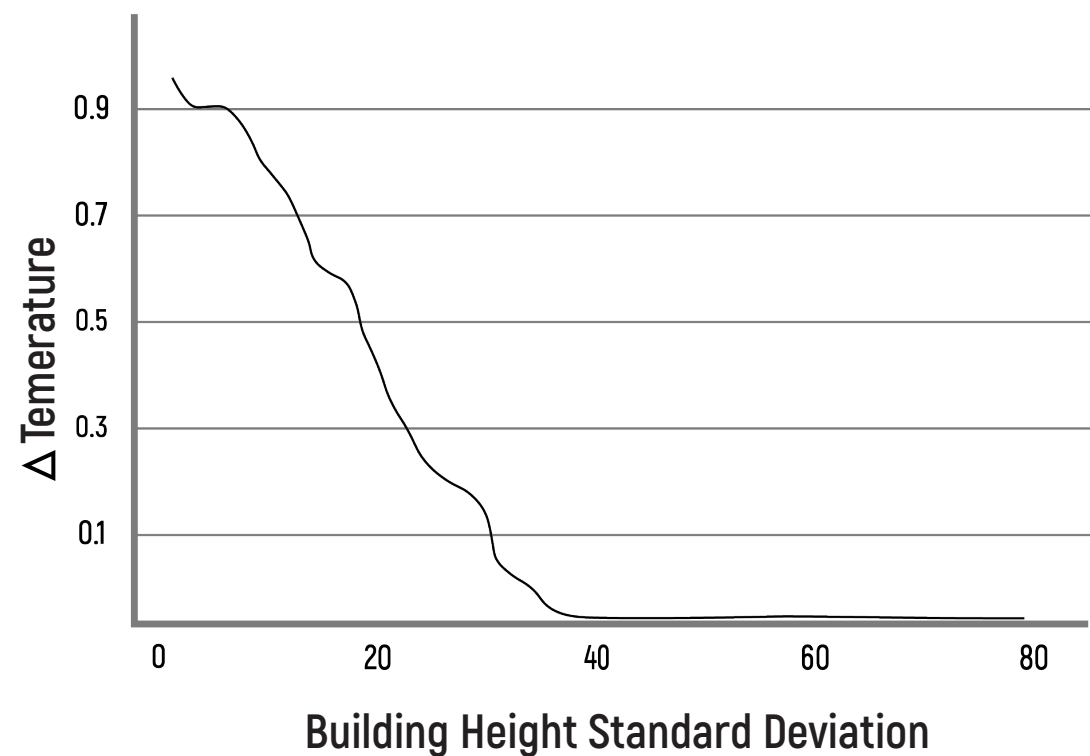
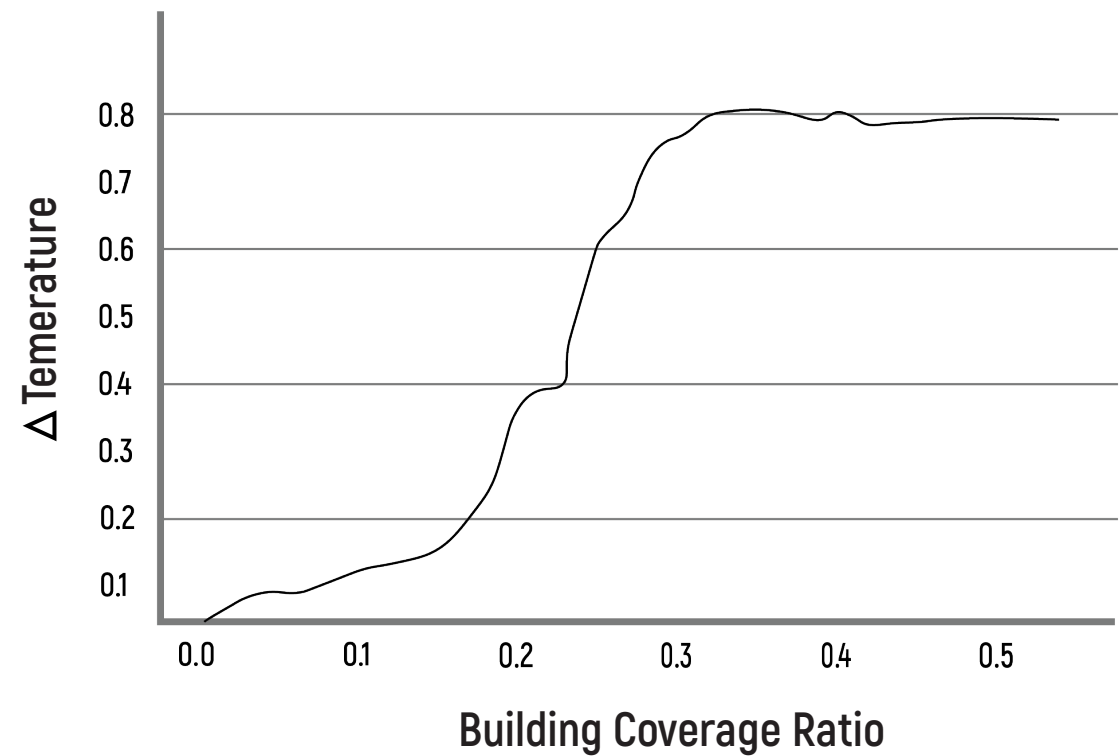
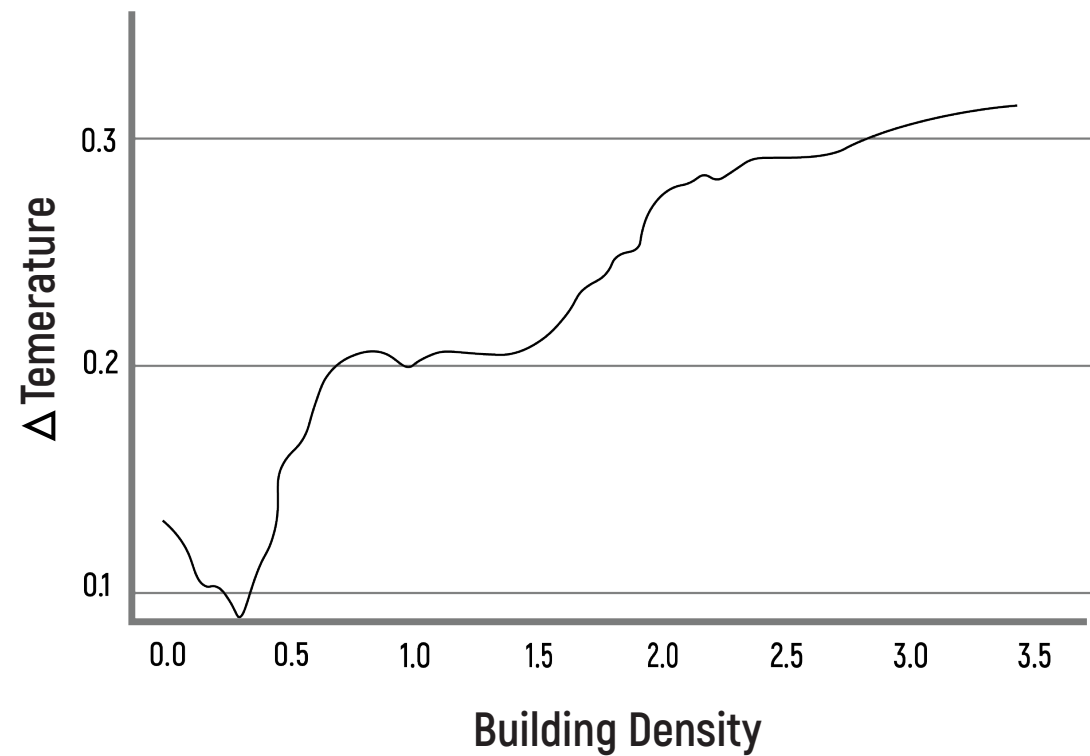


Factors contribute to heat: Landcover

Source: Modified from Voogt, (2004)

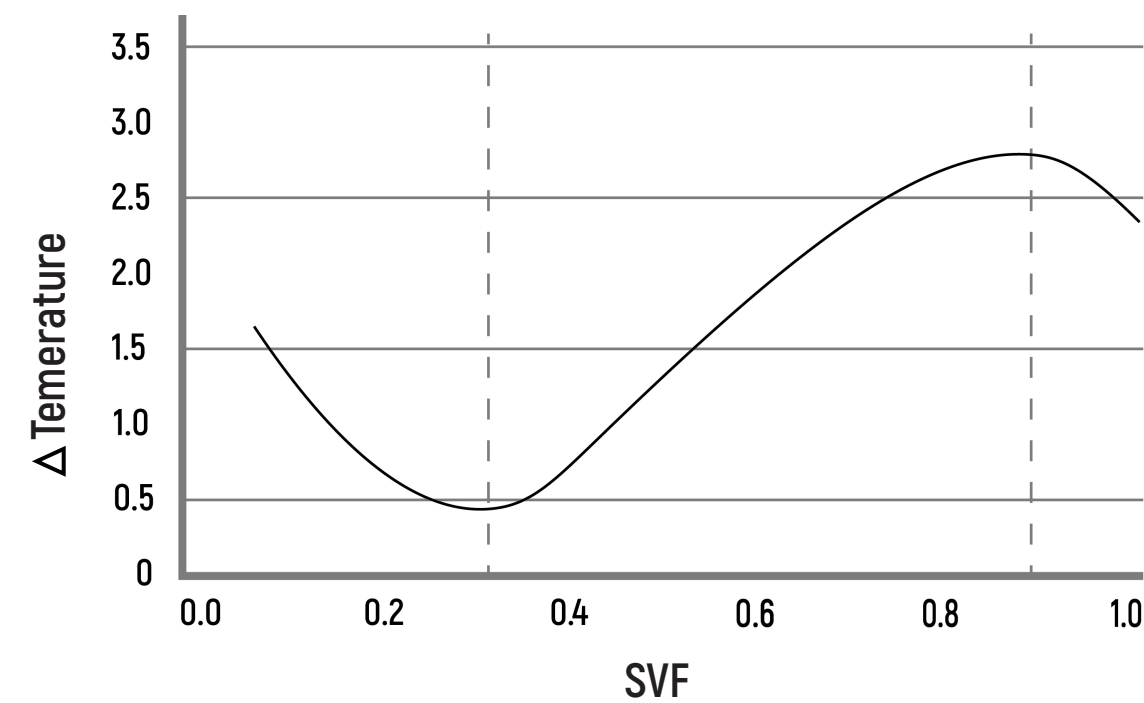
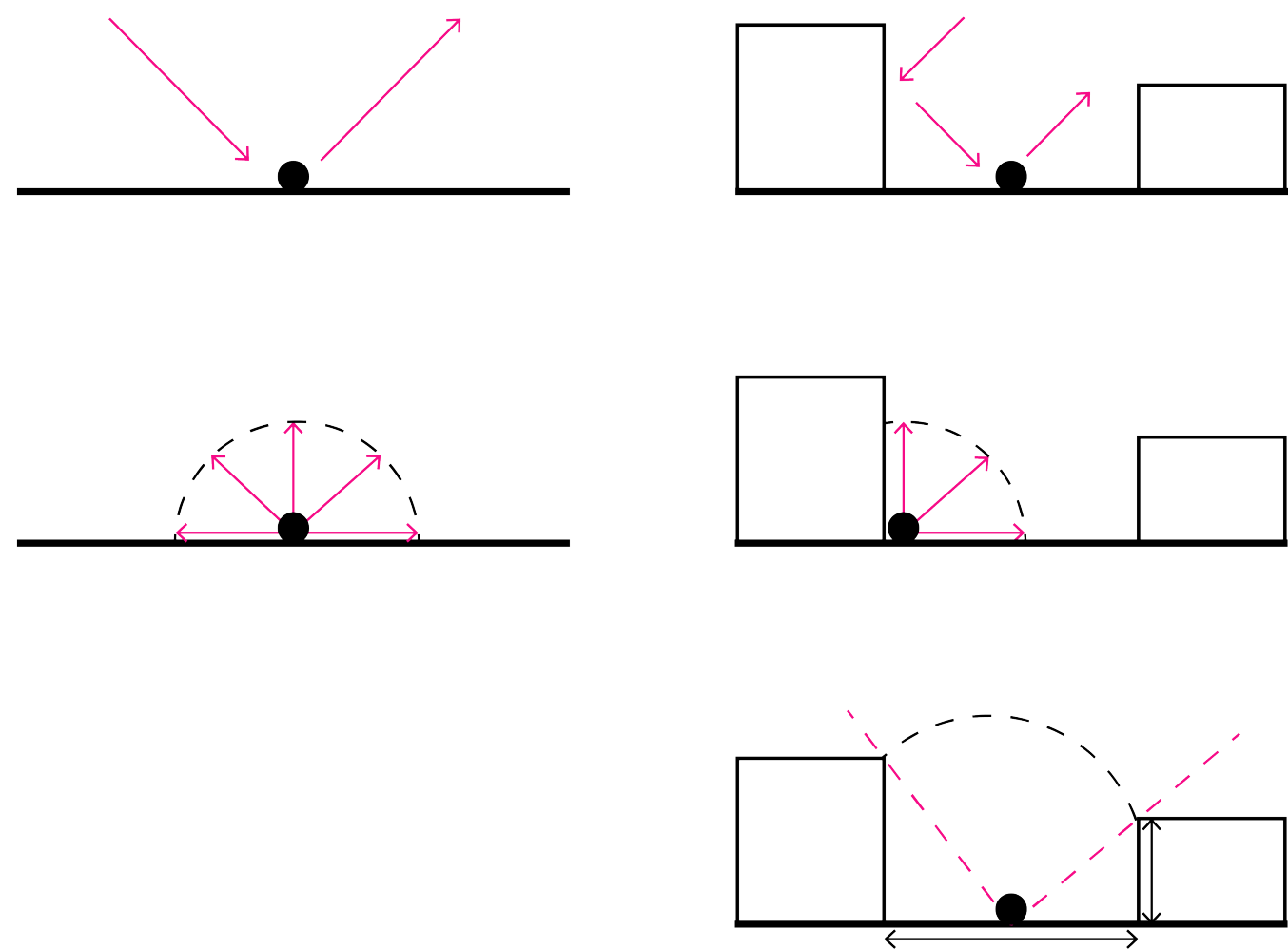


Factors contribute to heat: Urban morphology

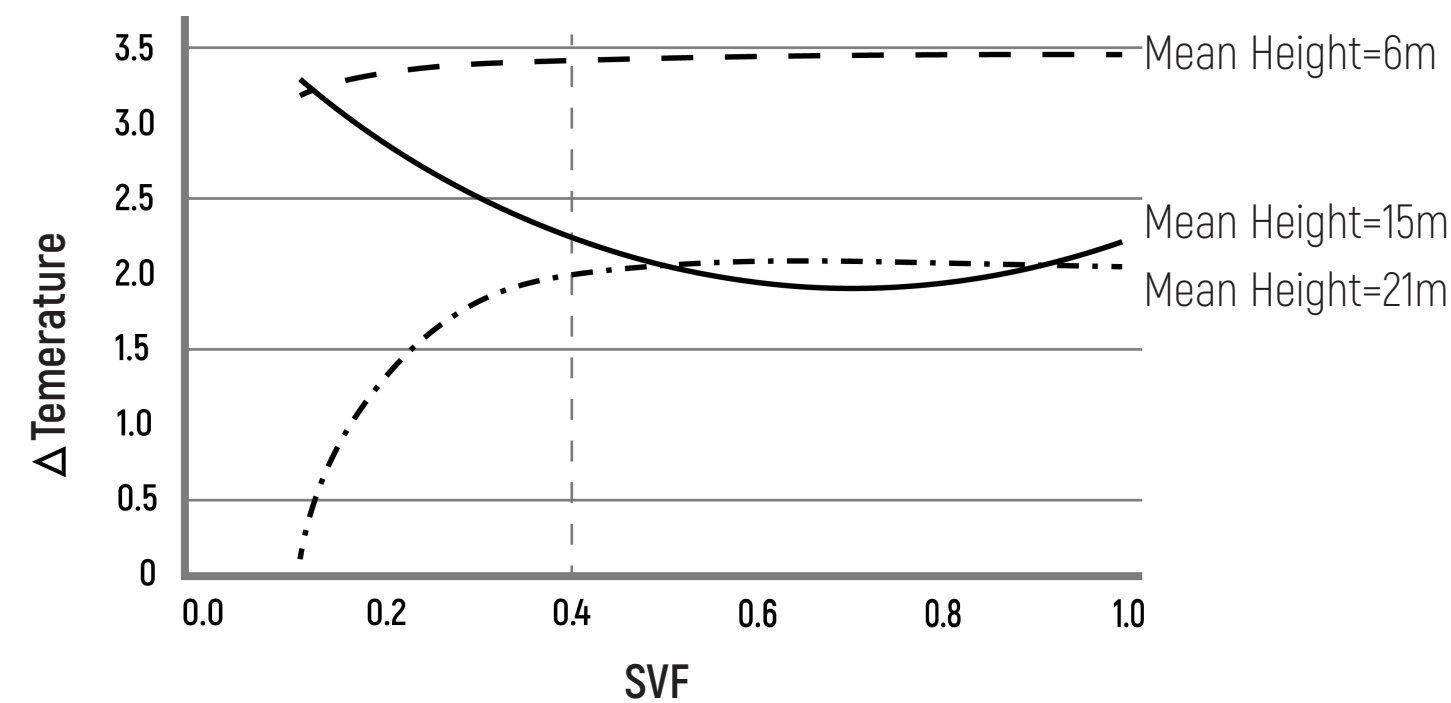


Source: Adapted from He et al. (2021)

Factors contribute to heat: Urban morphology--Sky View Factor (SVF)



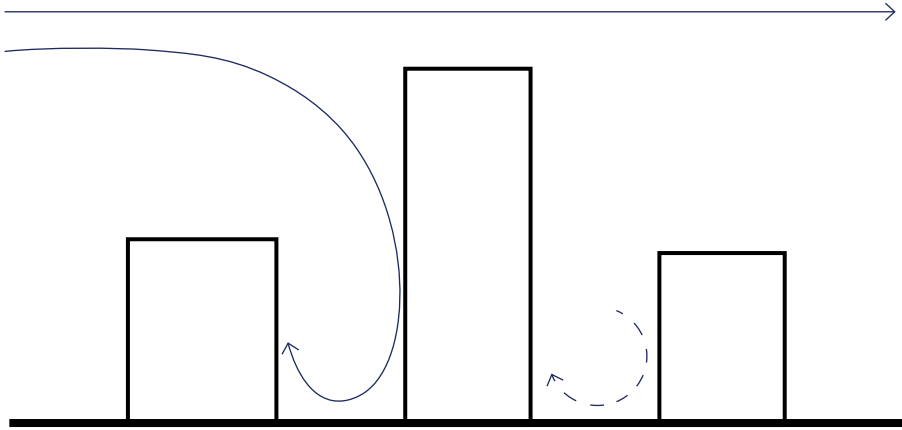
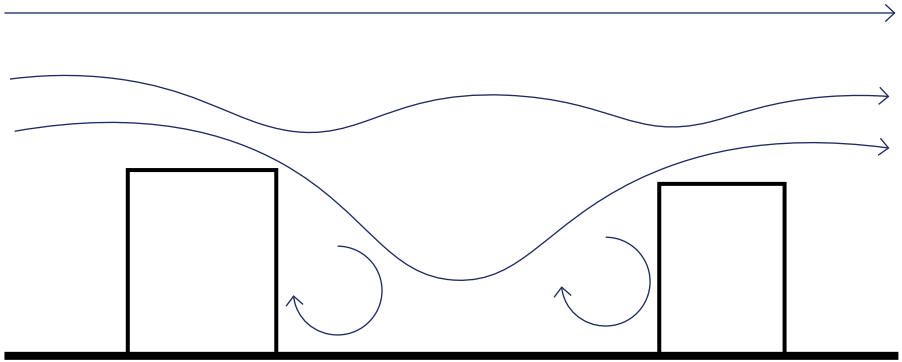
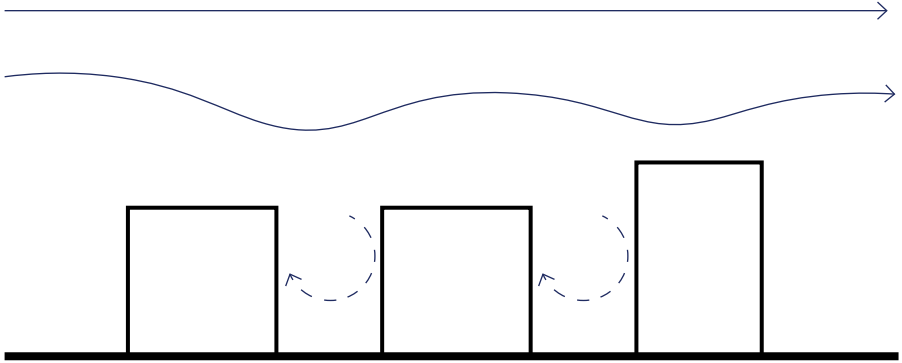
Date: June 27



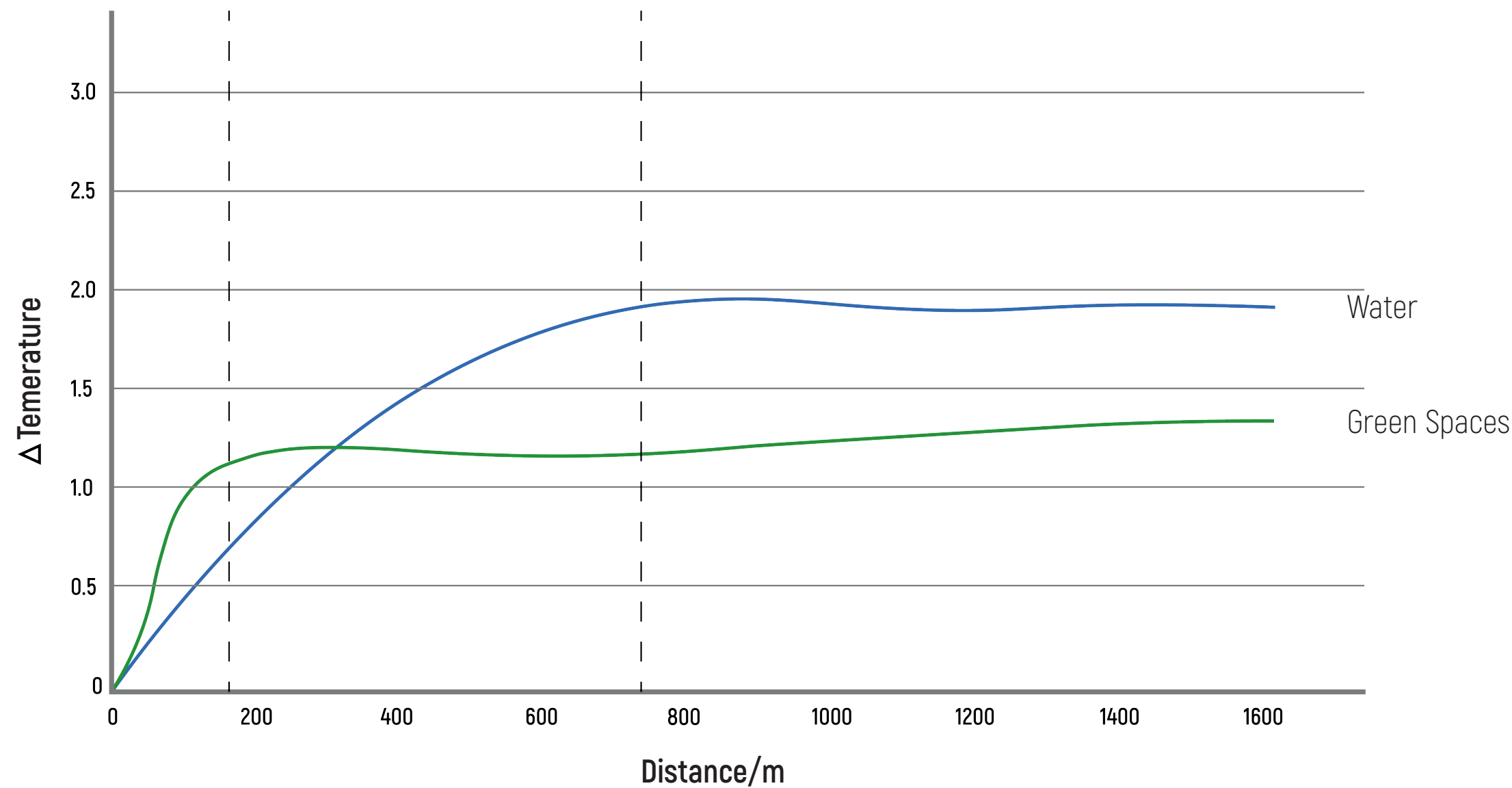
Source: Adapted from Urban Climate

Source: Adapted from Chen et al. (2021)

Factors contribute to heat: Urban morphology--Wind

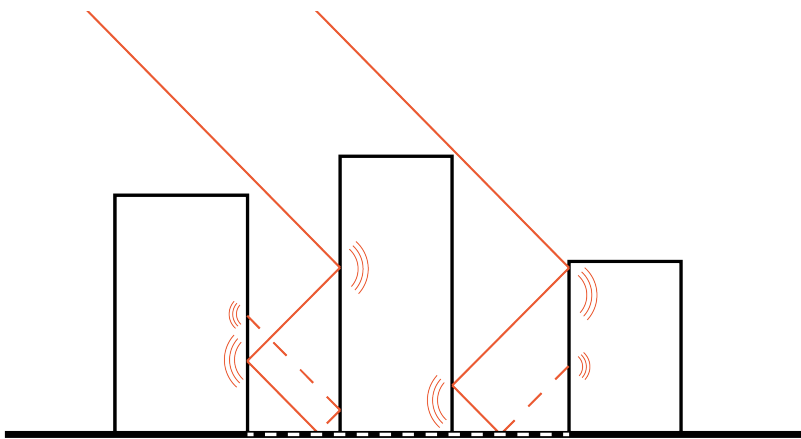


Factors contribute to heat: Blue-green infrastructure

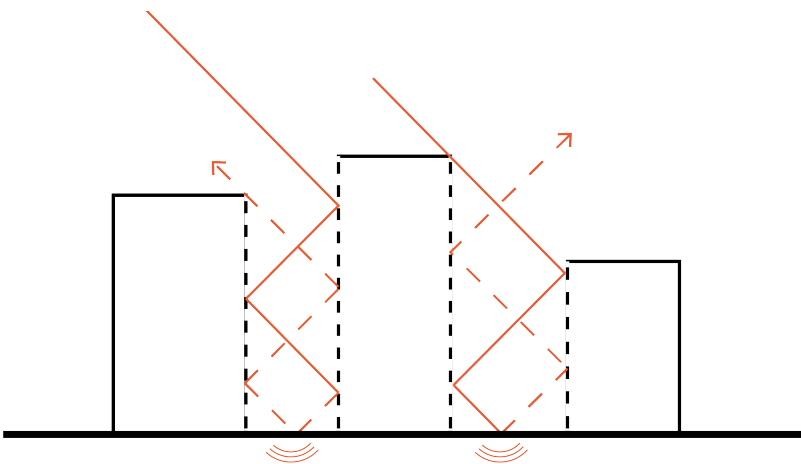


Source: Adapted from Cai et al. [2023] & Wu et al. [2019]

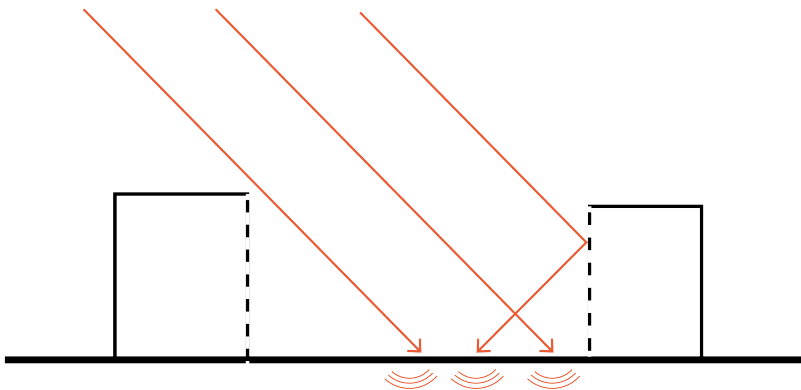
Factors contribute to heat: Materials



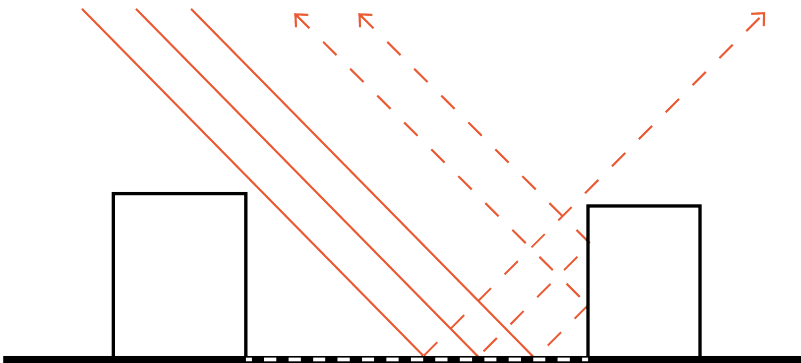
High Density Area—Road Albedo



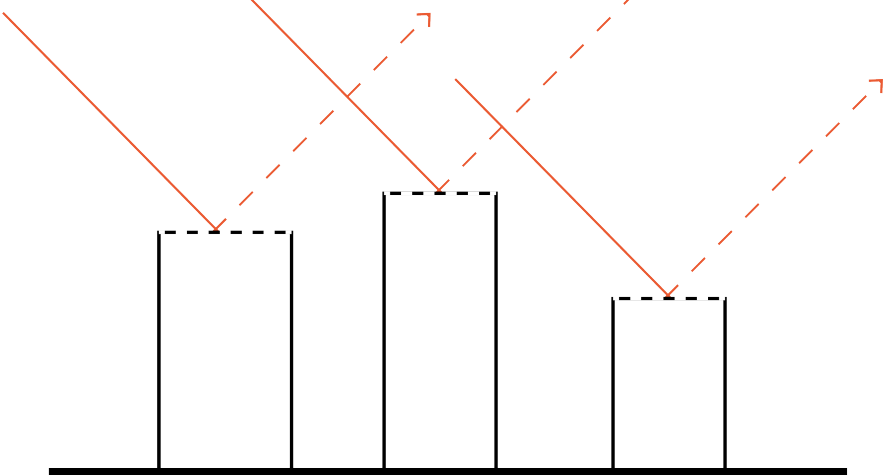
High Density Area—Wall Albedo



Low Density Area—Wall Albedo



Low Density Area—Road Albedo



High Density Area—Roof Albedo

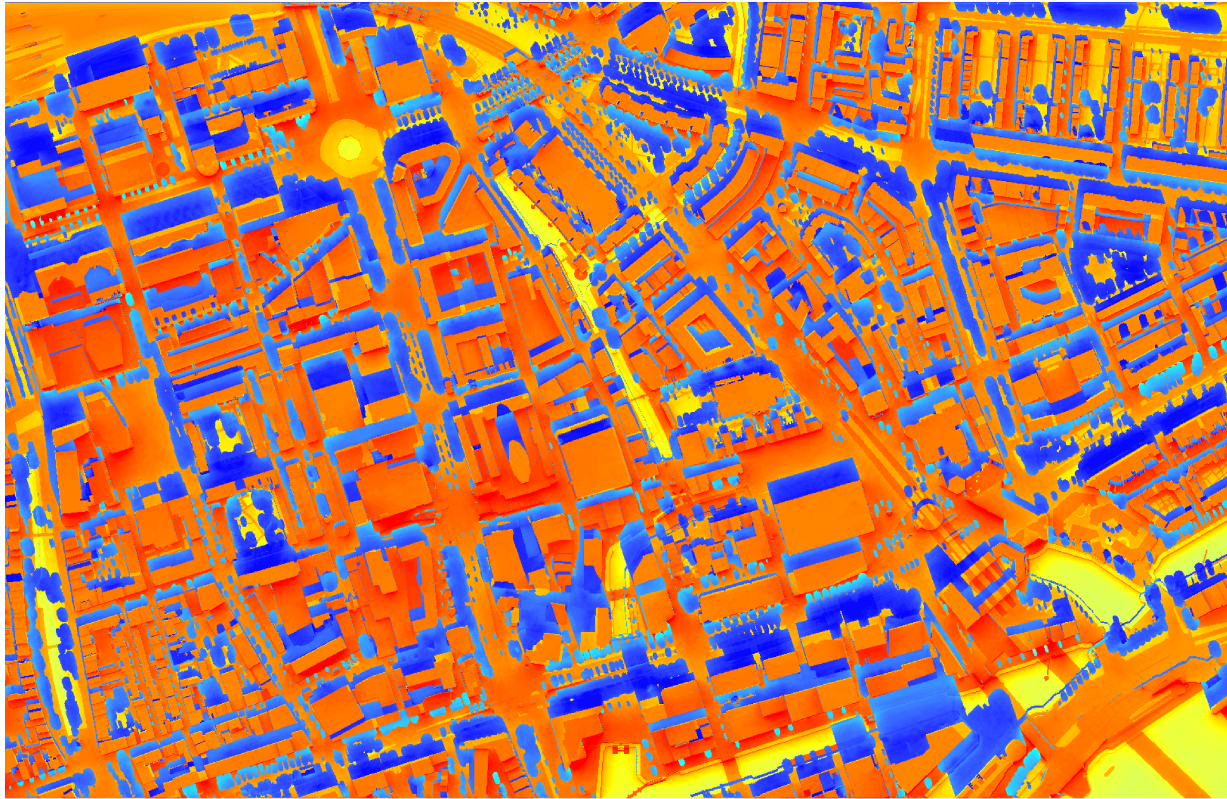
Summary

What kinds of urban, environmental and morphological factors contribute to urban outdoor temperature?

Model Parameter	Solar Radiation	Wind	Evaporation	Variable Setting
Climate	●	●	○	Constant
Landcover	●	○	●	Variate
Urban Morphology	●	●	○	Variate
Blue-Green Infrastructure	●	○	●	Constant
Materials	●	○	○	Variate
Human Activities	○	○	○	Constant

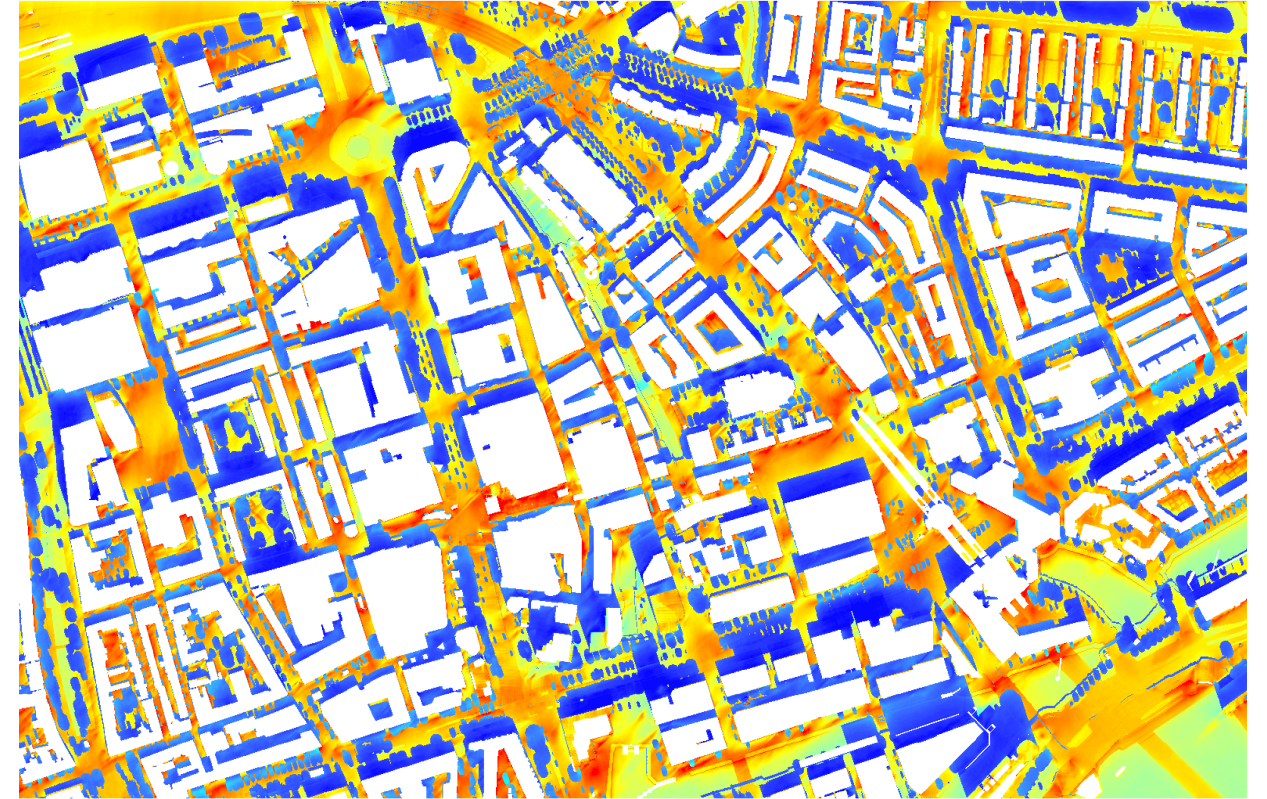
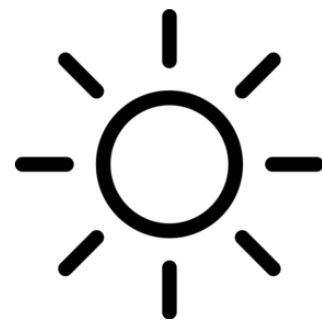
METHODOLOGY

Temperature Indicator



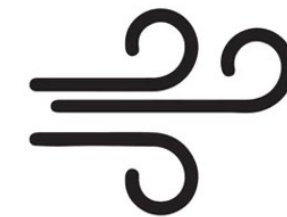
Mean Radiant Temperature (MRT):

The combined effect of all surrounding thermal radiation received by the human body.

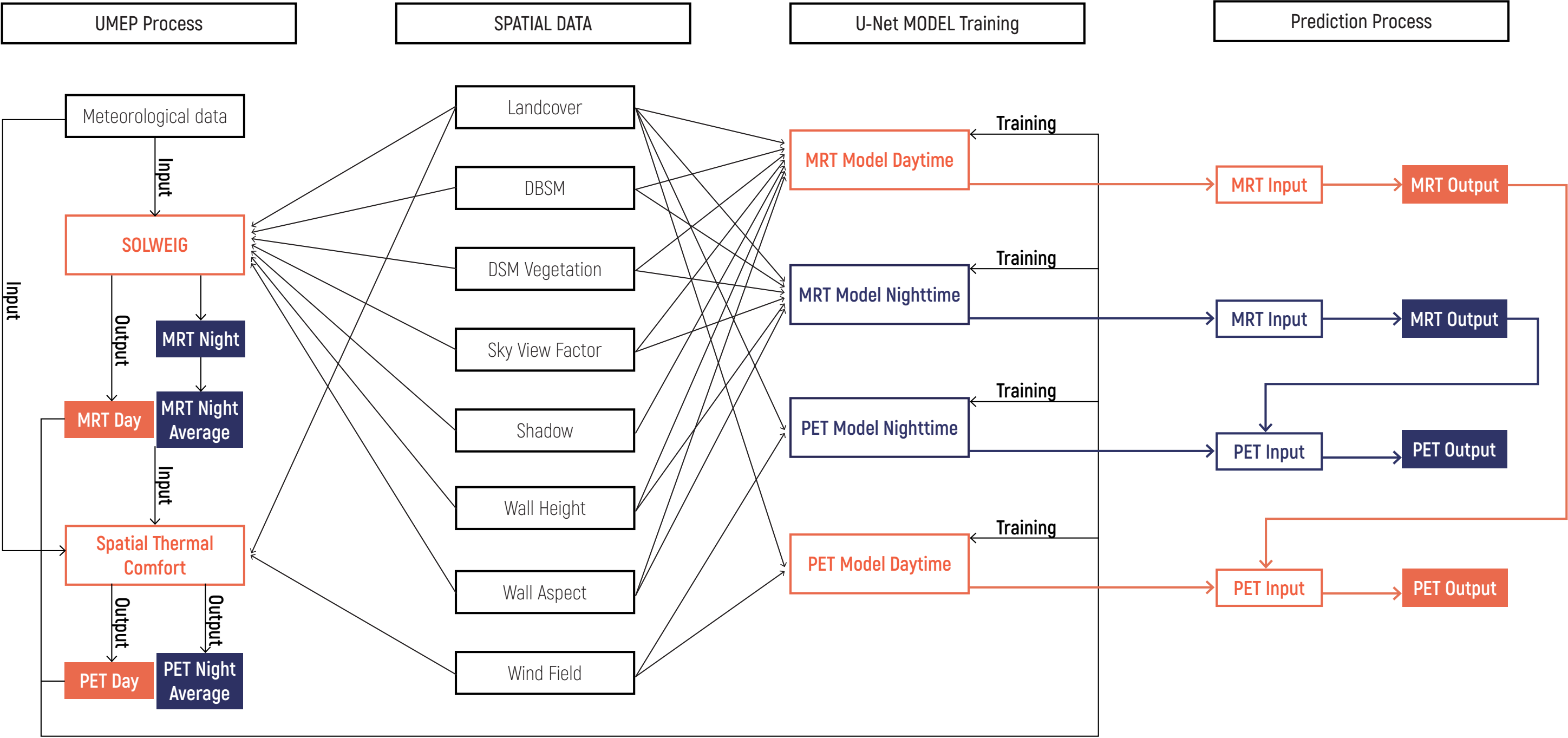


Physiological Equivalent Temperature (PET):

A thermal comfort index that reflects how humans perceive outdoor thermal conditions based on radiation, wind, air temperature, and humidity.



General Processes



Meteorological Data Selection

- **Representativeness**

The selected data should represent typical climatic conditions relevant to the study, especially key situations such as heatwaves.

- **Extremity Condition**

Extreme or high-temperature conditions should be prioritized to capture the maximum thermal stress in urban environments.

- **Continuity & Stability**

The data should cover a continuous period with relatively stable weather conditions to reduce short-term variability and improve model reliability.

- **Consistency**

The selected period should have consistent meteorological conditions (e.g., clear sky, high-pressure system) to minimize external disturbances.



2022.8.10-8.14

Heat Risk Period

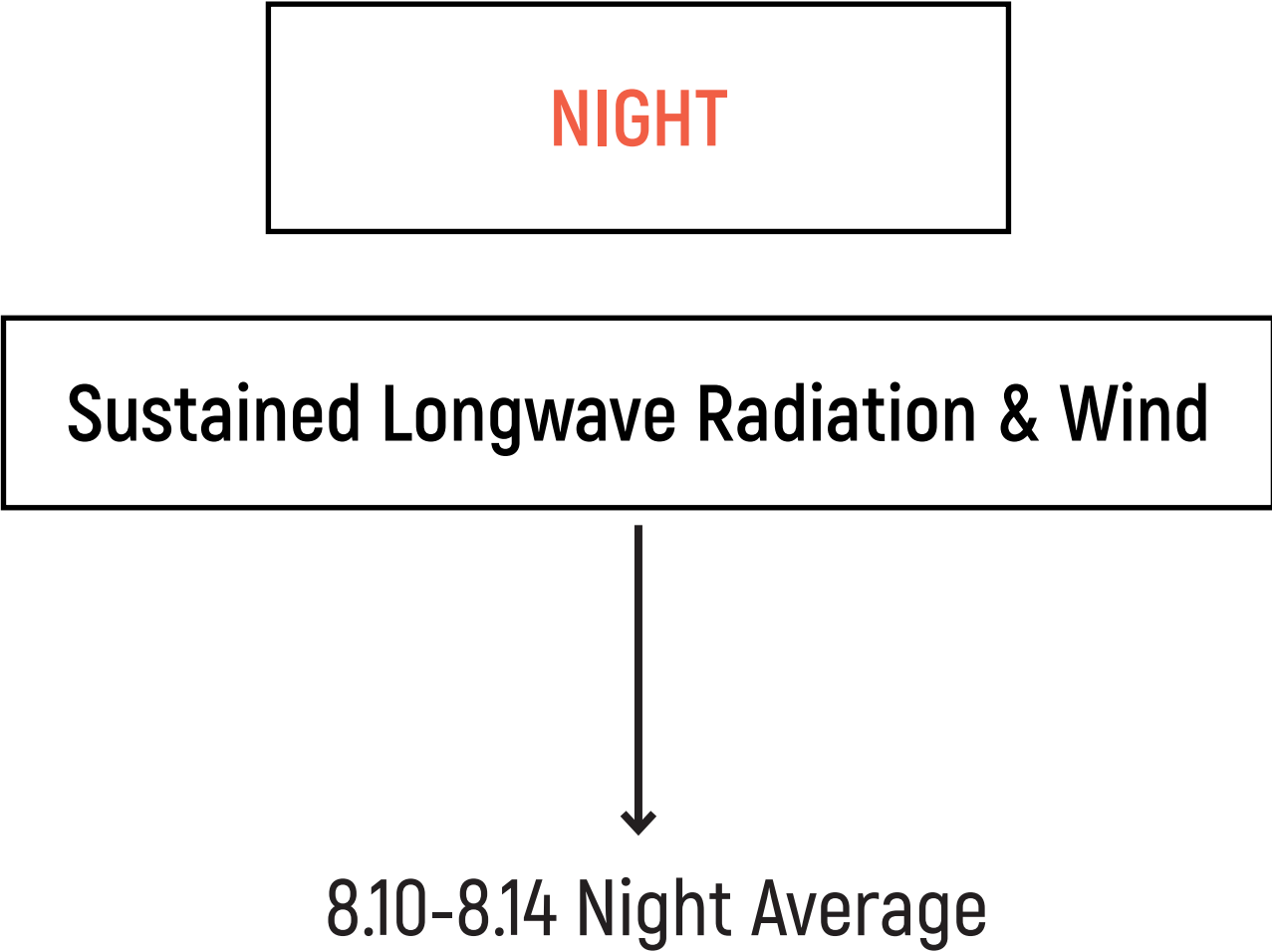
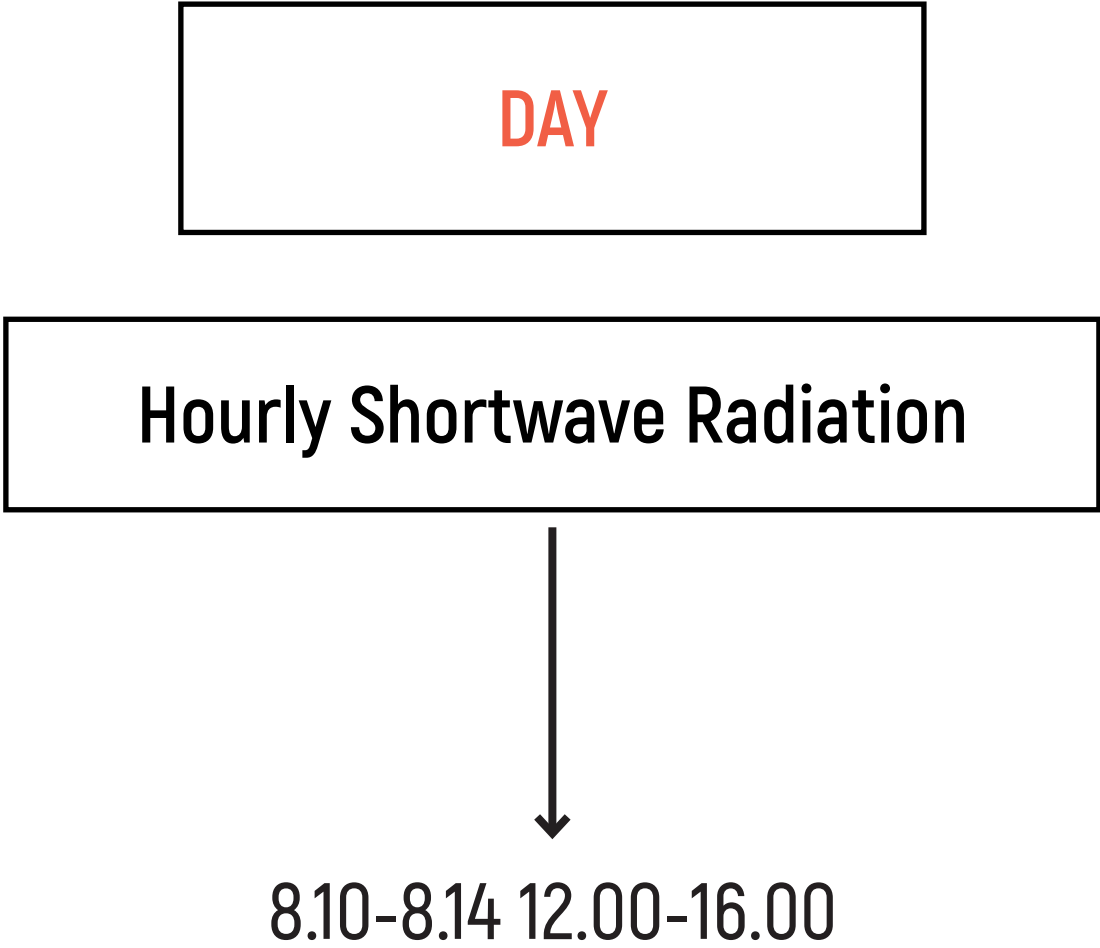


12.00-16.00

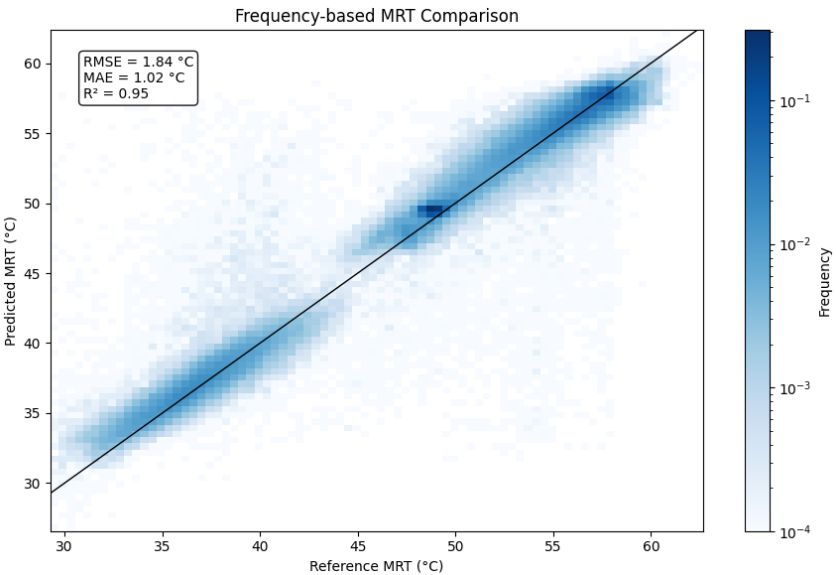
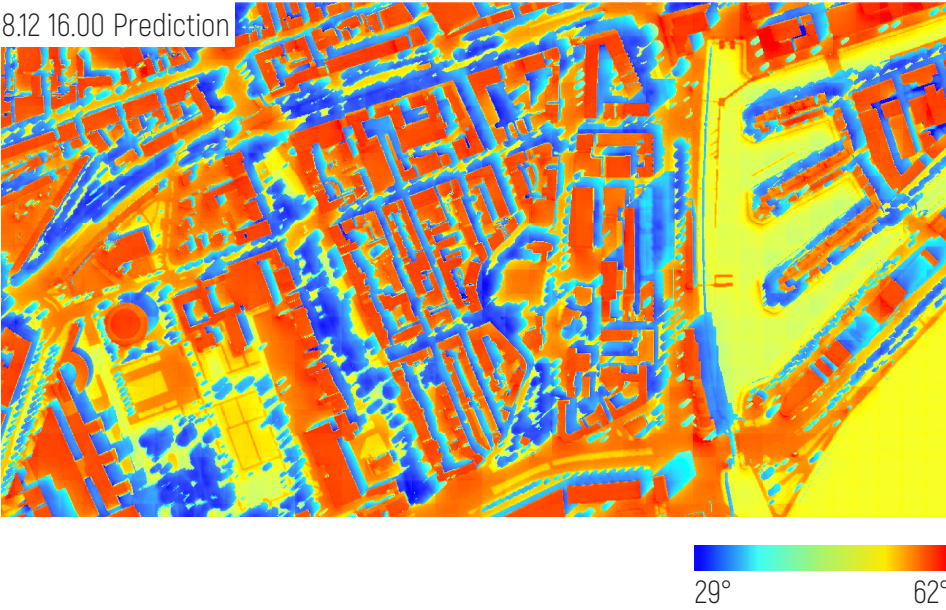
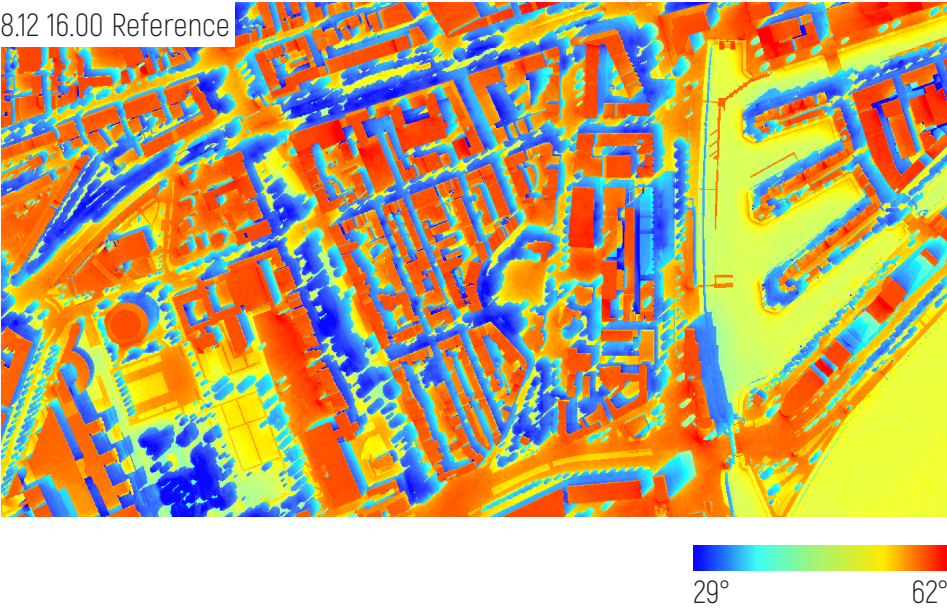
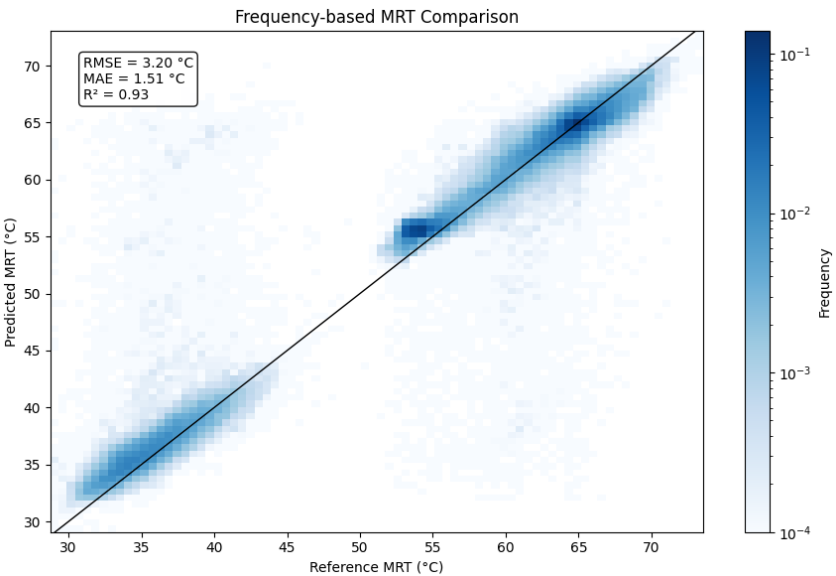
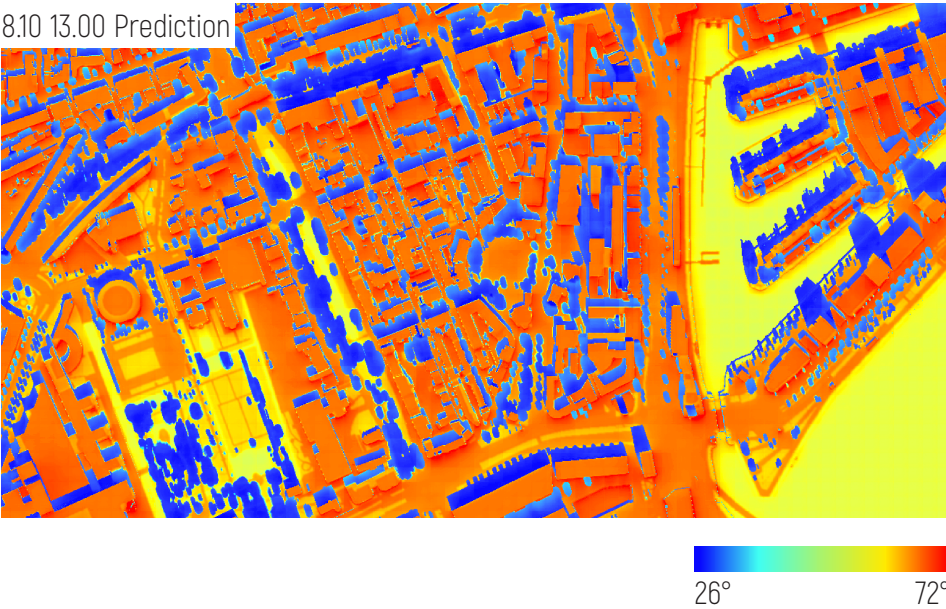
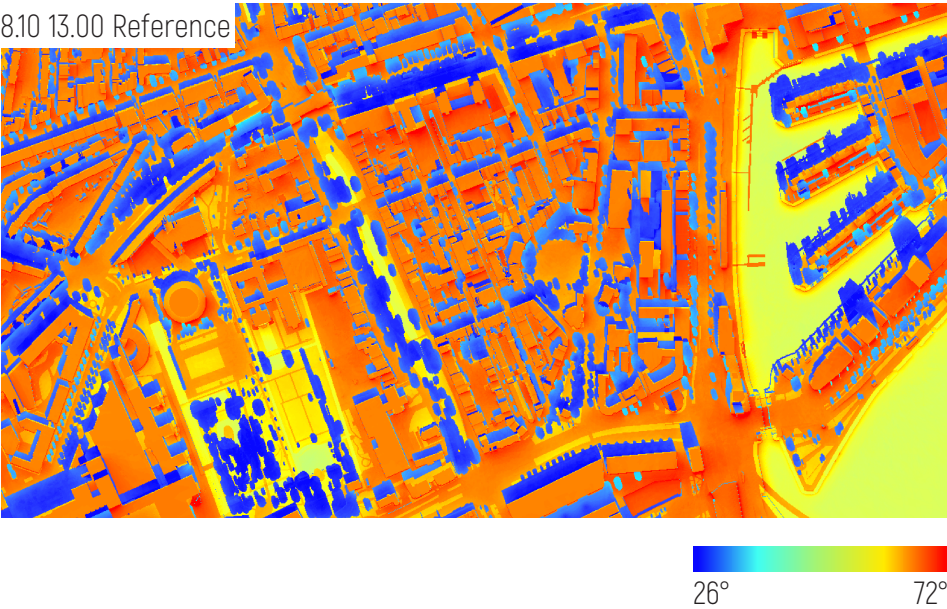


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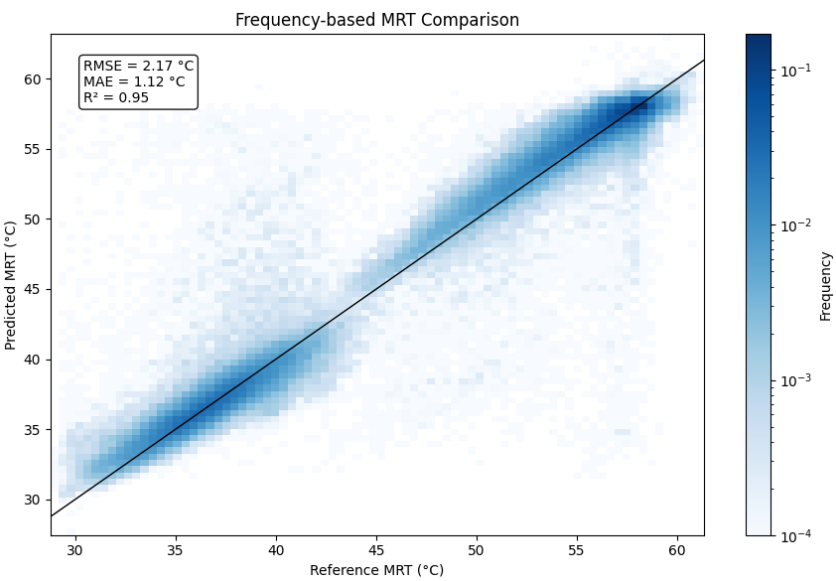
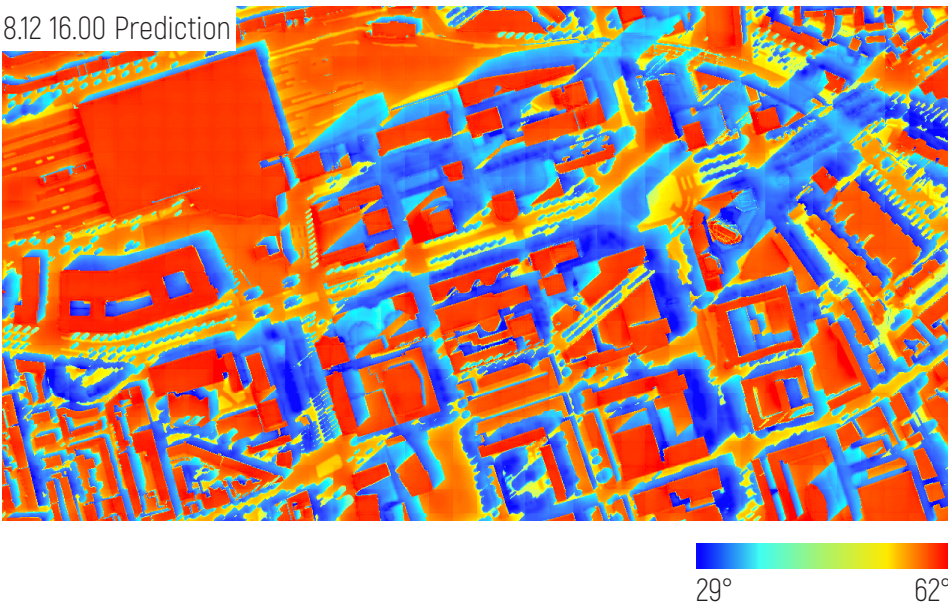
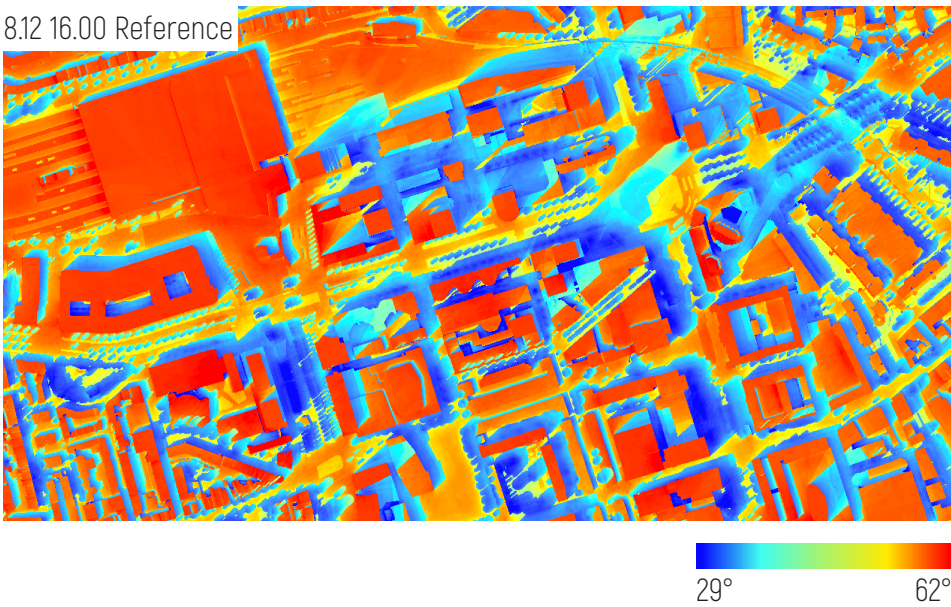
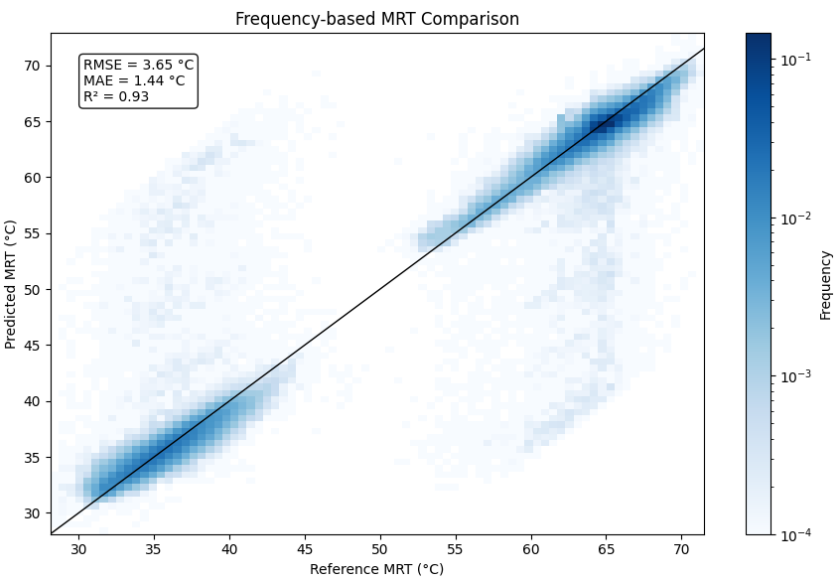
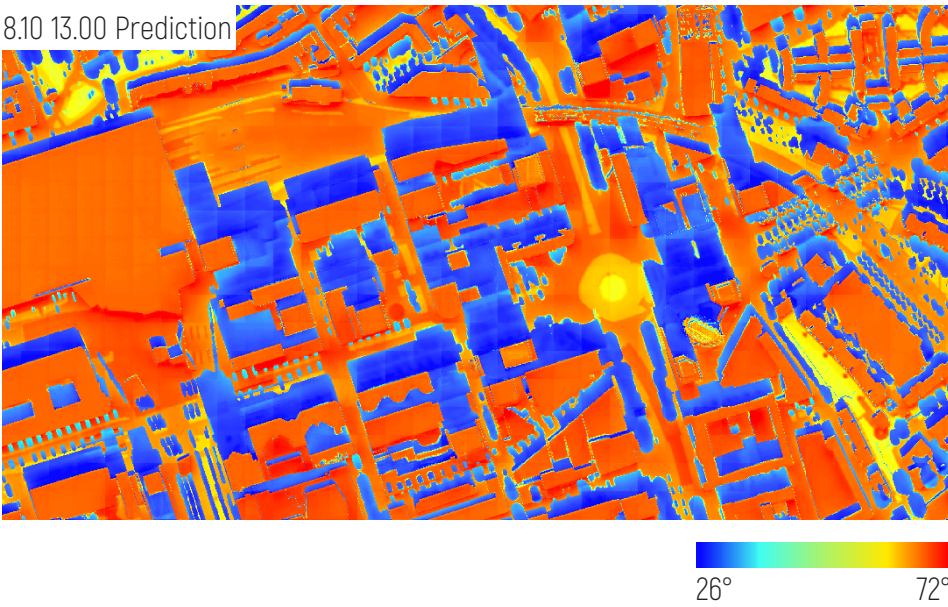
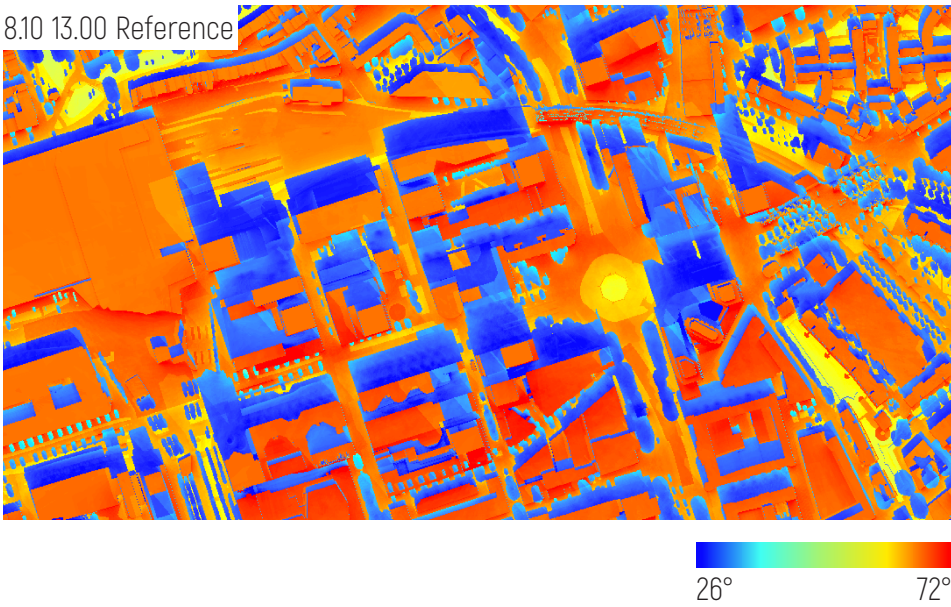
Thermal Mechanism and Training Method



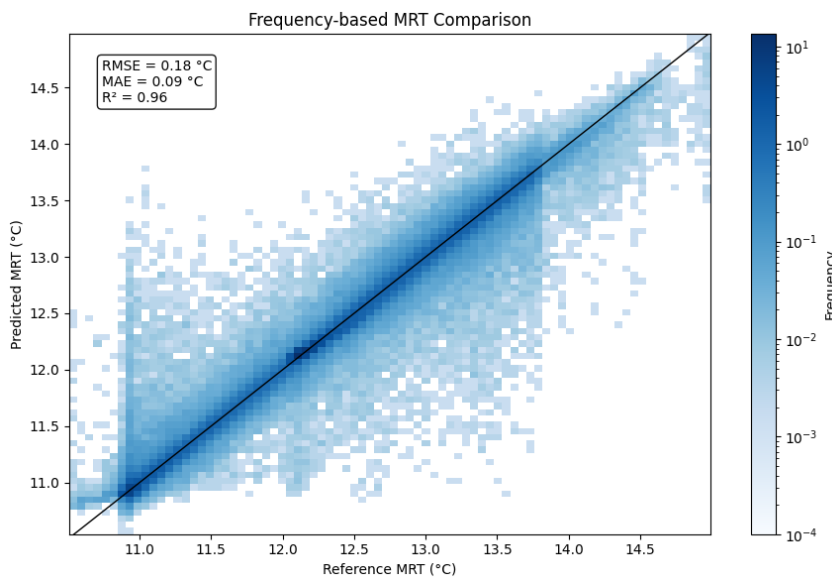
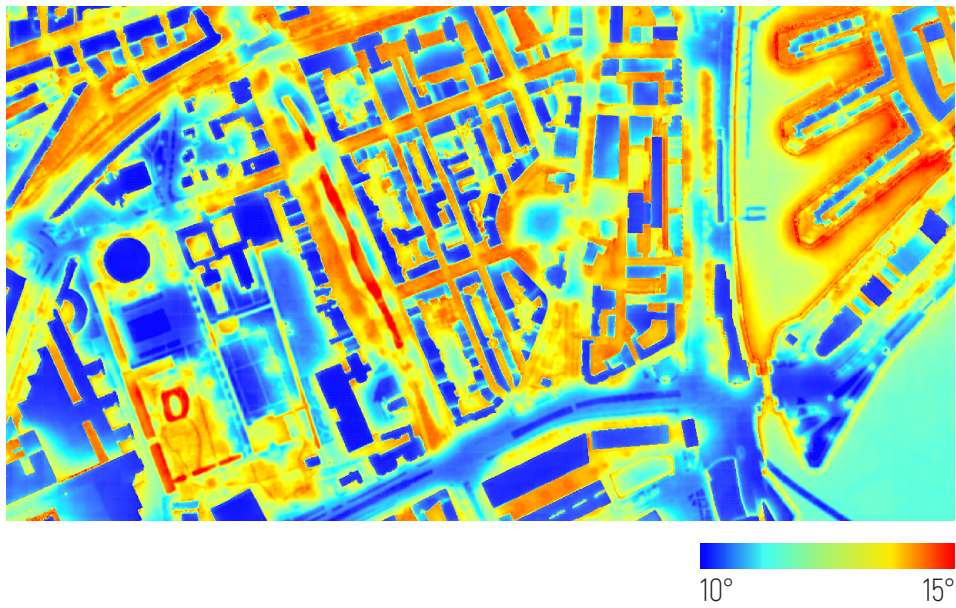
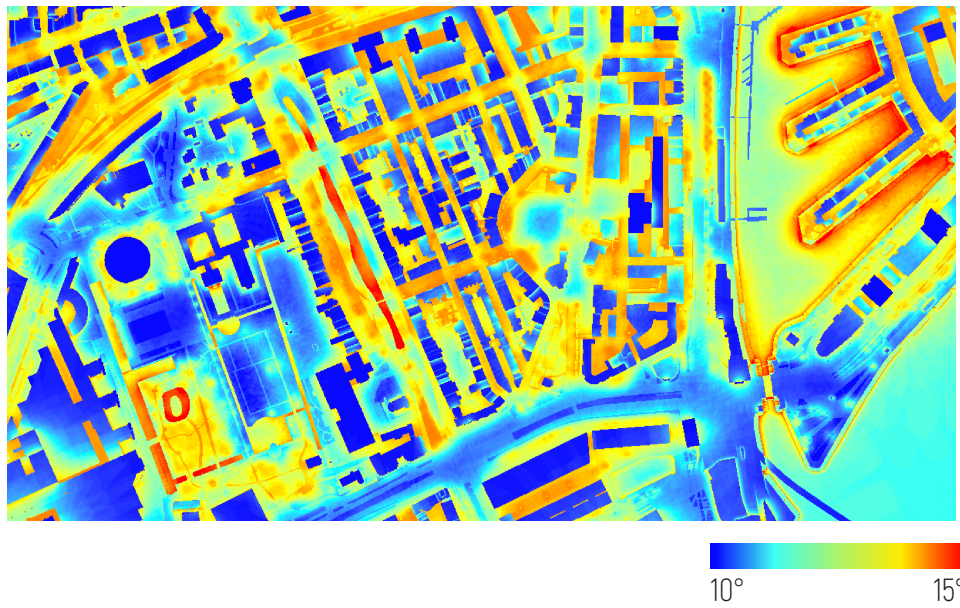
Evaluation: Day MRT



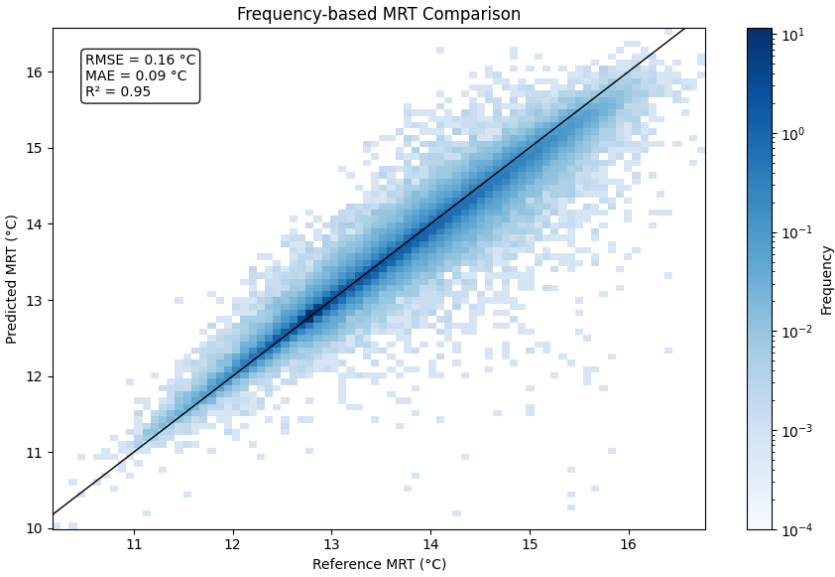
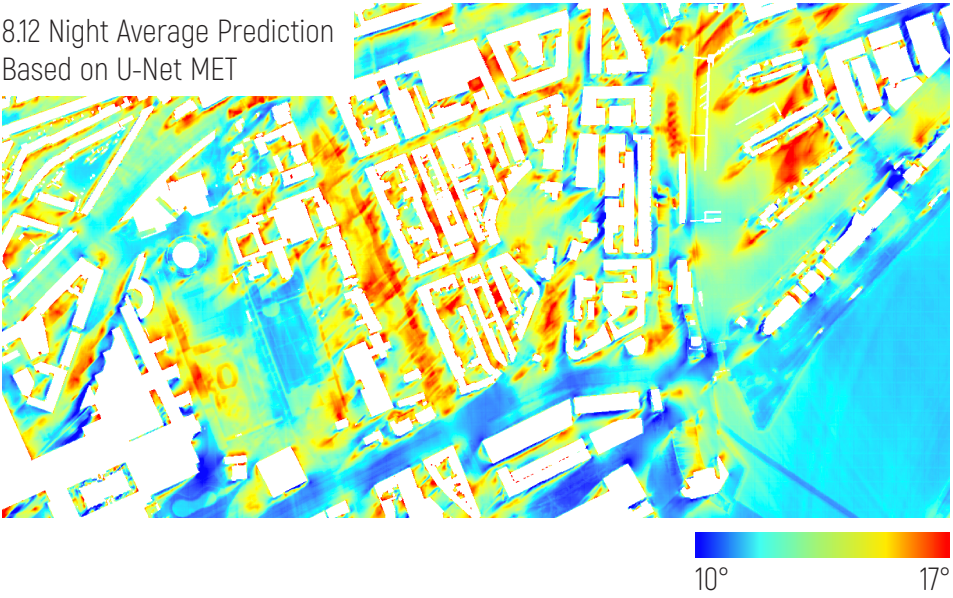
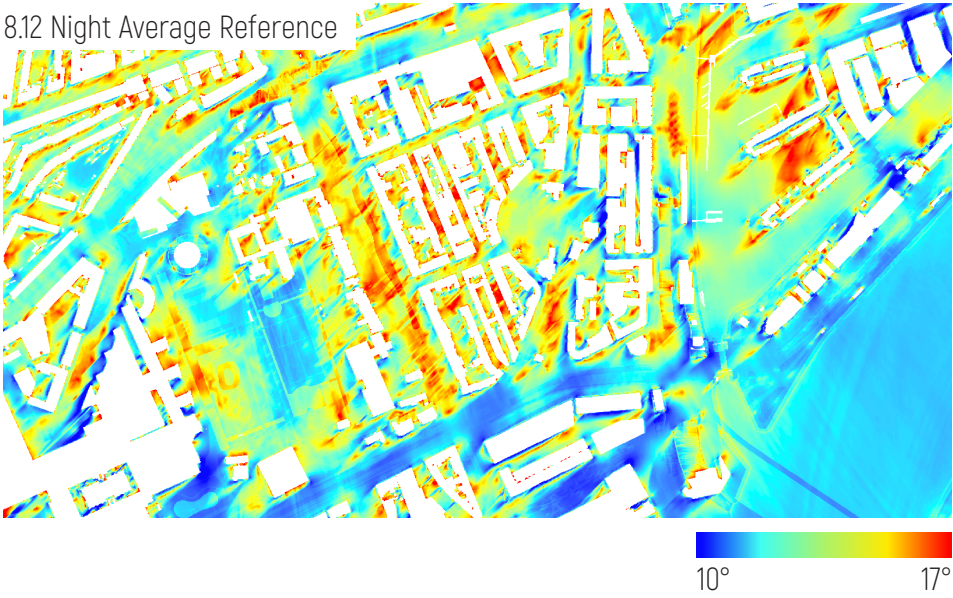
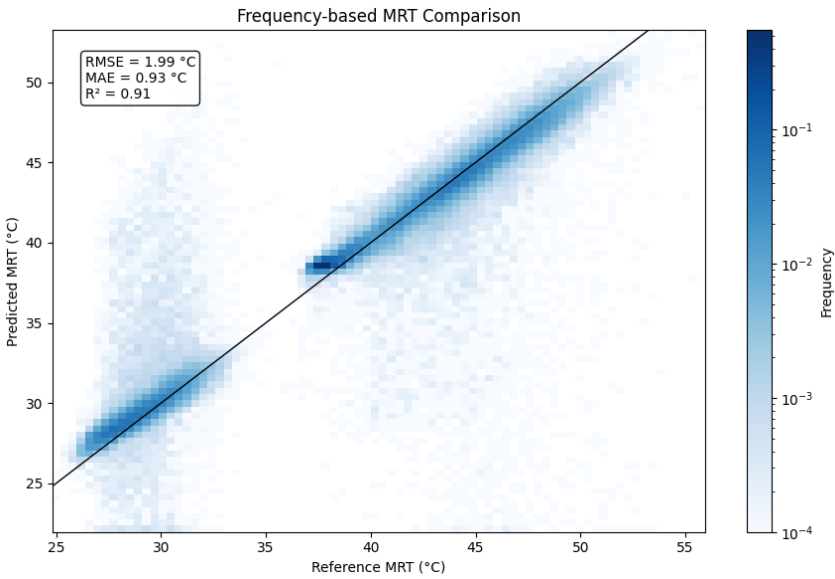
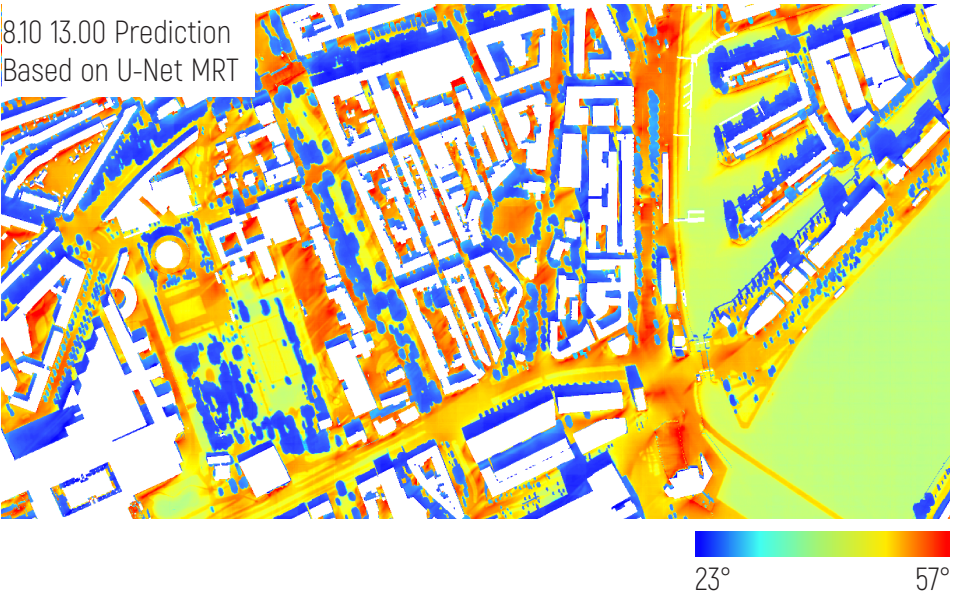
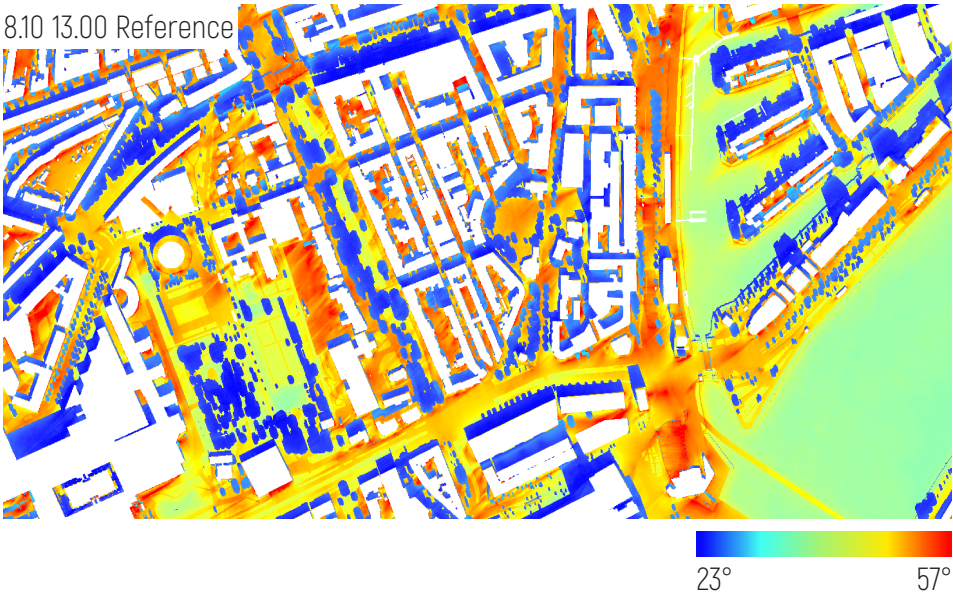
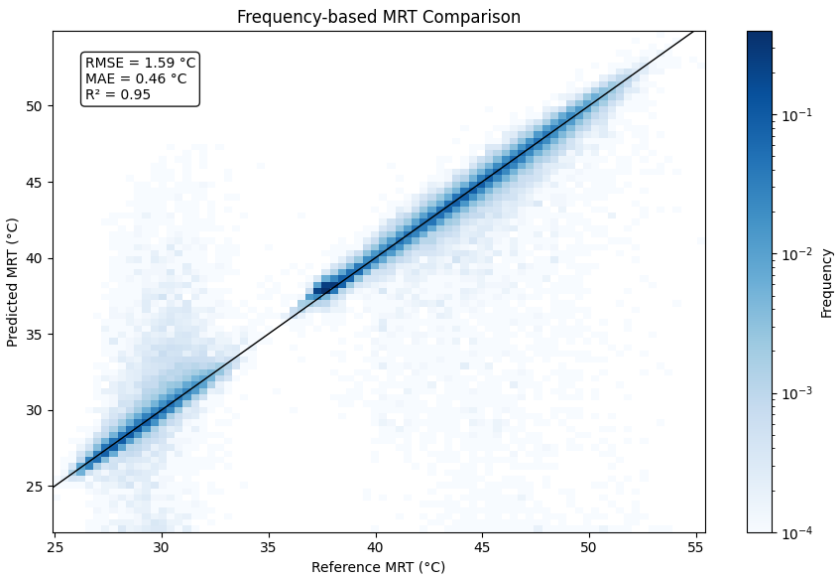
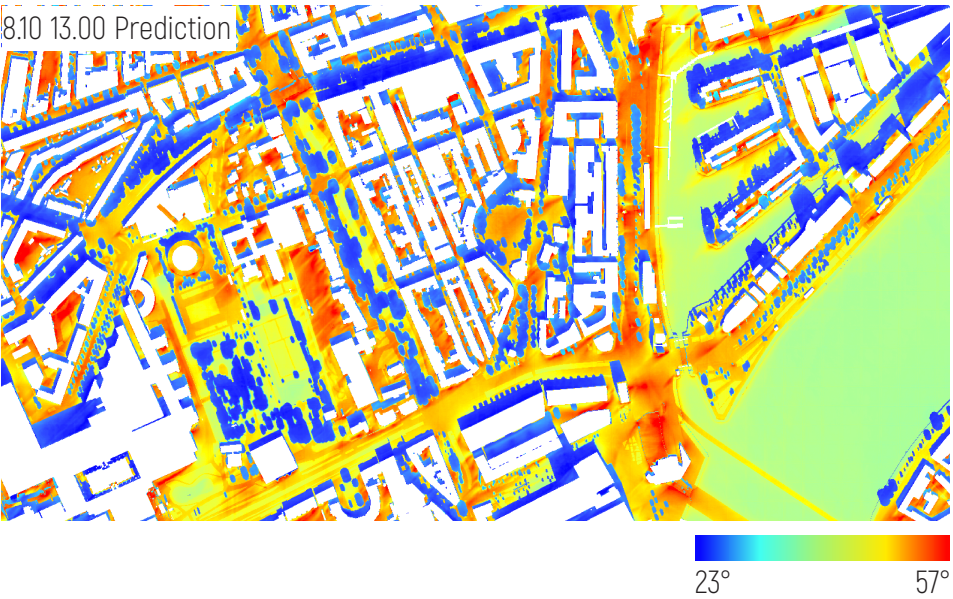
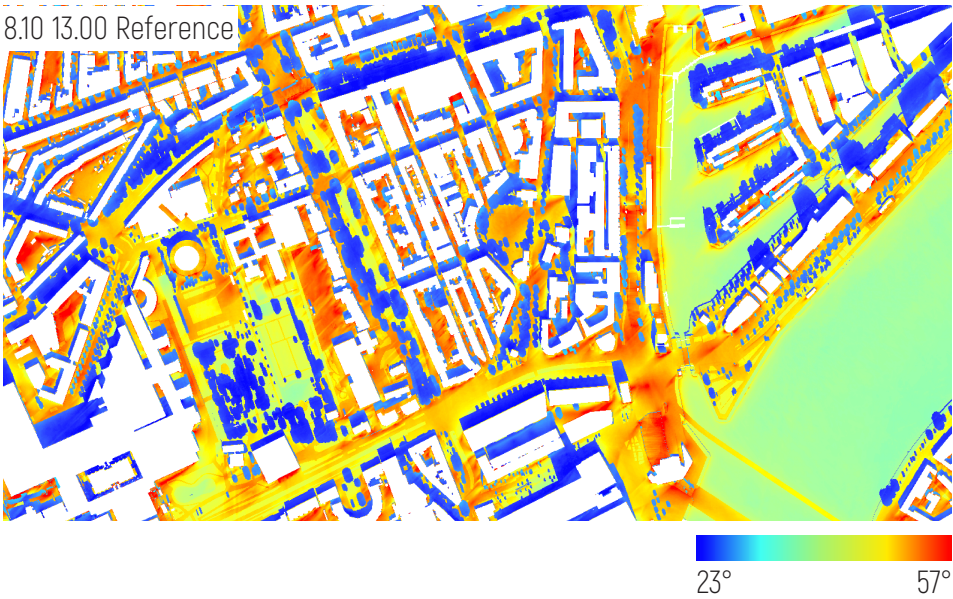
Evaluation: Day MRT



Evaluation: Night Average MRT



Evaluation: PET



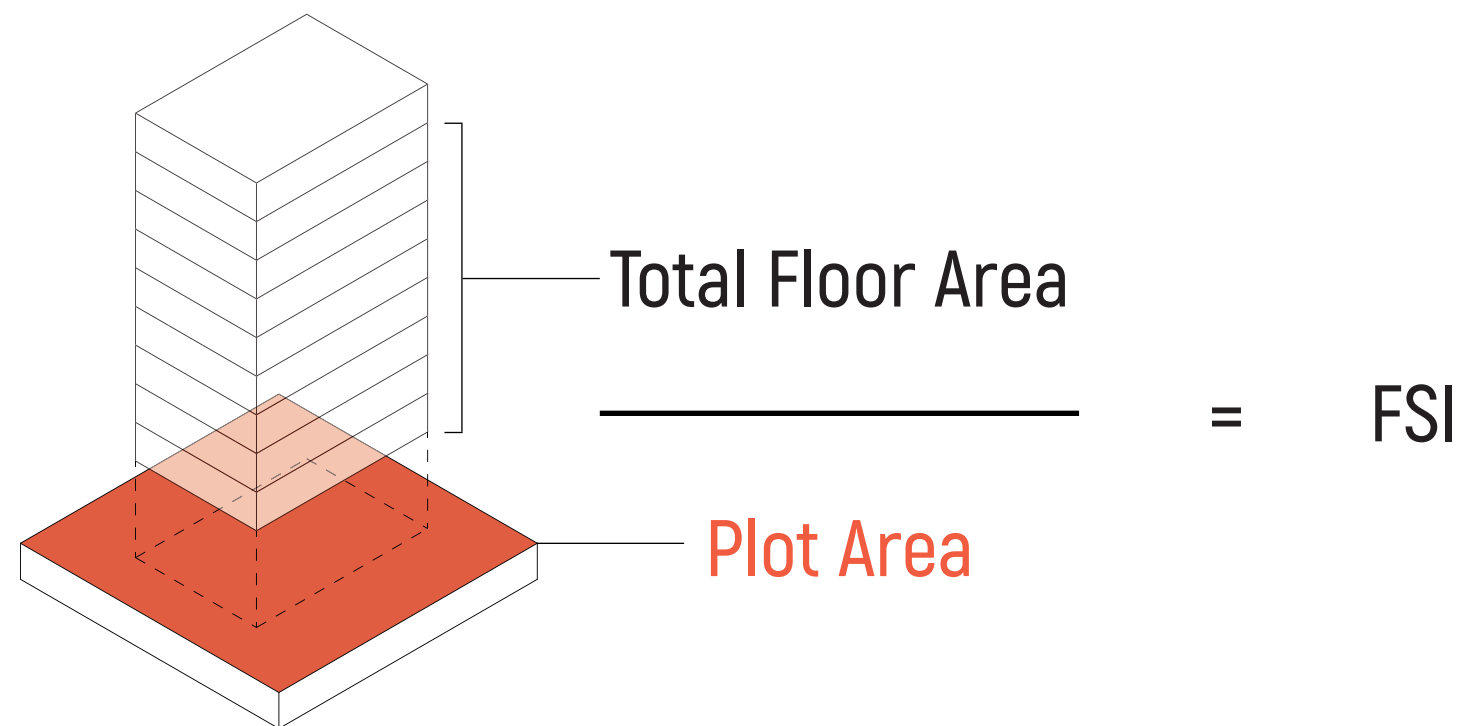
How can technology helps simplify and strengthen the prediction of urban outdoor temperature?

- Much faster than physical models while maintaining high accuracy
- Handles large-scale raster data with rapid output
- Captures complex relationships (shadow, wind, land cover)
- Enables quick testing of multiple design scenarios

Exploration of Densification Scenarios

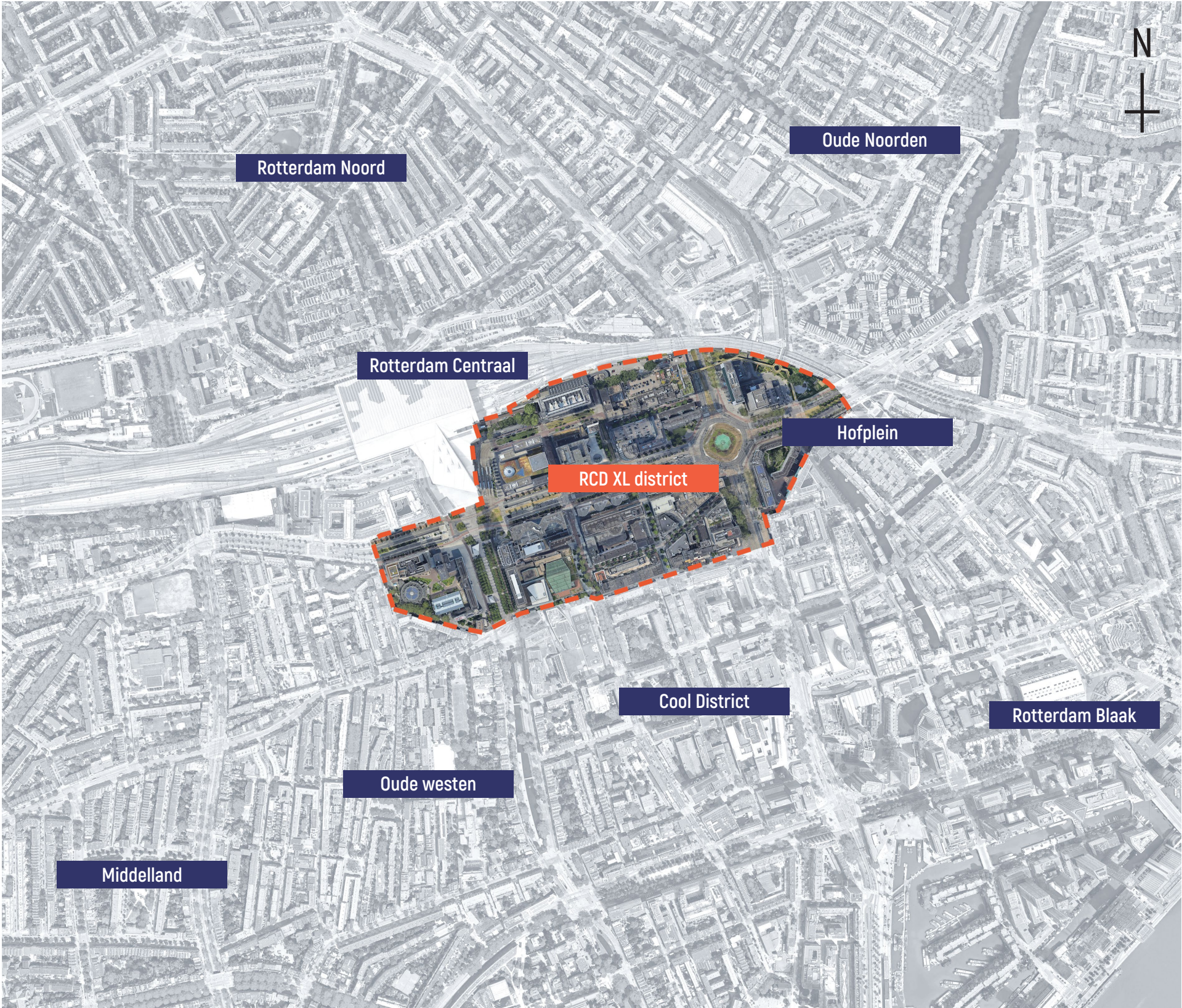
Floor Space Index (FSI)

Floor Space Index (FSI) is the ratio of a building's total constructed floor area to the size of its land plot, determining maximum building density.



Location

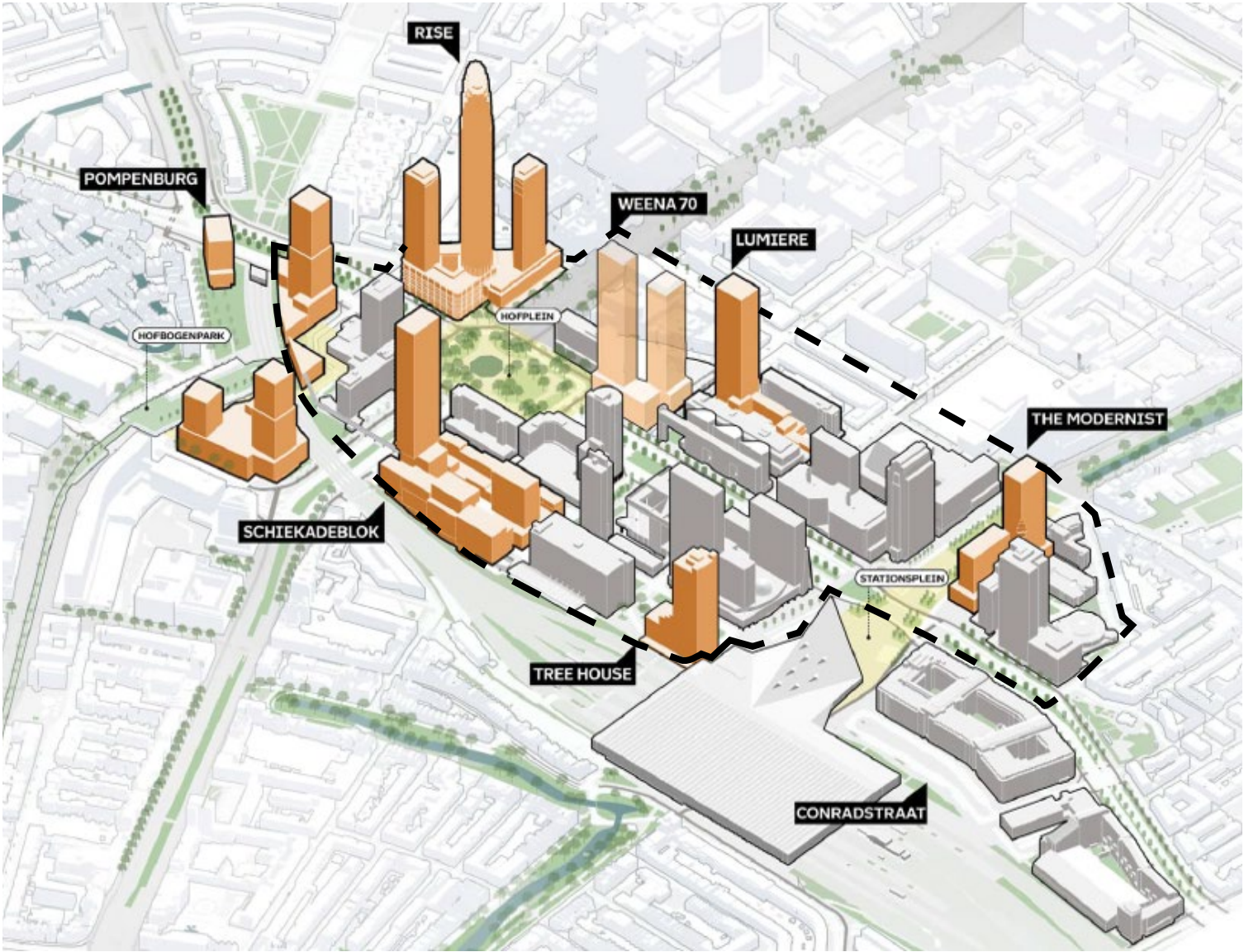
Floor Space Index (FSI) = 3.6



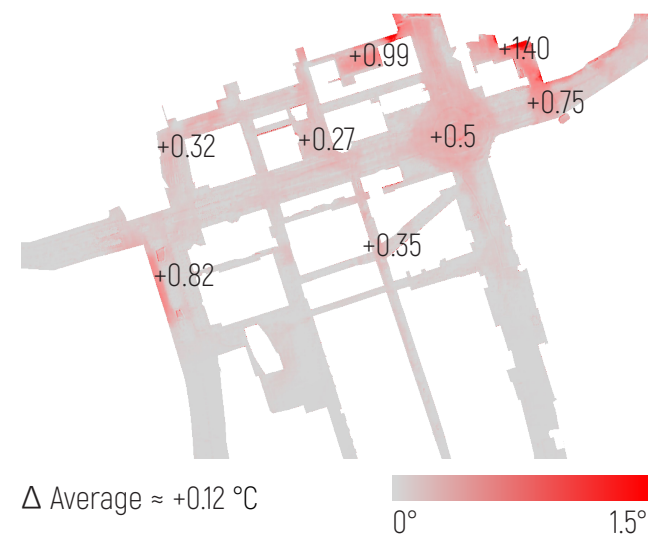
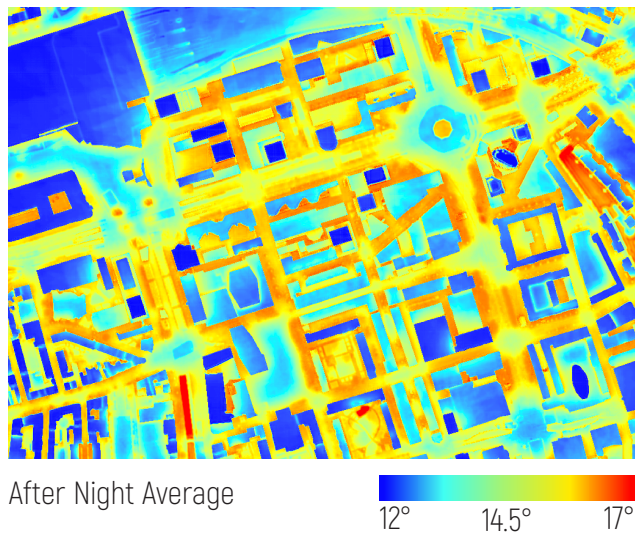
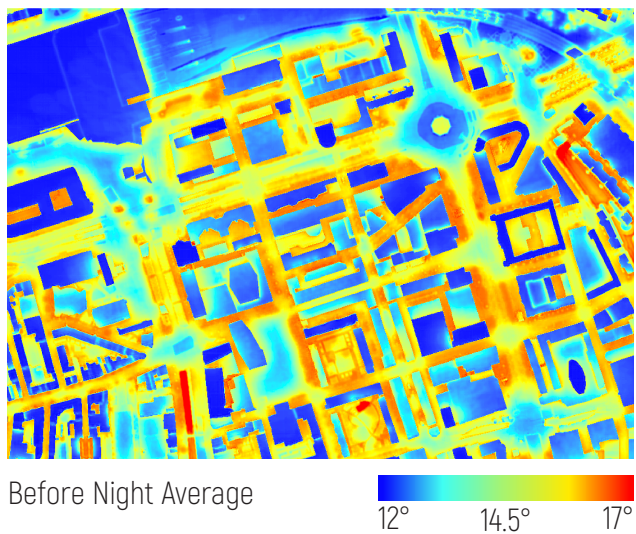
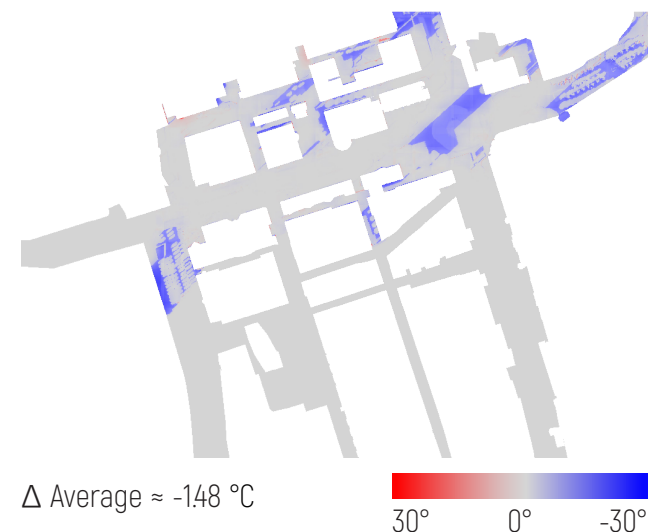
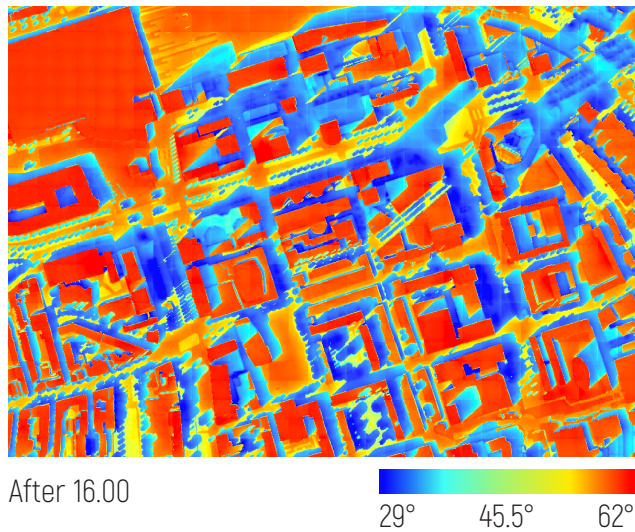
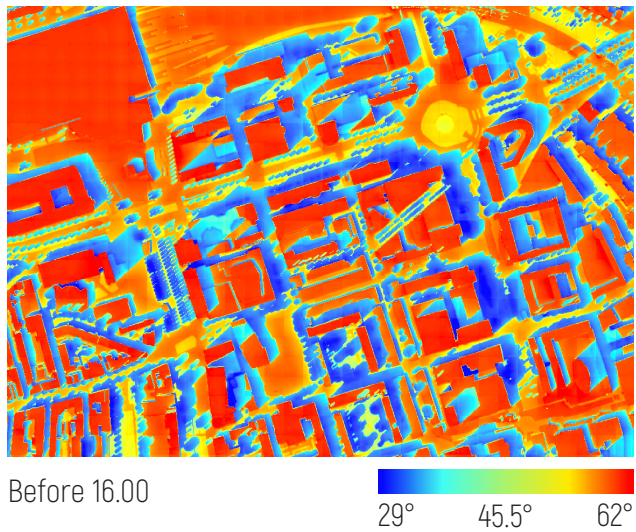
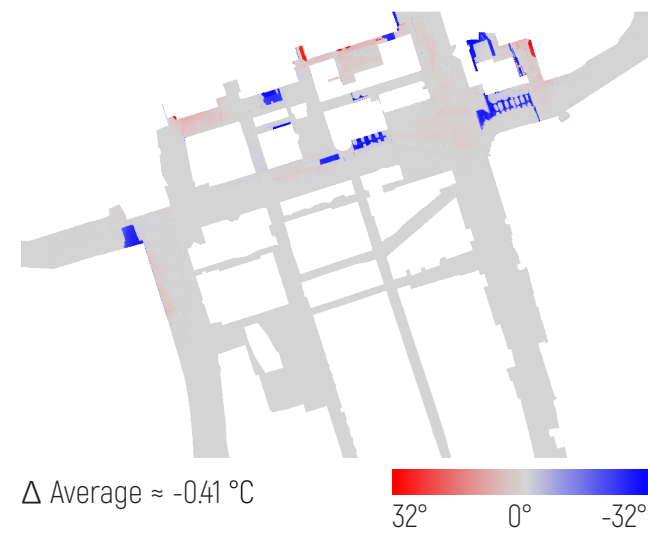
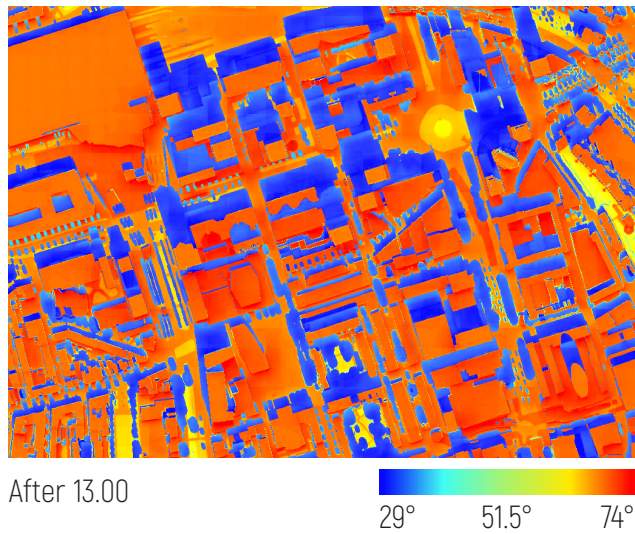
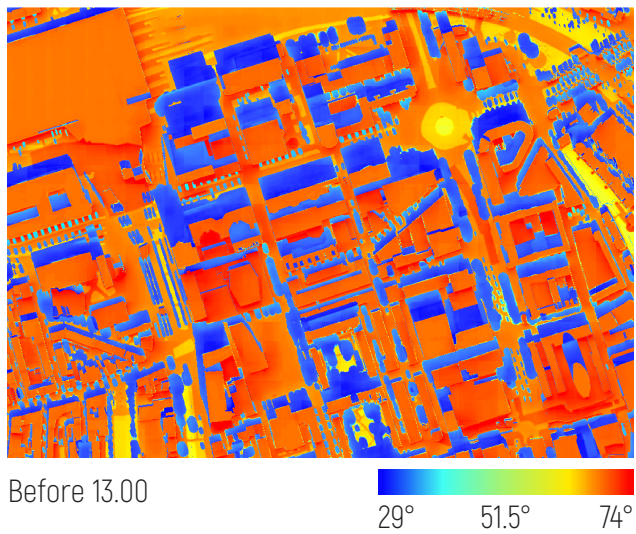
Densification Scenario from Rotterdam

District	Project	Tower	Height (m)
Stadsdriehoek	Post	Toren 1	155
	Pompenburg	Toren 1	125
		Toren 2	115
		Toren 3	70
		Toren 4	70
		Rise	Hofpleintoren
		Weenatoren	158
		Coolsingeltoren	143
CS-Kwartier	Treehouse	Toren 1	130
	Schiekadeblok	Toren 1	200
		Toren 2	70
	The Modernist	Toren Noord	70
		Toren Zuid	125
Cool	Weena 70	Toren 1	200
		Toren 2	150
	Lumiere	Toren 1	155

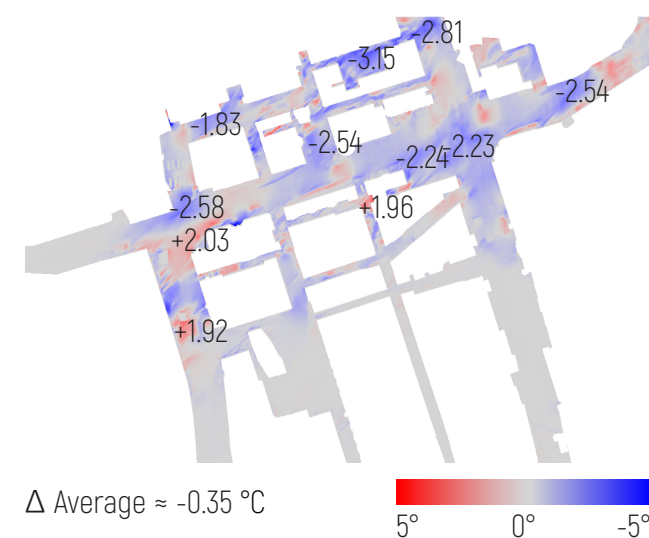
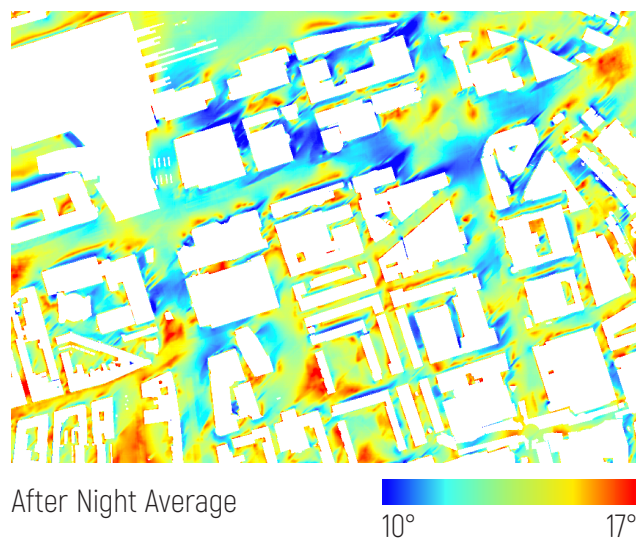
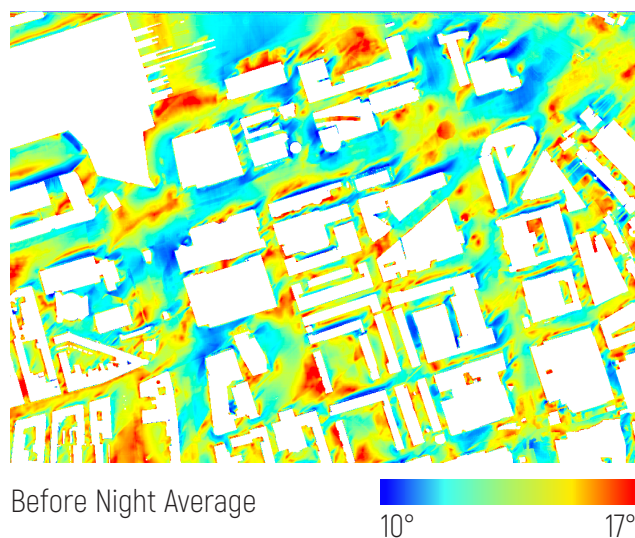
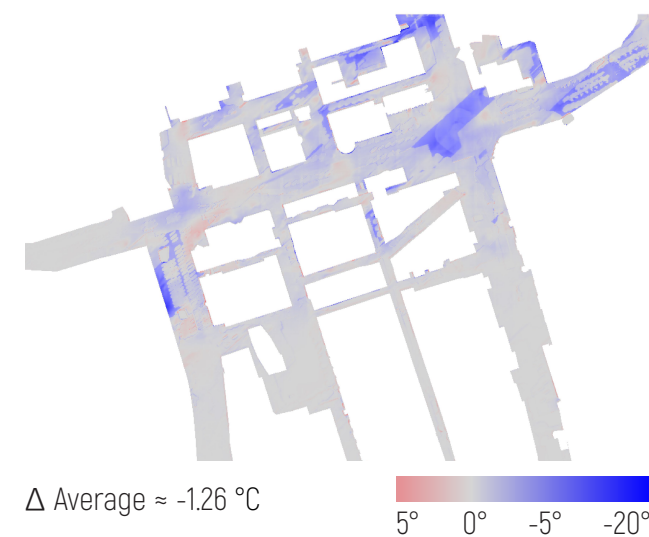
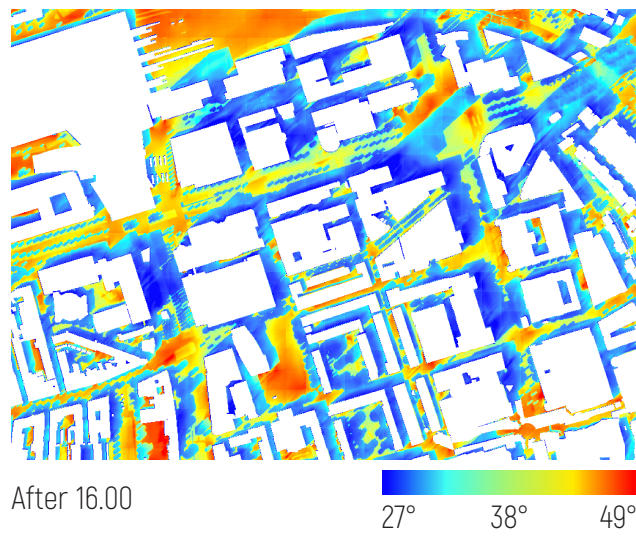
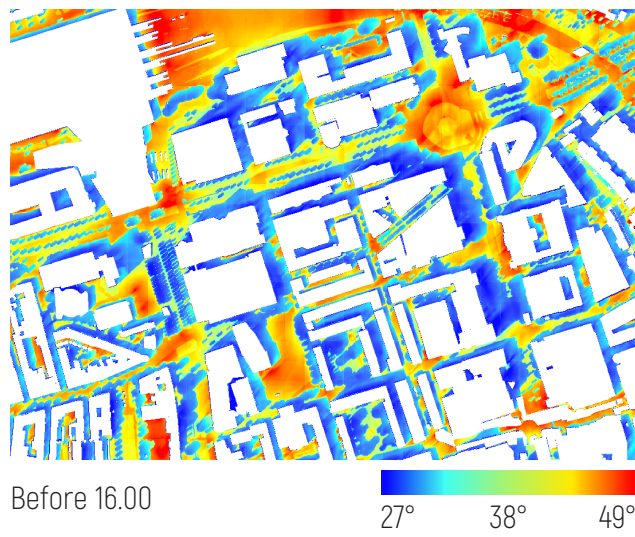
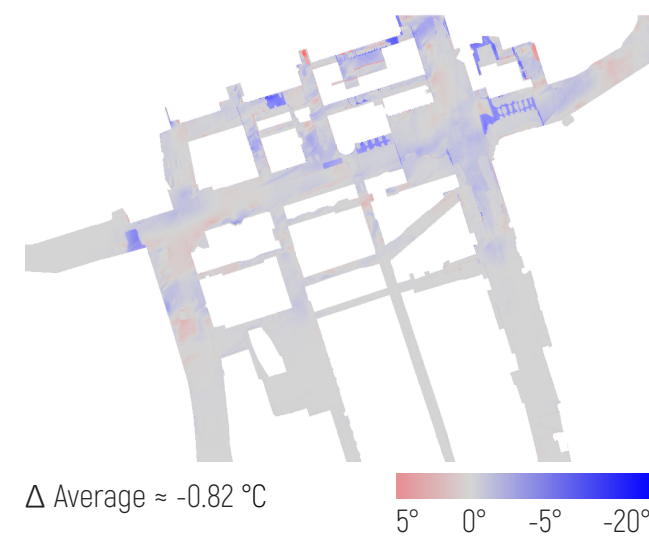
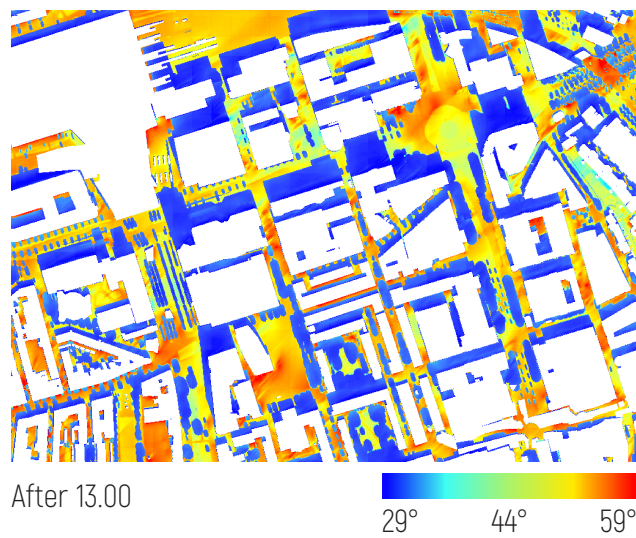
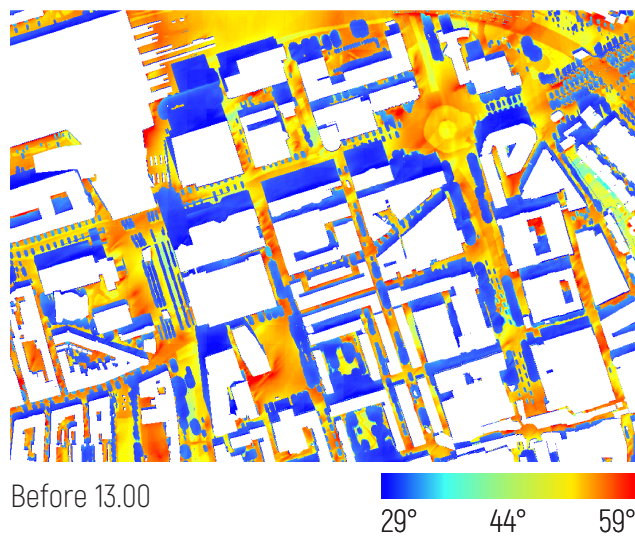
Floor Space Index (FSI)= 5.8



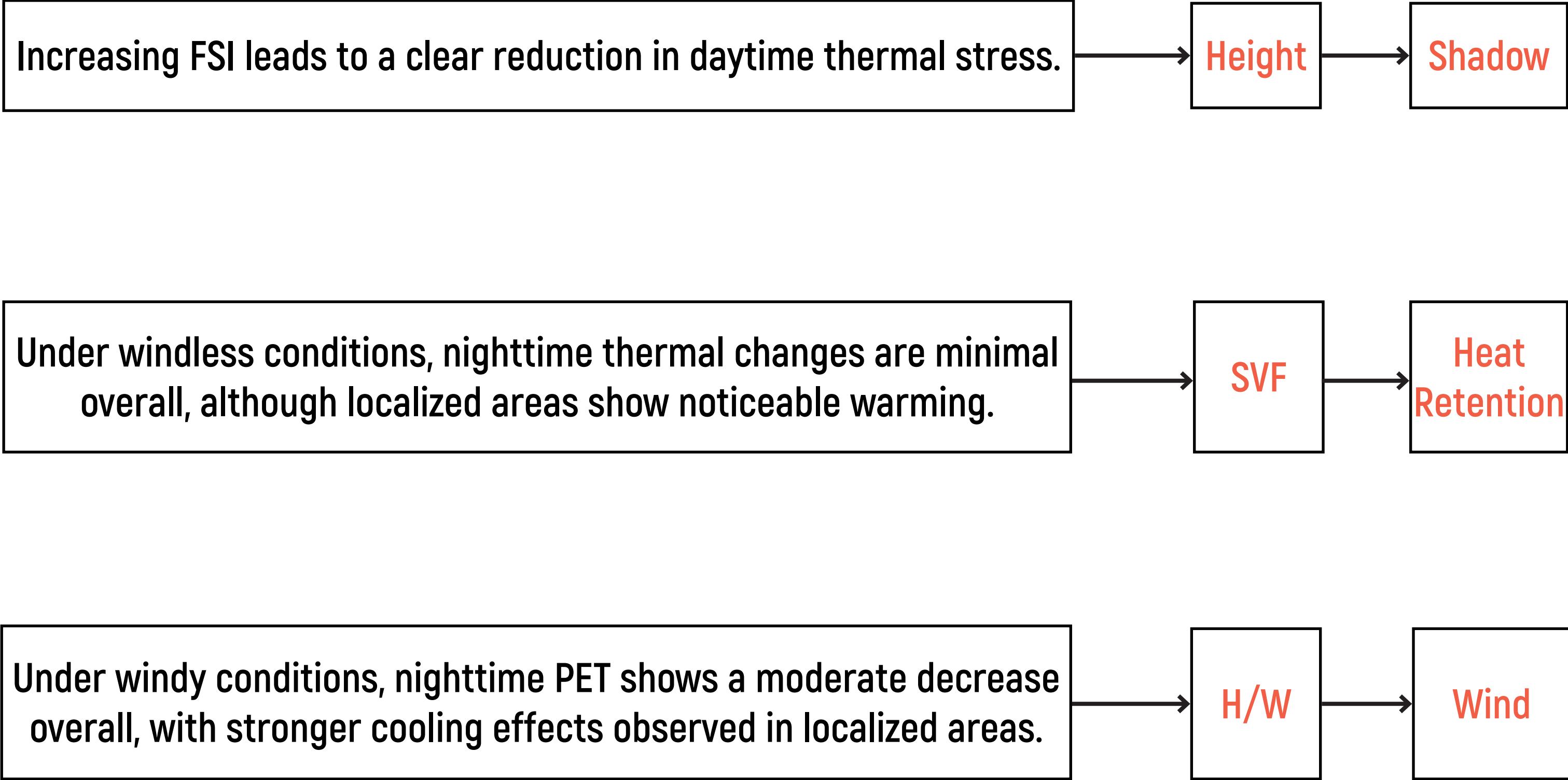
Comparison Before and After Densification: MRT



Comparison Before and After Densification: PET



Conclusion



SPATIAL CONFIGURATION EXPLORATION

Design Logic

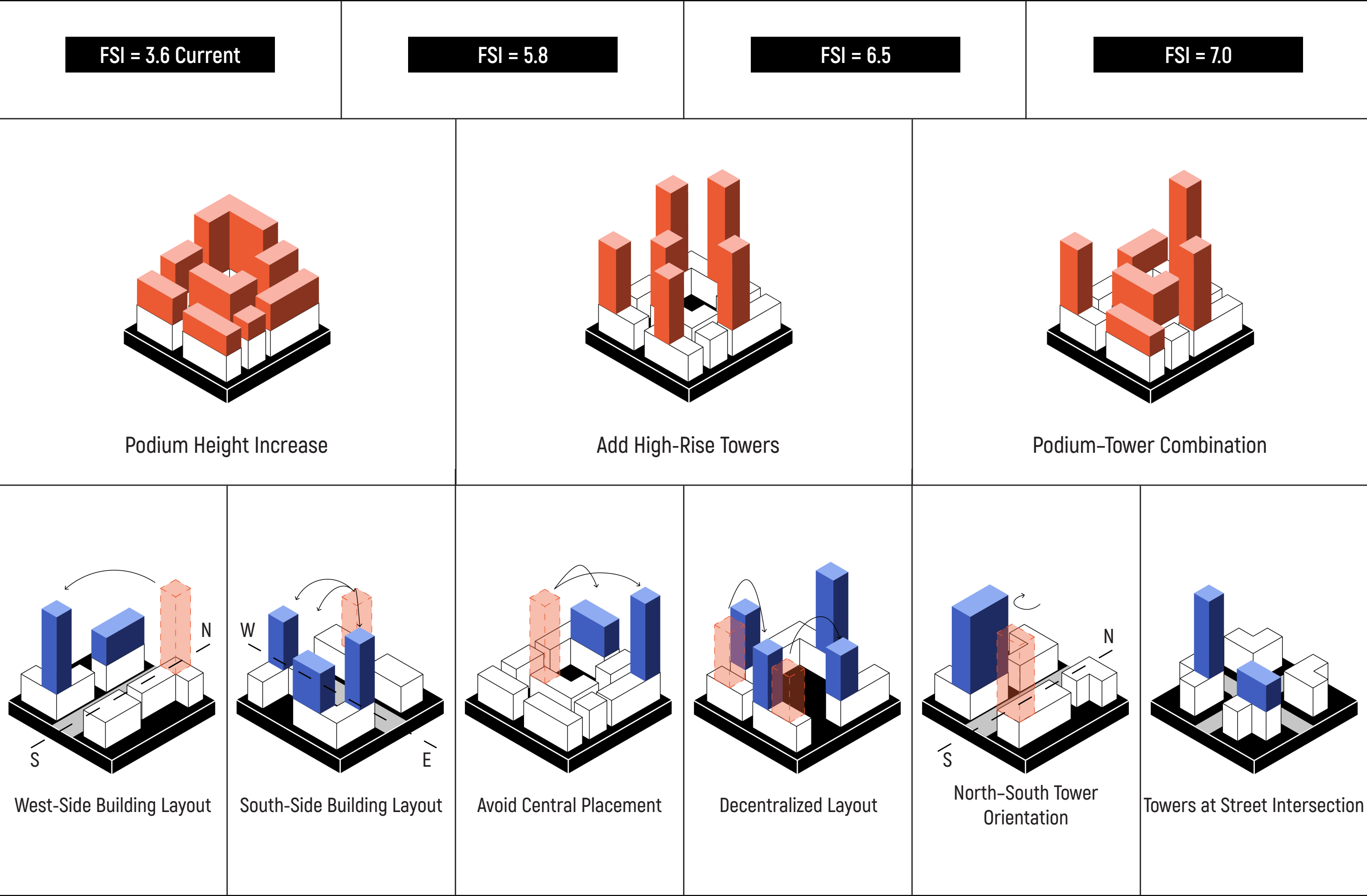
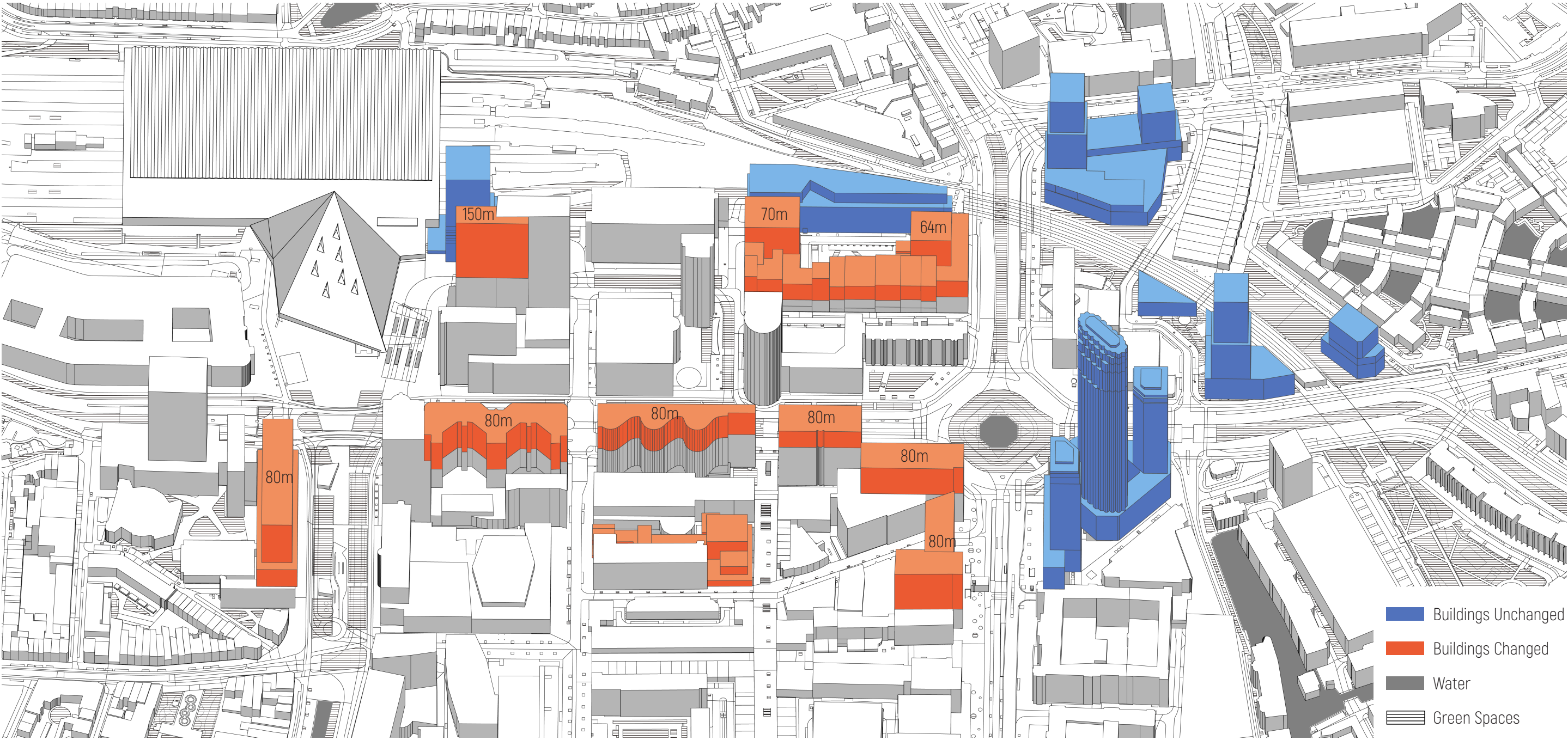
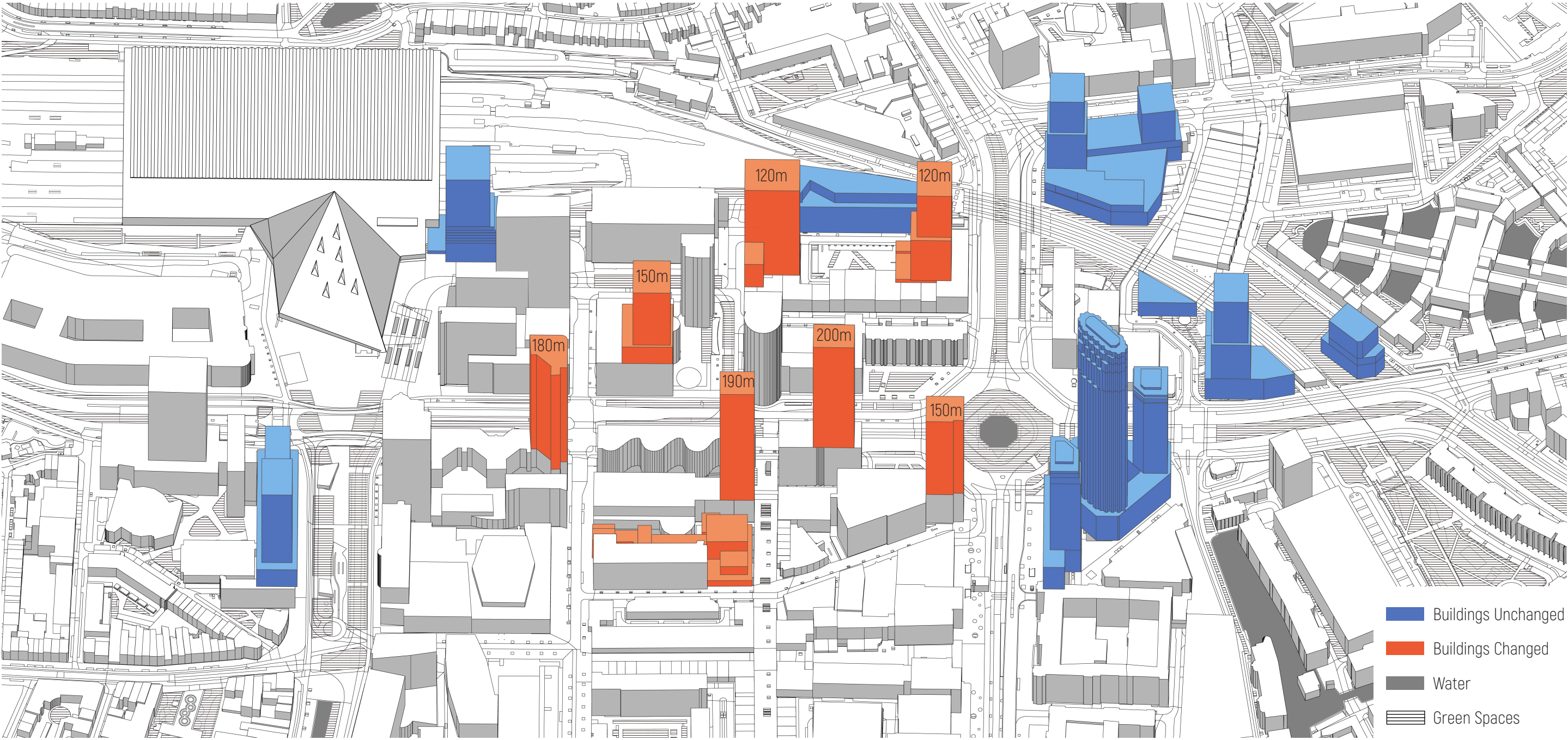


Figure x: Design Logic of Densification Scenarios. [Source: By Author]

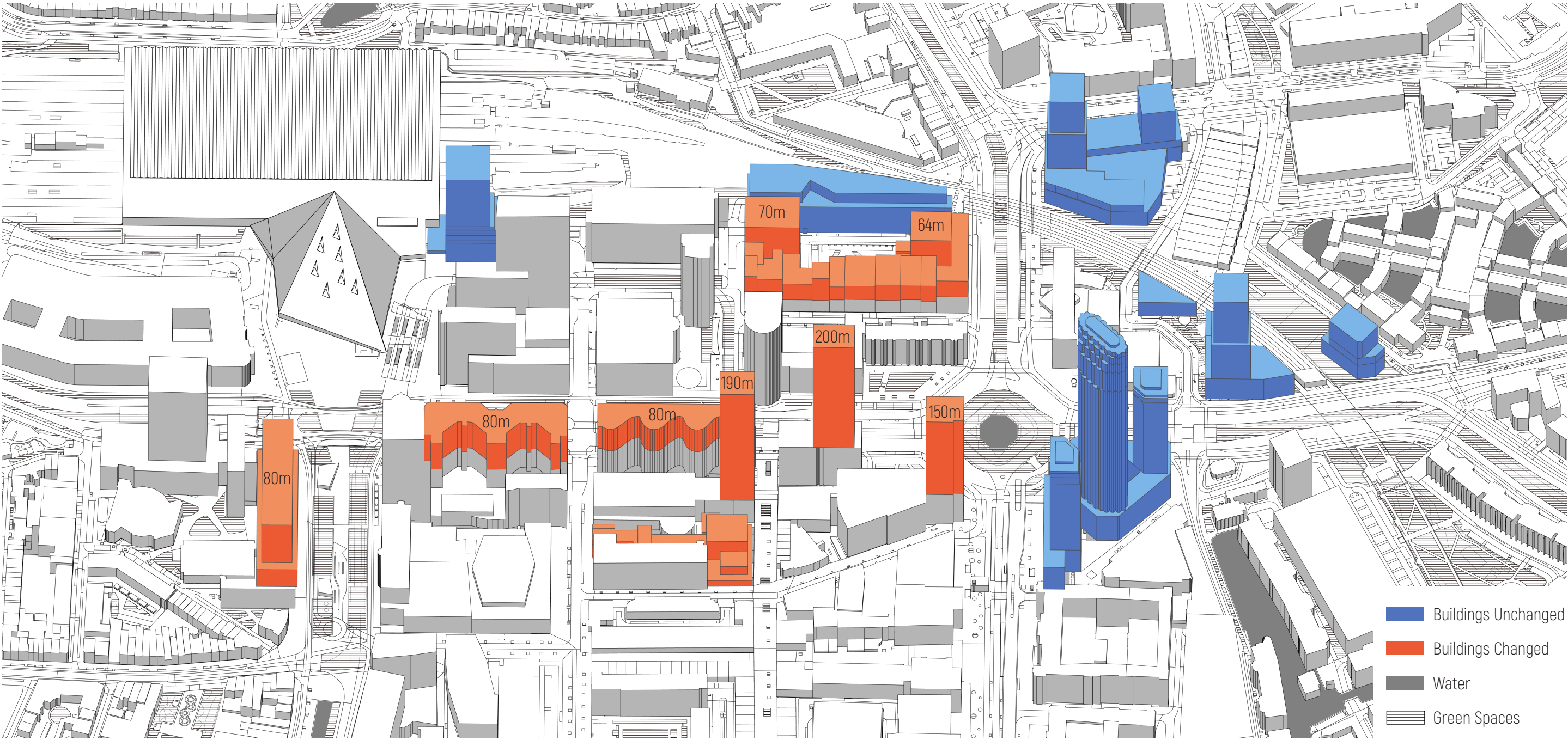
FSI 5.8 POIDUM



FSI 5.8 TOWER



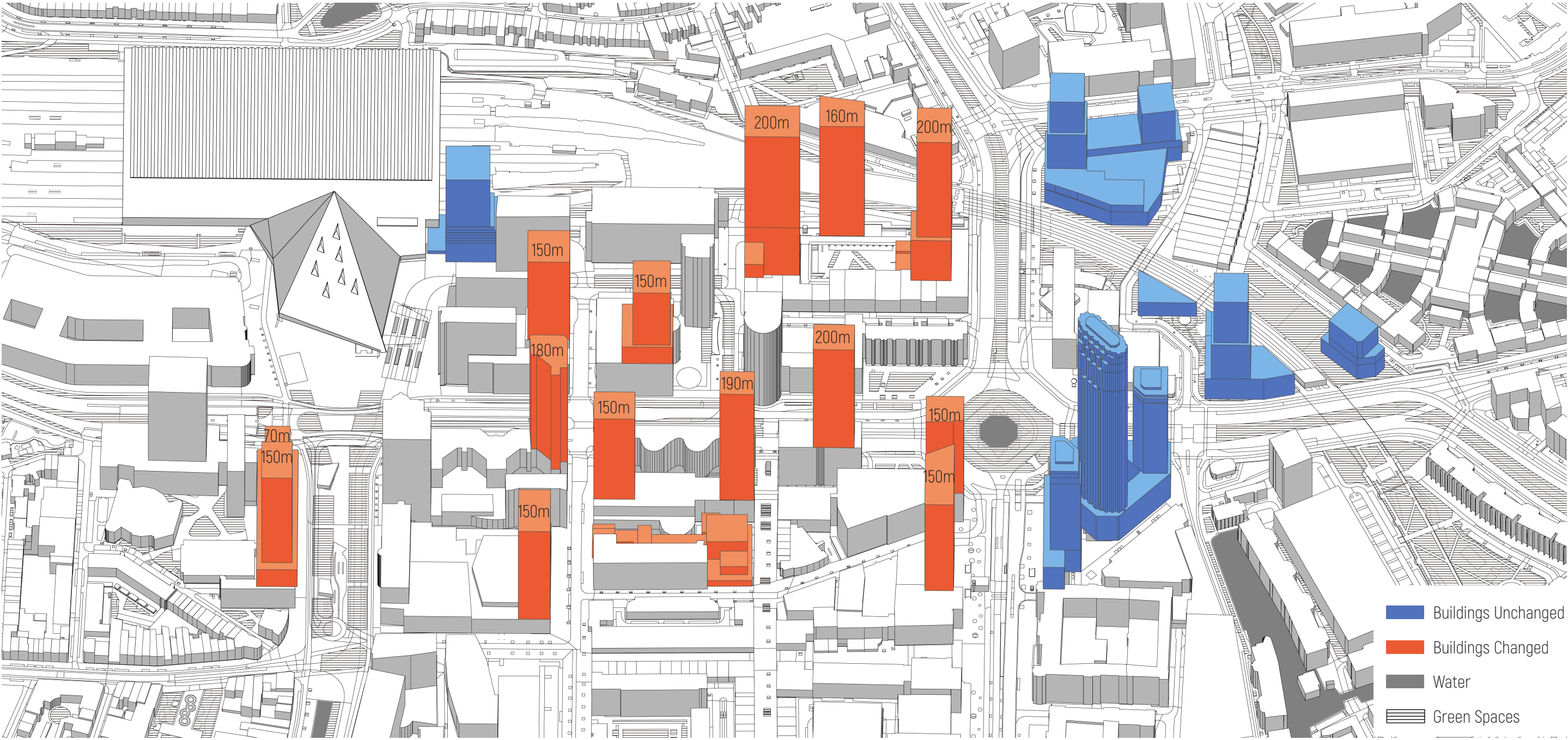
FSI 5.8 COMBINATION



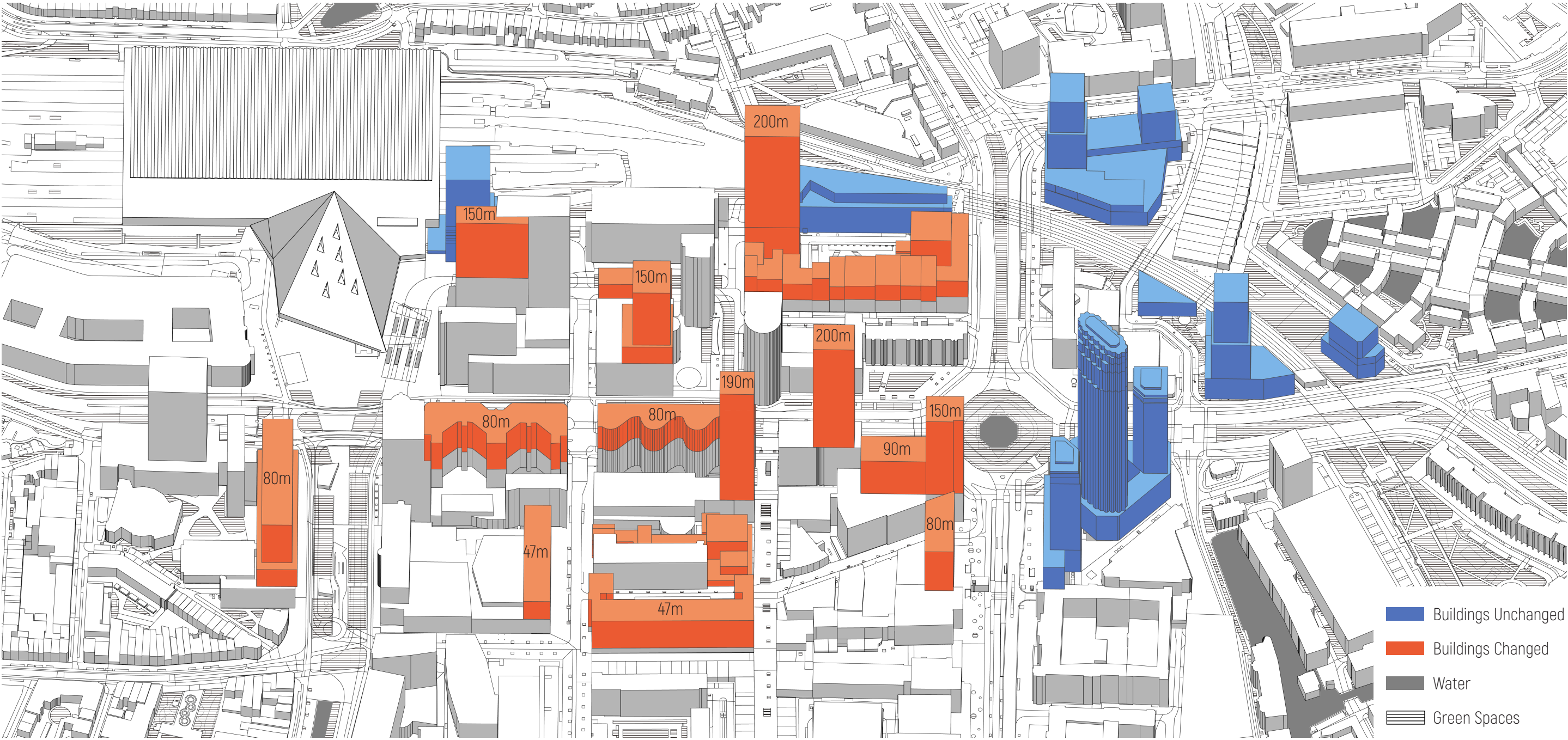
FSI 6.5 POIDUM



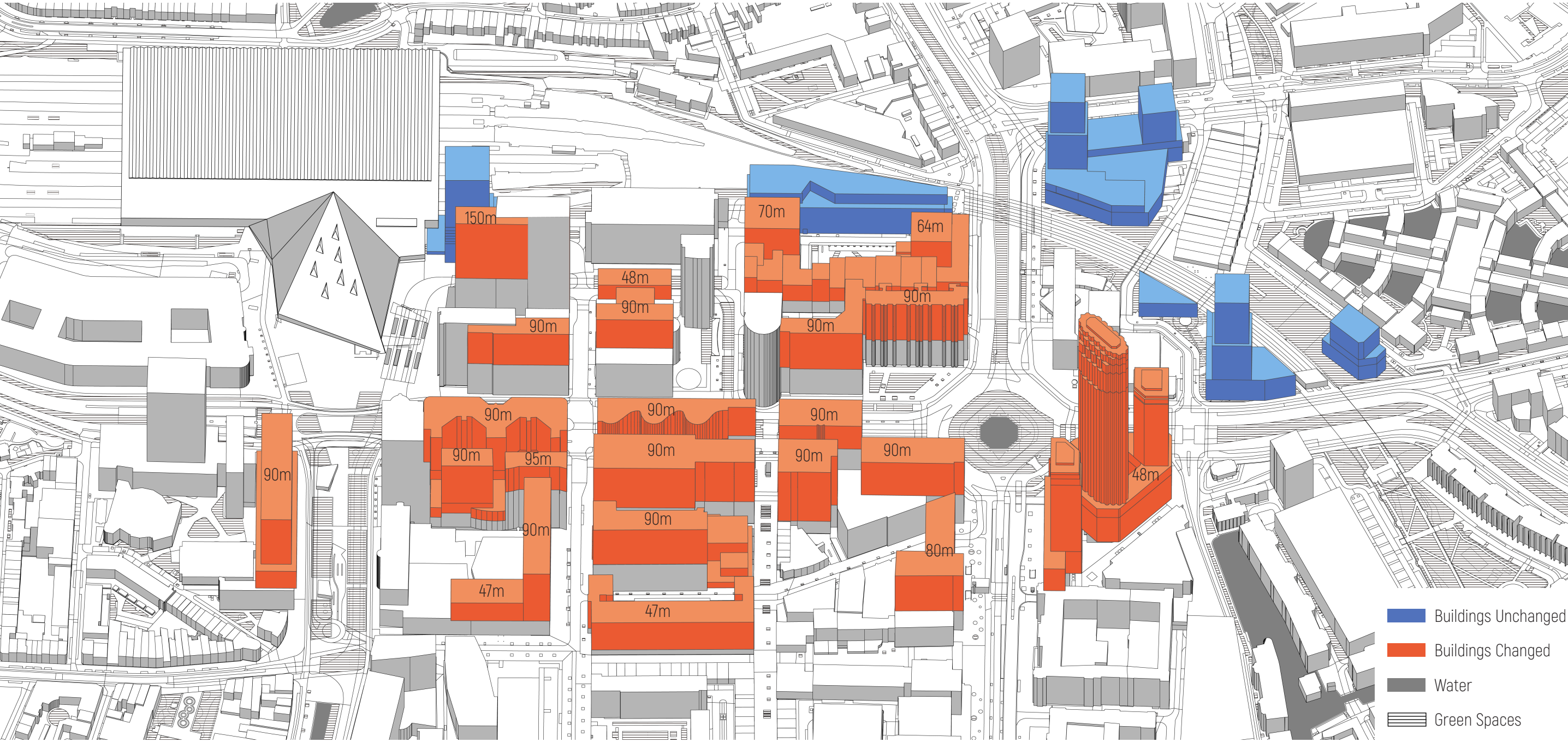
FSI 6.5 TOWER



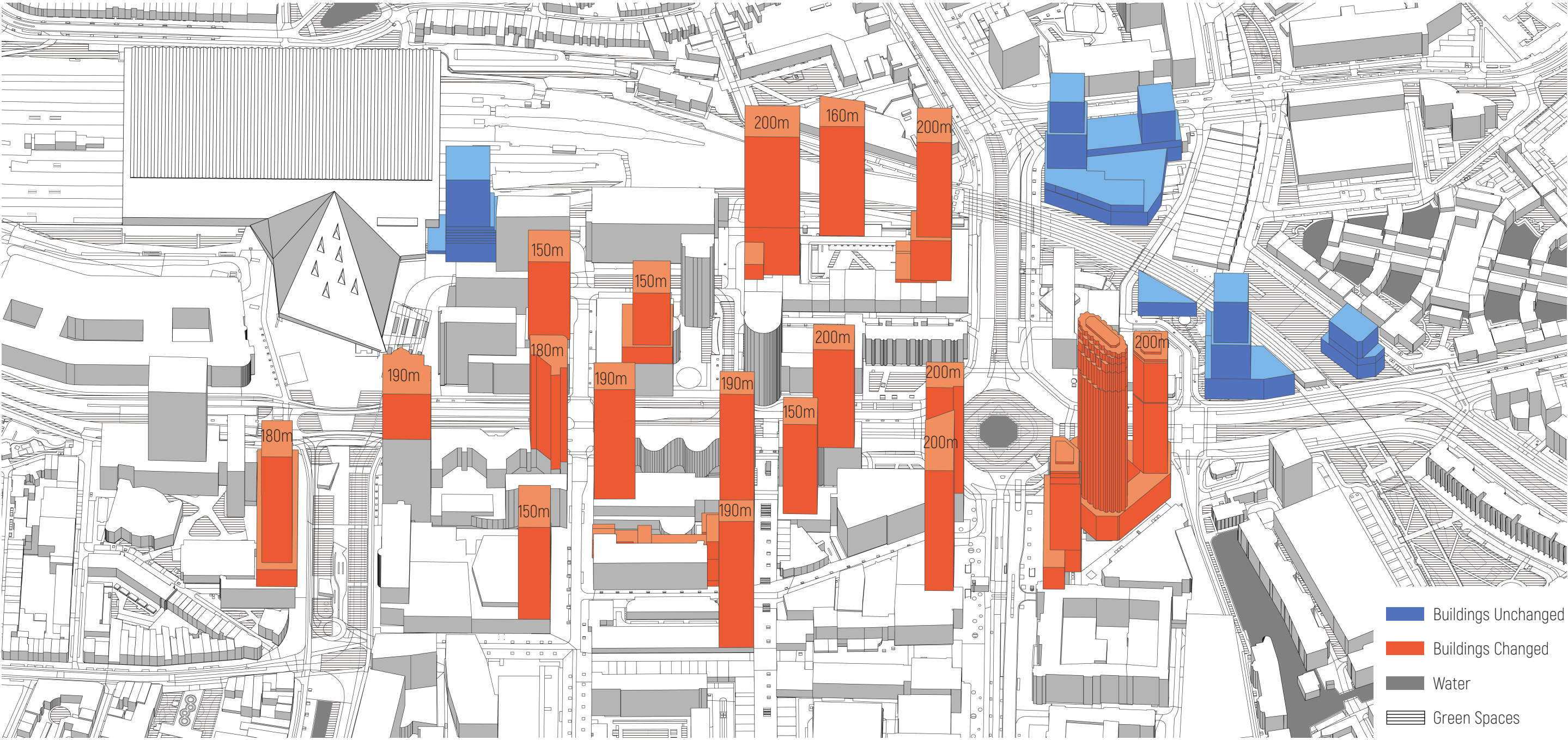
FSI 6.5 COMBINATION



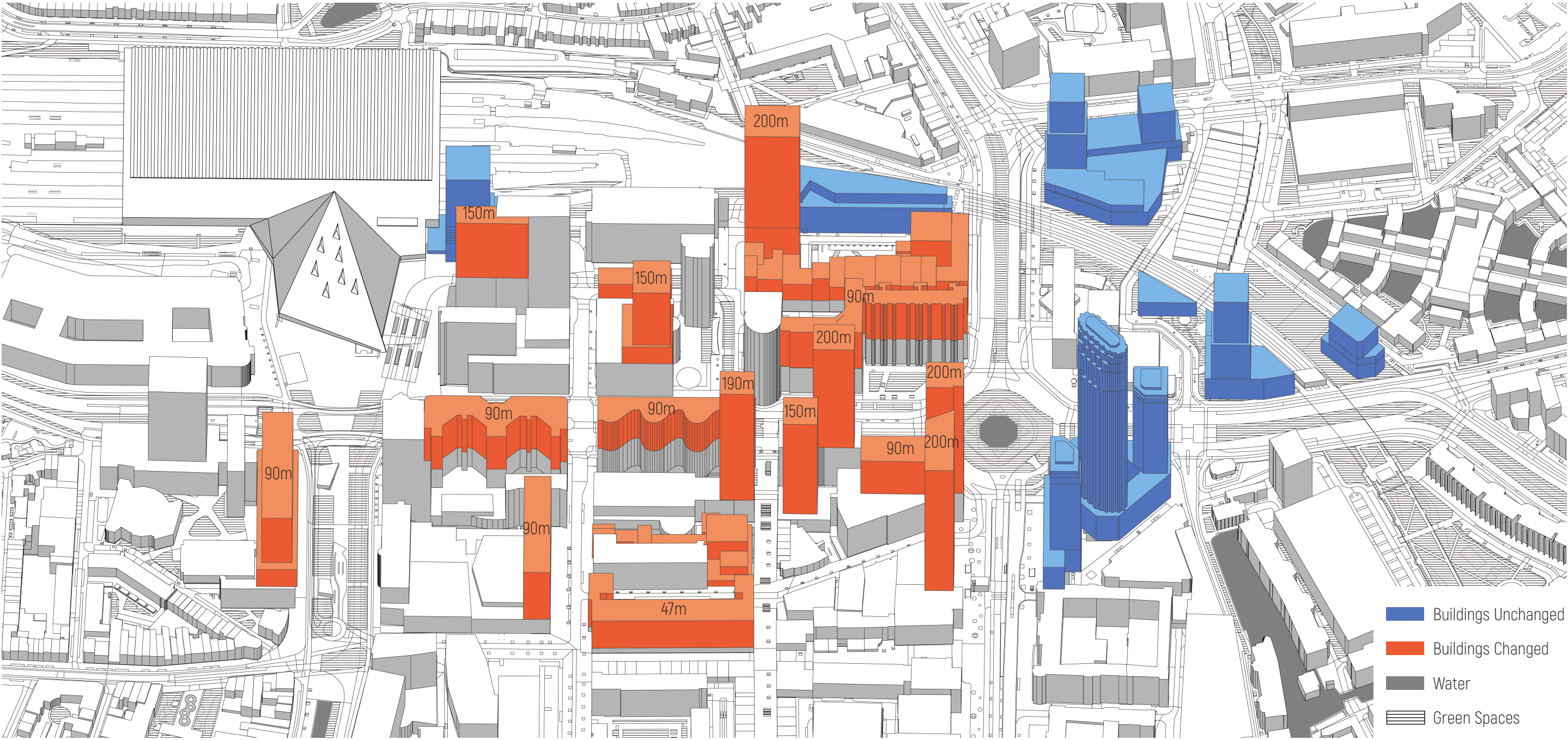
FSI 7.0 POIDUM



FSI 7.0 TOWER



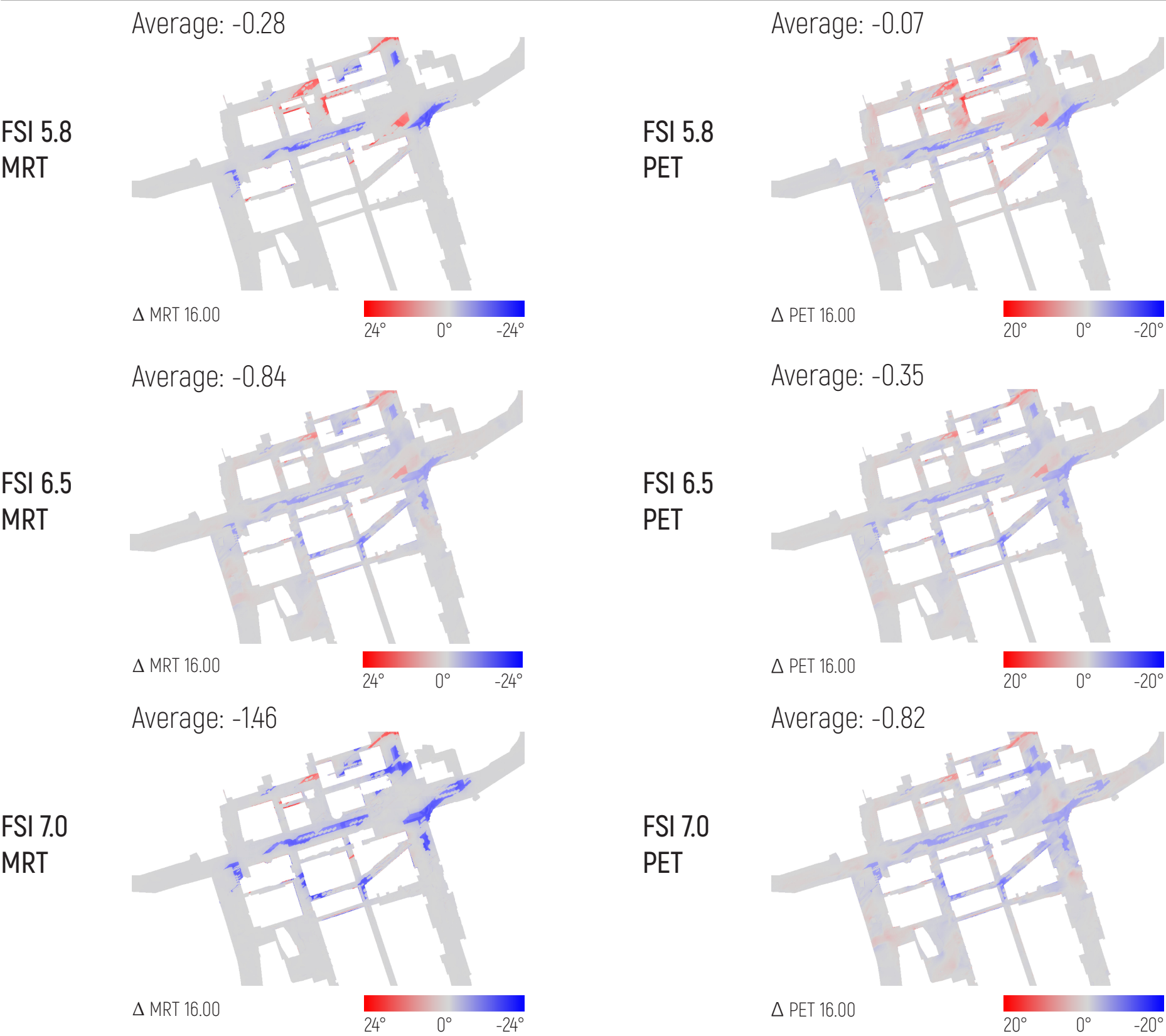
FSI 7.0 COMBINATION



Effect of FSI

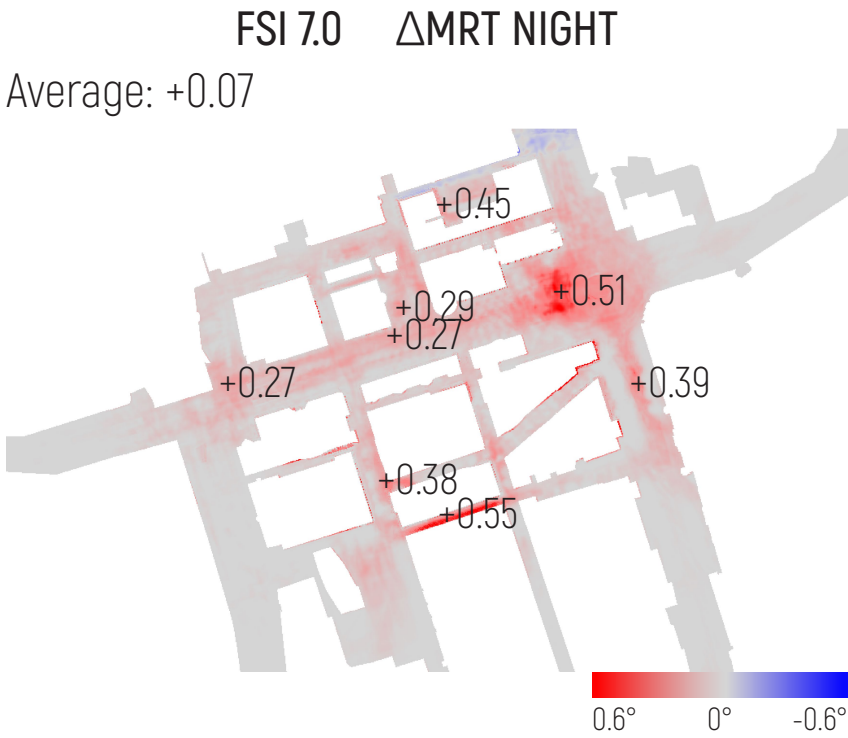
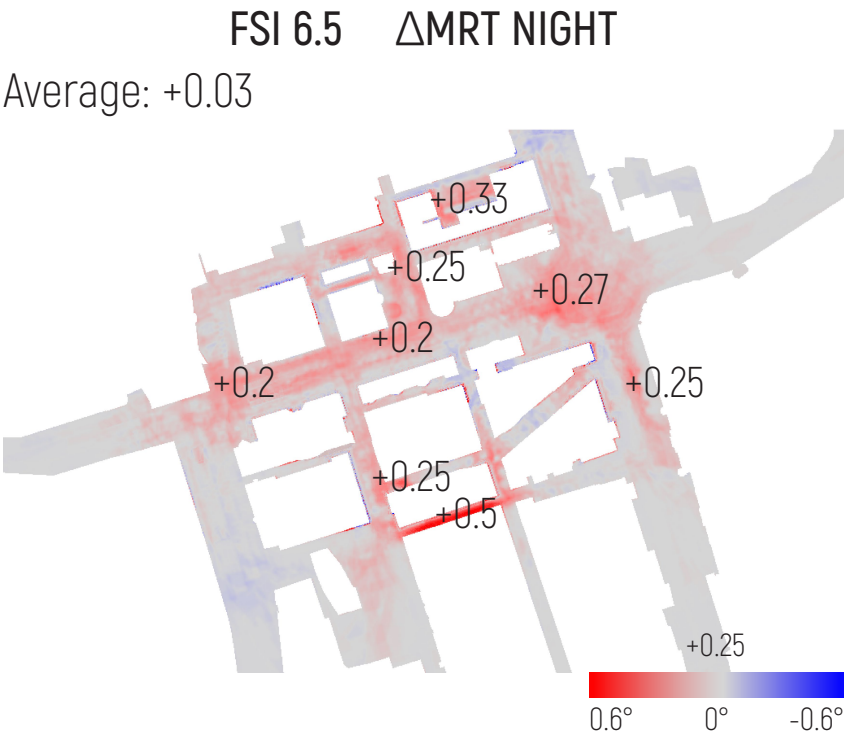
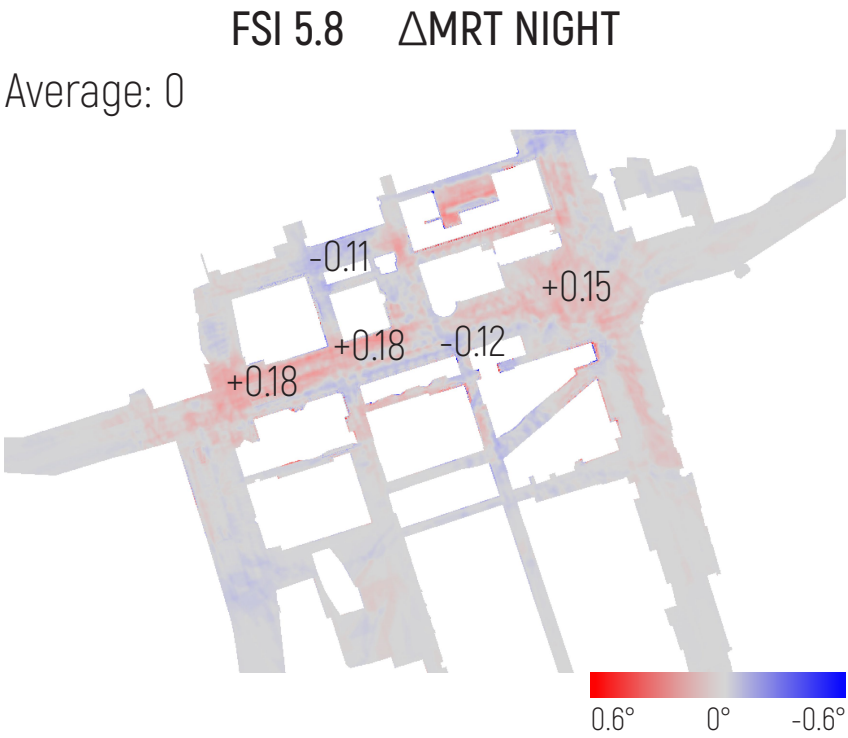
Conclusion: Effect of FSI

Increasing FSI reduces daytime MRT and PET due to enhanced shading.



Conclusion: Effect of FSI

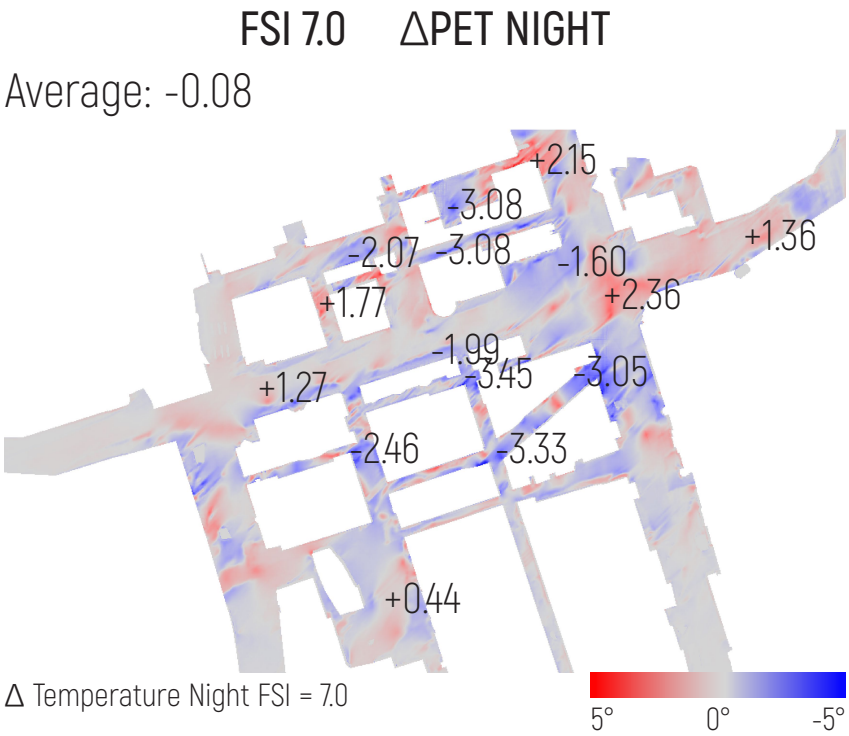
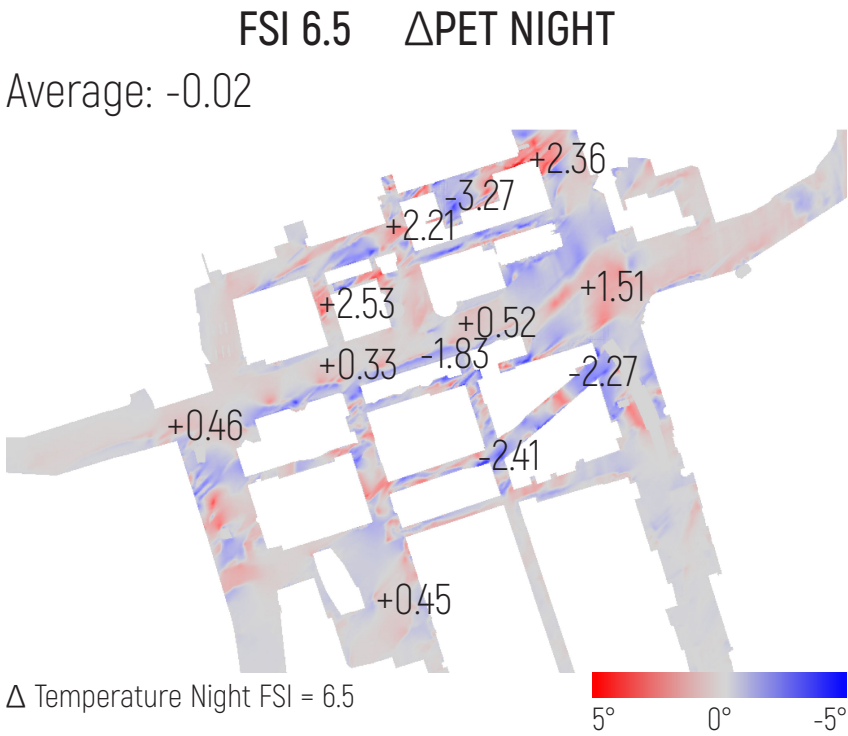
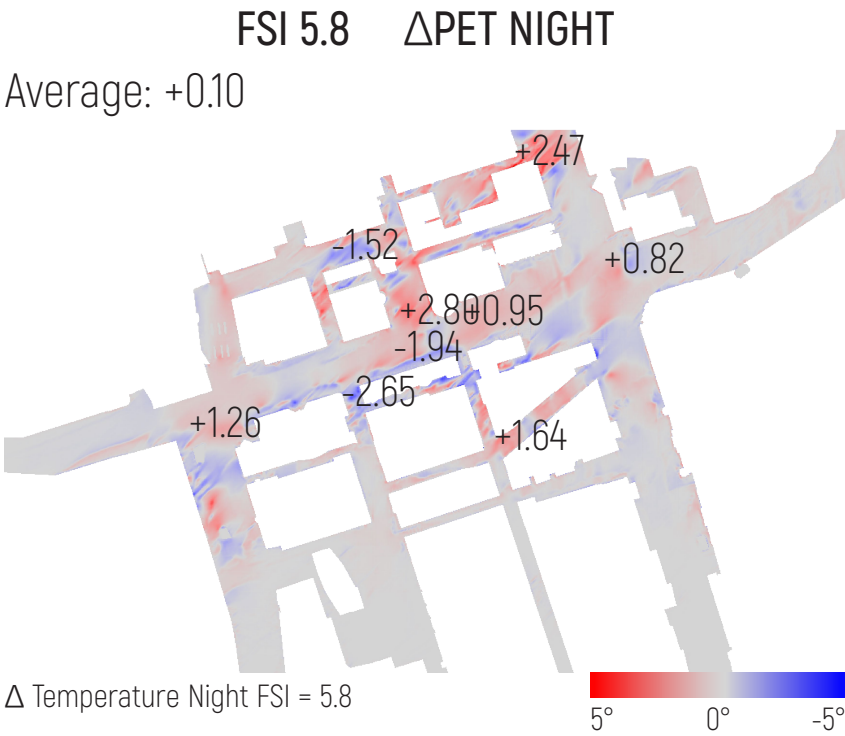
On windless nights, higher FSI leads to increased heat retention, but only in certain localized areas.



MRT Night Combination - MRT Night Original Scenario

Conclusion: Effect of FSI

On WINDY night, higher FSI leads to higher wind speed, due to the deeper street canyon and downwash effect.



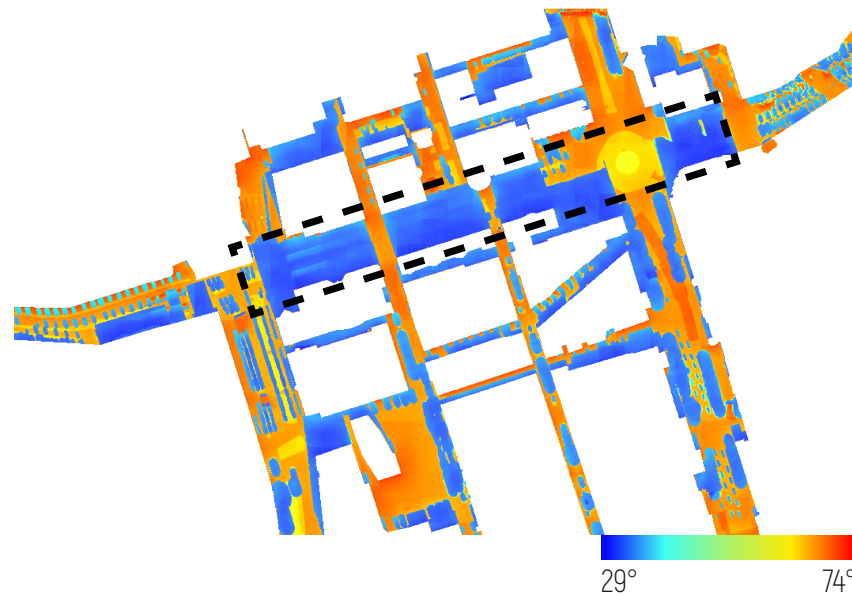
PET Night Combination - PET Night Original Scenario

Podiums VS High-Rise Towers

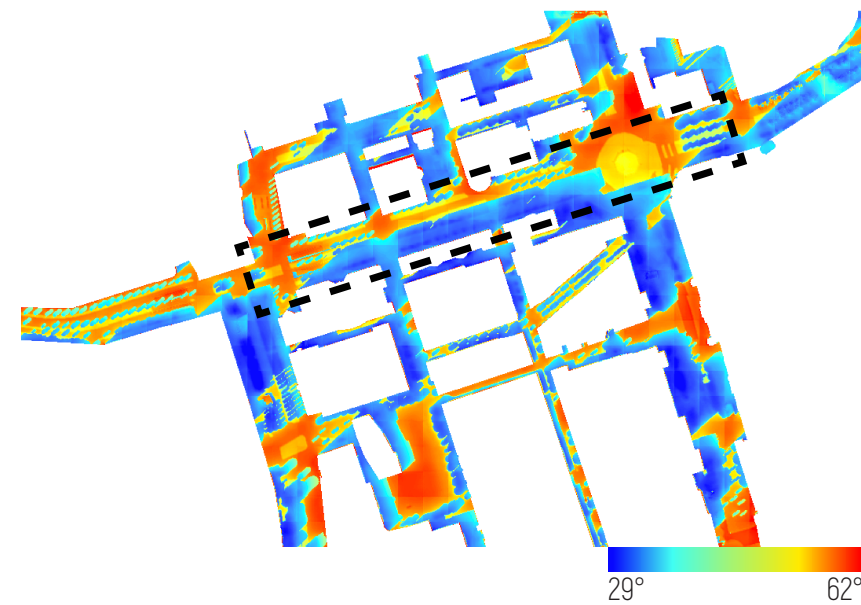
Conclusion: Podium VS High-rise Tower

Podium provide more continuous street-level shading, but the effectiveness of podiums' shadow is time-dependent and decreases at lower solar angles.

FSI 5.8 Podium MRT 13.00

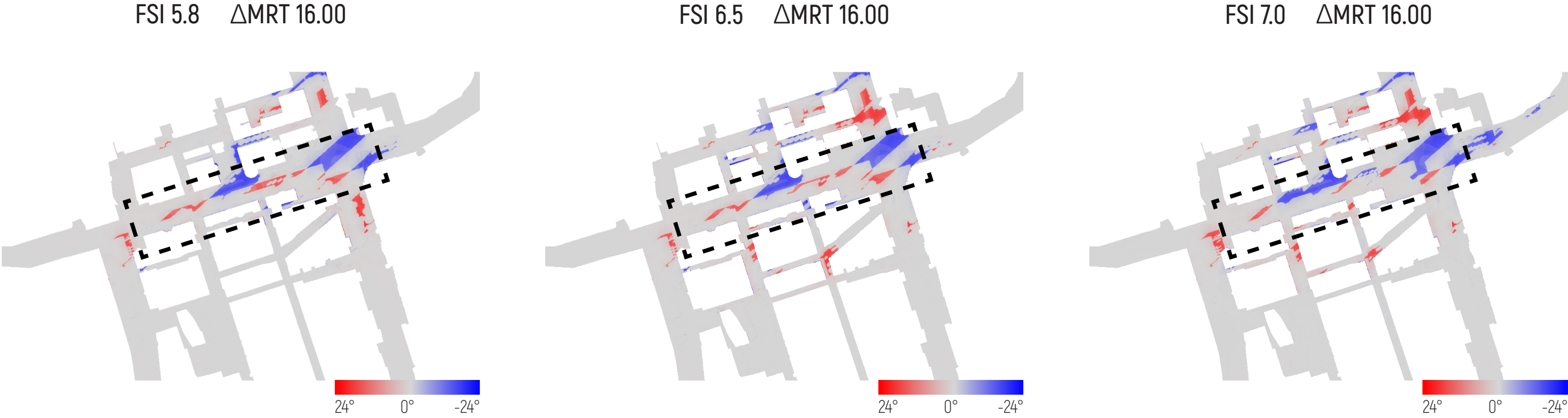


FSI 5.8 Podium MRT 16.00



Conclusion: Podium VS High-rise Tower

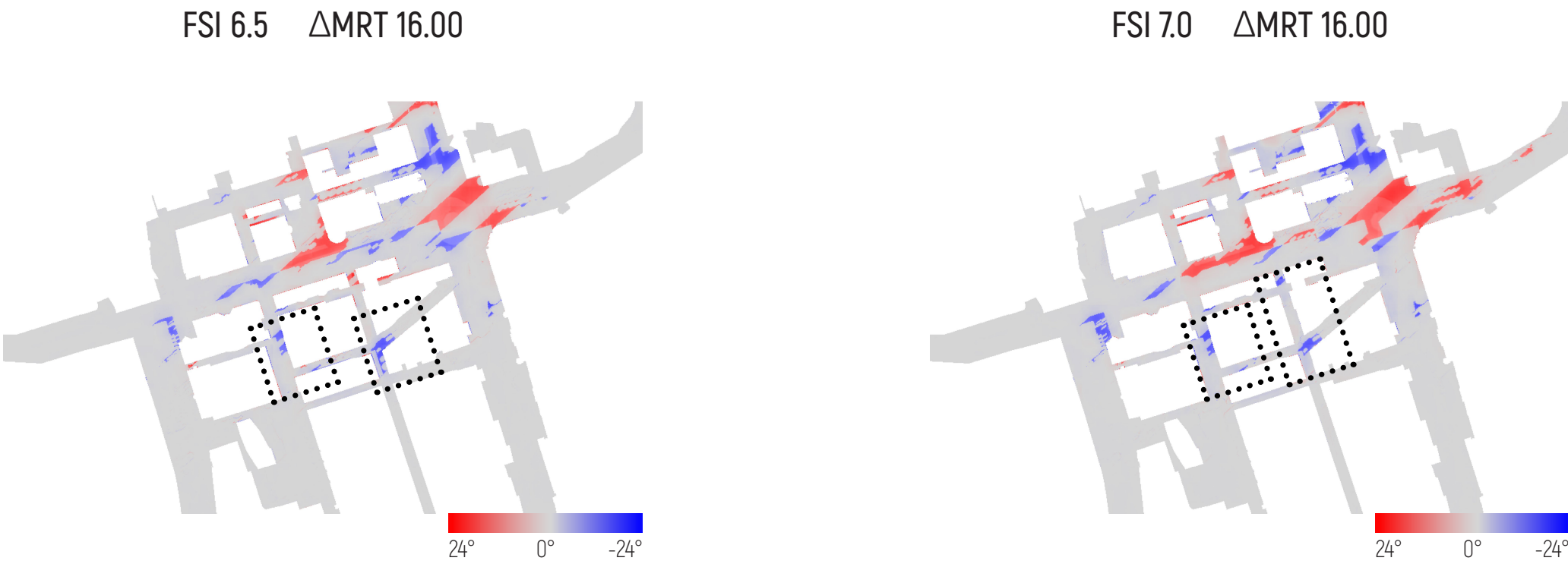
TOWERS are more effective at cooling in WIDER streets and open spaces than PODIUMS during the daytime



MRT h16.00 Tower - MRT h16.00 Podium

Conclusion: Podium VS High-rise Tower

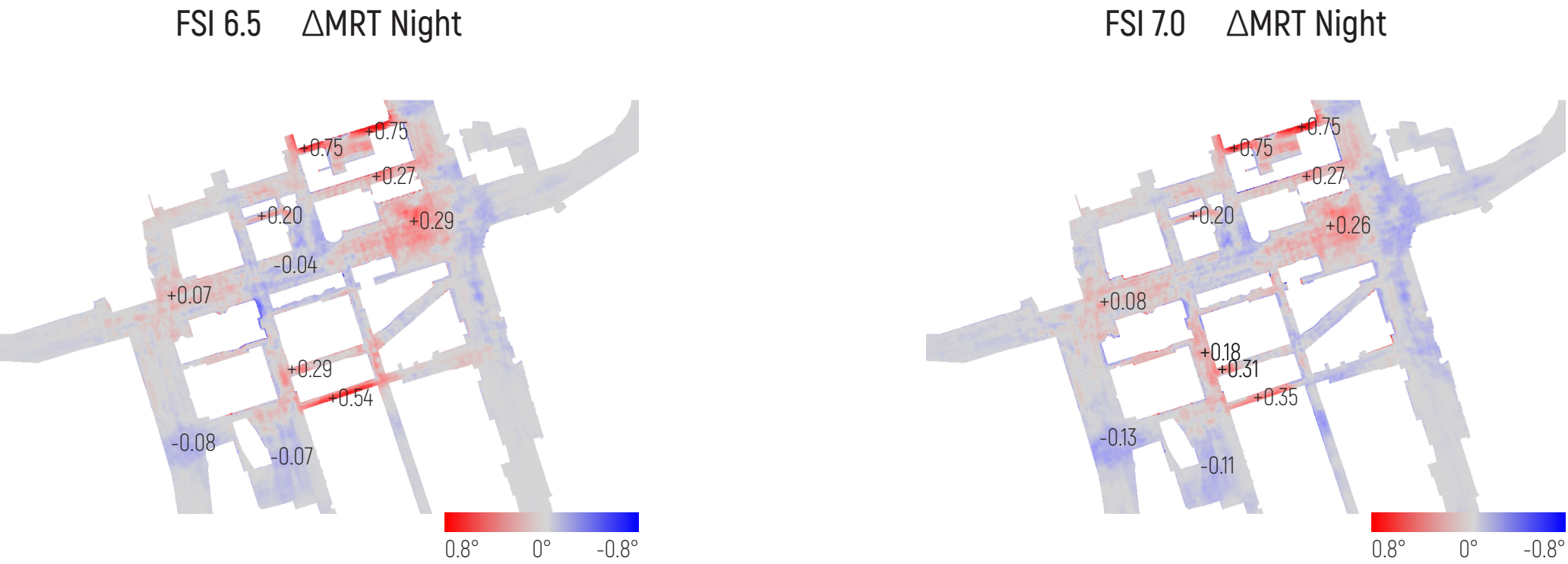
PODIUMS are more effective at cooling in NARROWER streets than TOWERS during the daytime



MRT h16.00 Podium - MRT h16.00 Tower

Conclusion: Podium VS High-rise Tower

In narrower spaces, podiums exhibit greater localized heat retention than towers under the same FSI conditions.

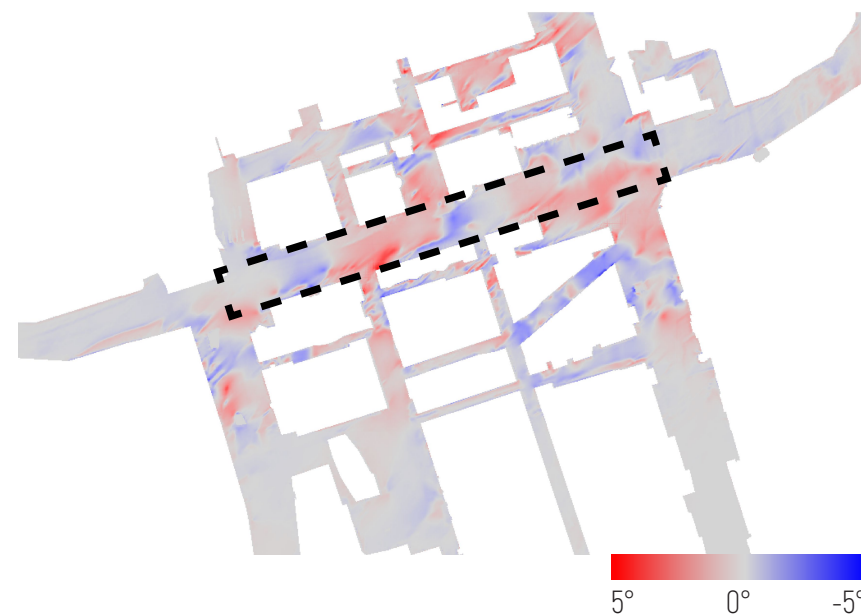


MRT Night Podium - MRT Night Tower

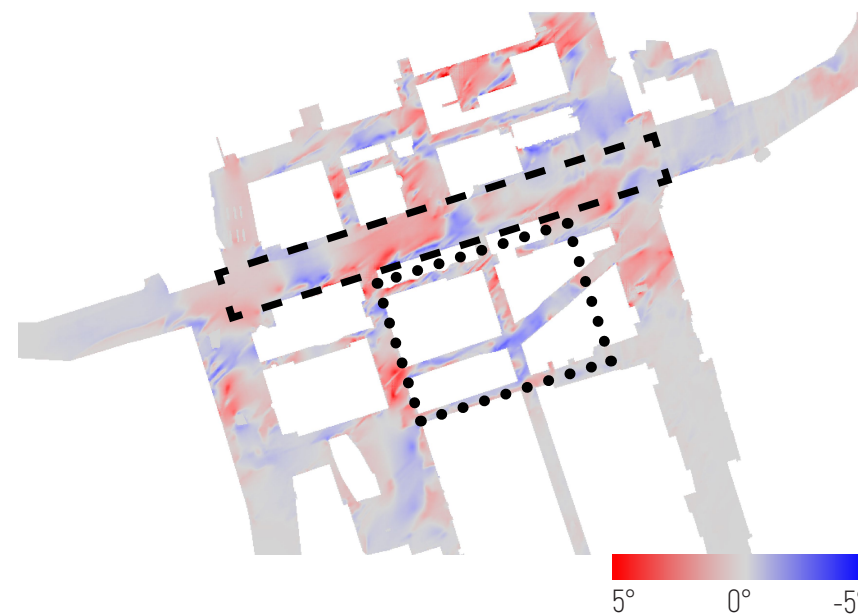
Conclusion: Podium VS High-rise Tower

PODIUMS can enhance wind speed at narrower streets, due to deeper street canyon. **TOWERS** can increase wind speeds around wider streets and open areas, due to downwash effect.

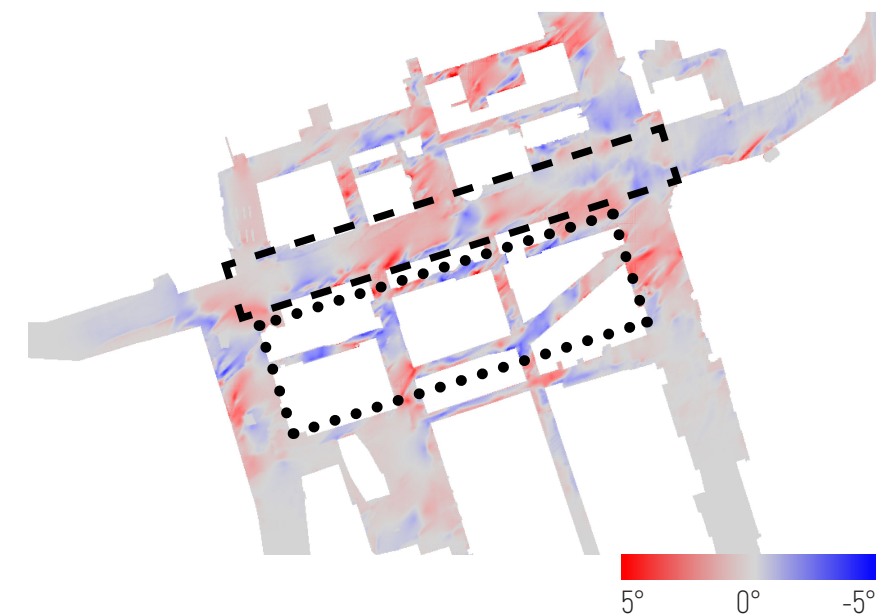
FSI 5.8 Δ PET NIGHT



FSI 6.5 Δ PET NIGHT

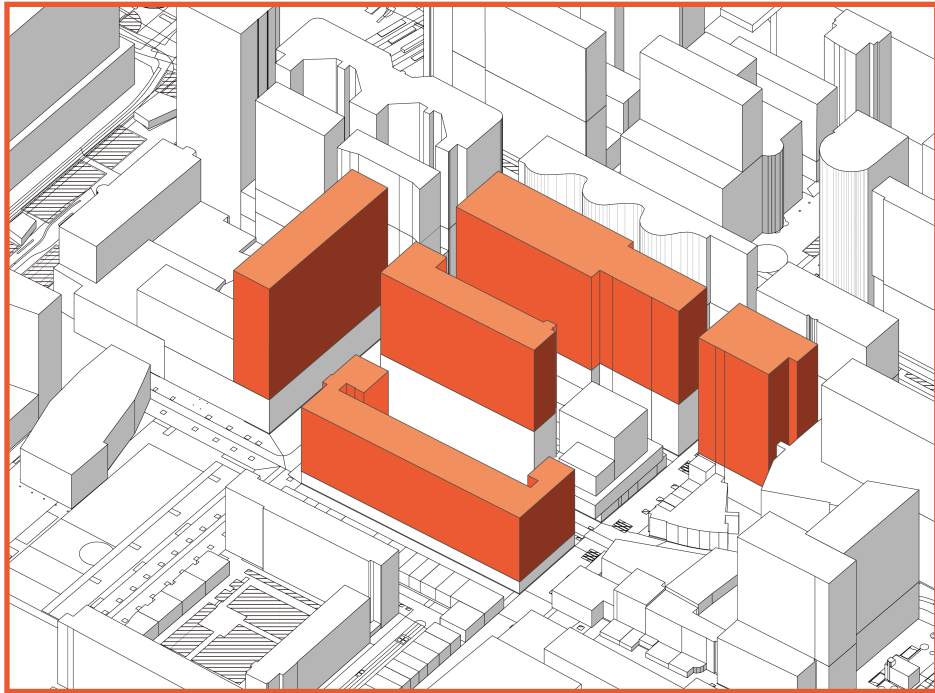


FSI 7.0 Δ PET NIGHT

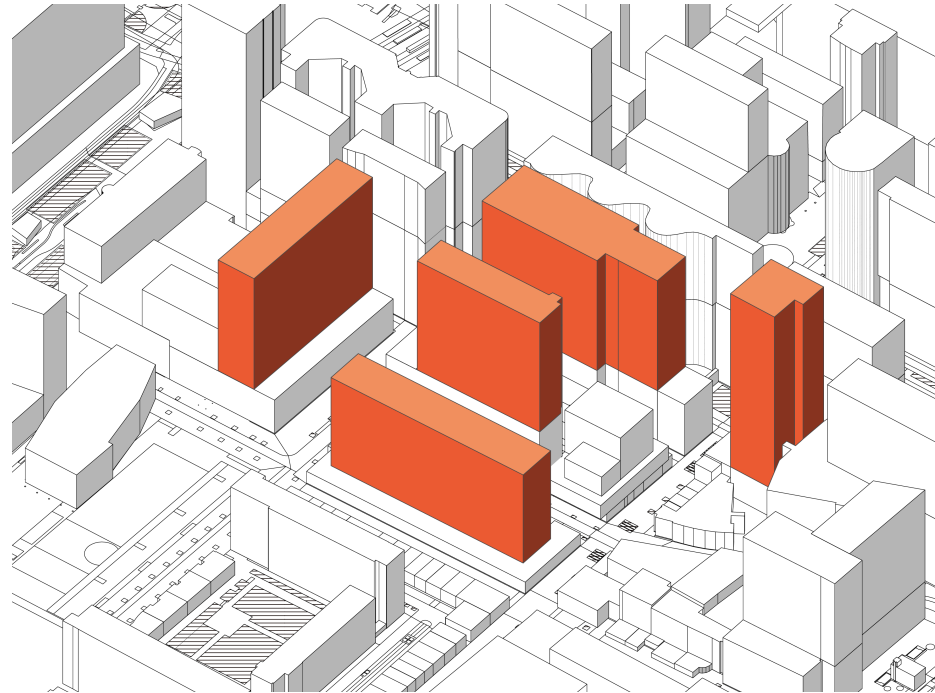


PET Night Podium - MRT Night Tower

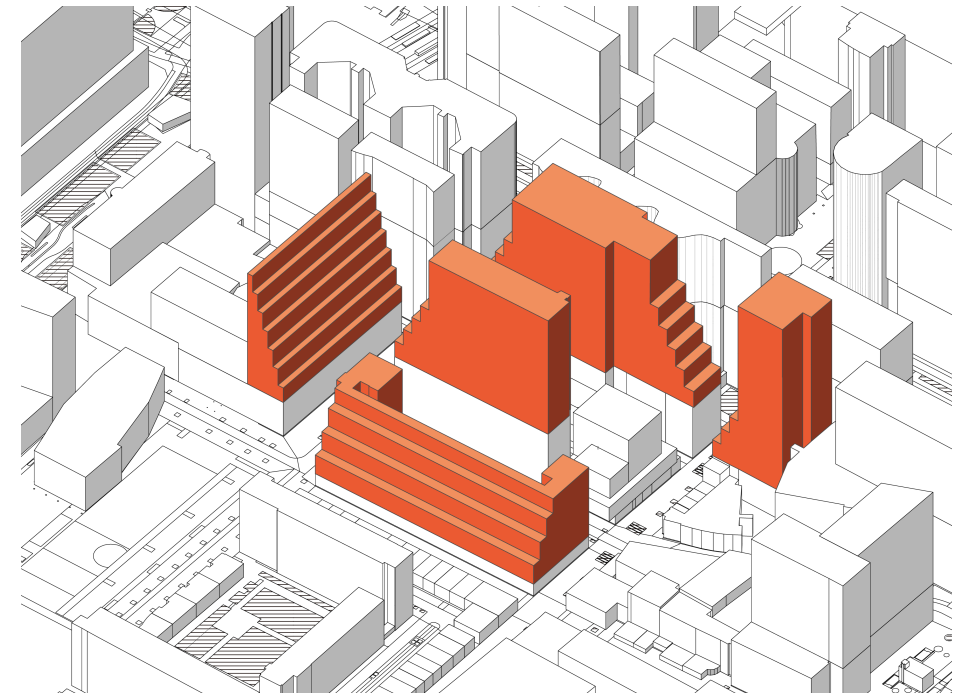
BUILDING MORPHOLOGY EXPLORATION



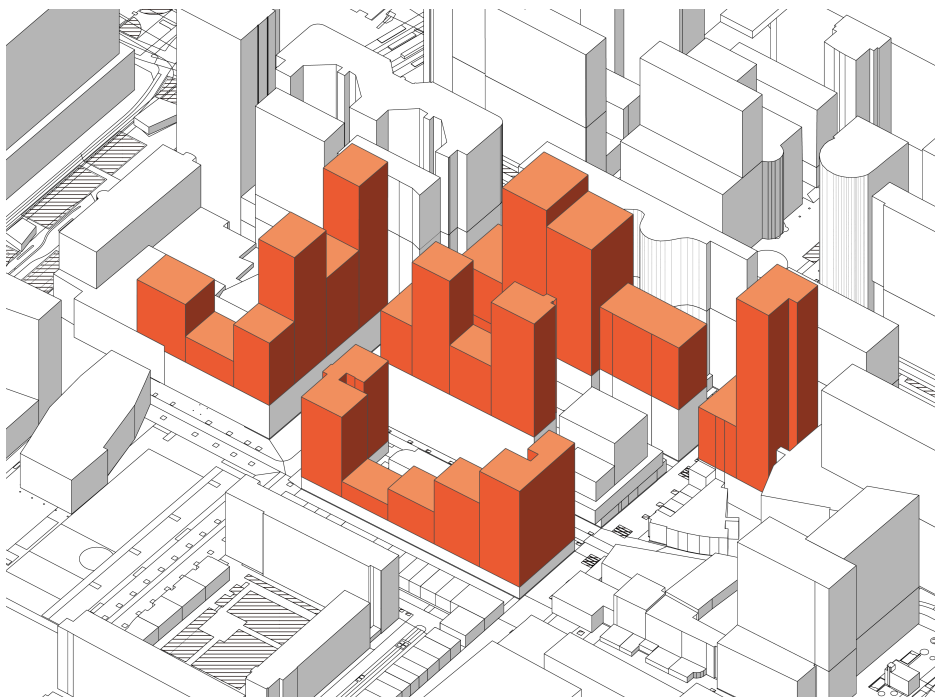
FSI 7 Podium



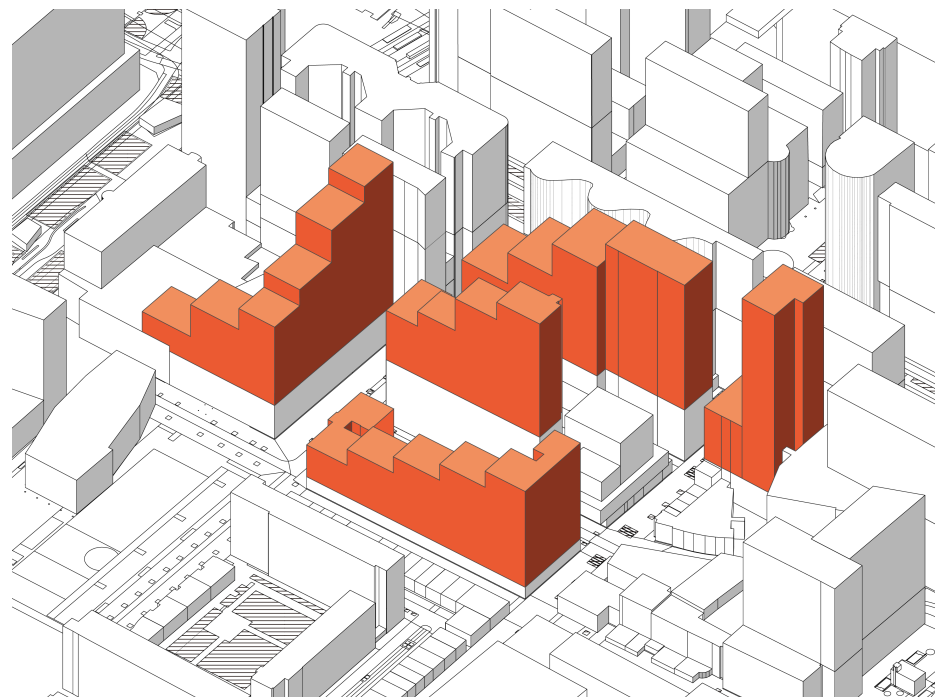
FSI 7 Setback Podium



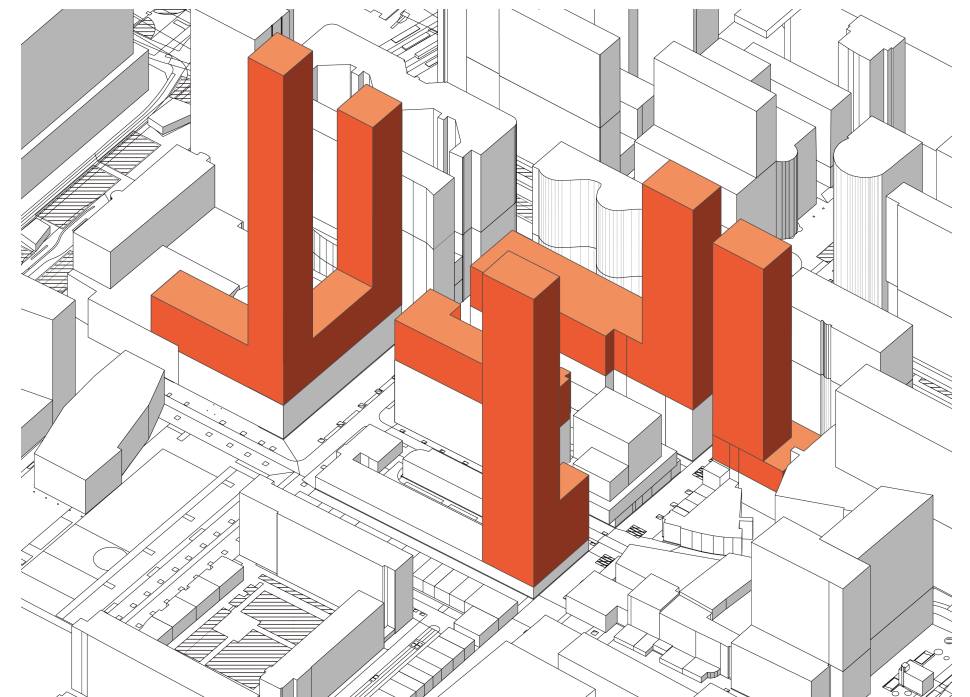
FSI 7 Stepped Podium



FSI 7 Height-varied Podium 1



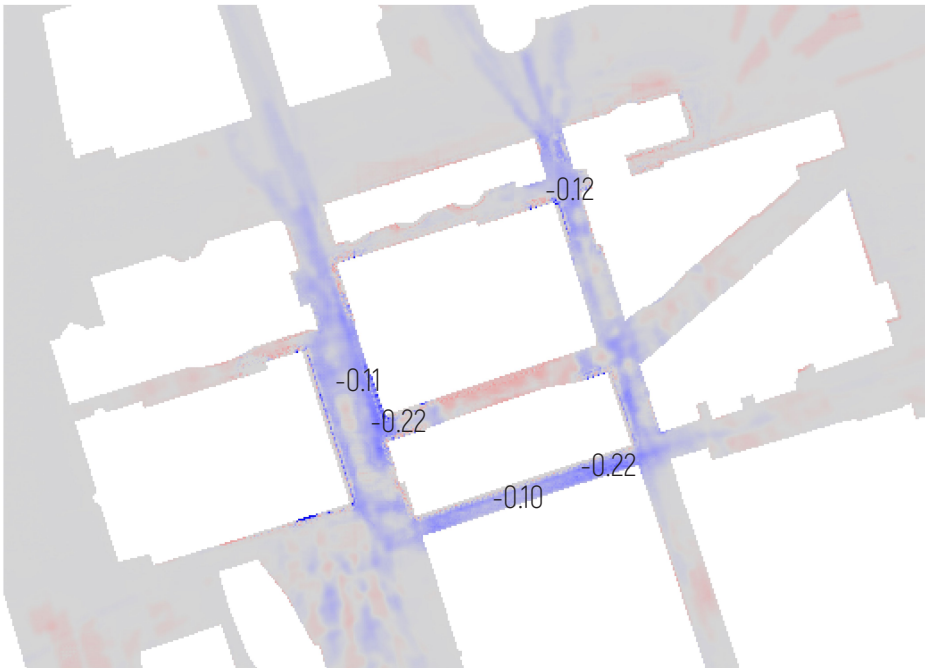
FSI 7 Height-varied Podium 2



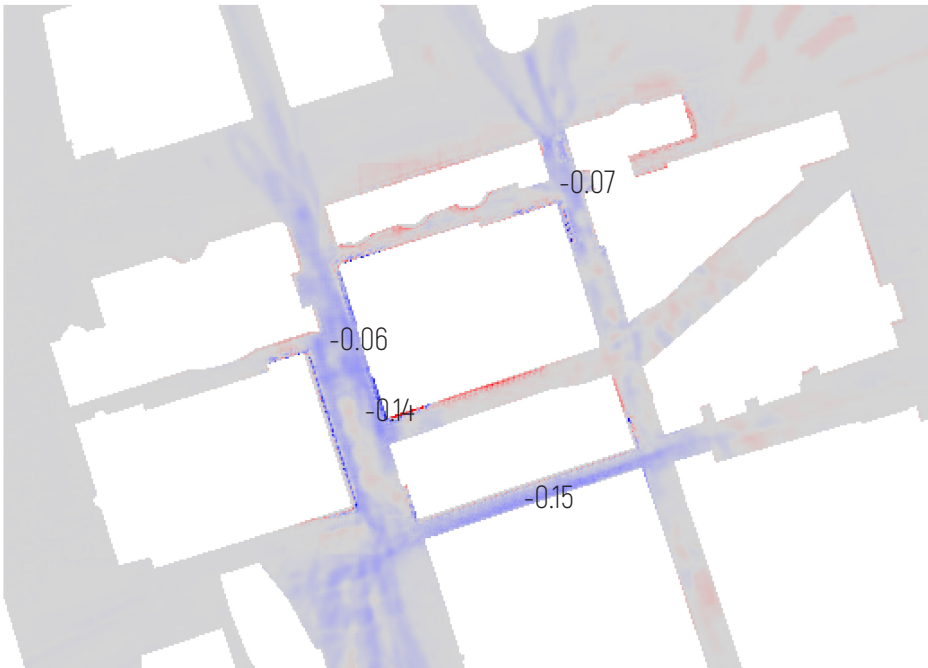
FSI 7 Combination

Conclusion: Podium VS High-rise Tower

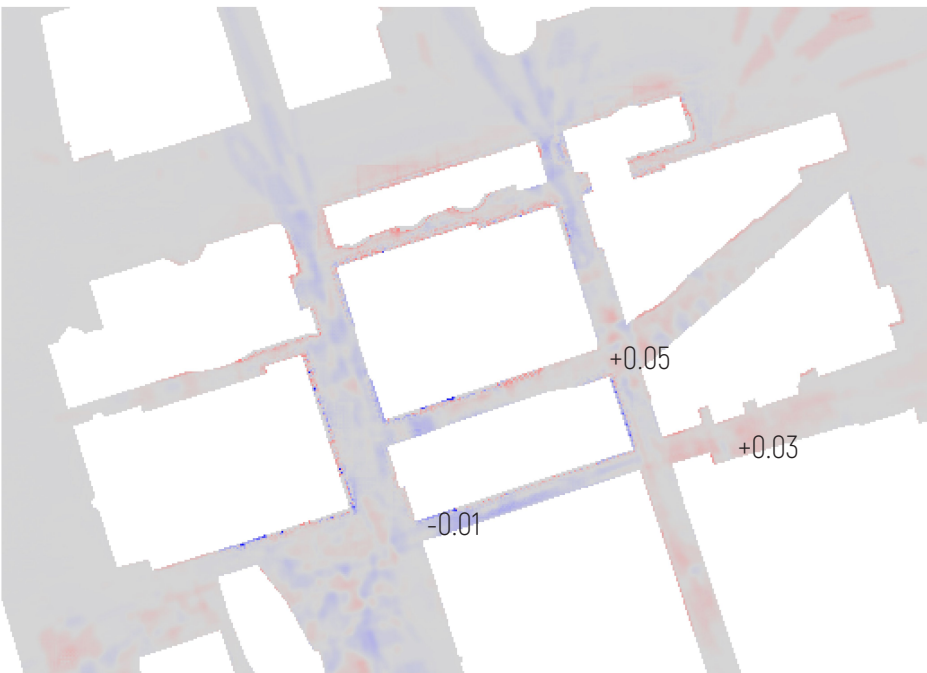
New building morphology - FSI 7 Podium



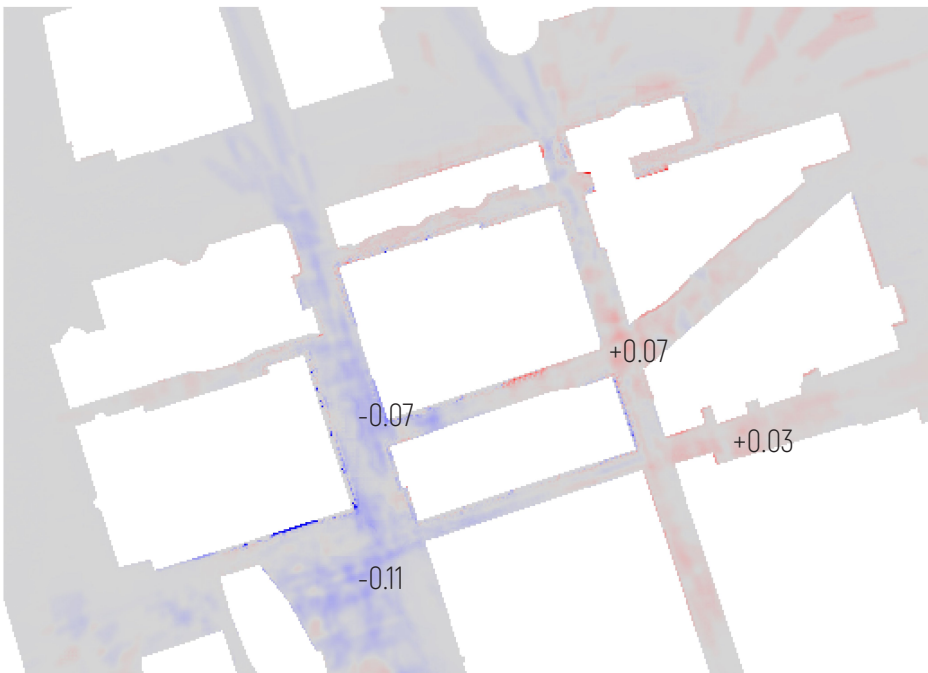
FSI 7 Setback Podium - FSI 7 Podium



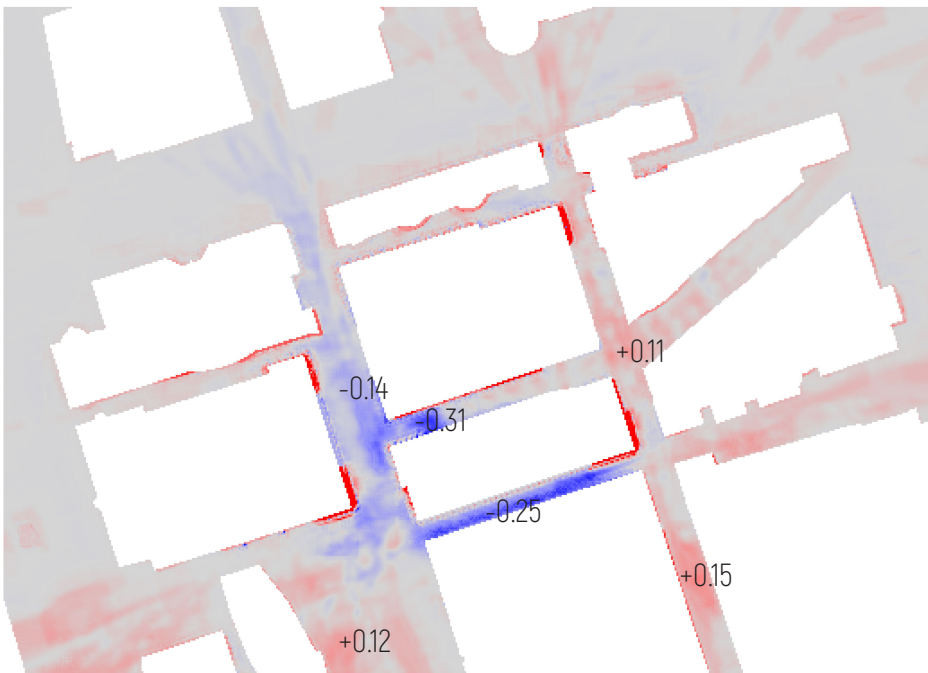
FSI 7 Stepped Podium - FSI 7 Podium



FSI 7 Height-varied Podium 1 - FSI 7 Podium



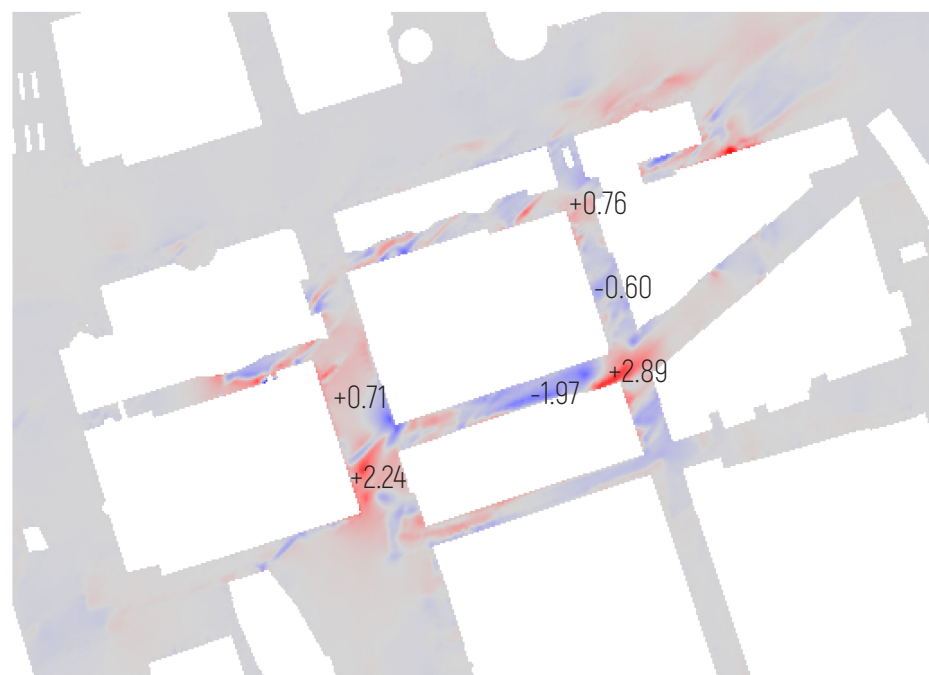
FSI 7 Height-varied Podium 2 - FSI 7 Podium



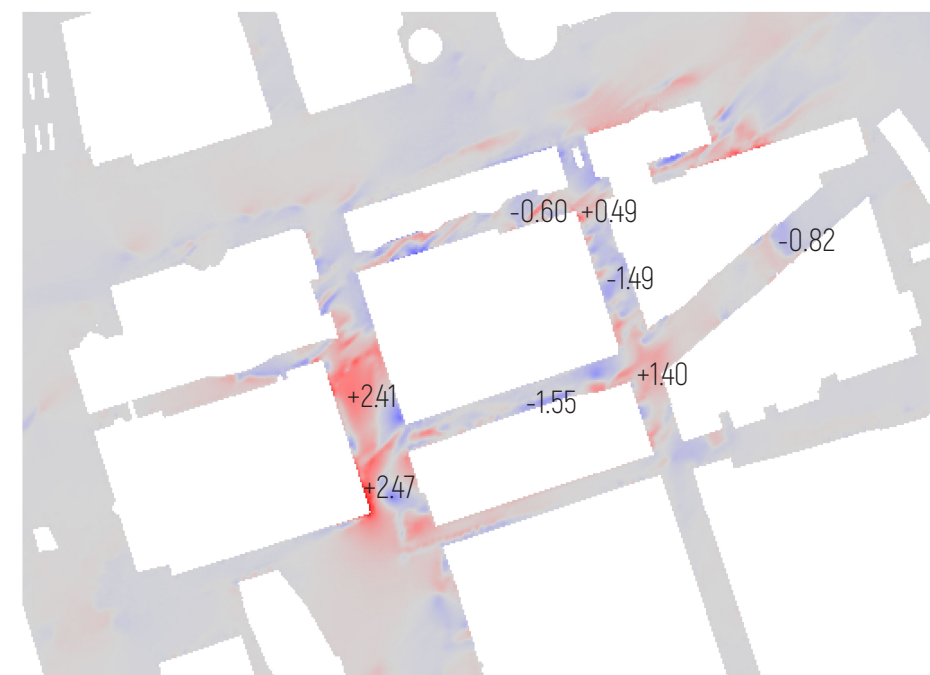
FSI 7 Combination - FSI 7 Podium



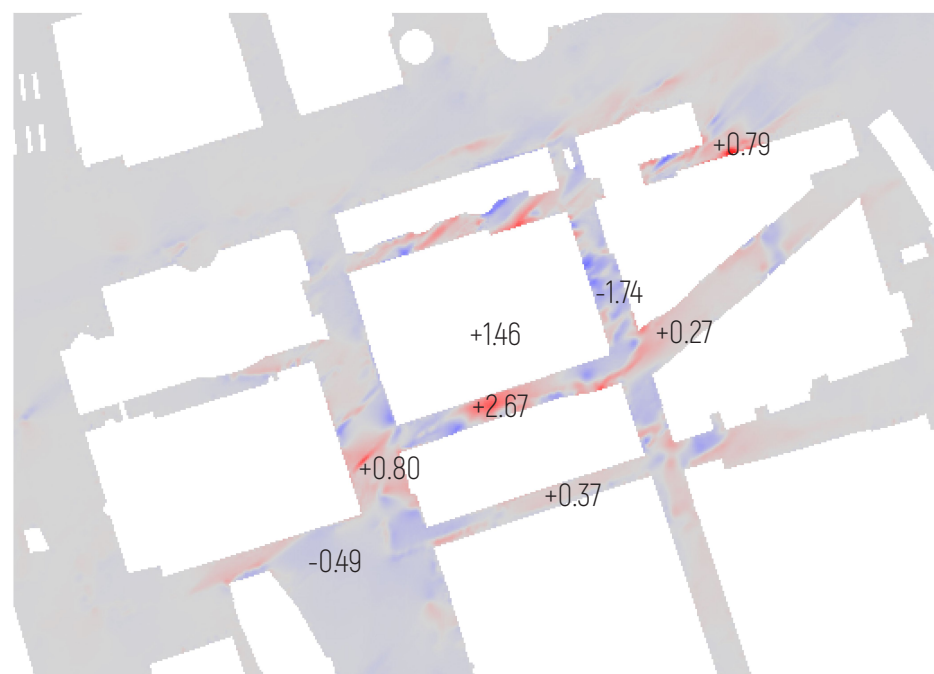
New building morphology - FSI 7 Podium



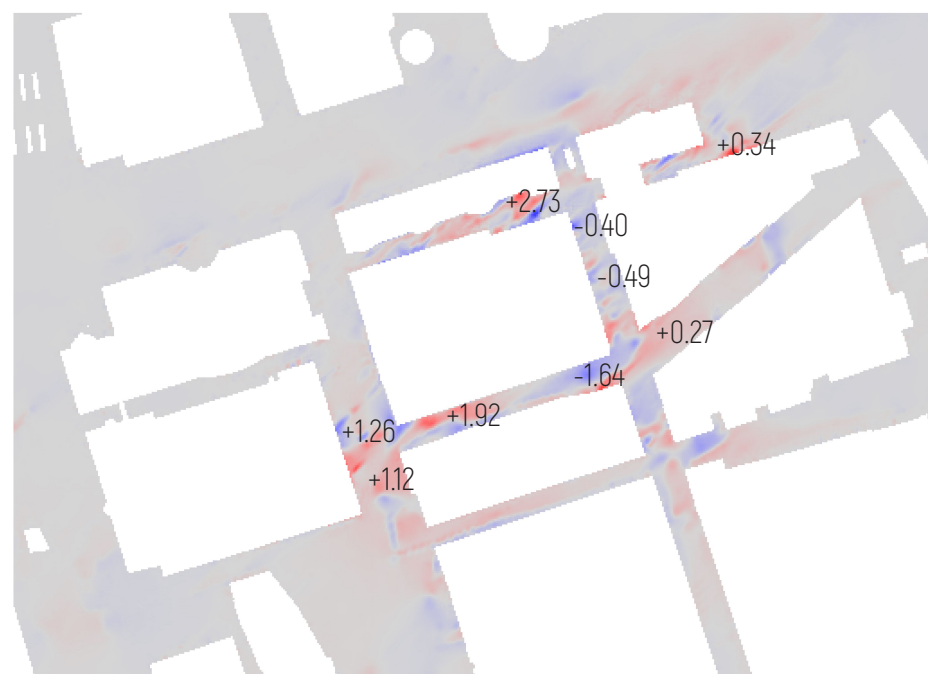
FSI 7 Setback Podium - FSI 7 Podium



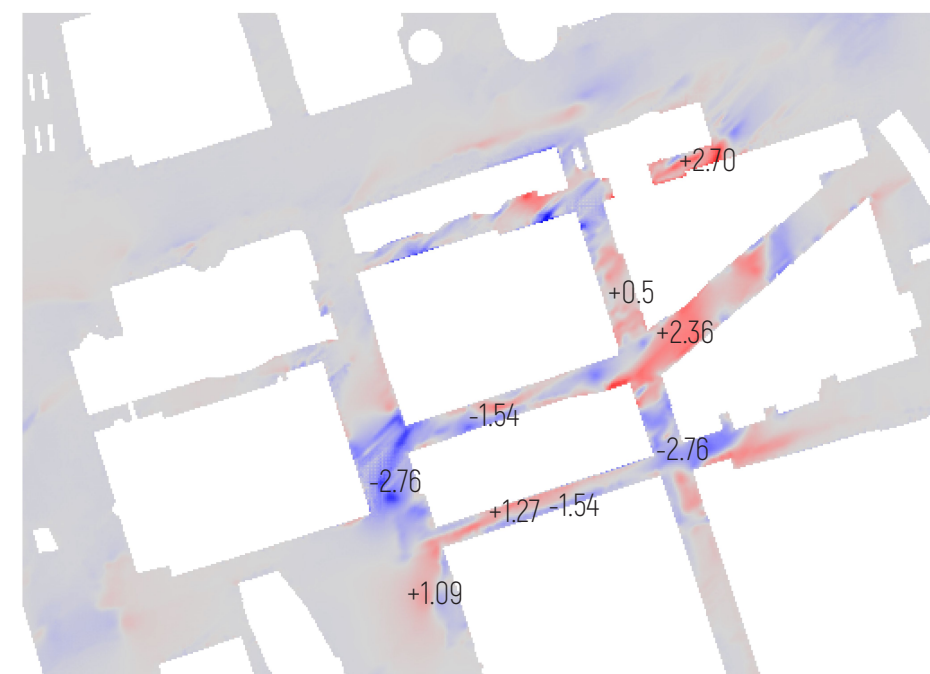
FSI 7 Stepped Podium - FSI 7 Podium



FSI 7 Height-varied Podium 1 - FSI 7 Podium



FSI 7 Height-varied Podium 2 - FSI 7 Podium



FSI 7 Combination - FSI 7 Podium

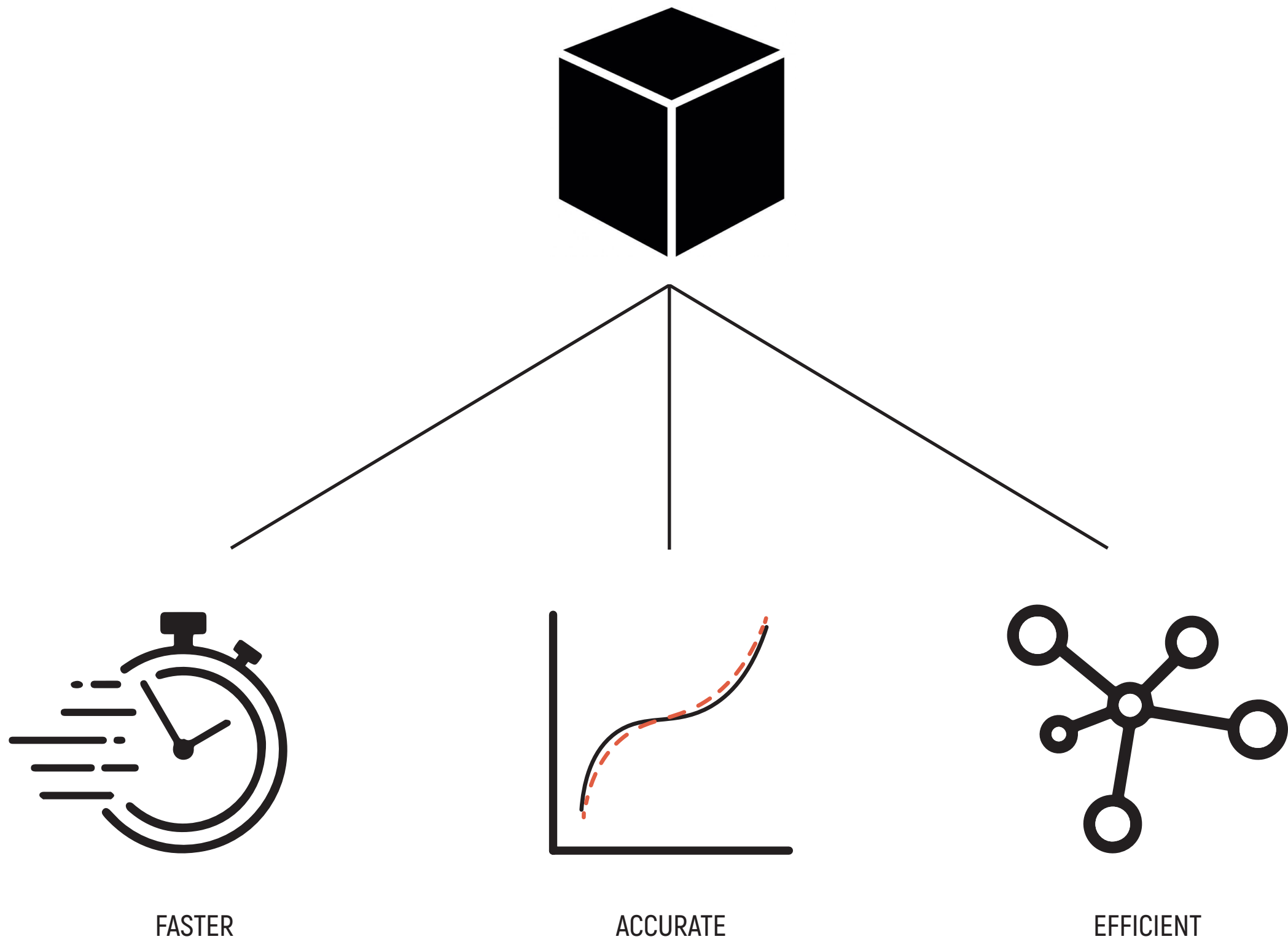


Conclusion: Building Morphology

Morphological interventions have a limited effect on reducing nighttime heat retention.

Continuous and deep street canyons can help enhance wind speed under certain wind conditions.

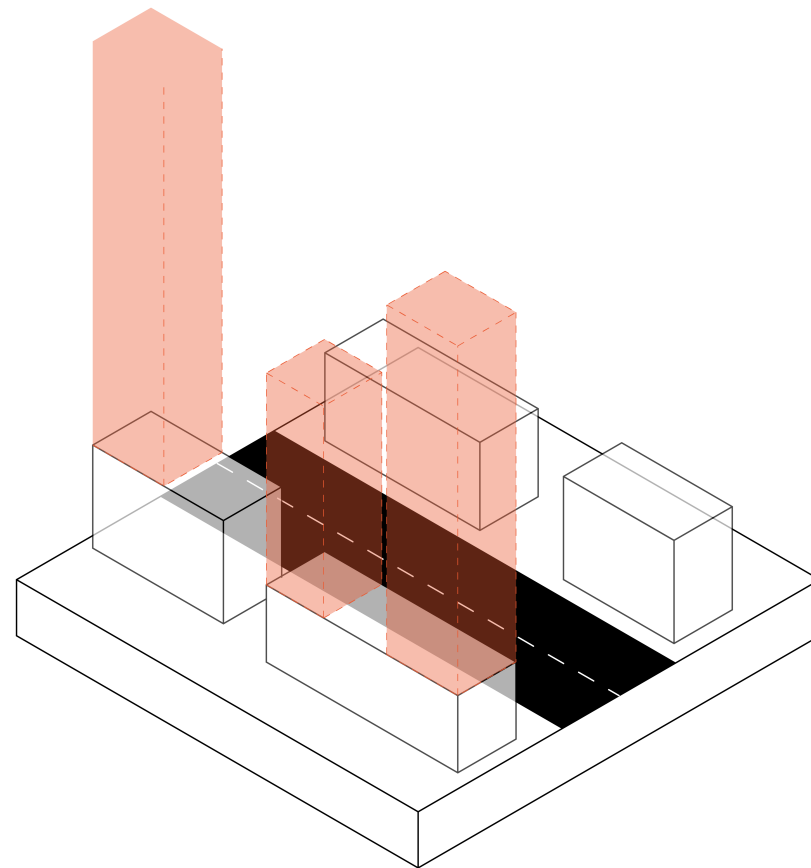
Conclusion: Deep Learning Model



GUIDELINES

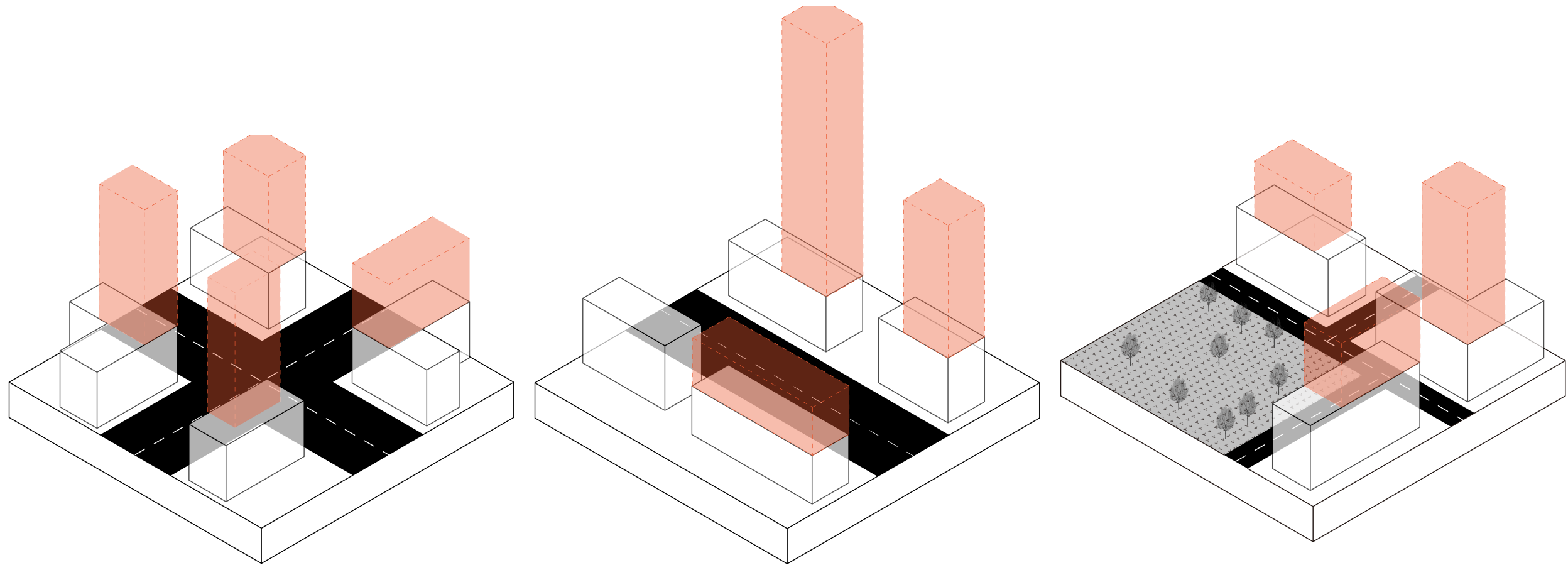
URBAN DEVELOPMENT GUIDELINES

Conduct Spatially Concentrated Densification



Urban Development Guidelines

Prioritize densification in wider streets and open spaces

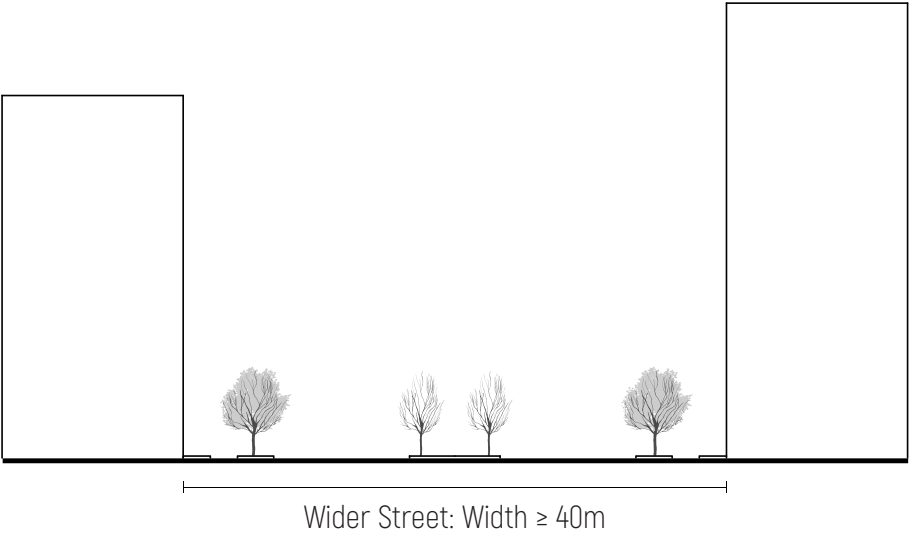
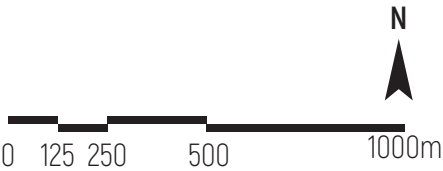


Urban Development Guidelines



➔ Development Along Wider Streets + Development Along Open Areas ■ Water

Figure 8.3: Priority Development Areas in Rotterdam City Center (Source: By Author)



Urban Development Guidelines

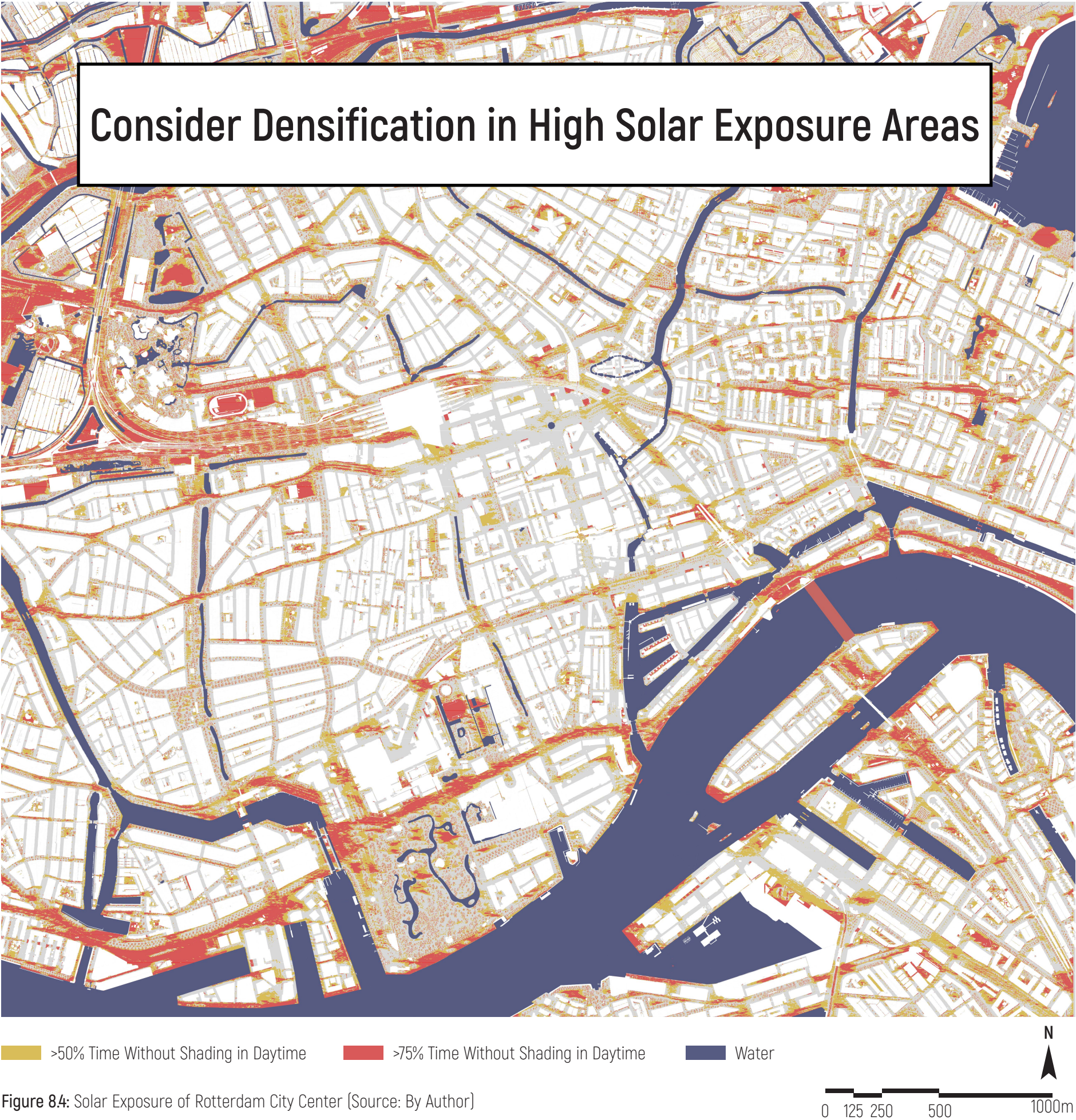
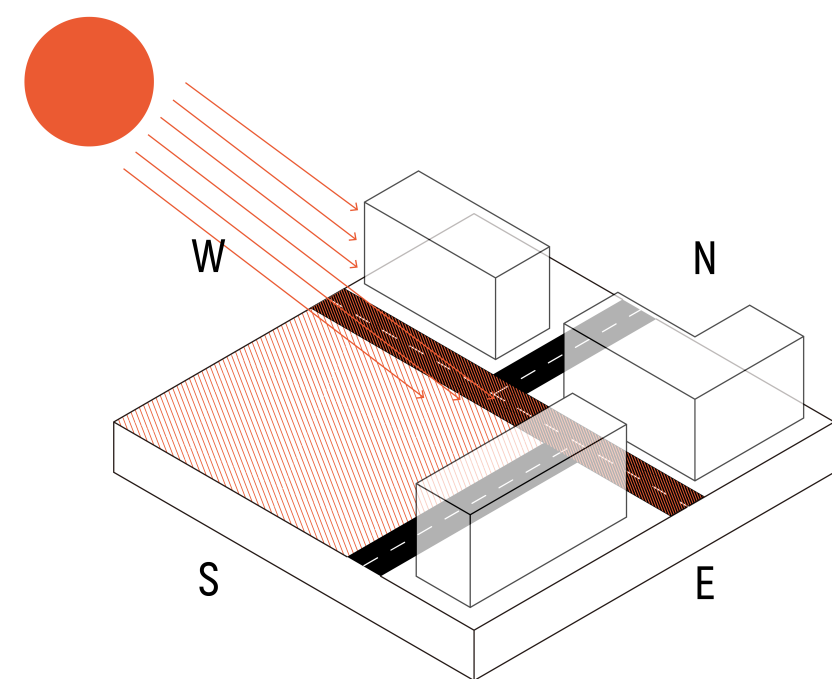
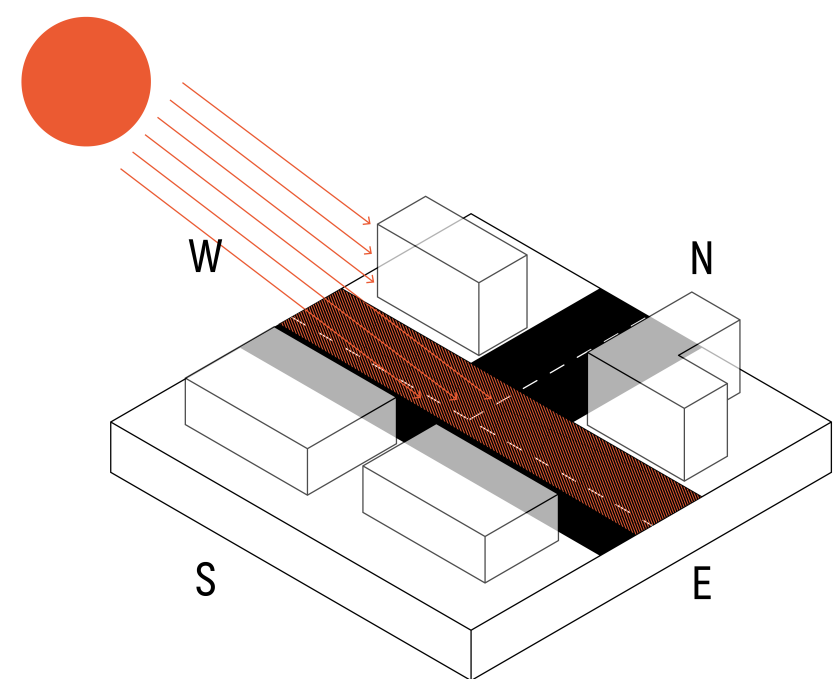


Figure 8.4: Solar Exposure of Rotterdam City Center (Source: By Author)

Urban Development Guidelines

Consider densification in High Solar Exposure Areas

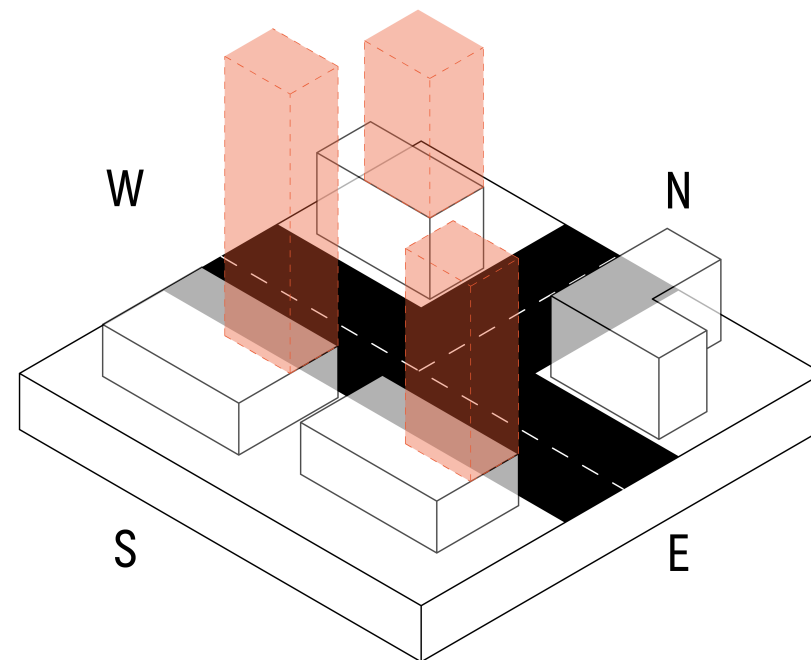


BUILDING LAYOUT GUIDELINES

Building Layout Guidelines

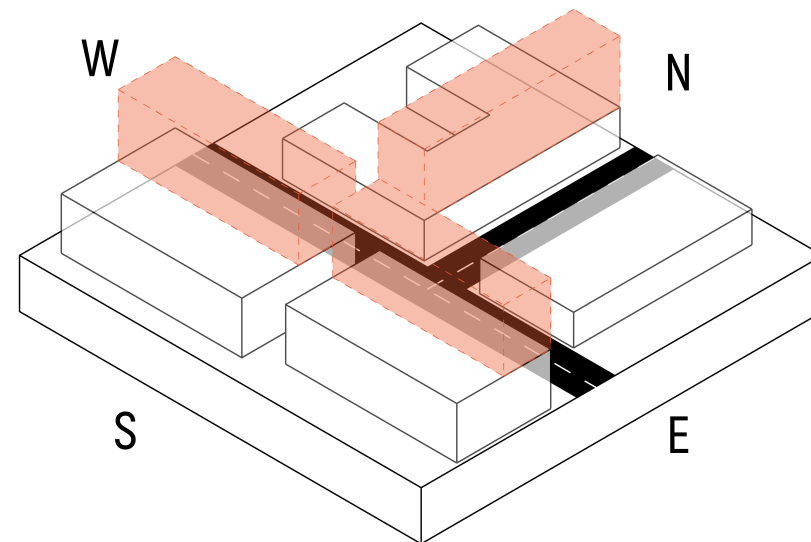
Prioritize Vertical Development in South and West sides of wider streets and open spaces

Localize Vertical Development Along Street Edges



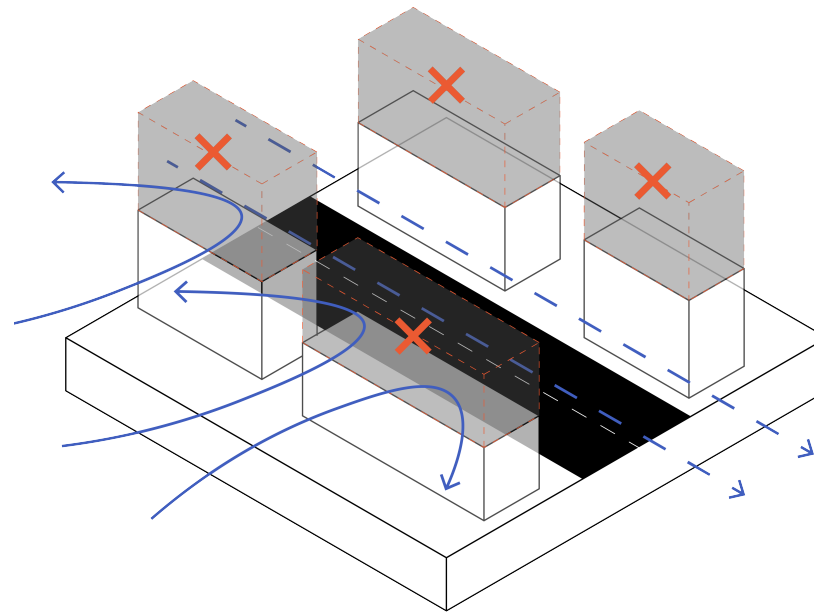
Building Layout Guidelines

Prioritize Horizontal Development in South and West sides of Narrower Streets



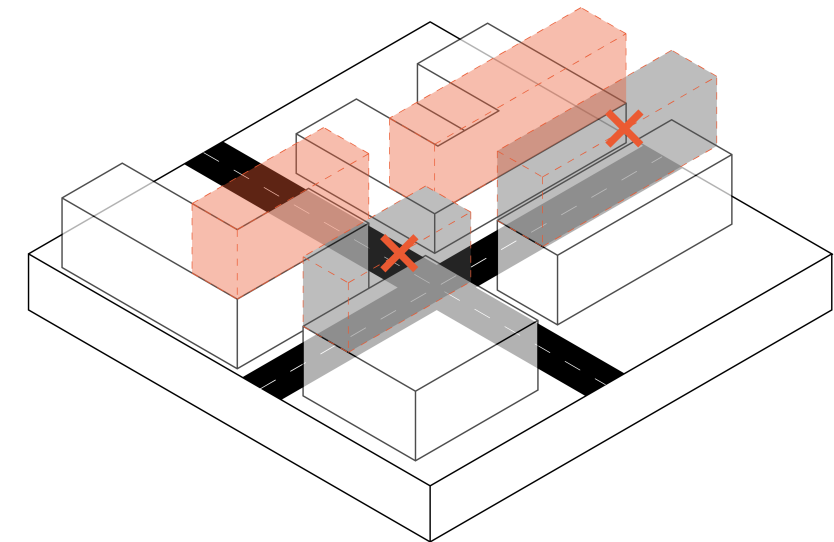
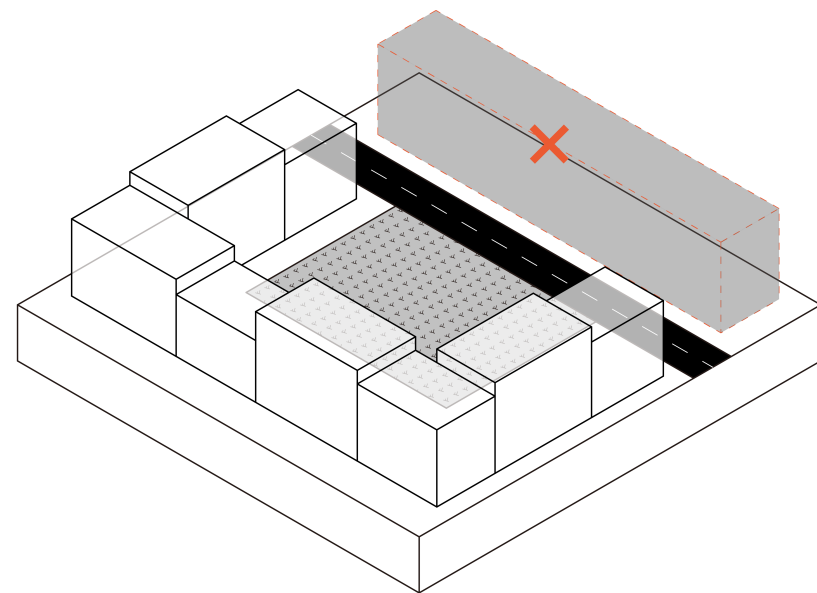
Building Layout Guidelines

Avoid Horizontal Development in Wider streets and Open Areas

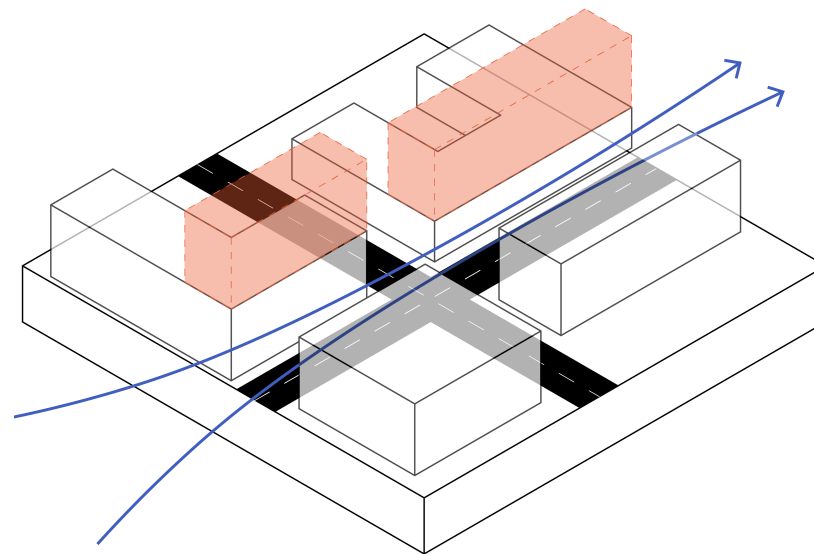


Building Layout Guidelines

Avoid Horizontal Development on Both Sides



Implement Continuous Podium in Narrow Streets



FUTURE.....