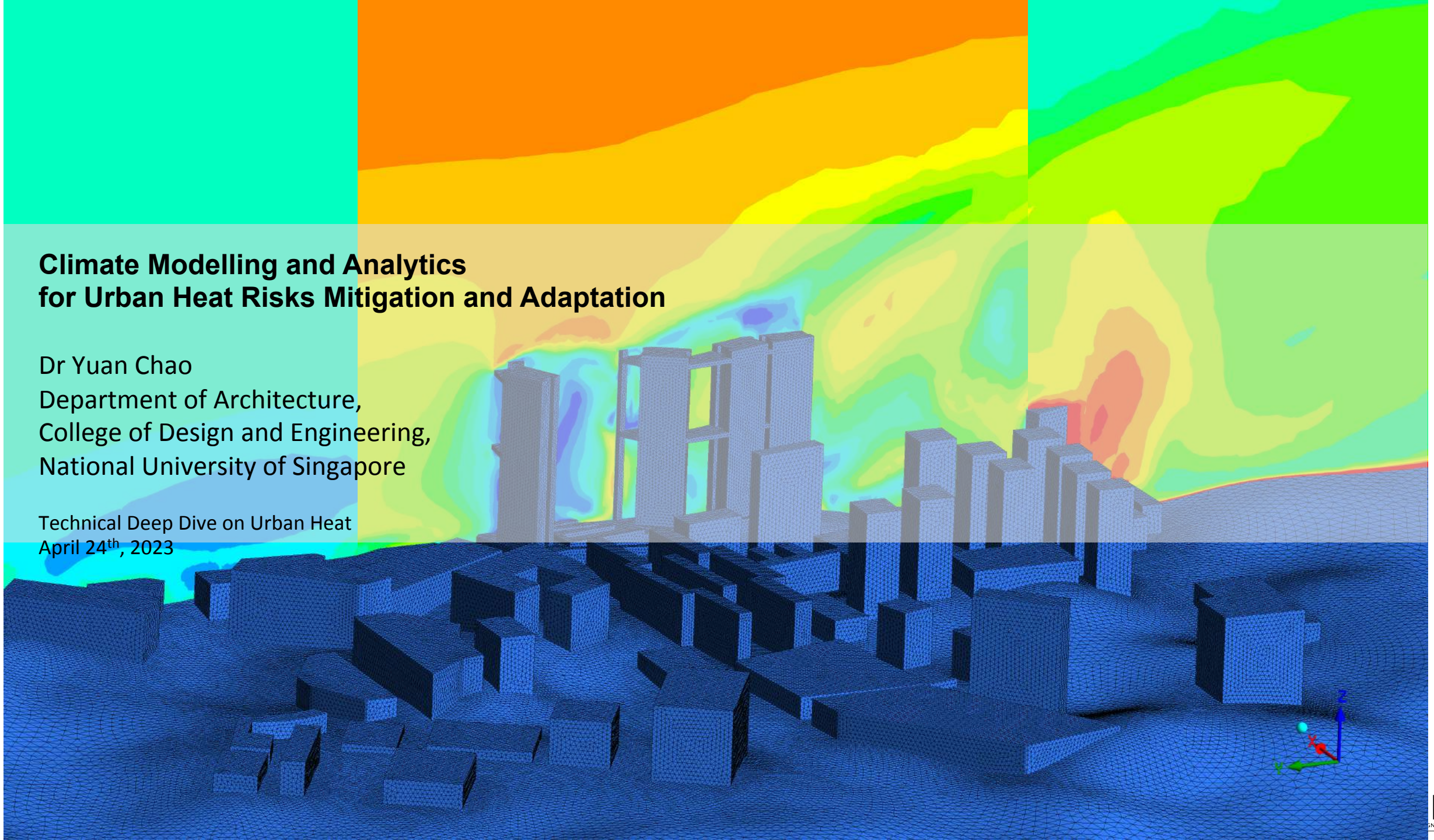

Climate Modelling and Analytics for Urban Heat Risks Mitigation and Adaptation

Dr Yuan Chao
Department of Architecture,
College of Design and Engineering,
National University of Singapore

Technical Deep Dive on Urban Heat
April 24th, 2023

Grant Vision

Nowcasting System

Dissemination and Communication

Response Capability

Climate Resilience

Grant Vision: To build a climate resilient present and future for all who live in cities and are at heat risk from climate change and urbanization.


The Lancet Planetary Health
Volume 6, Issue 8, August 2022, Pages e648-e657

Articles

The effects of night-time warming on mortality burden under future climate change scenarios: a modelling study

Cheng He PhD [a], Prof Ho Kim PhD [b], Prof Masahiro Hashizume PhD [c], Whanhee Lee PhD [d e], Prof Yasushi Honda PhD [f g], Prof Satbyul Estella Kim PhD [f g], Prof Patrick L Kinney PhD [h], Prof Alexandra Schneider PhD [i], Yuqiang Zhang PhD [j], Yixiang Zhu MS [a], Lu Zhou MS [a], Prof Renjie Chen PhD [a], Prof Haidong Kan PhD [a k]

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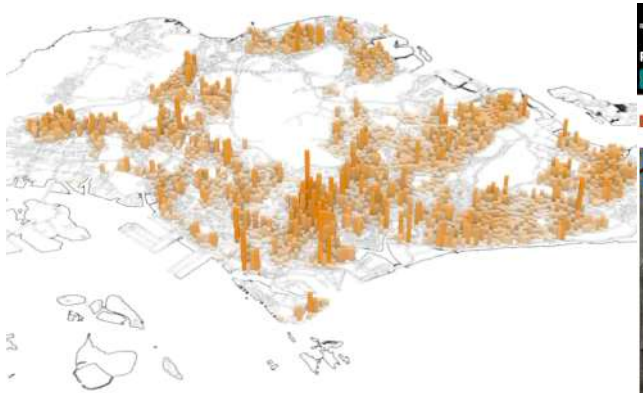

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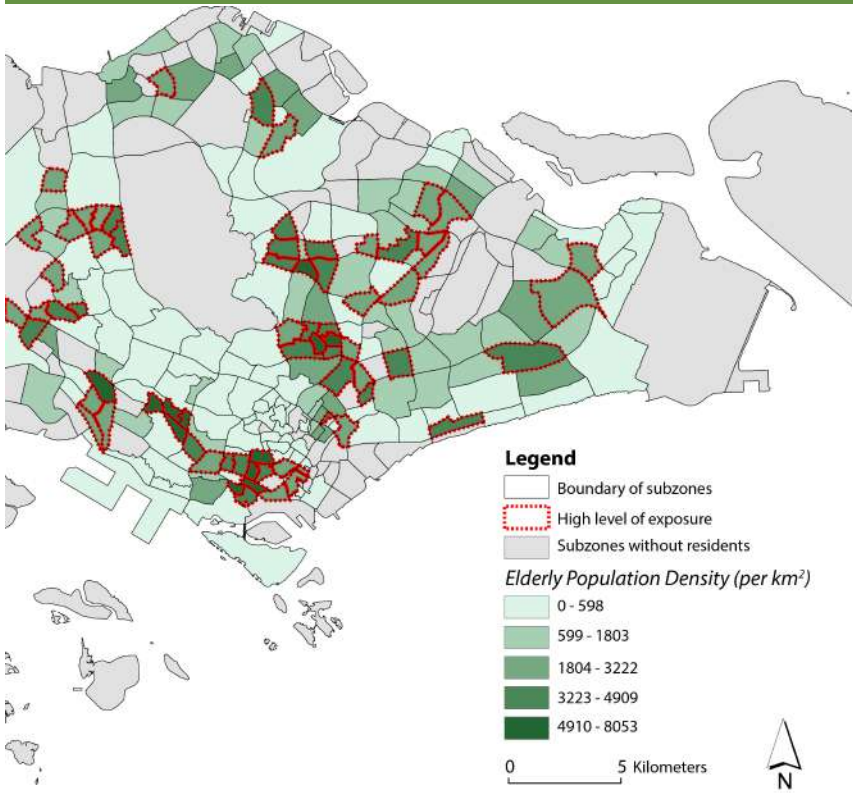
Key Insights on the Problem

Current Problems:

Microclimate uncertainties in the immediate living environment

Regional/city scale climate modelling/projection downscaling from global scale often results in huge uncertainties

Varying individual risks to heat stress



Different demographic and socioeconomic groups in cities also experience different degree of exposure to the heatwaves

Lag in timely mitigation and adaptation actions

Heat does not cost immediate and visible destructive damages like their counterparts, e.g., typhoon, flooding, and landslides

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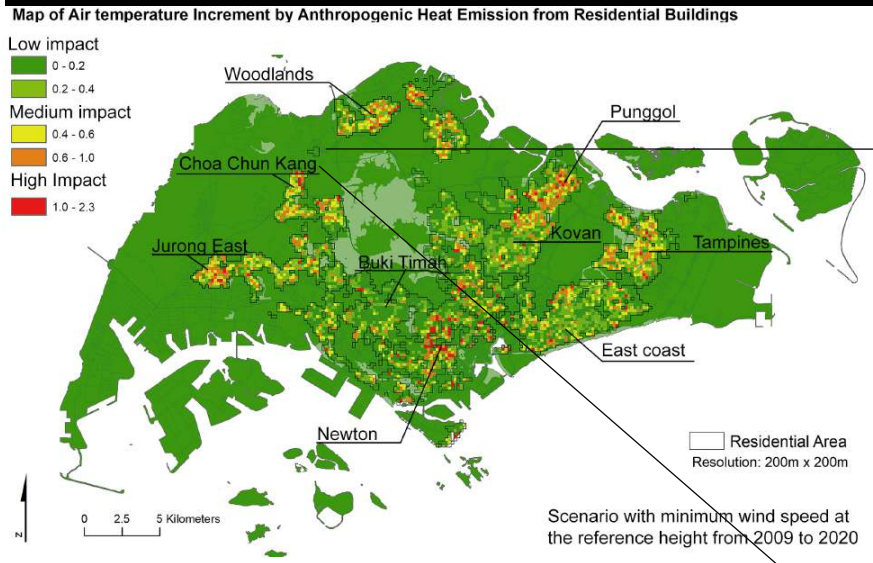
Objectives

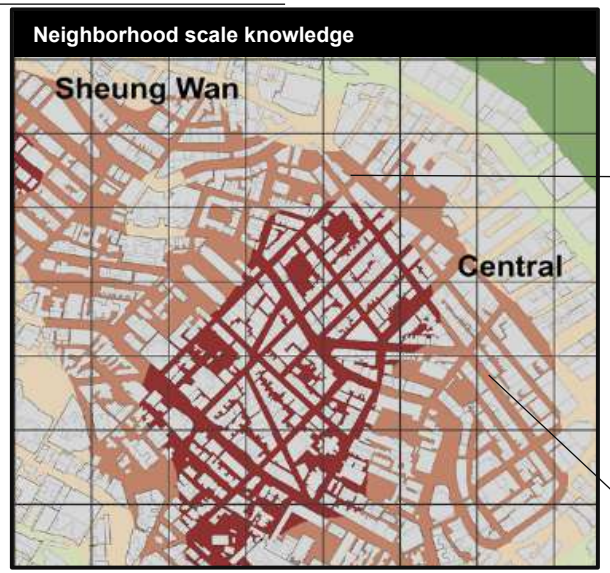
Mitigation strategies at different spatial scales should be consistent with each other, and systematic.

Urban scale knowledge



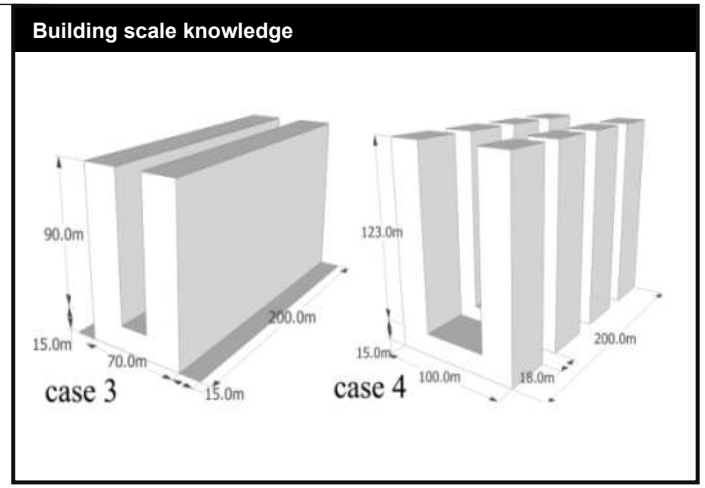
Urban scale knowledge:
Potential air paths and the critical areas with wind issues can be identified.

Neighborhood scale knowledge



Neighborhood scale knowledge:
Practical modelling method is developed to evaluate the wind environment in the neighborhood scale.

Building scale knowledge



Building scale knowledge:
Design knowledge before modelling

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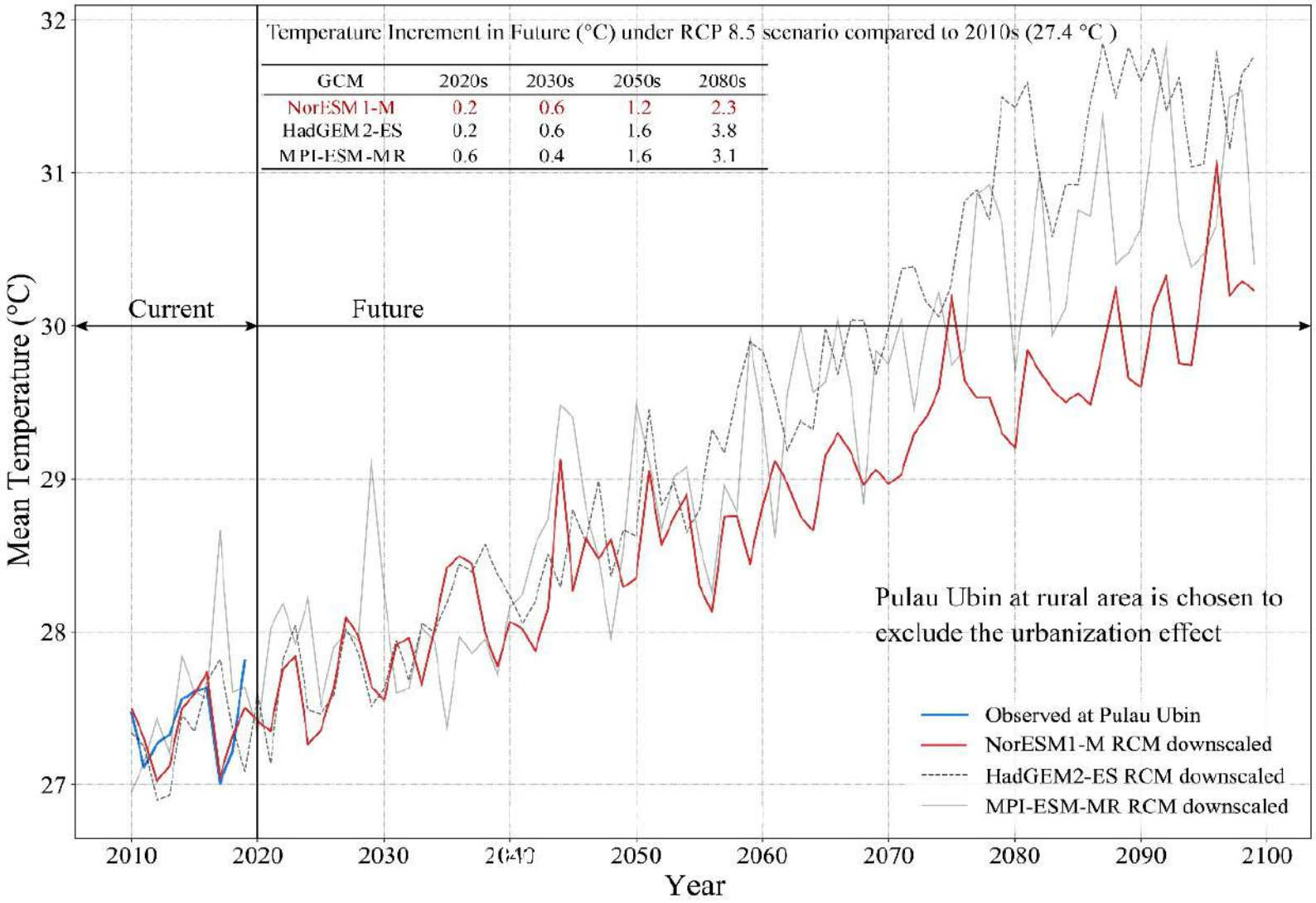
Urban Heat Risk Factor

Factor I. Climate Change



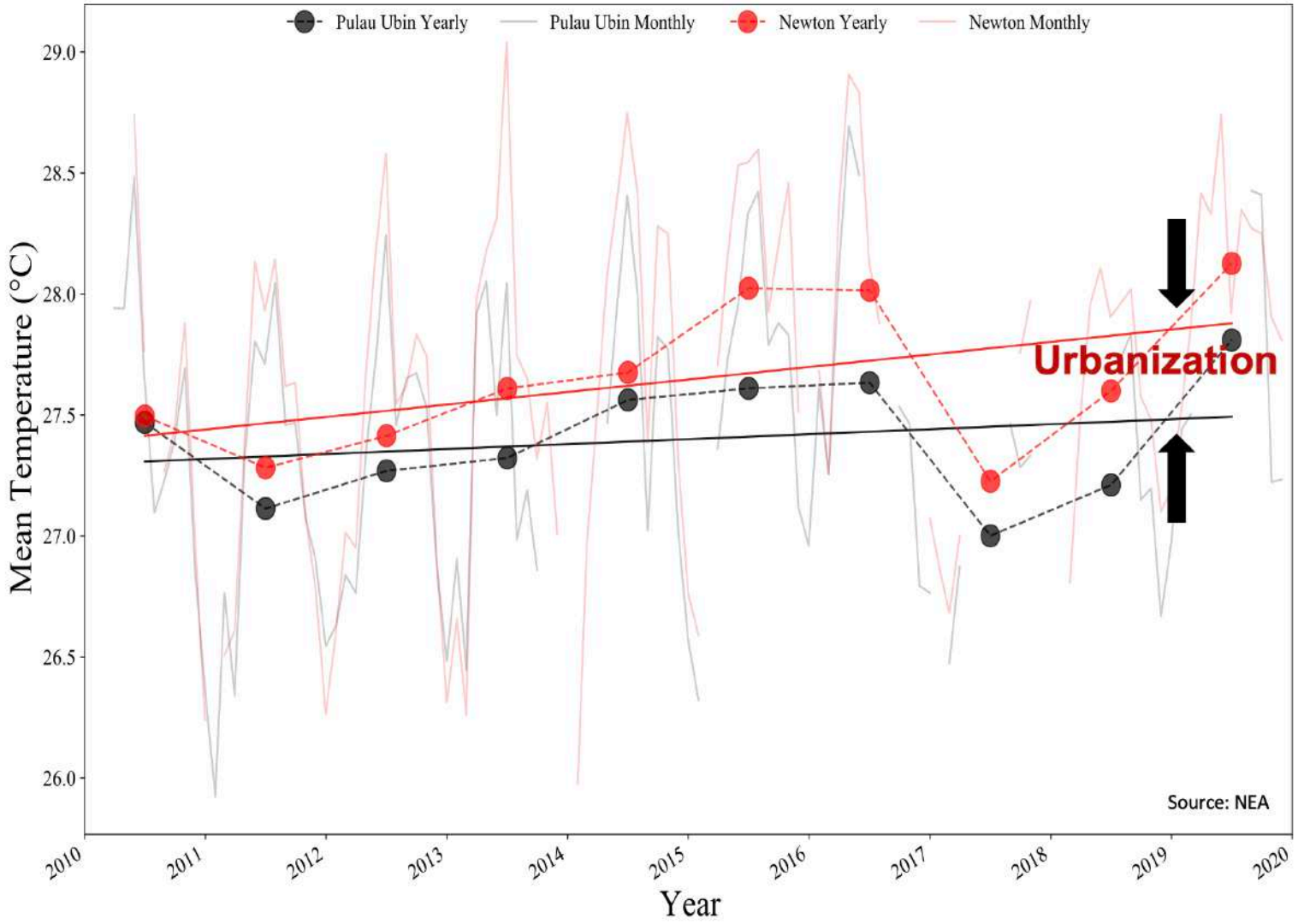
Downscaling three global climate modelling results to local impact in Singapore:

- **0.4 - 0.6 degree** air temperature increment in 2030;
- **1.2 - 1.6 degree** air temperature increment in 2050;
- **RCP 8.5** as the scenario to do projection.

He, W., Zhang, L., & Yuan, C. 2022, Future air temperature projection in high-density tropical cities based on global climate change and urbanization – a study in Singapore. Urban Climate, 42, 101115.

Urban Scale

Effect of Urbanization on Ambient Air Temperature in Singapore



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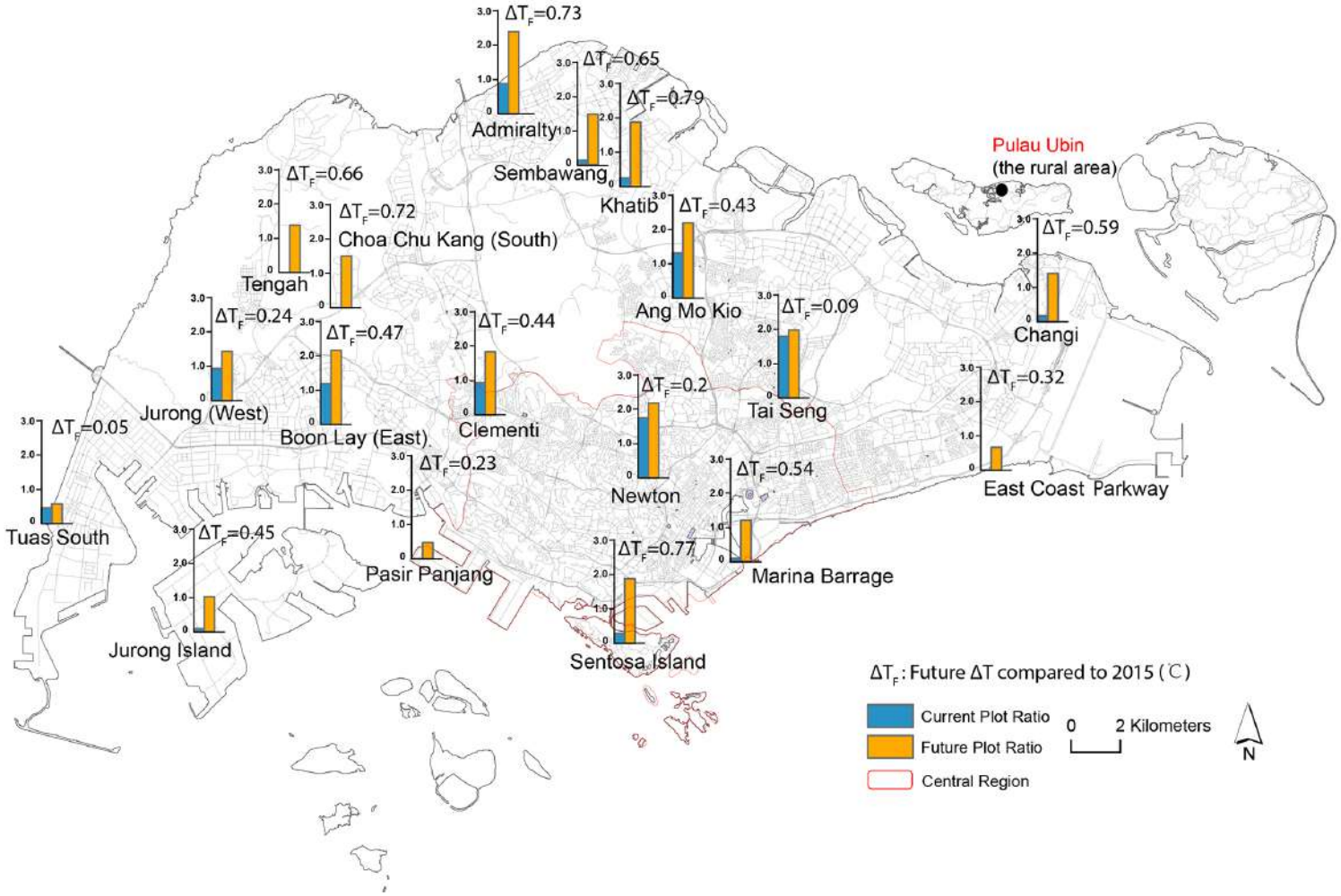
Coupled effects of global climate change and urbanization on air temperature



By 2030s,

- Air temperature would increase about 0.6°C due to global warming.
- Air temperature would additionally increase about 0.05 - 0.79°C by urbanization.

He, W., Zhang, L., & Yuan, C. 2022, Future air temperature projection in high-density tropical cities based on global climate change and urbanization – a study in Singapore. Urban Climate, 42, 101115.

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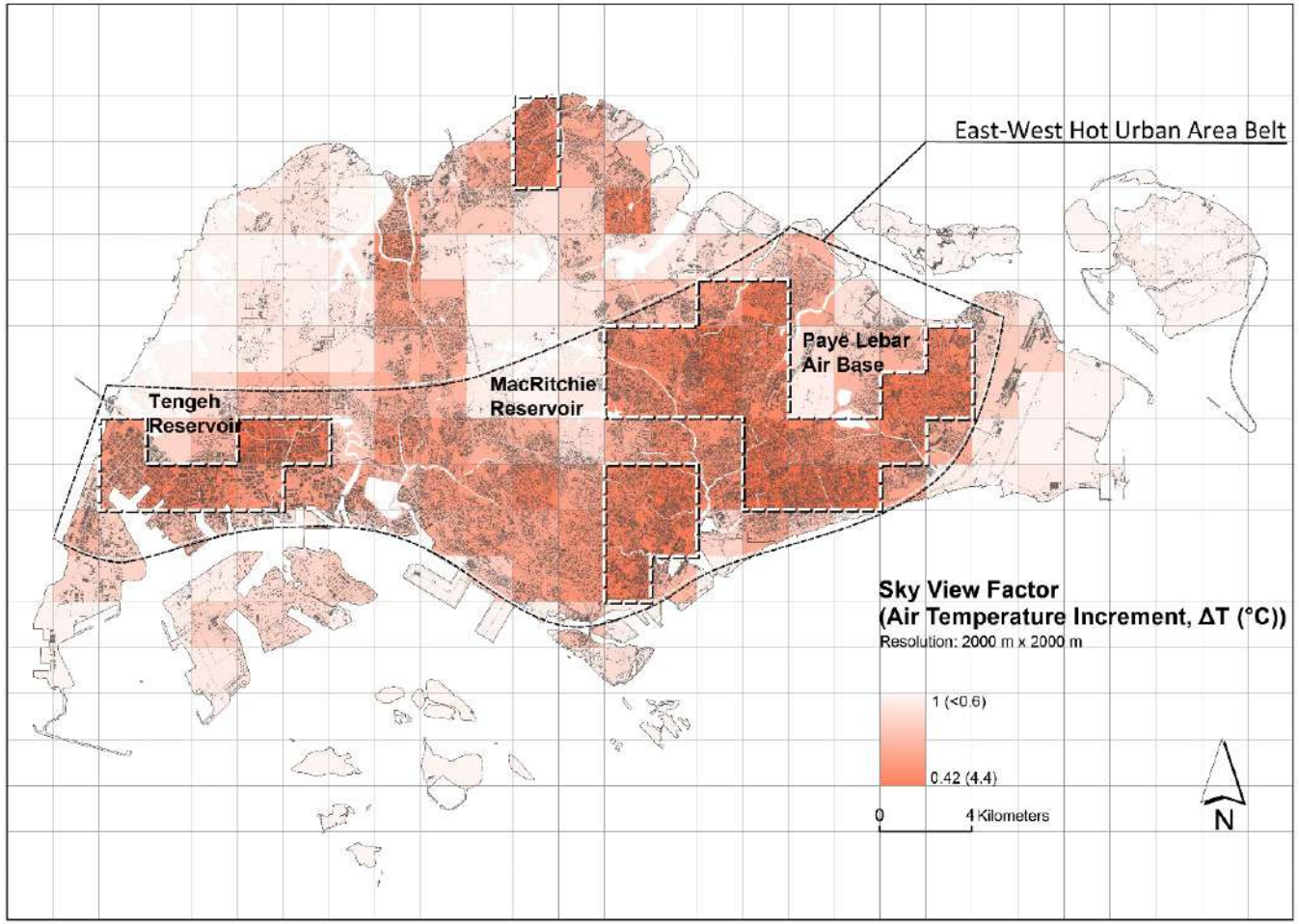
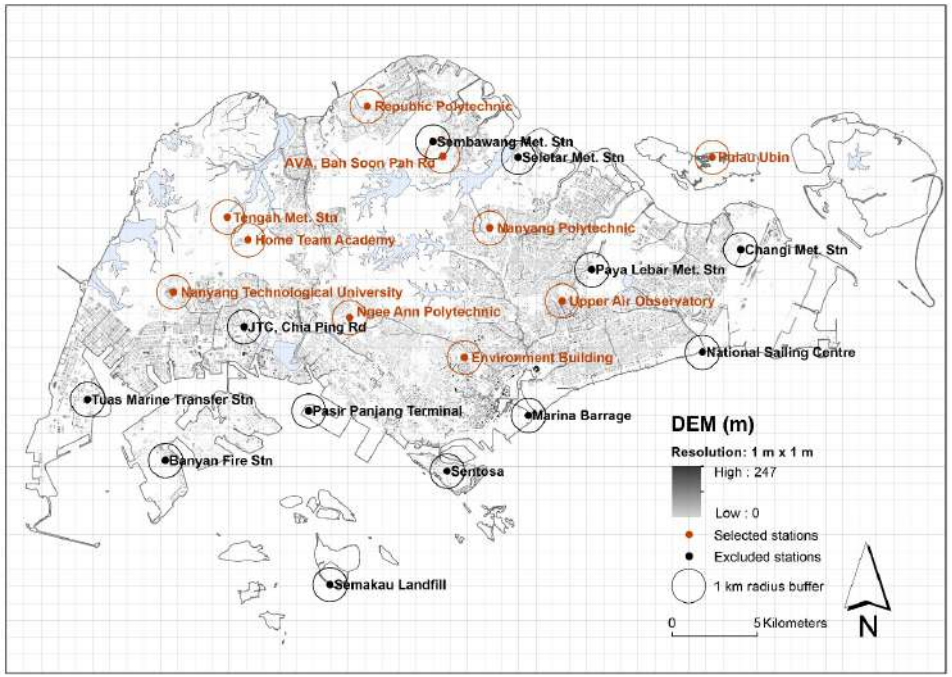
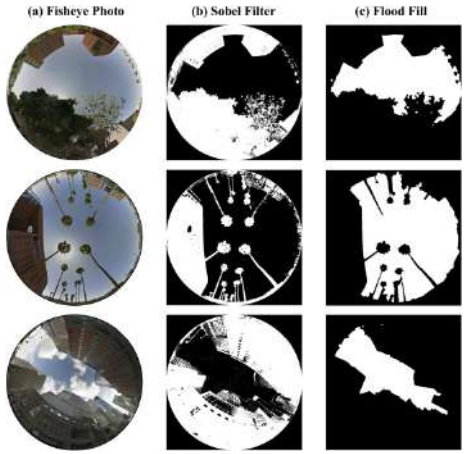
Urban Scale

Urban Heat Island

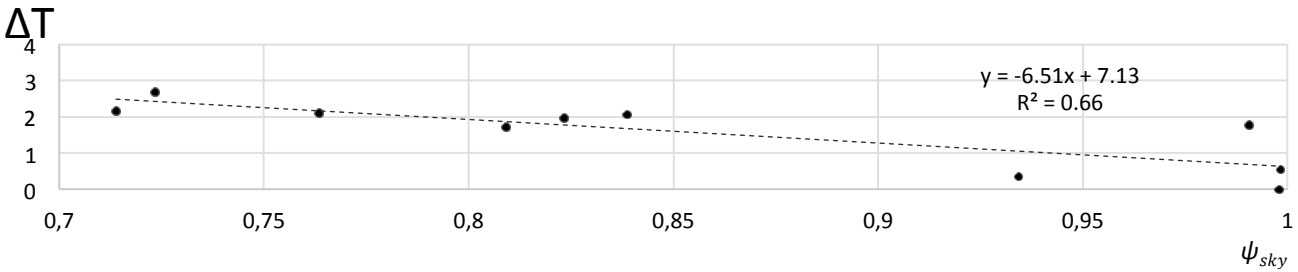




NEA weather station measurement



Sky view factor



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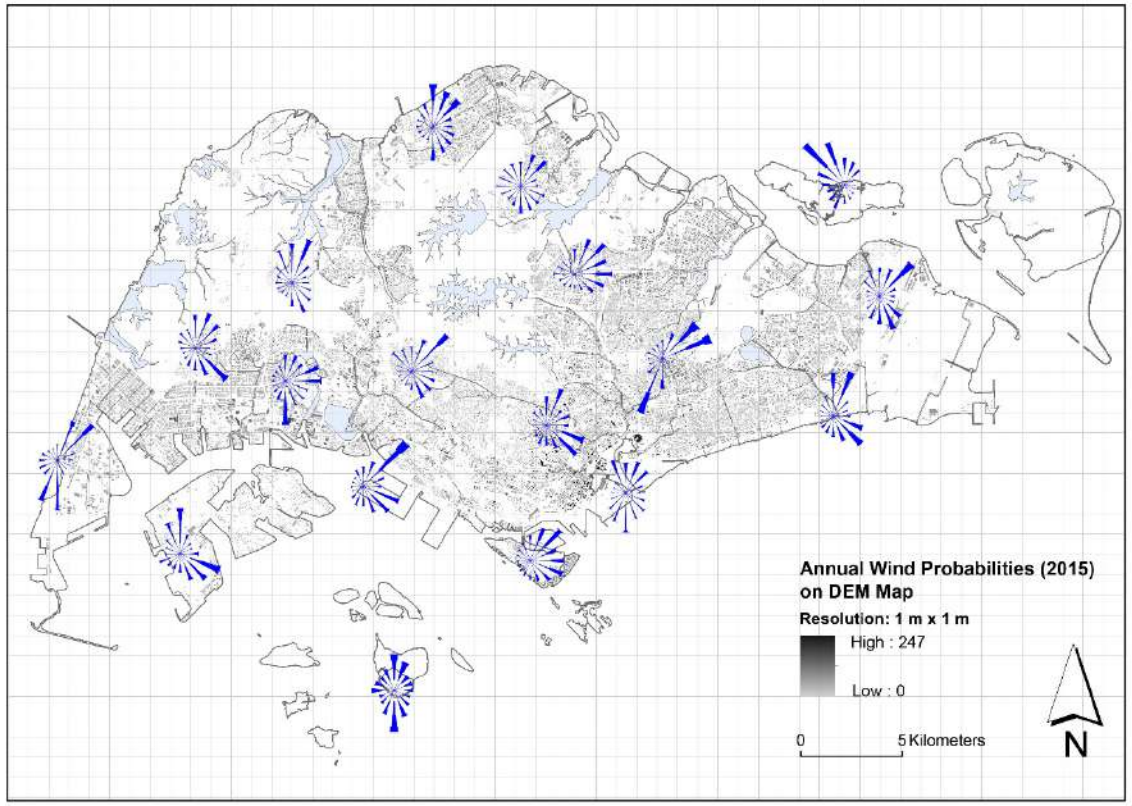
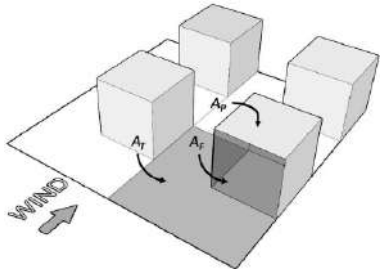
Urban Scale

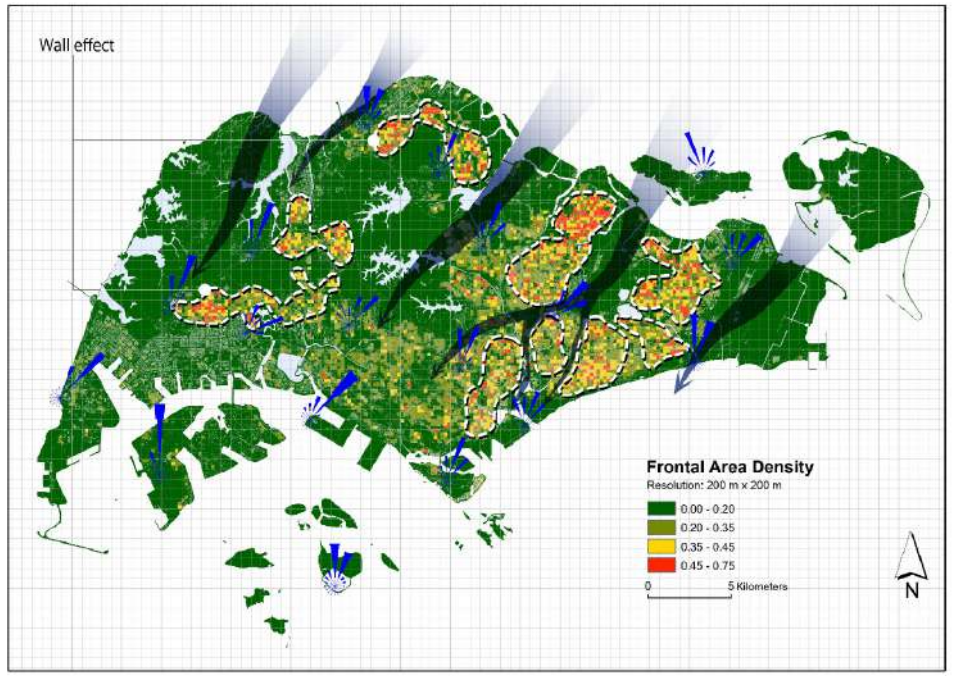
Urban Heat Island



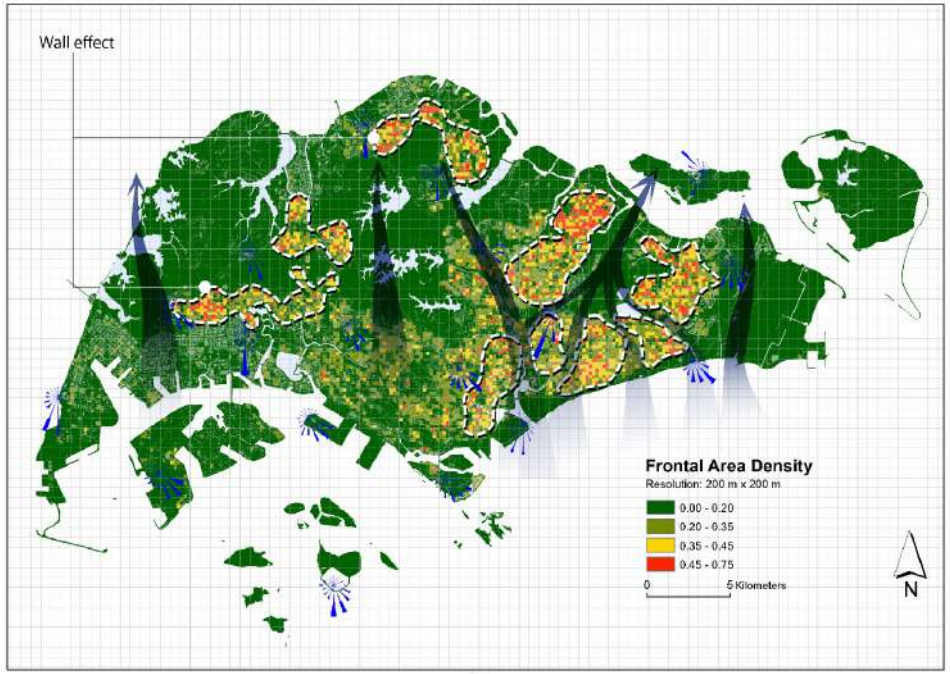
NEA weather station measurement



Definition of frontal area density



a



b

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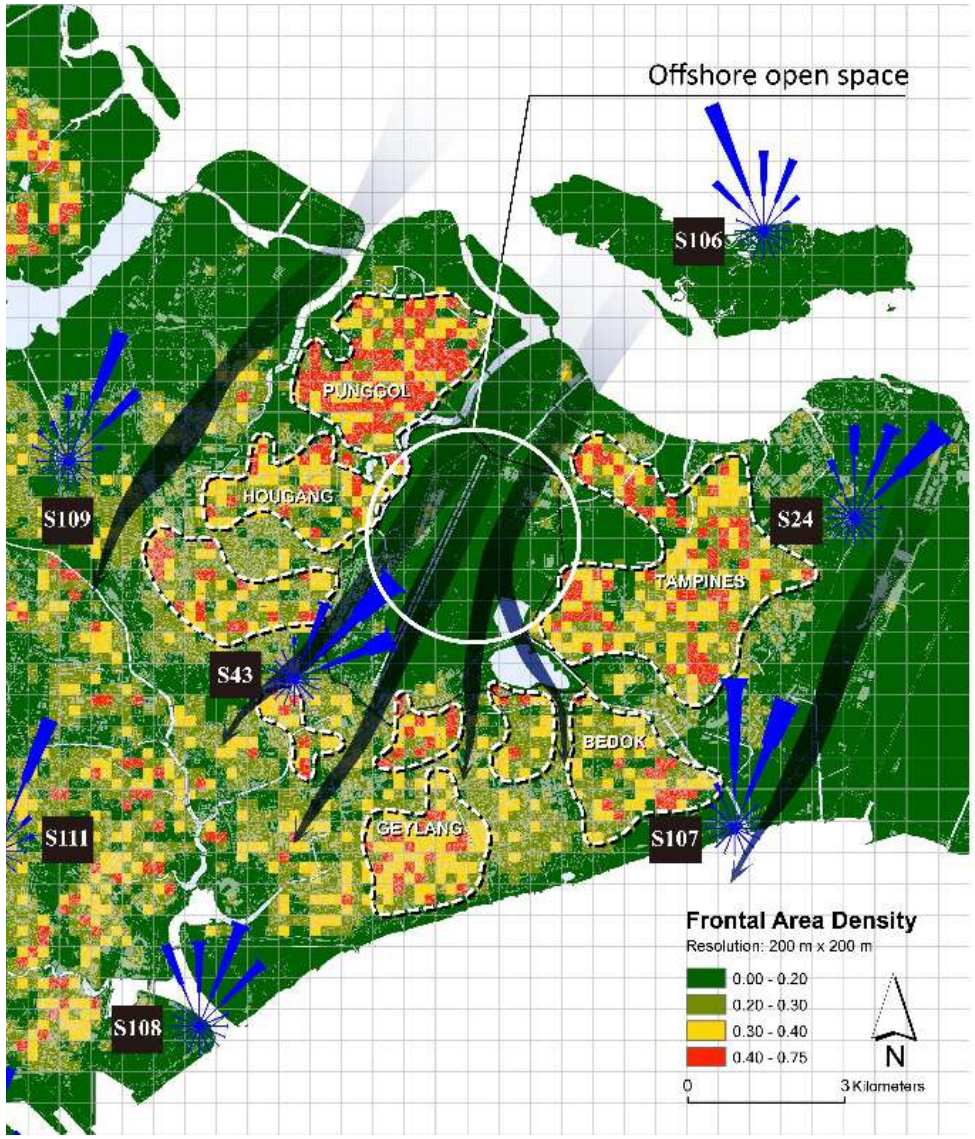
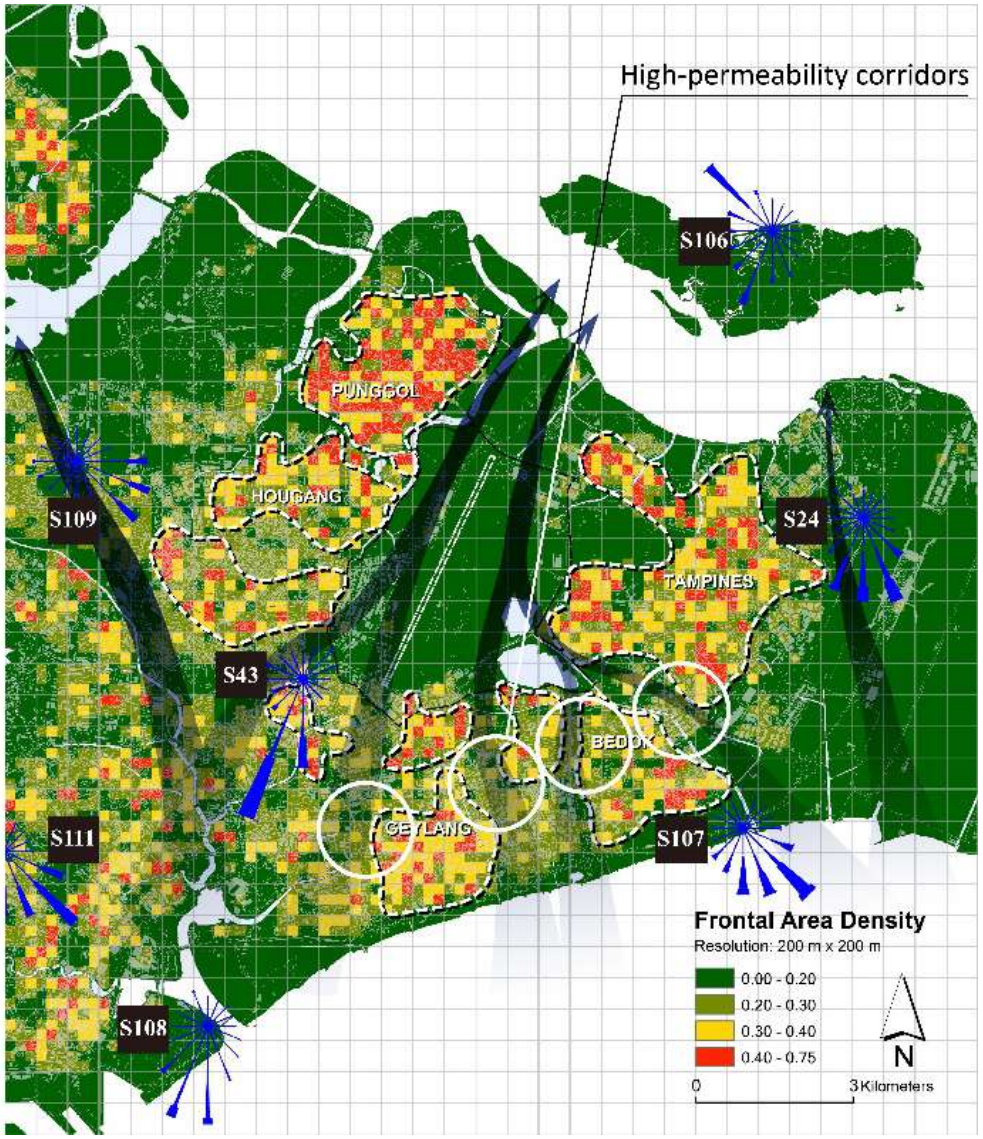
District Scale

Urban Heat Island





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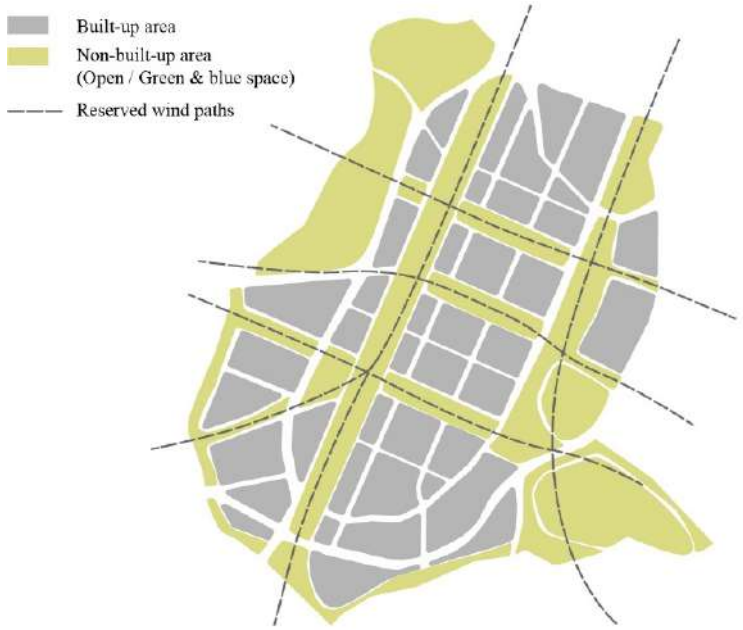
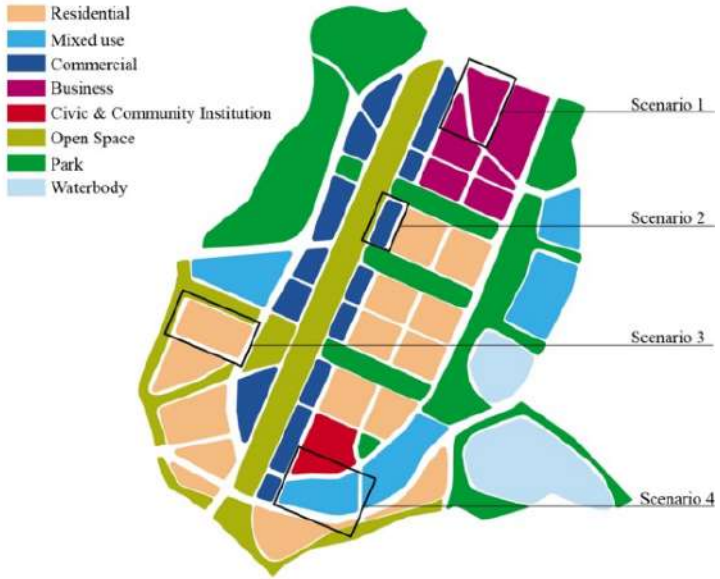
District Scale

Urban Heat Island

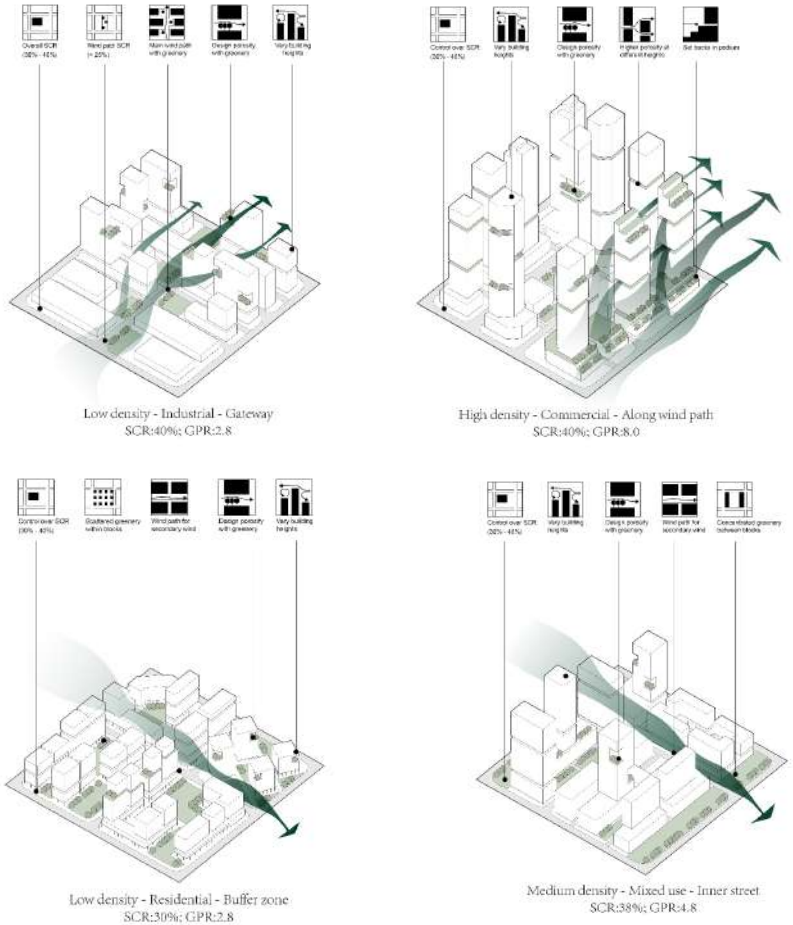


District structure



Land use pattern

Climate-sensitive
prototypes of building morphology



To separate urban heat islands and make sure air flow go through the site.

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Urban Scale

Anthropogenic Heat

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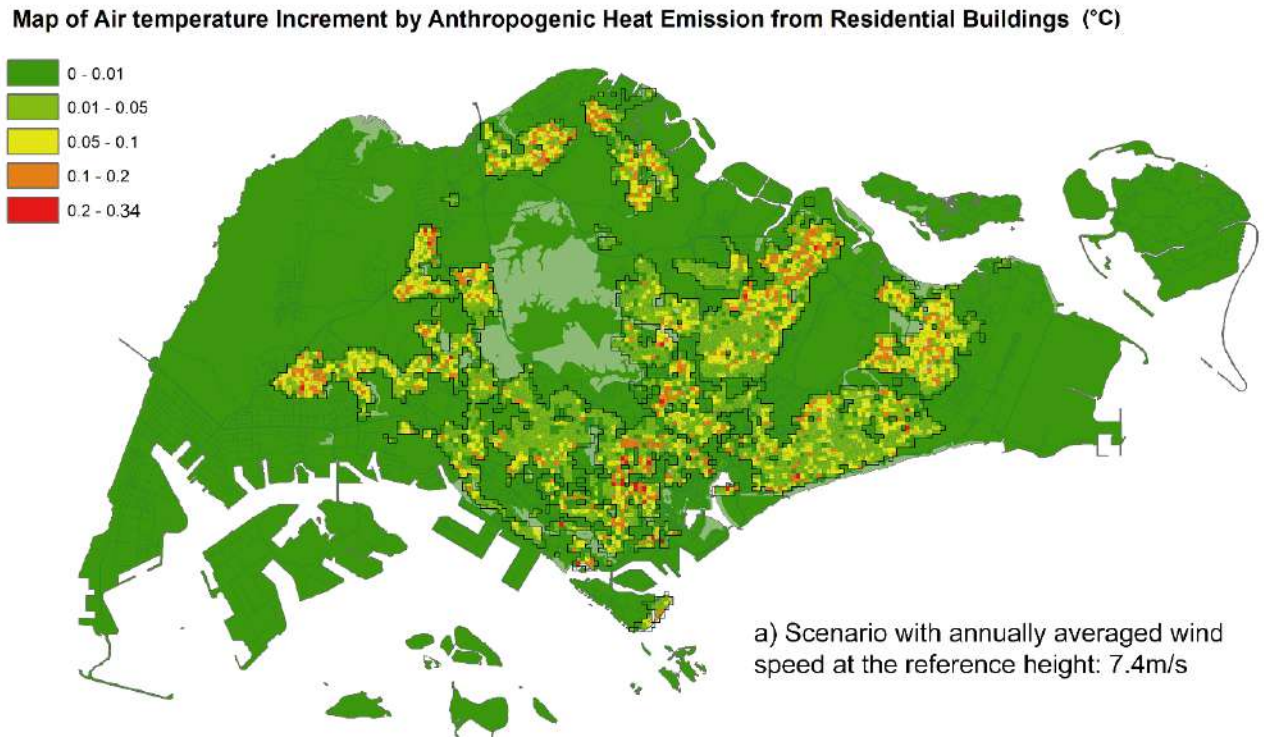
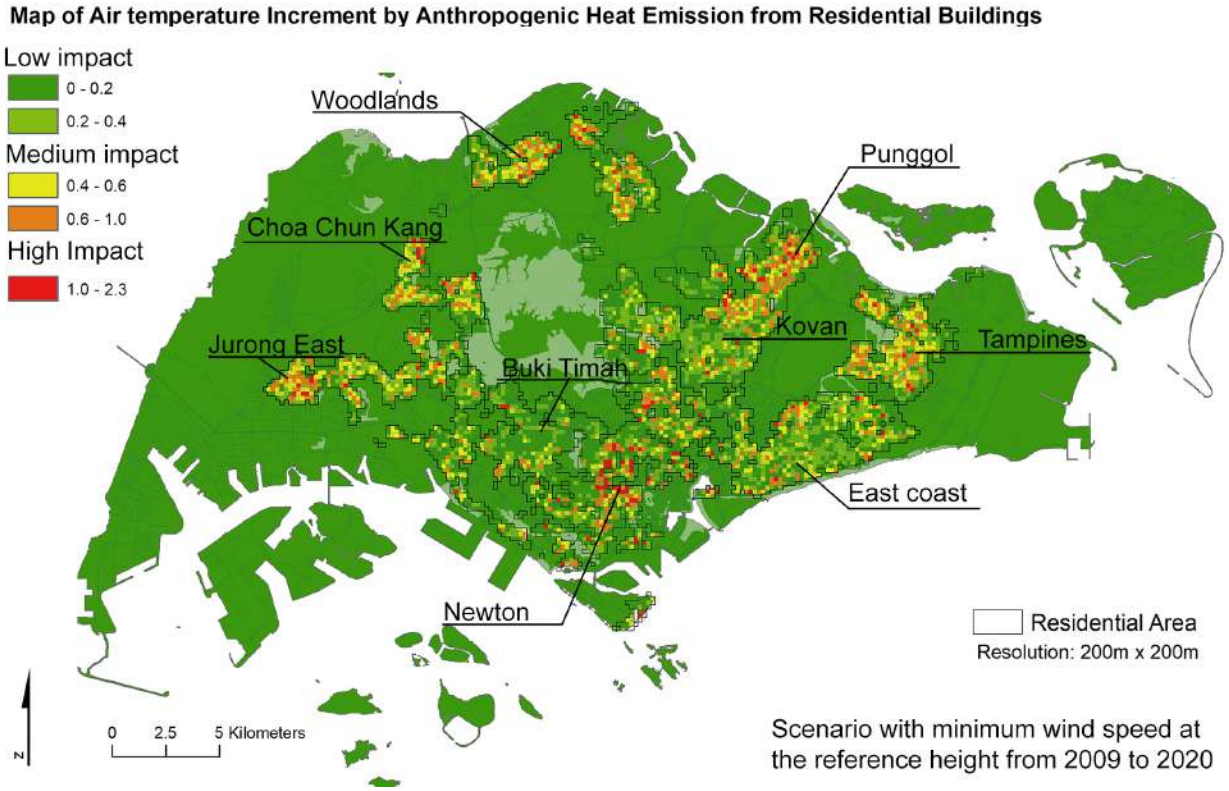
Urban Scale

Annual wind speed



Extreme low wind speed



Yuan C, Adelia AS, Mei SJ, He WH, Li XX, Norford L, 2020, Mitigating intensity of urban heat island by better understanding on urban morphology and anthropogenic heat dispersion, Building and Environment, 176, pp 106876.

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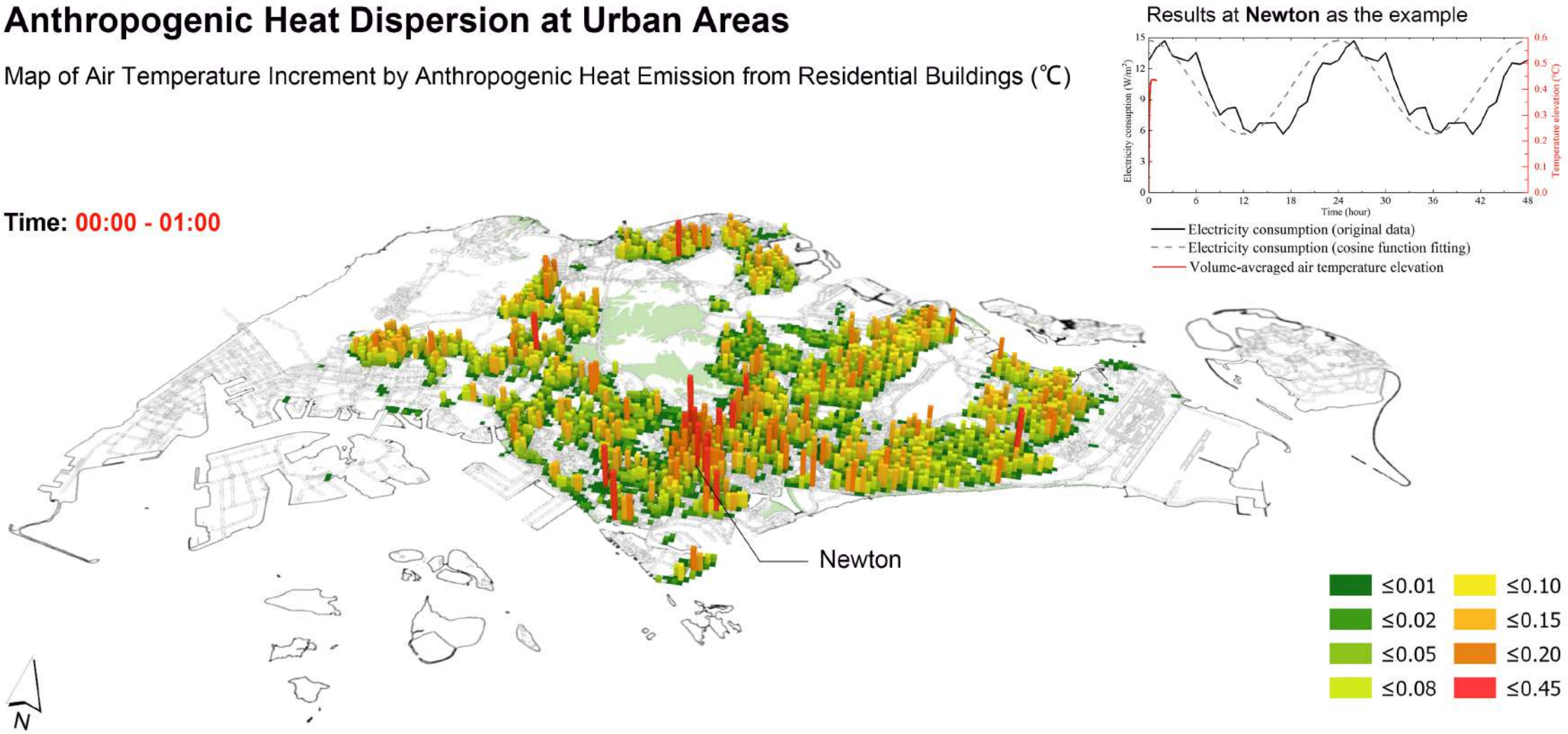
Anthropogenic Heat Dispersion at Urban Areas

Map of Air Temperature Increment by Anthropogenic Heat Emission from Residential Buildings (℃)



Unsteady state modelling --- Time scale study at the city scale

Resolution: 200m x 200m

Mei, SJ. and Yuan, C. 2021, Analytical and numerical study on transient urban street air warming induced by anthropogenic heat emission. Energy and Buildings, 231, 110613.

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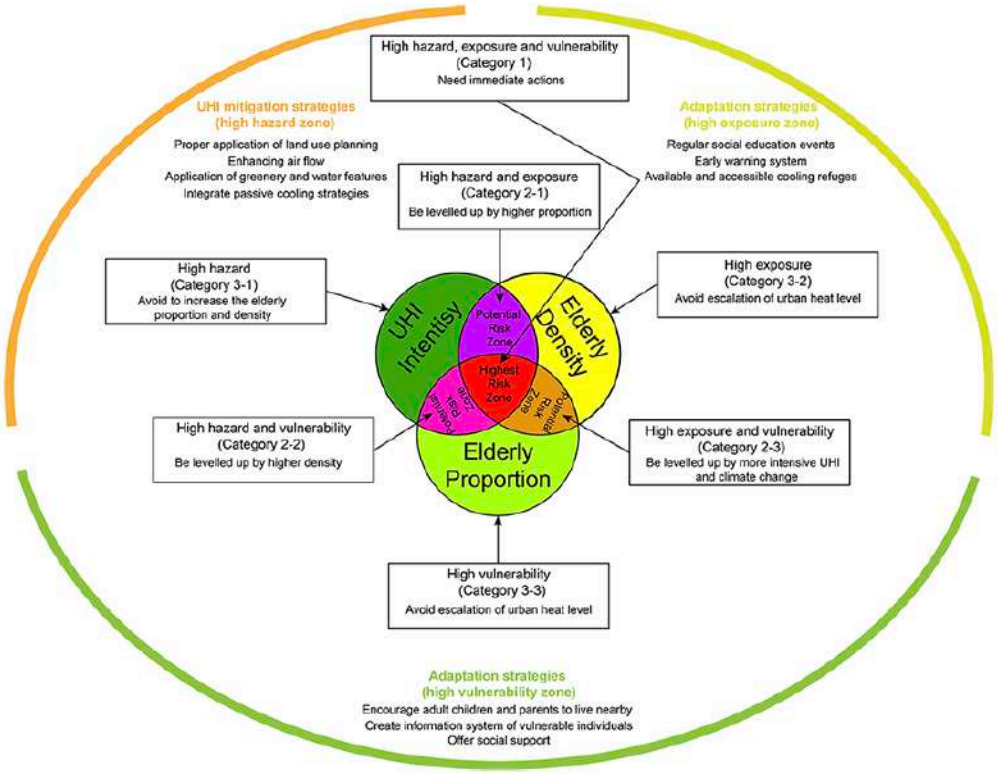

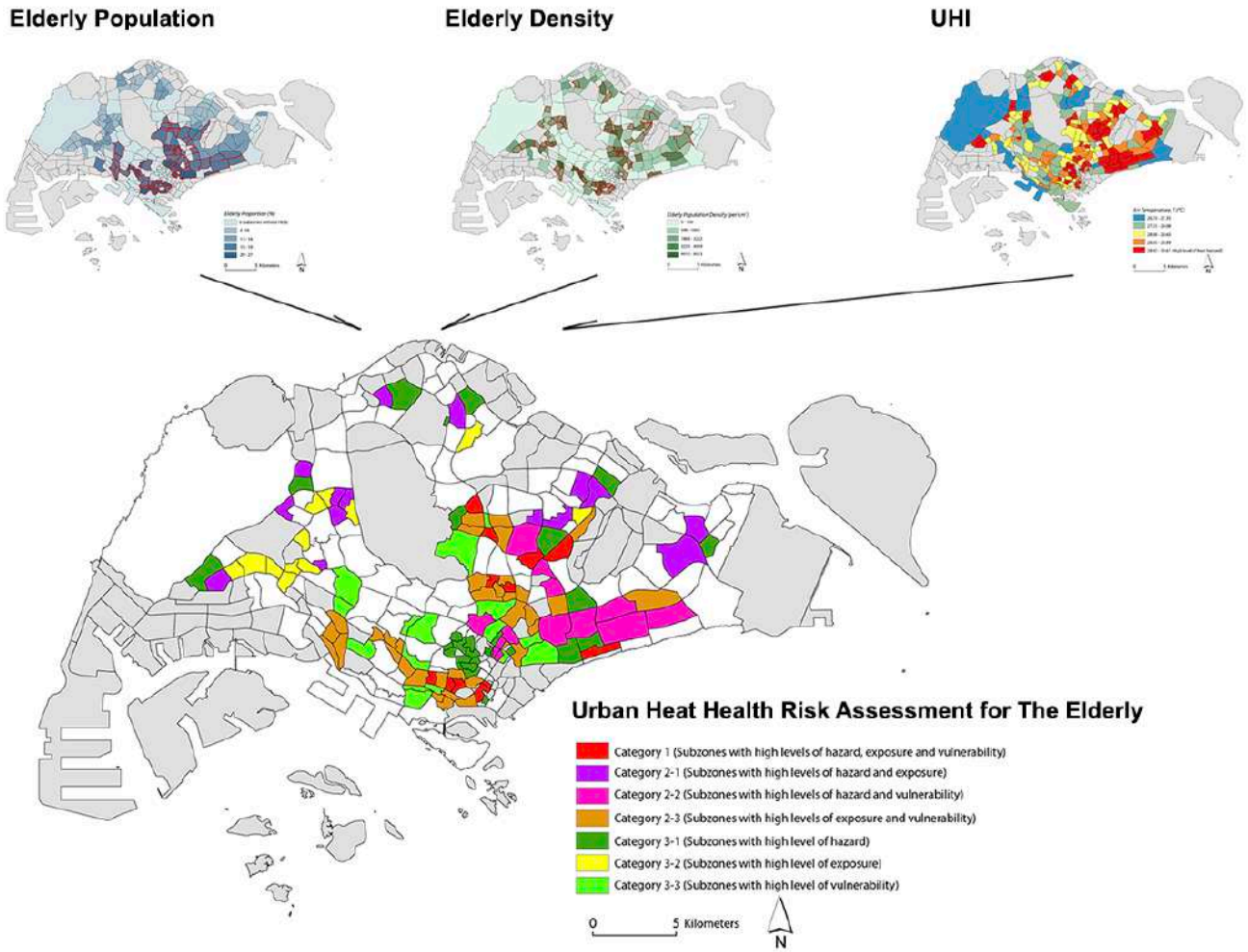

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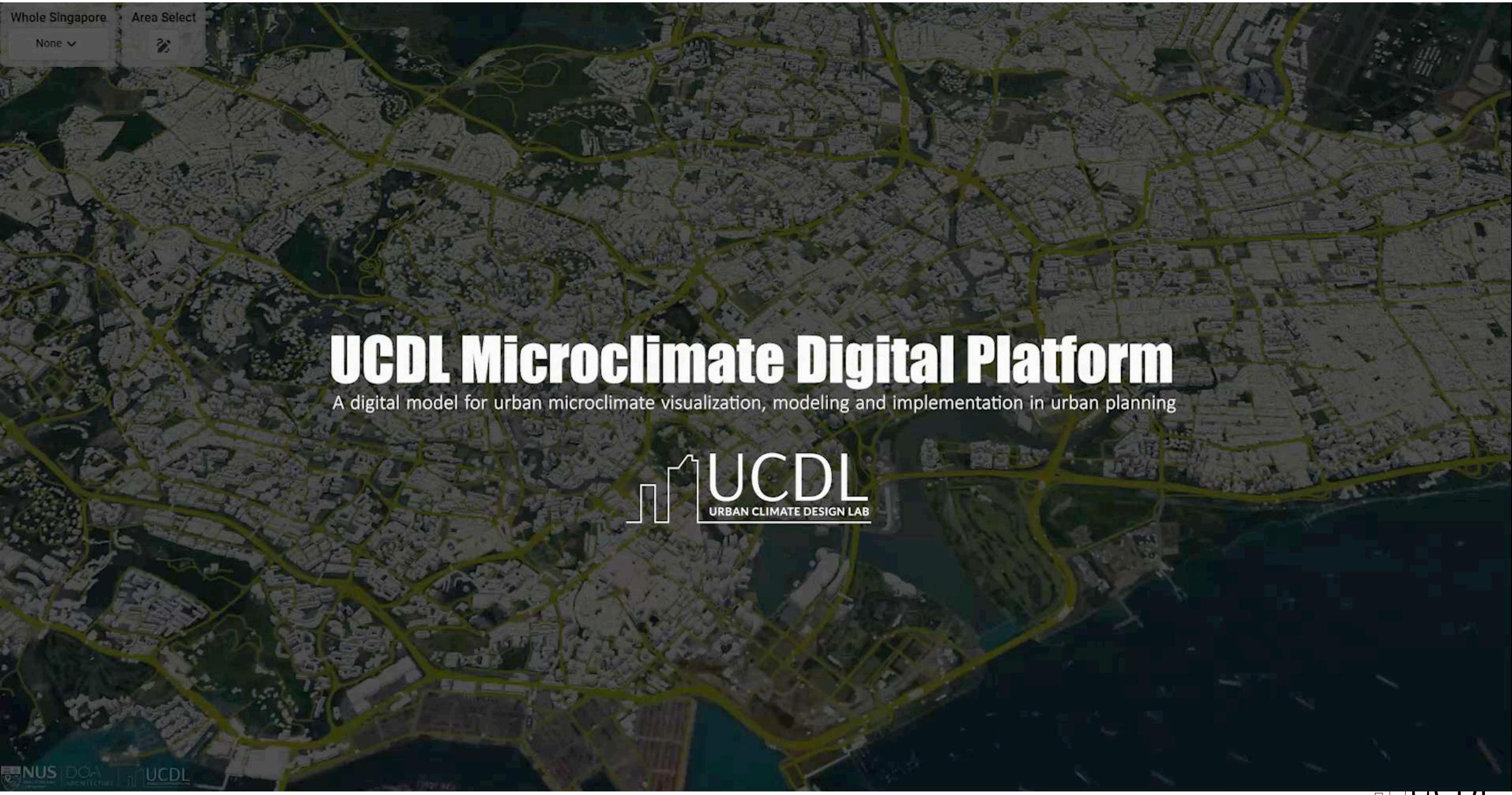

UCDL Microclimate Digital Platform

A digital model for urban microclimate visualization, modeling and implementation in urban planning

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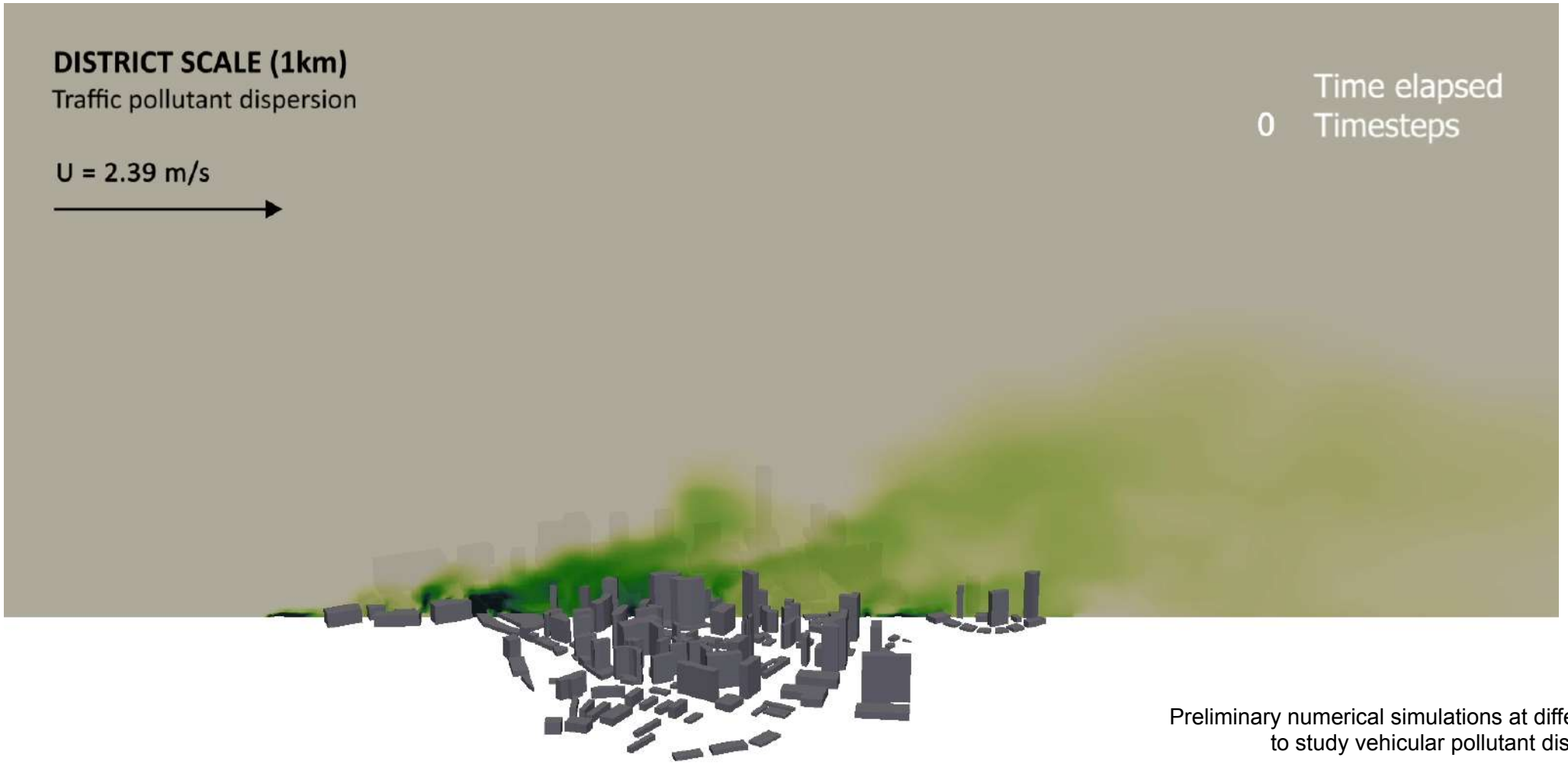
Neighborhood Scale



Preliminary numerical simulations at different wind speeds
to study vehicular pollutant dispersion

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Neighborhood Scale

Effect of buoyancy on urban ventilation and heat dispersion at urban areas

- **The buoyancy-driven airflow** at a high-density urban area is crucial for **airflow** and **heat dispersion** in a no wind condition.

- Mei, SJ. and Yuan C., 2021, Three-dimensional simulation of building thermal plumes merging in calm conditions: Turbulence model evaluation and turbulence structure analysis, Building and Environment, 203, 108097
- Mei, SJ. and Yuan, C., 2022, Urban buoyancy-driven air flow and modelling method: A critical review. Building and Environment, 210, 108708.

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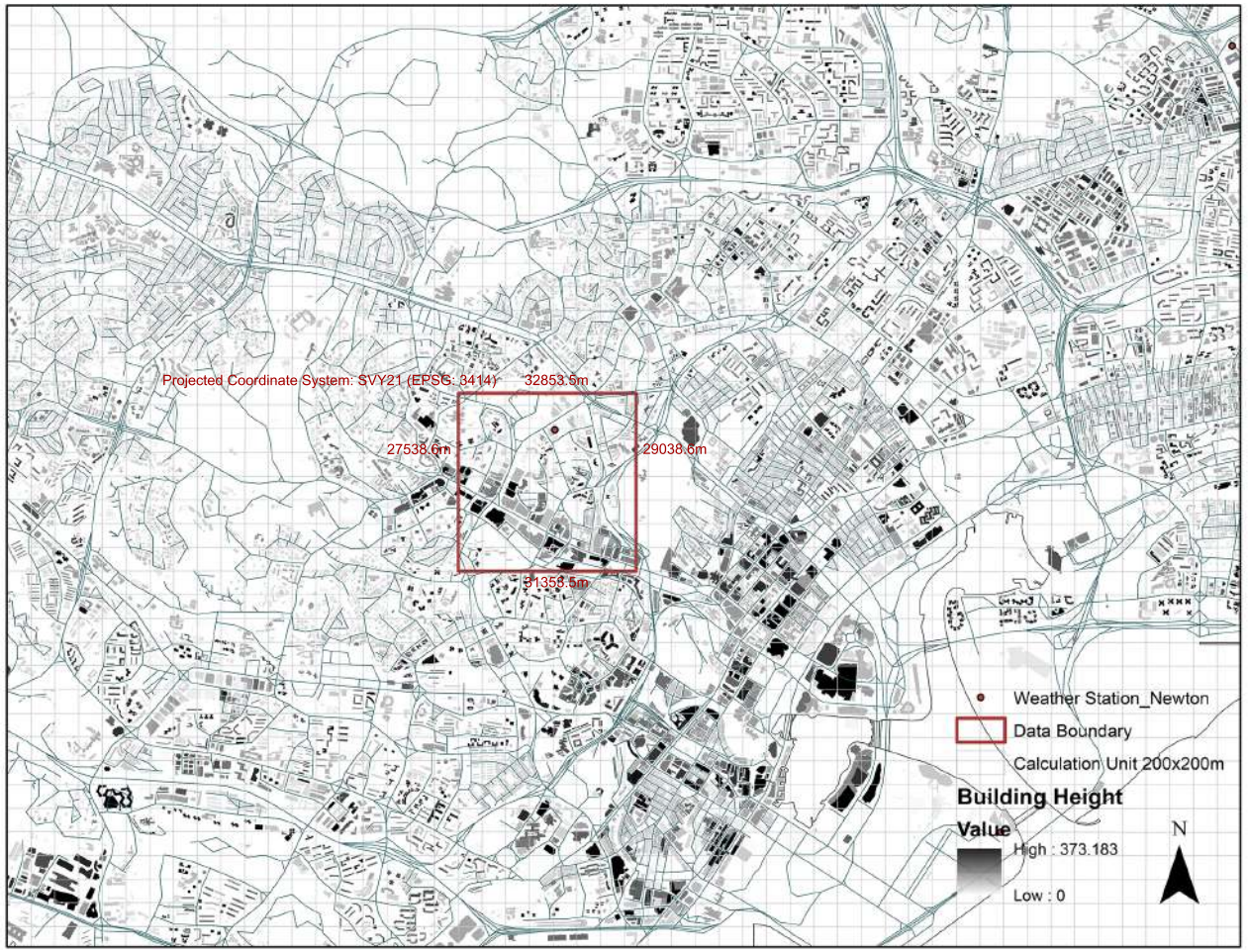
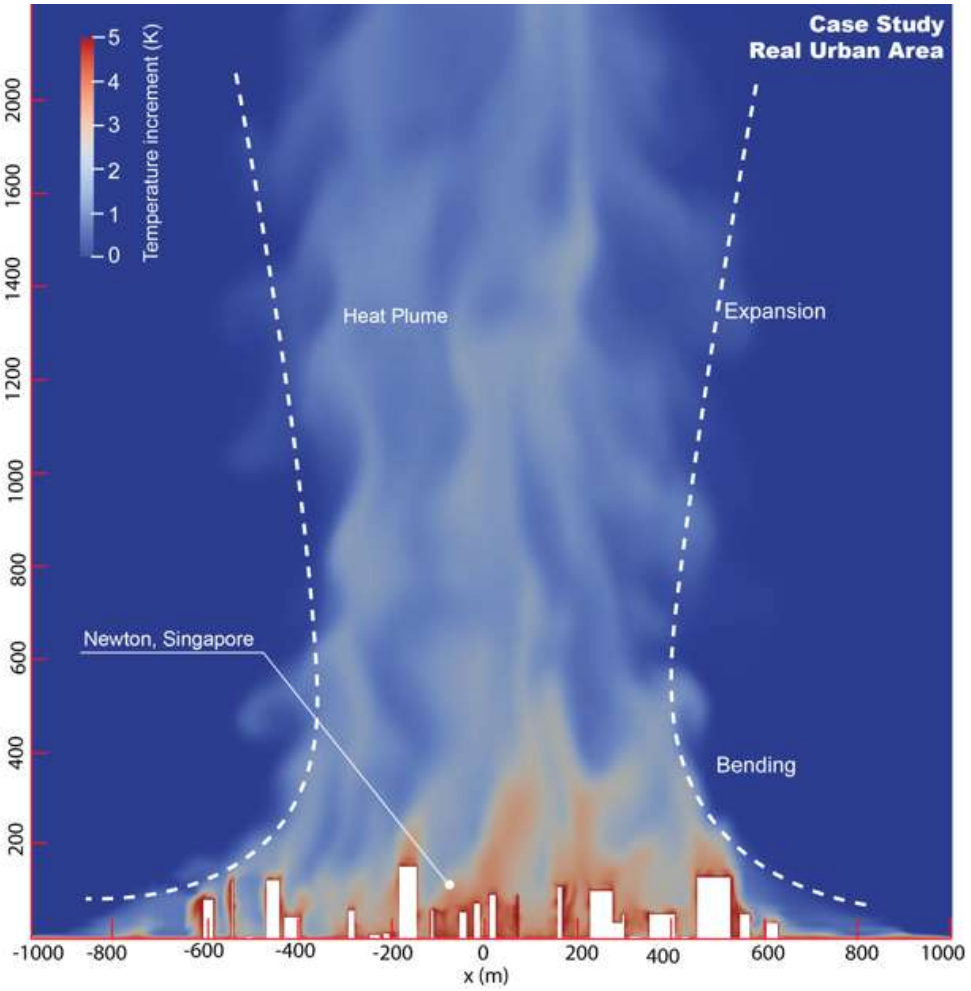
Neighborhood Scale

Effect of buoyancy on urban ventilation and air quality at urban areas





Time-averaged air temperature increment distributions a vertical plane

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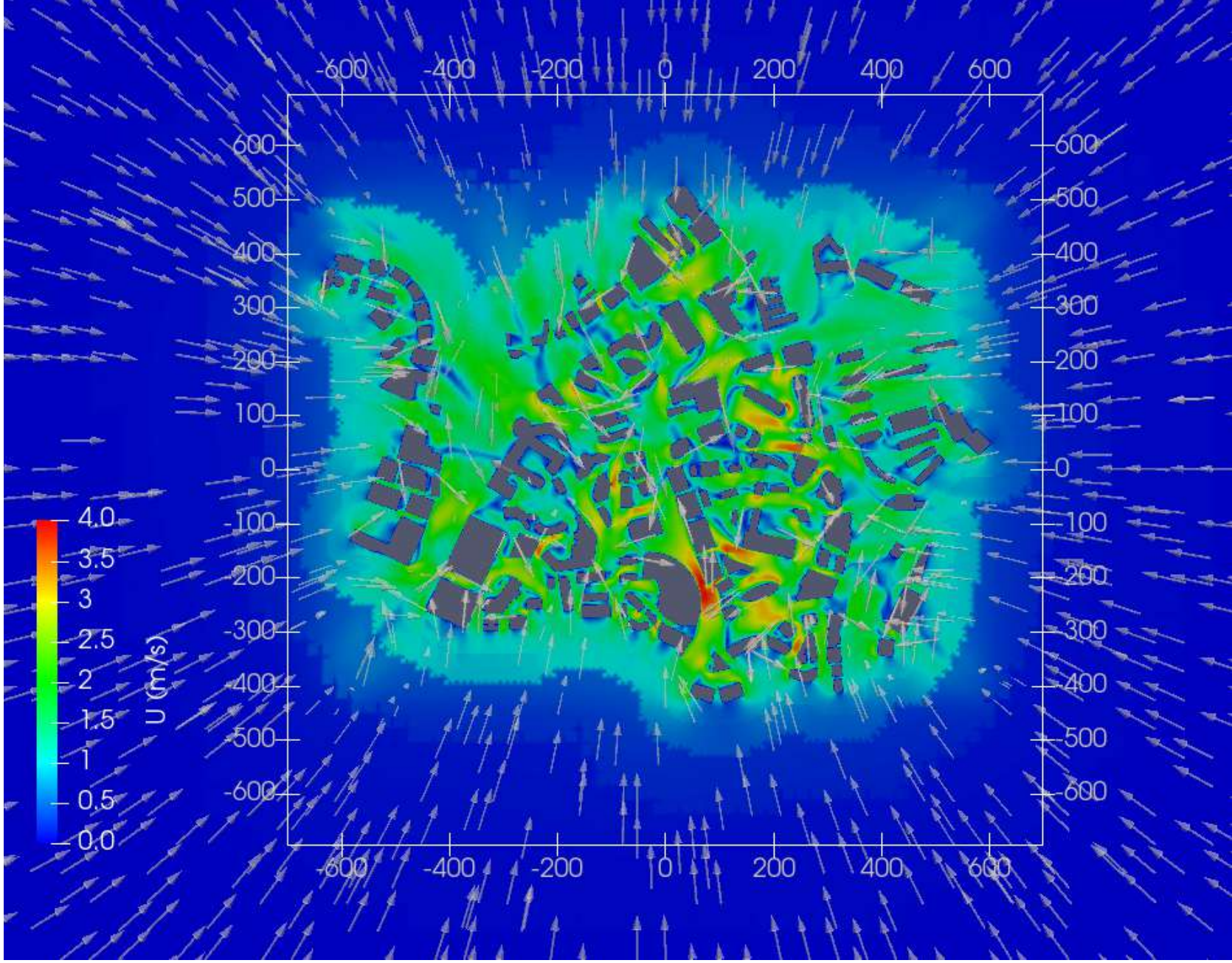
Neighborhood Scale

Buoyancy-driven scenario without incoming wind, i.e., the calm condition

Wind speed at 2m above ground, i.e., pedestrian level.



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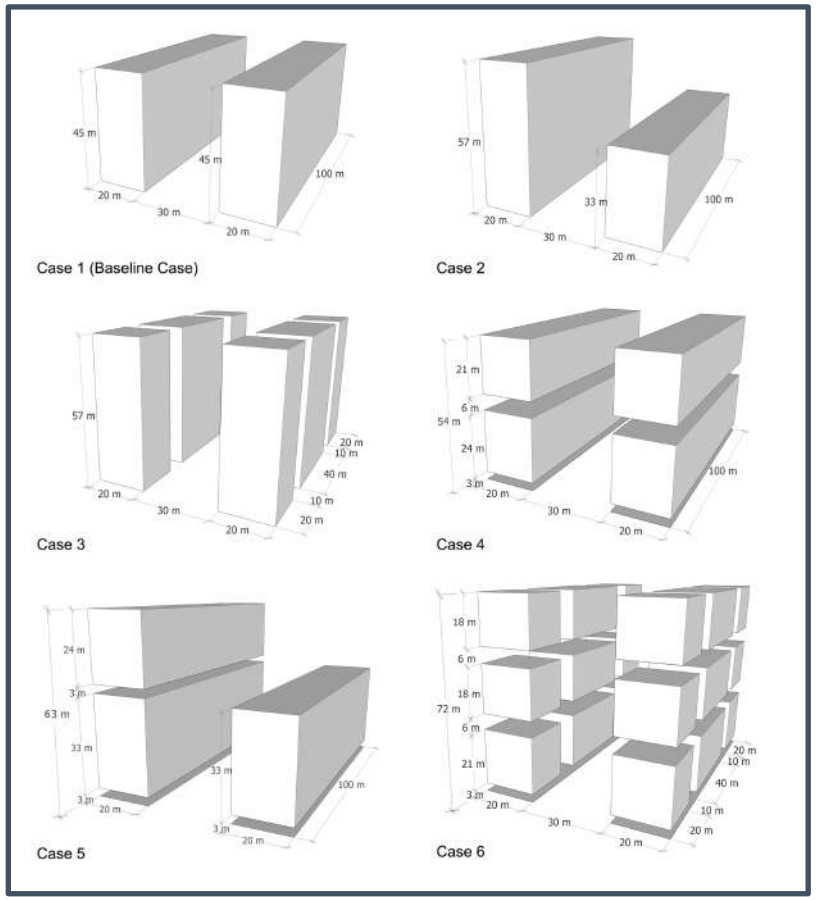
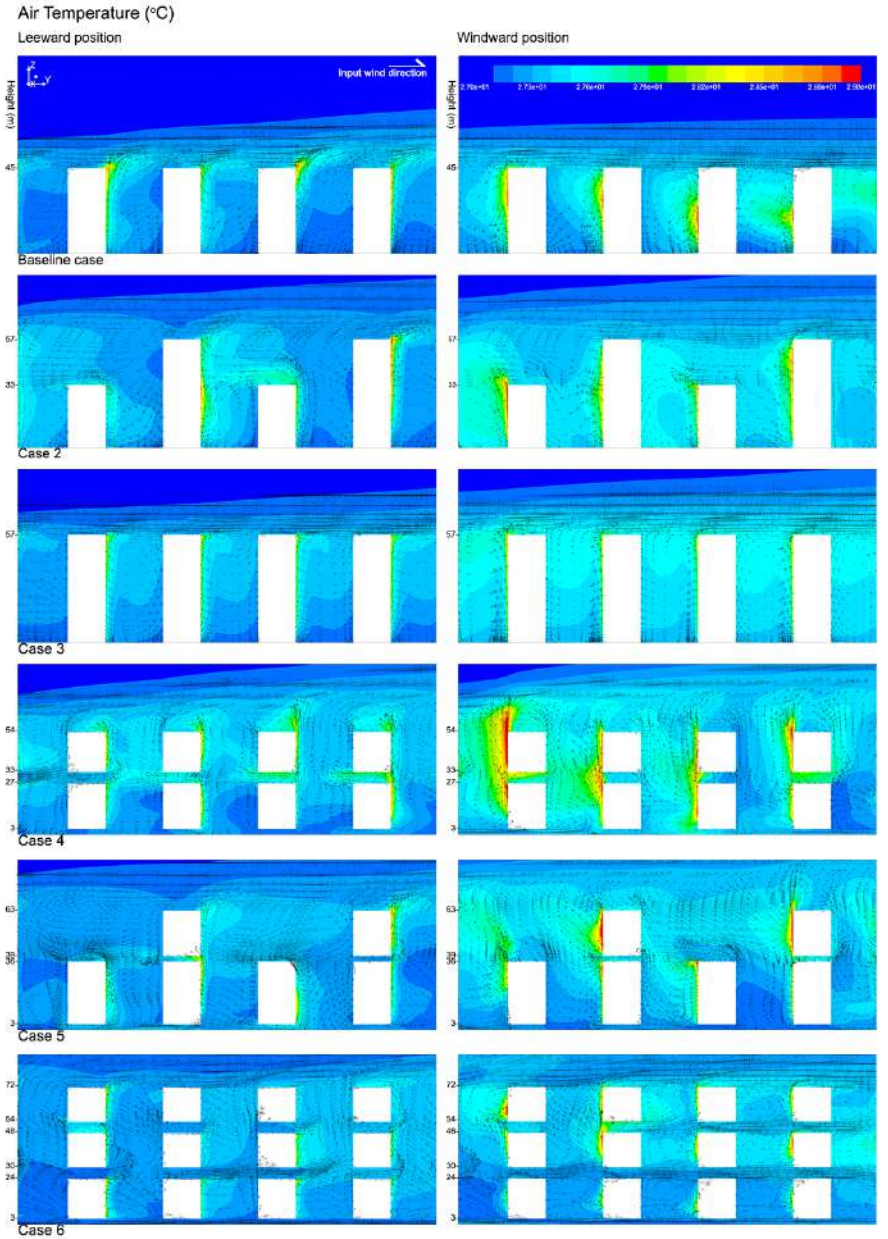
Building Scale

Parametric study for anthropogenic heat impact at the building scale





Adelia AS, Yuan C, Liu L, Shan RQ, 2019, Effects of urban morphology on anthropogenic heat dispersion in high-density tropical cities, Energy and Buildings, 186, pp 368-383.

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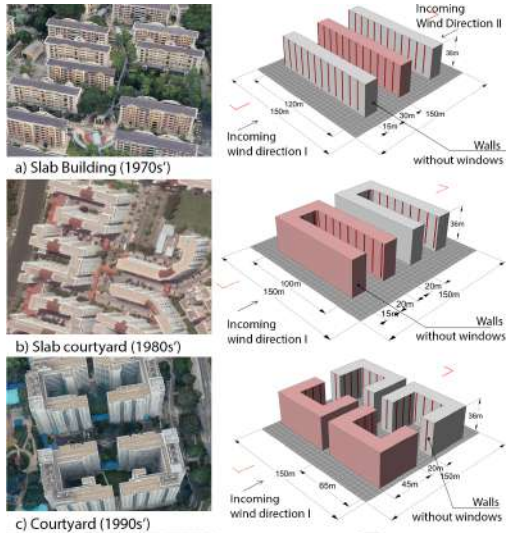
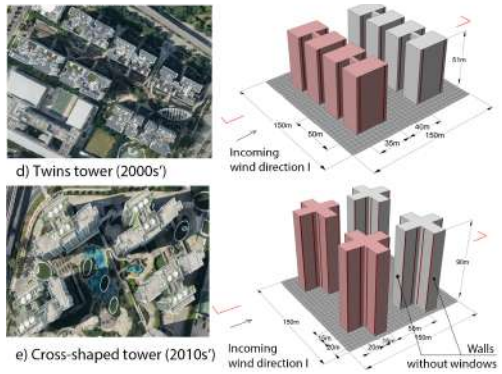
Building Scale

Impact of anthropogenic heat on indoor thermal comfort

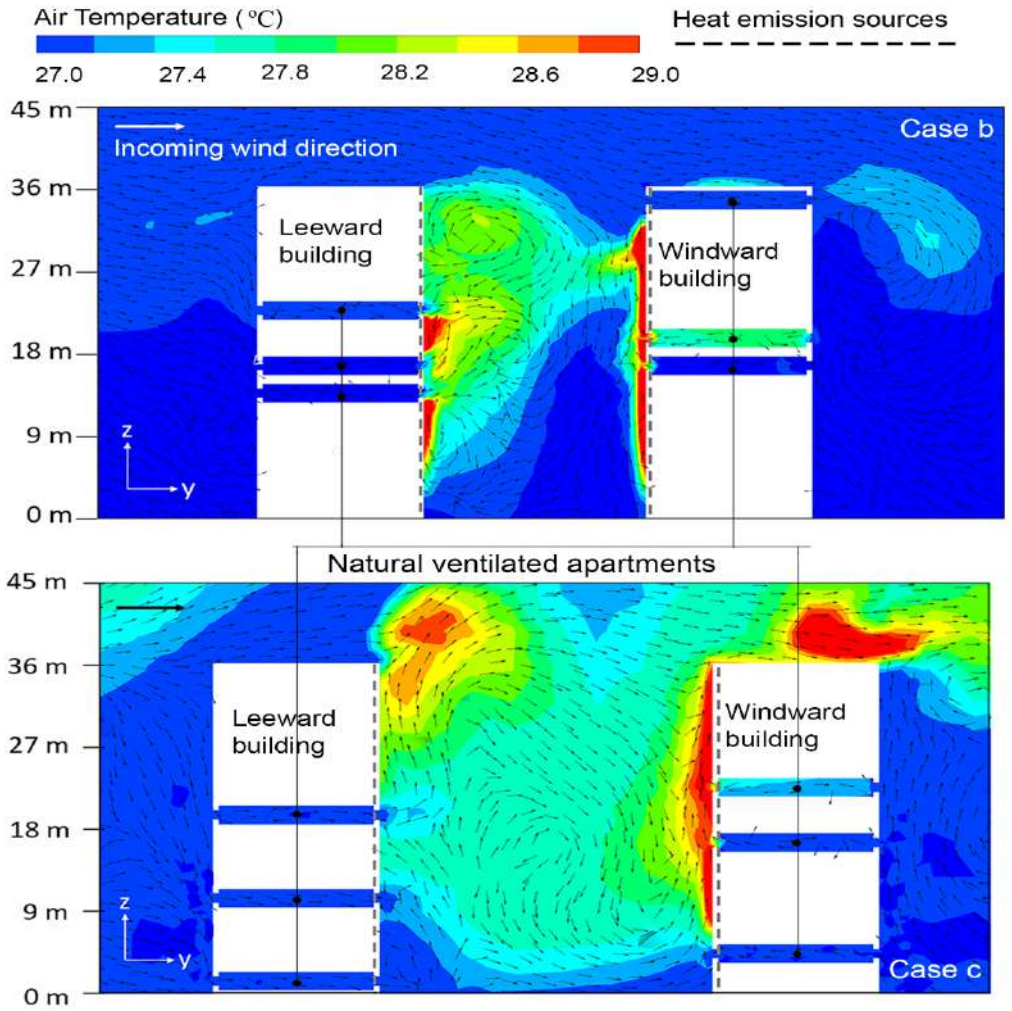




Parametric cases designed based on HDBs built in different generations (1970s-2010s) in Singapore.

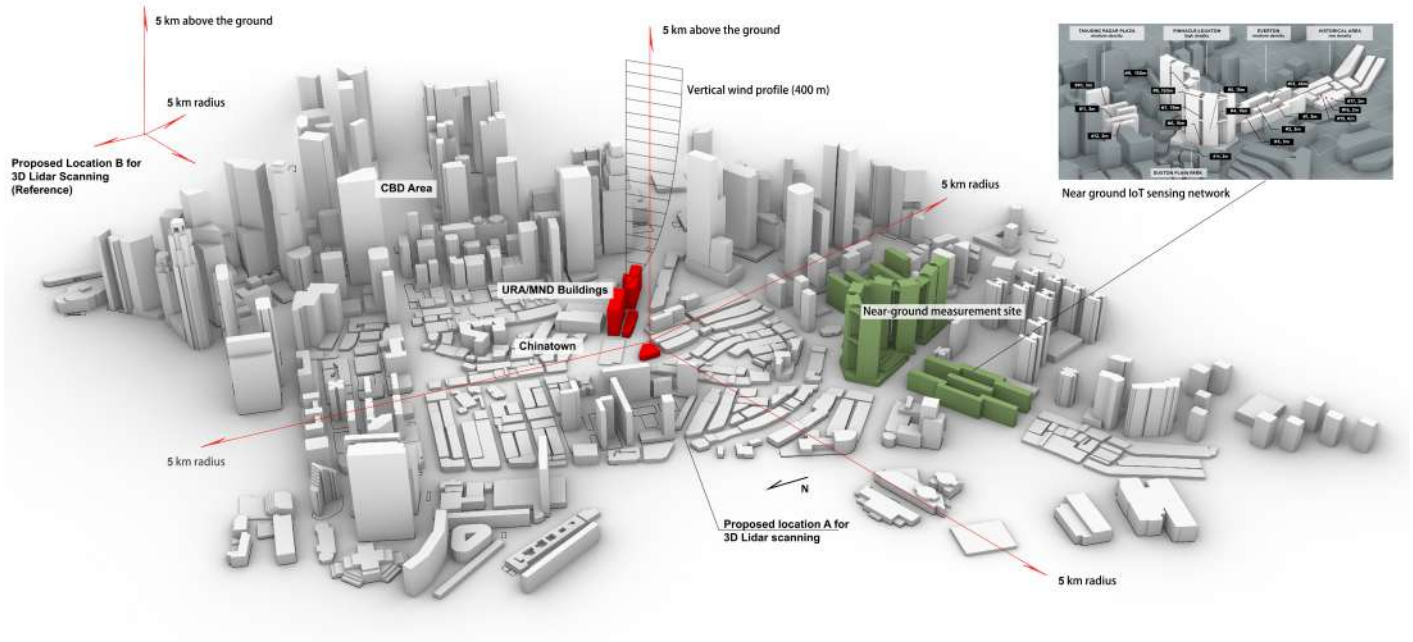
- Due to outdoor AH, the air temperature increases up to $4.2℃$ in natural ventilated apartments, which is found at 1970s' HDB.
- On average, the natural ventilated apartments in 1990s' and 2000s' HDB show $0.2-0.3℃$ air temperature increment, which is much lower $1.1℃$ in 1970s' HDB.
- The indoor air temperature increment (ΔT) increases with floor elevation due to accumulated anthropogenic heat at higher elevation.

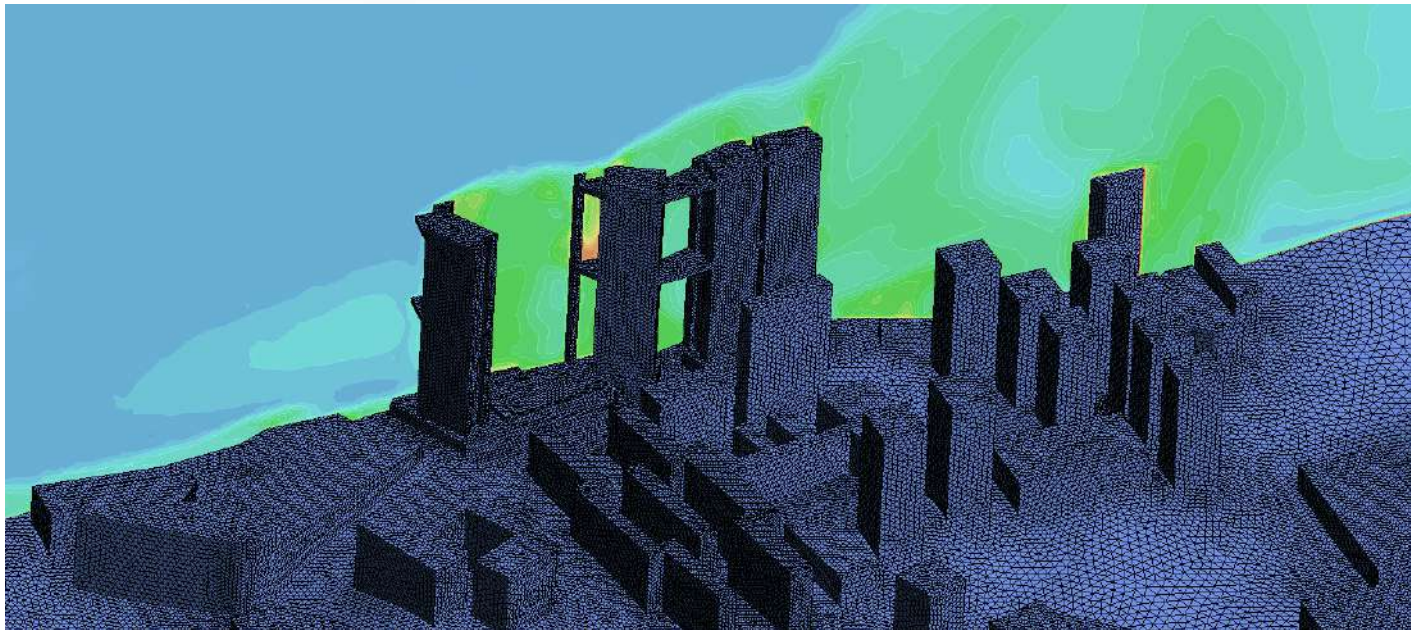
Yuan C., Zhu R.X., Tong S.S., Mei S.J., Zhu W. 2022, Impact of Anthropogenic Heat from Air-Conditioning on Air Temperature of Naturally Ventilated Apartments at High-Density Tropical Cities. Energy and Buildings, accepted



Vertical cross-section of outdoor/indoor air temperature contour.

Heat Forecasting and Nowcasting





- **Real-Time Observation**
- **High-Fidelity Modelling**
- **Fine spatiotemporal Scale Climate Risk Evaluation**

Thank you !

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