EPFL

CIVIL-309: URBAN THERMODYNAMICS

Assist. Prof. Dolaana Khovalyg

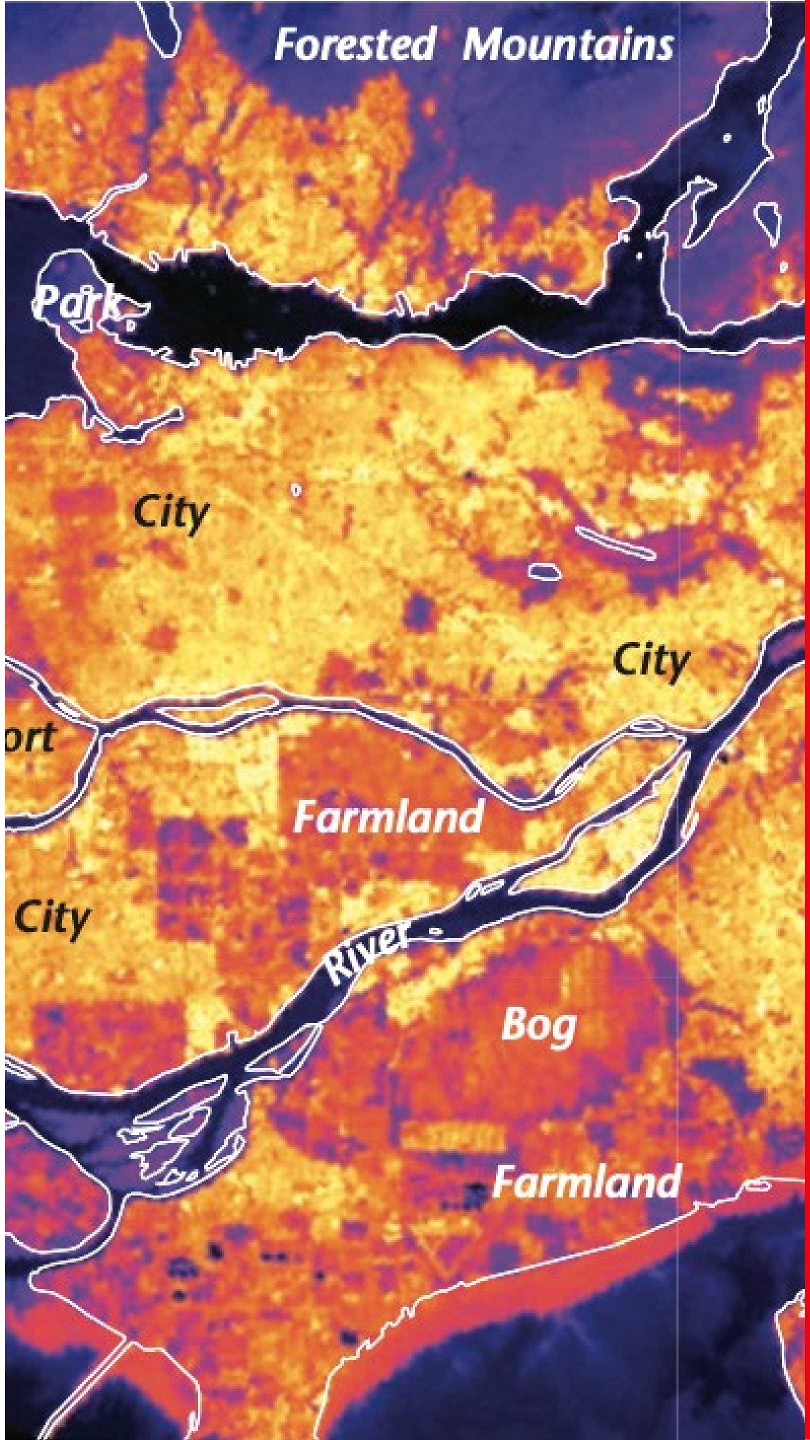
Lecture10:

Climate sensitive urban design

9 December 2024

Course Schedule

Week	Date	Time	ID	Topics	Responsible
12	25.11	2 x 45’	**L9**	**Human Outdoor Comfort:** Parameters affecting human comfort and comfort indices (UTCI, PET)	DK
		1 x 45’	**P9**	**Group work – simulation practice based on L9:** methods to calculate thermal comfort indices from ENVI-met simulation, dynamic thermal comfort simulation	KL
13	02.12	3 x 45’	--	**Intermediate presentations of group projects**	DK, KL
14	09.12	2 x 45’	**L10**	**Climate-Sensitive Urban Design:** complex interaction of all urban elements and their effect on UHI and outdoor environmental quality	KL
		1 x 45’	**P10**	**Group work – simulation practice based on L10:** developing an integrated solution in ENVI-met for the climate-sensitive urban design	KL
15	16.12	2 x 45’	**L11**	**Urban Energy** (renewable energy sources in cities). **Summary of the course.**	DK
		1 x 45’	**P11**	**Group work** - finalizing the analysis and the report	KL
Submission of group projects and peer-evaluation by 23.12 (12:00)					



CONTENT:

I. Climate sensitive urban design
  - Introduction
  - Integrated solution to urban heat
  - Urban design and planning decision making and limitations

II. Urban mitigation strategies

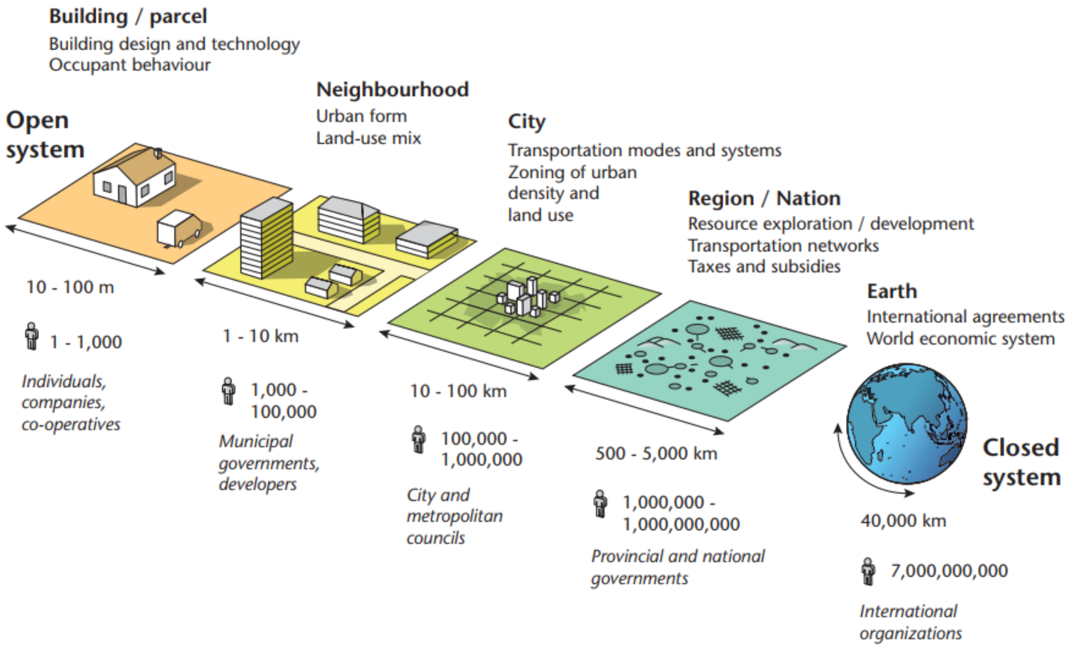
III. Example research and projects
  - Cooling Singapore
  - SWICE

Climate-sensitive Urban Planning and Design

- **What makes a well-planned and designed city from a climatic perspective?**
    1. Energy and resource efficiency: Low carbon city planning and design, renewable energy, compact city
    2. Positive urban microclimate: Urban heat mitigation
    3. Heat resilience: Urban heat adaptation, especially for vulnerable population and infrastructure
- **Multiscale perspective to climate sensitive urban planning and design**
    1. Planning and design practices are embedded within overarching systems of governance.
    2. Planning: larger scale decisions on the spatial organization of urban functions. Design: smaller scale decisions on aspects of urban forms.
    3. As urban effect are related to a scale and surface modification, strategies effective at one scale interact with each other and with other scales.

The neighbourhood scale is the most propitious scale to manage microclimates

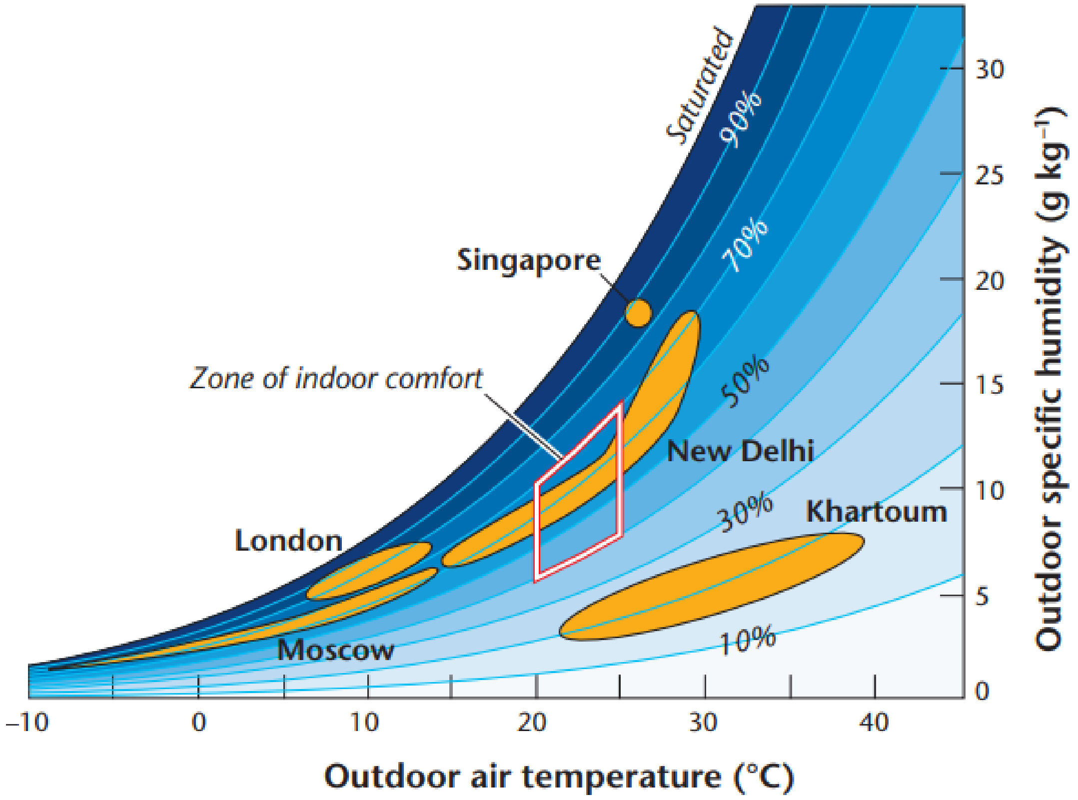
Hierarchies of governance for Urban Decision-making



Source: Oke (2012) https://doi.org/10.1016/j.enbuild.2015.06.023

Urban climate influencing factors

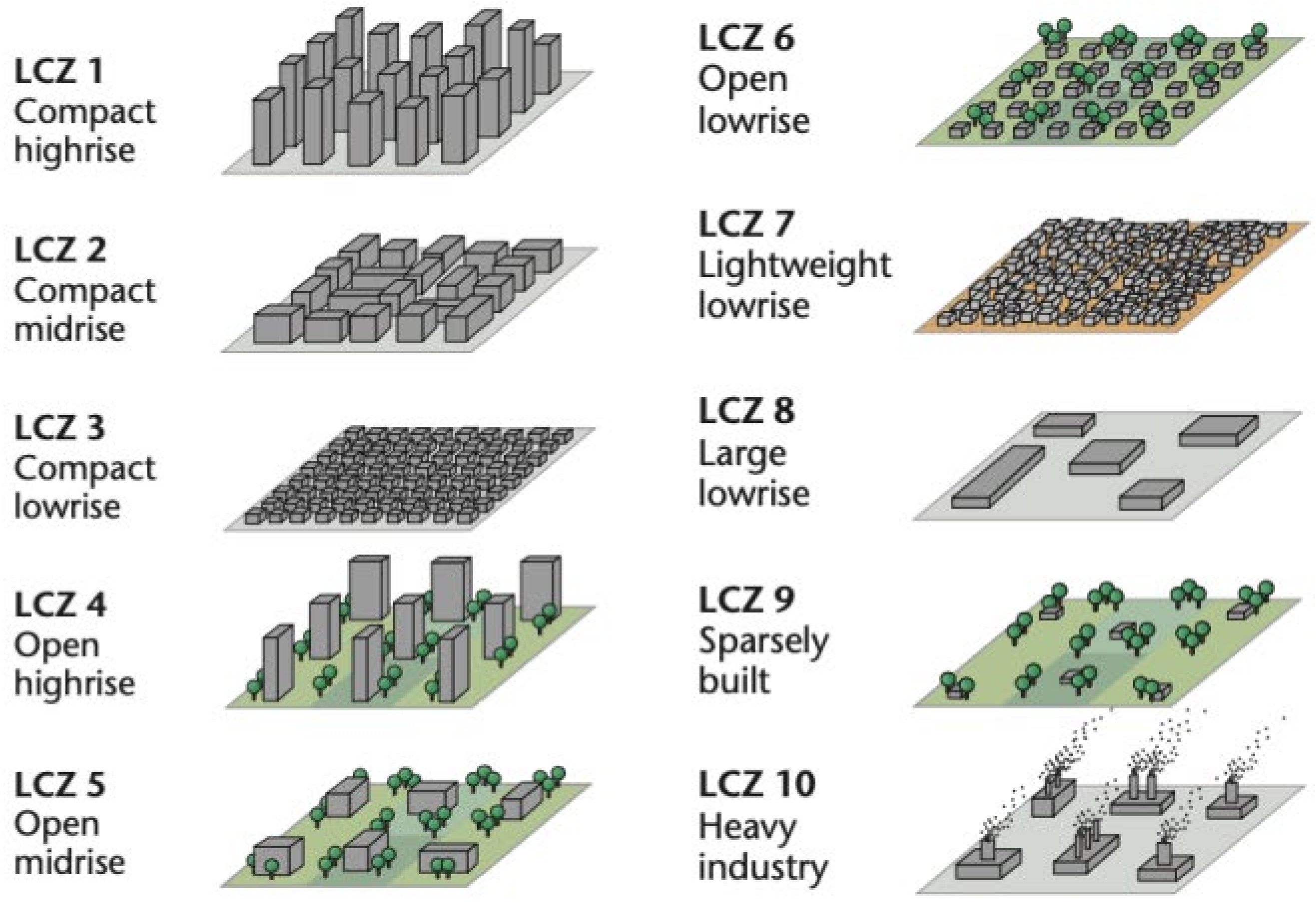
- Urban climate effects are an unintended (even if predictable) outcome of **countless decisions** that have shaped particular **urban form** (e.g. street layout, building density and character, surface cover mix) and **urban function** (e.g. transport modes and networks, dominant fuel and energy systems and land use mix). However, microclimate can be managed through purposeful design.
- The magnitude and timing of urban effects on climate depends on the **background climate** and the nature of development of the city . Principles of good design practice must be modulated to fit each city .

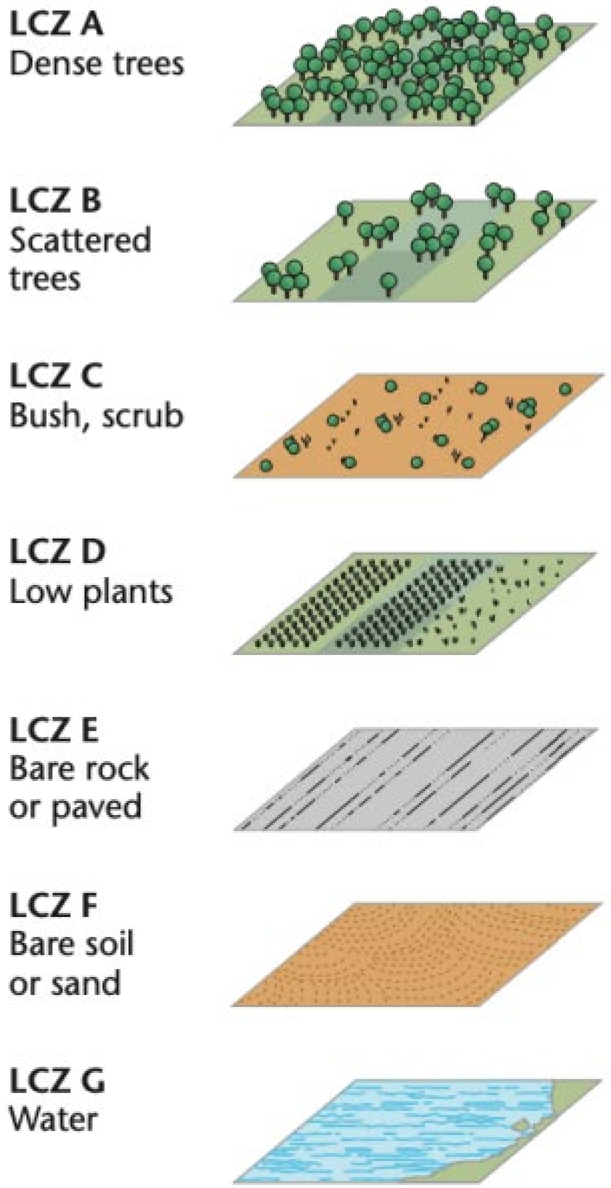


Source: Oke, Urban Climates, p. 412

Cities and urbanism: Urban characteristics

- **Local climate zones (LCZ):**
  categorization of the urban landscape types per their ability to modify local surface climates

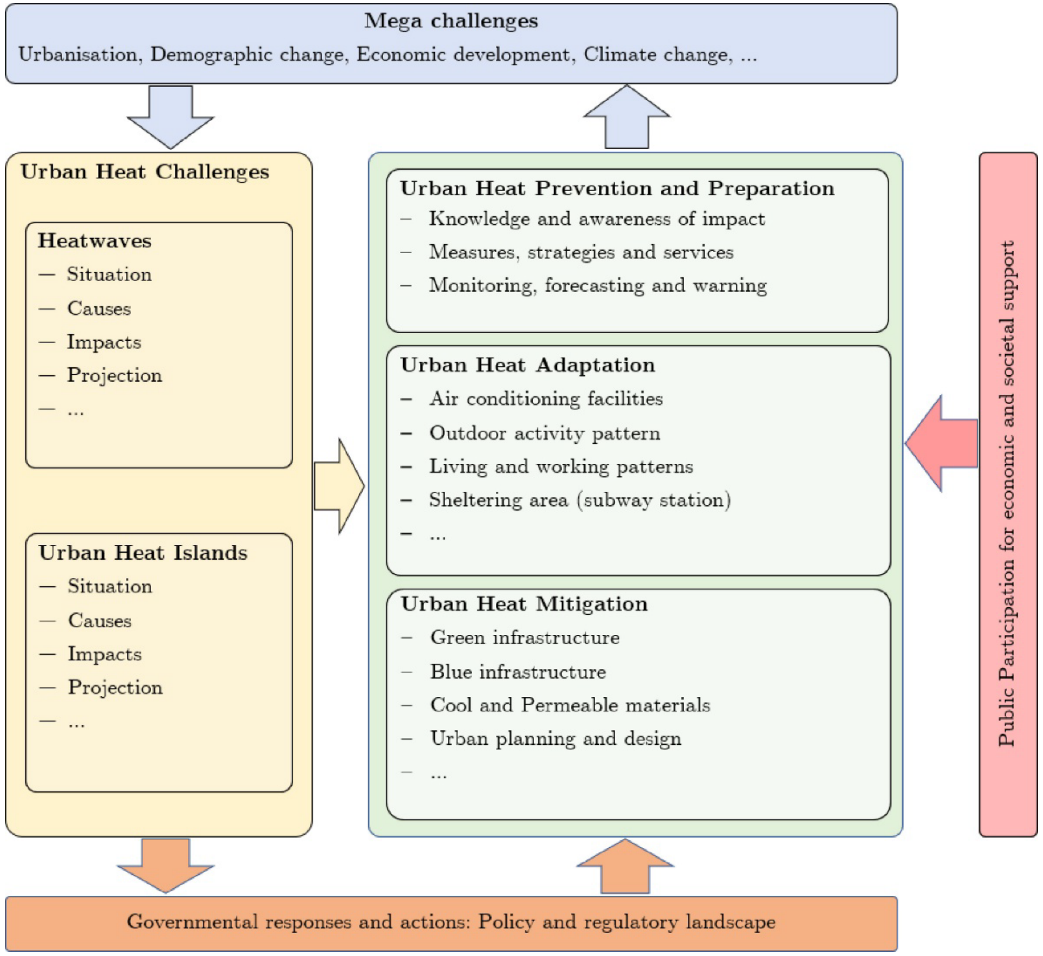




Source: Oke, Urban Climates, p. 26

Integrated solutions to heat challenge

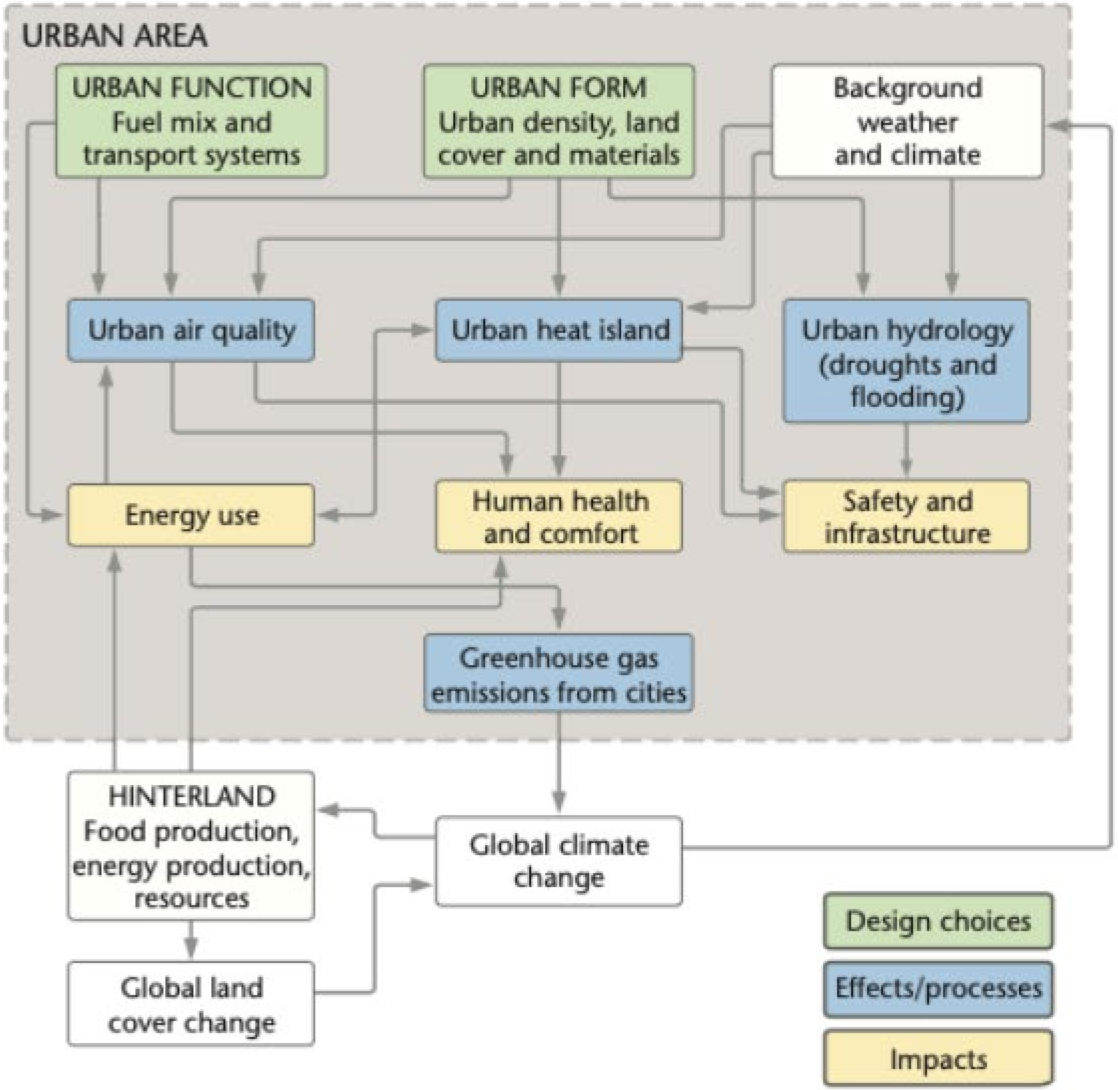
- The UHI management is now part of urban policies to create more sustainable and resilient cities.
- Mitigation: reduction of the UHI magnitude and duration, by modulating the causes of heat entrapment (e.g., urban materials and anthropogenic heat), or by leveraging heat sinks and dispersion mechanisms.
- Adaptation: improve resilience and adaptation of urban dwellers to the UHI effect and heatwaves, by “hard” form measures, such as heat safe building envelops, indoor air conditioning, urban infrastructure, “soft” form measure, such as personal exposure management, public information and awareness campaigns, heatwave monitoring and warning systems.
- Mitigation technologies have the potential to eradicate locked-in vulnerabilities and emissions in a long-lasting and fully-fledged fashion, thus standing as the backbone of deep-rooted climate resilience in the built environment



Source: Gilbert et al., 2016 https://doi.org/10.1016/j.enbuild.2015.06.023

Urban Planning and Design

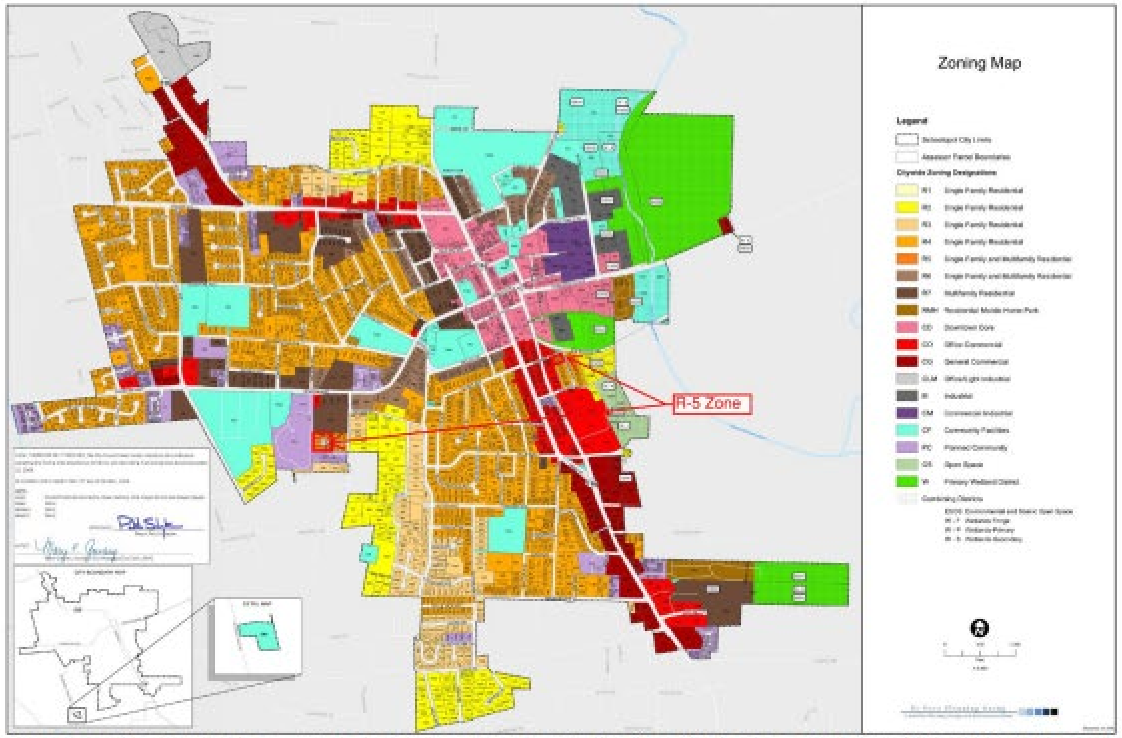
- **Urban planning** and **building design** are useful to decrease the UHI intensity but not only.
- They have an **impact** on:
  - Comfort for pedestrian
  - Energy use of buildings
  - Health and mortality
  - Global climate change
  - Greenhouse gas and pollutant emissions
- The UHI is *intertwined* with urban air quality, urban hydrology, urban extreme weather events, which can also be managed through appropriate **urban planning**.



Source: Oke, Urban Climates, p. 440

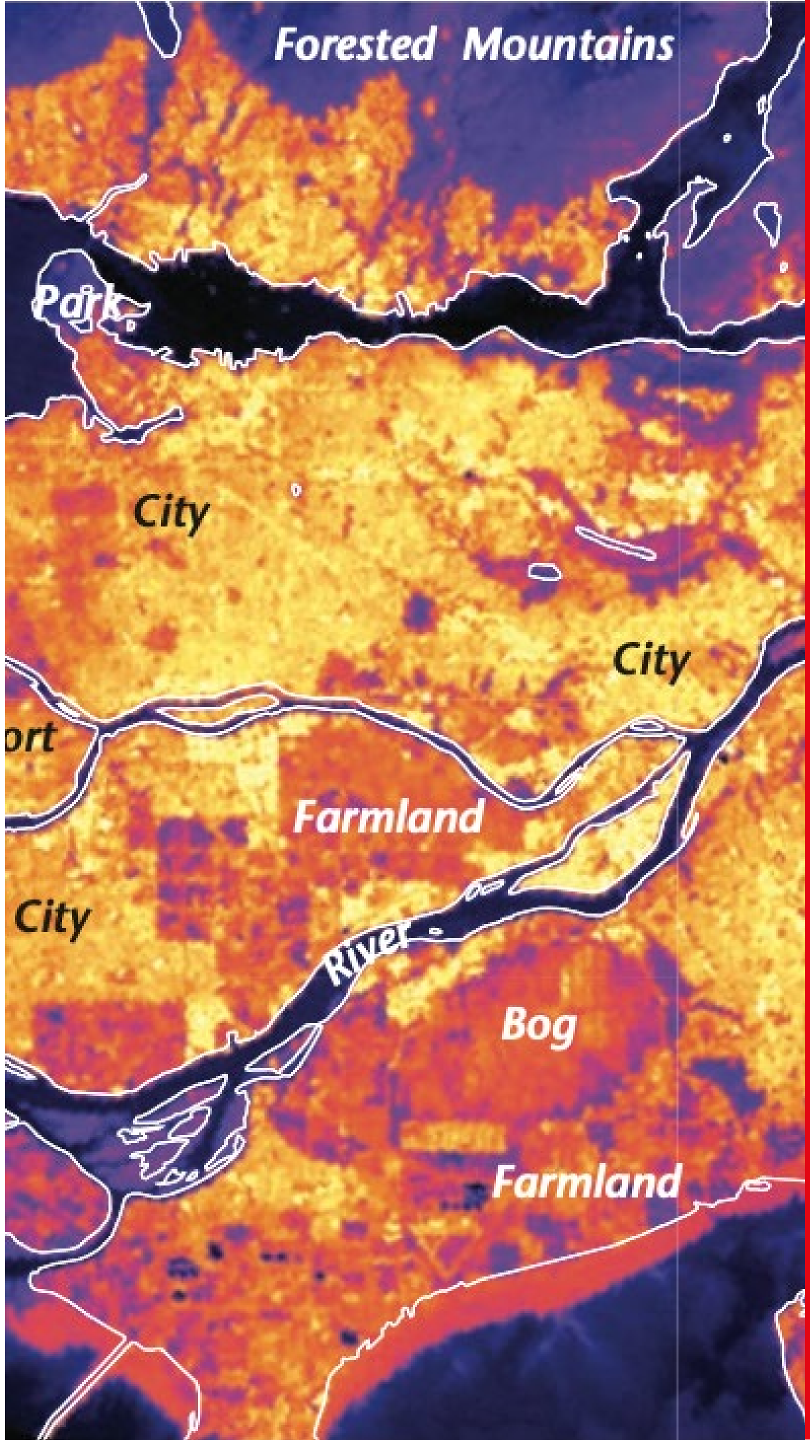
Global Design: Limits and Challenges

- In practice, the **urban sustainable design is limited** by:
  - Cities generally **fractured** into several political territories with different powers and agendas.
  - Urbanization in *less wealthy region* occurs **informally** and **independently** from *any legal context*.
  - **Opportunities for change** on an already developed landscape are **greatly limited with a building life-span of decades** and **a road network life-span of hundred of year**.



Source: small town urbanism » urban design thoughts through the filter of living in a small town (fritzarchitecture.com)

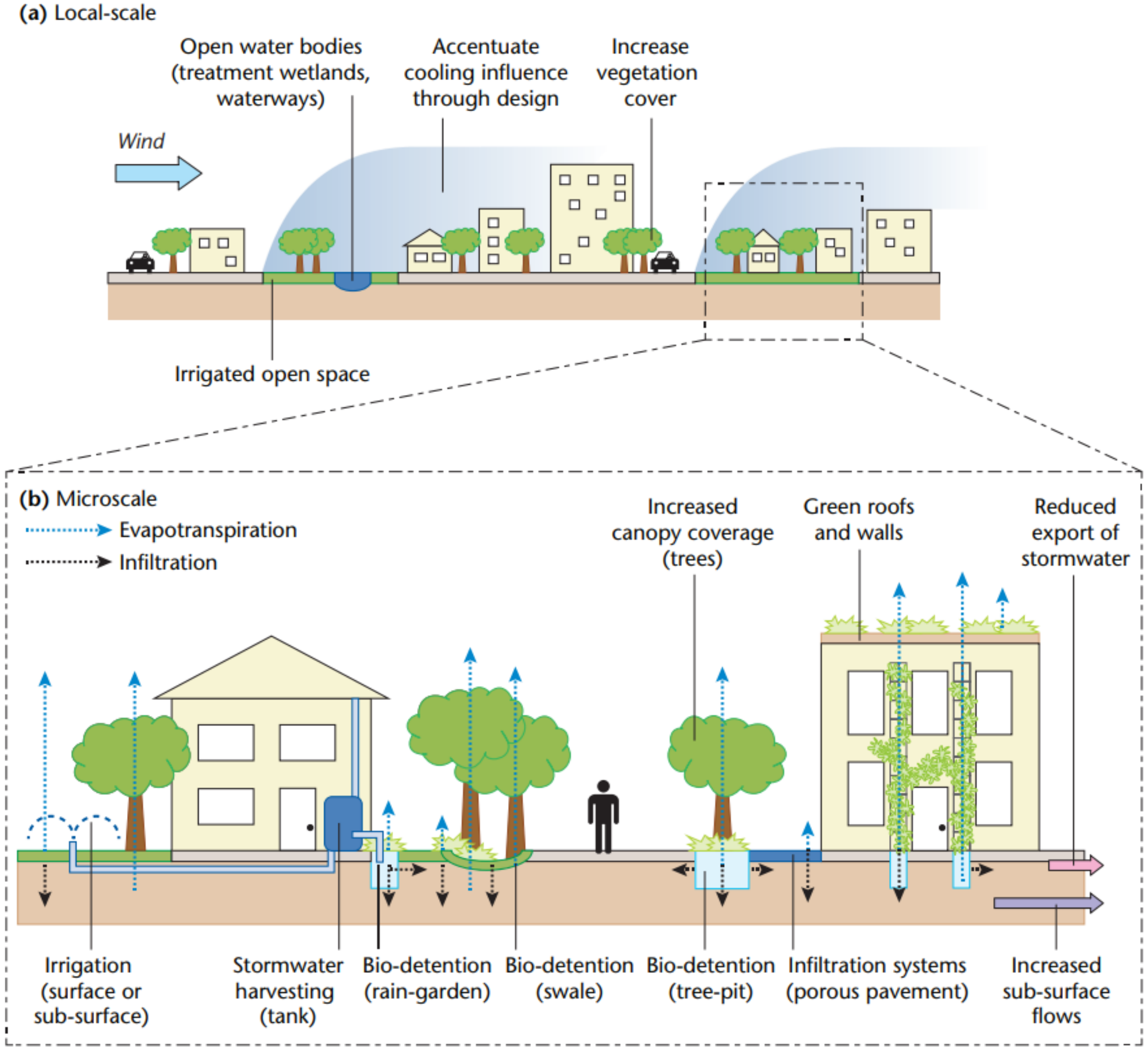
- **Challenges for future urban sustainable design:**
  - Decisions on urban layout have long-term implications. It can be easier to change the associated functions than alter form.
  - *Identify* and *protect* natural resources through appropriate zoning.
  - *Accommodate* conflicting demands.


Forested Mountains
Park
City
City
ort
Farmland
City
River
Bog
Farmland

CONTENT:

Mitigation strategies: Blue Bodies and Water Control

- Blue bodies act as thermal mass and reservoirs of water for evaporative cooling.
- The cooling effectiveness (magnitude and distribution) of bluespaces depends on their size, spread of such spaces, and distance from them. Square or round geometries are more efficient than irregular shapes due to increased temperature and humidity gradients.
- Large waterbodies have greatest cooling effect adjacent to their boundaries and in downwind areas, size and length of the spread depend on wind velocity. Urban configuration needs to be designed to allow for the penetration of the cooler air. **Wind corridors** can be planned.
- Cooling effect influenced by urban context, e.g., higher surface temperature of surrounding urban areas may enhance cooling distribution with increased temperature gradient.

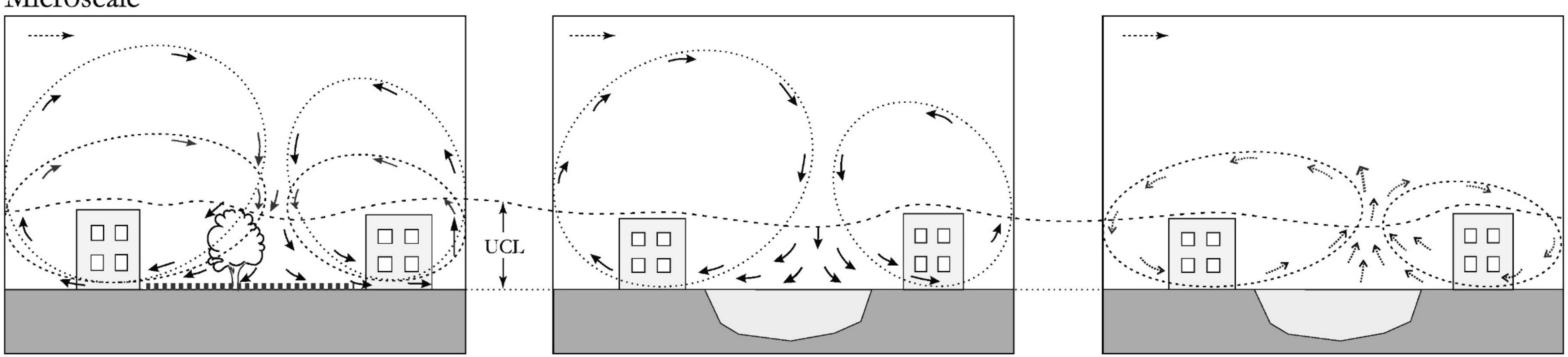


Source: Oke, Urban Climates, p. 443

Mitigation strategies: Blue Bodies and Water Control

- Water can be employed when and where it is needed when spread on street facets. It can reduce surface temperature by up to ~13°C on hot days if regularly spread. However, this strategy requires considerable manual effort and supply of water.
- Waterbody-breeze system differ during daytime and night-time due to the water body being warmer than surrounding areas during night.

Source: Oke, Urban Climates, p. 440



Park breeze system (high by day, low by night) **Waterbody breeze system** (daytime cooling) **Waterbody breeze system** (night-time warming)

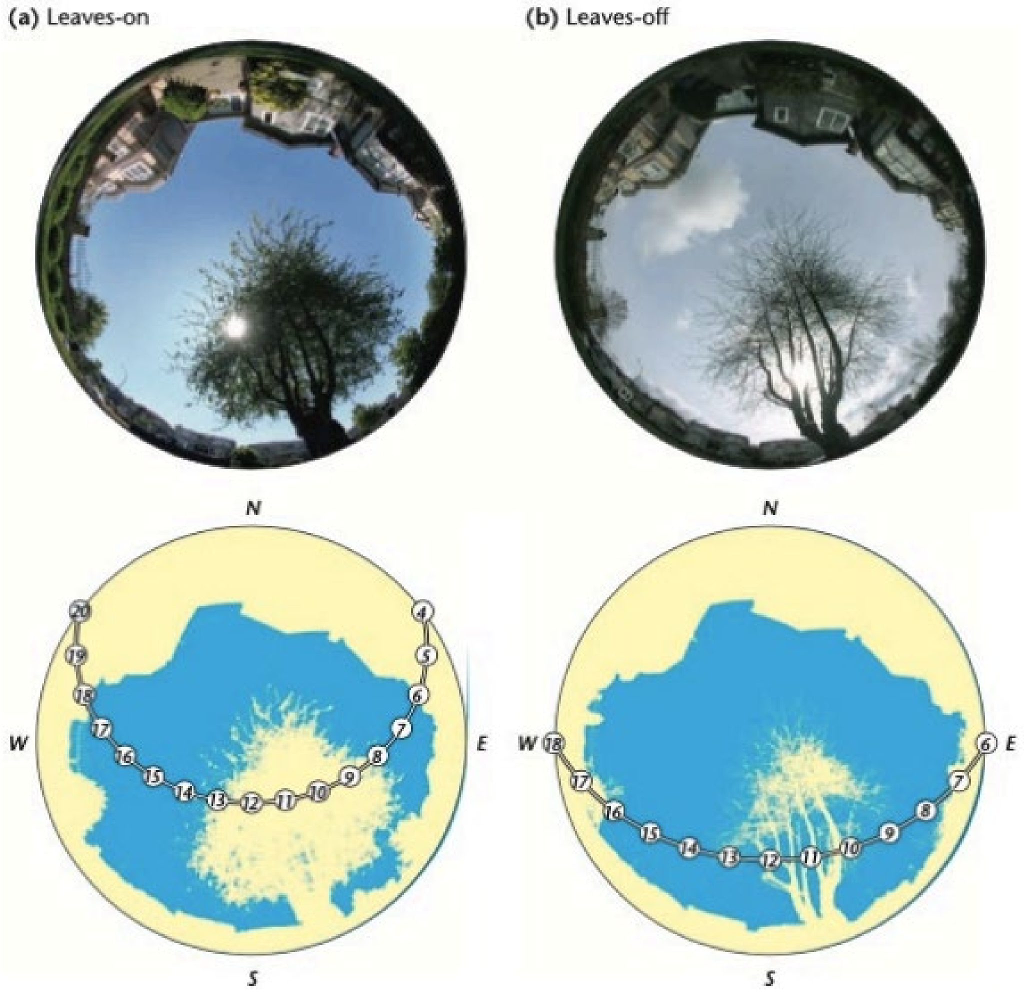
Mitigation strategies: Green Infrastructure

- Vegetation is used to control radiation exchange, airflow, ventilation of air pollutants, evaporation, temperature, erosion, runoff and noise levels.
- Green infrastructure: Strategically planned interconnected networks of greenspace (e.g., urban forests, parks, street trees and verges, private gardens, fringes of transport corridors and vegetated roofs and façades).
- Extent of cooling effect offered by GI can be as high as 4K and extending up to 440m (Gunawardena et al., 2017). This vary significantly both spatially and temporally.
- The distribution of cooling is strongly influenced by **wind systems, part size and shape**. Low velocity wind under anticyclonic conditions enables park-breeze system while high velocity (>5 m/s) impede vertical movement and disrupt buoyancy driven effects. Horizonal distribution was observed to be disrupted with higher wind velocities.

Source: Oke, Urban Climates, p. 440

Mitigation strategies: Green Infrastructure

- The climate impact varies with plant architecture and physiology (species, age and health). Hedges and shrubs have a limited vertical extent. Effective to provide wind shelter near ground and noise barriers. Trees are the most effective option for natural cooling as they combine shading and evapotranspiration
- Trees can regulate solar access for a selected surface at specific times of the day and year. However, shading prevent night radiative loss.
- Trees modify air temperature and humidity directly as air passes through the canopy and indirectly with shading of the underlying surface .
- Tree wind blocking is proportional to its foliage density and varies seasonally . Total blocking is to avoid to preserve air quality enhanced by mixing.
- They need to be resistant to the unfriendly and harsh conditions (poor air quality, drought) of the urban environment .



Source: Oke, Urban Climates, p. 440

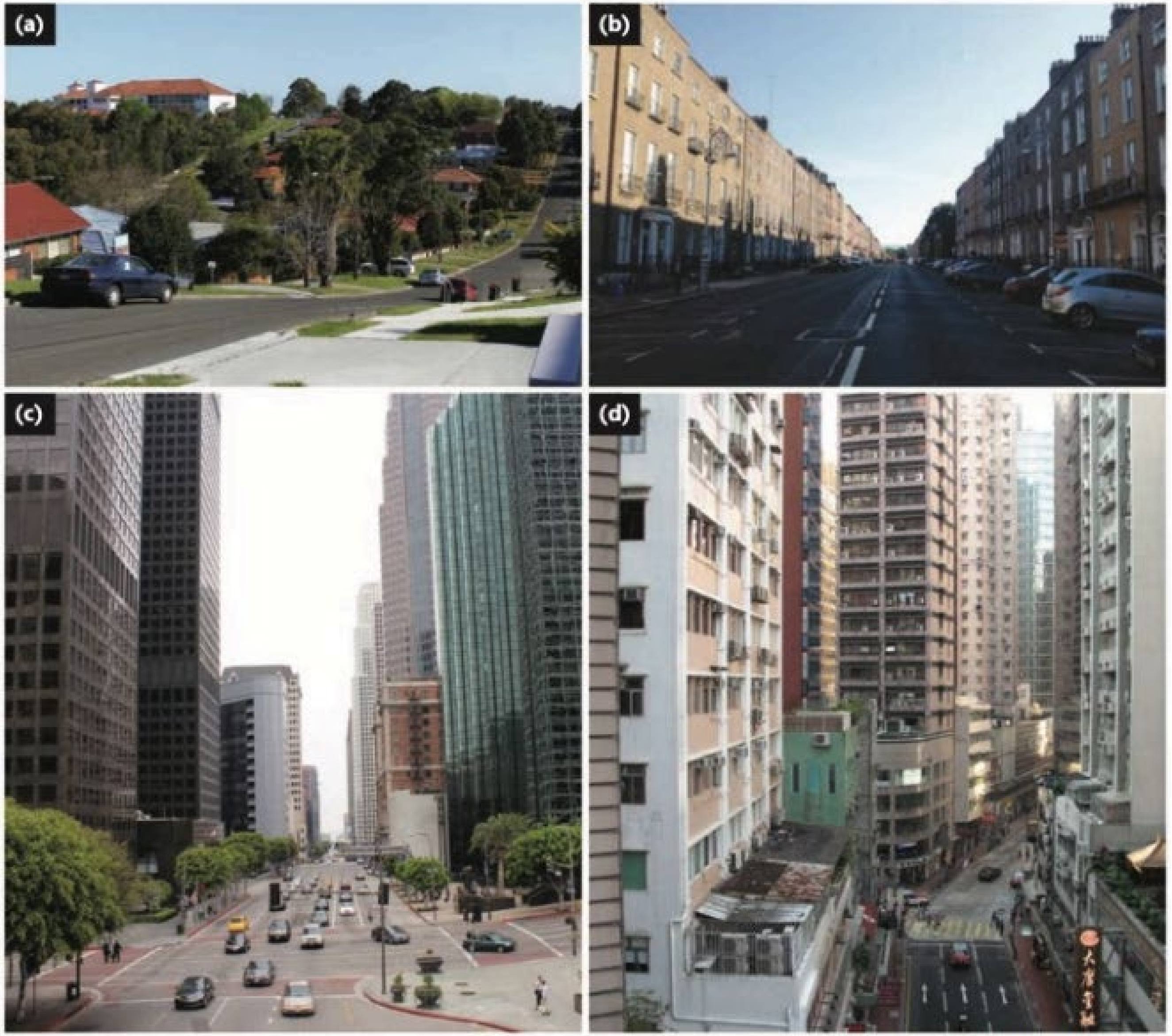
Mitigation Strategies: Density of cities

- **Dense cities** are the most efficient: residents consume less area, less energy and have lower GHG emissions.
- On the other hand, dense cities reduce access to solar energy, limit ventilation, reduce green area fraction and enhance the UHI.
- **Intermediate densities** perform best for *outdoor comfort* and *health*.
- City design should consider topography and take advantage of local resources (e.g., a coastal city should promote the penetration of sea breeze into the city for natural cooling and ventilation).

Source: Oke, Urban Climates, p. 422

Mitigation strategies: Streets and Roads

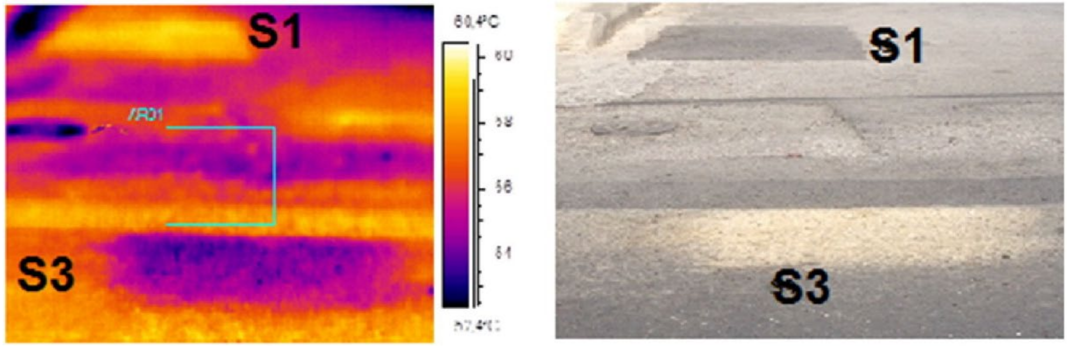
- The **form** and function of **streets and intersections** can exert considerable influence on the formation of microclimates, especially where neighborhoods are compact.
- The **canyon aspect ratio** and **orientation** are critical parameters that govern radiation exchanges.
  - *East-West street orientation* is best for building energy gain, although one side is always shaded.
  - *North-South street orientation* is best for natural ventilation and ensures equitable Sun repartition.
- The canyon aspect ratio manages the **sky view factor** which determines the solar access and radiative loss.



Source: Oke, Urban Climates, p. 432

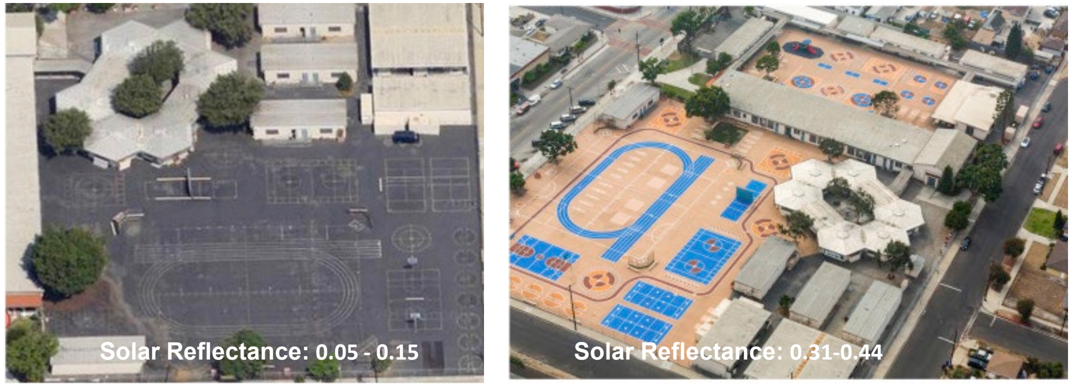
Mitigation strategies: reflective surface

- Use of albedo, vegetation and/or permeability as a means of managing the climatic impacts of selected facets.
- Sealed urban surfaces, once dry (water from rain evaporated or drained away), no exchange of moisture content with soil, surface temperature largely dependent on albedo property.
- A freshly laid asphalt road may have α values as low as 0.05 that after use will increase to 0.18 (see Table 15.1), consequently T0 can exceed 60°C on a hot day. Covering the asphalt with a white gravel topping can raise its α to 0.3–0.45 while replacing it with white concrete can raise α to 0.6–0.7 (Santamouris et al., Reference Christen, Coops and Crawford2011)
- Potential drawback:
  1. Visual discomfort
  2. Reflectivity may reduce with time due to surface deposits
  3. Energy maybe reflected and fall on other urban surfaces



Source: Kyriakodis & Santamouris, 2018 https://doi.org/10.1016/j.uclim.2017.02.002

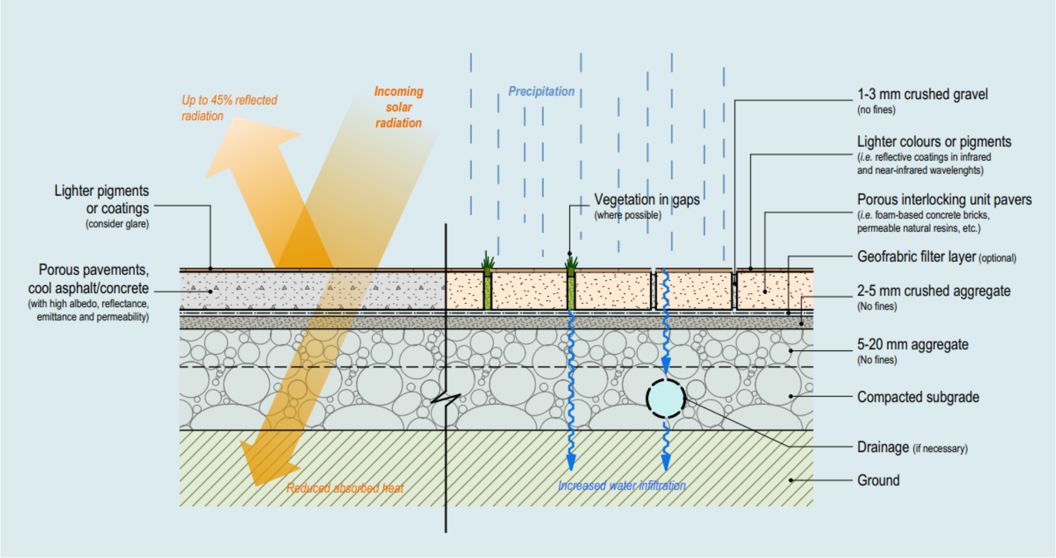
Gardena Elementary School cool schoolyard



Source: Gilbert et al., 2016 https://doi.org/10.1016/j.enbuild.2015.06.023

Mitigation strategies: Permeable surface

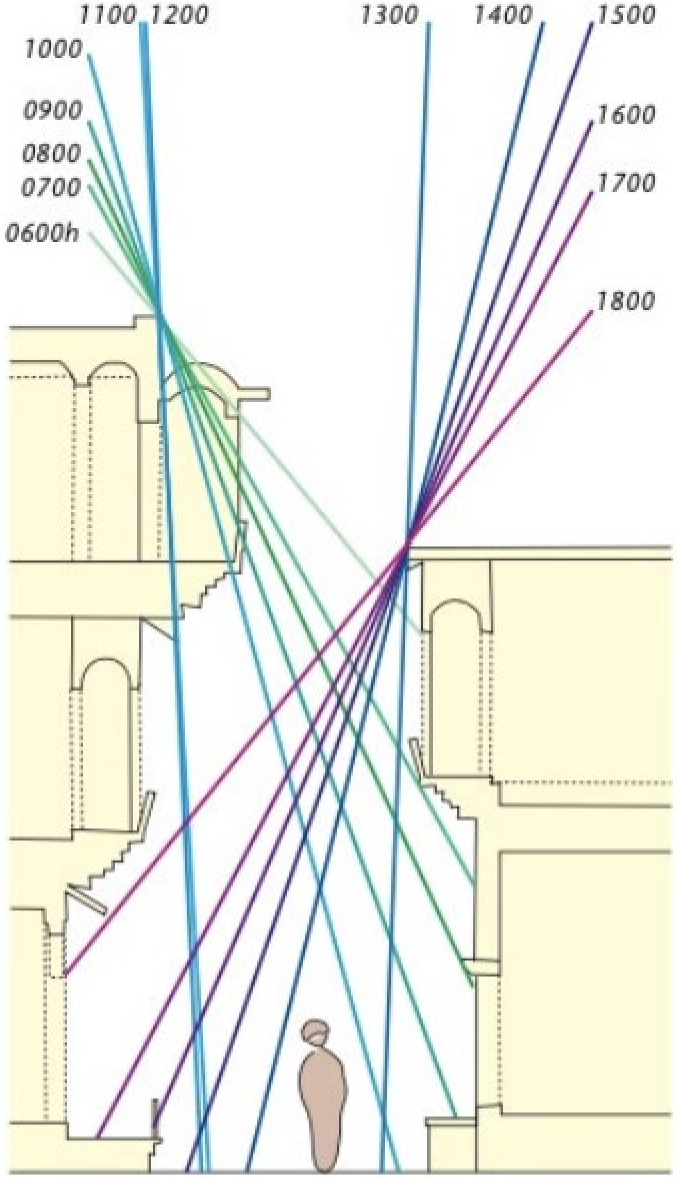
- Porous material (gaps in aggregate to allow water percolation) or blocks with interstitial spaces filled with porous materials that can support grass
- Permeable pavement uses the latent heat of vaporization to reduce their surface temperature (Santamouris, 2013).
- reducing stormwater run-off, recharging of groundwater, reducing the discharge of pollutants, improving air quality and reducing noise on roads and highways
- Permeable surface under dry condition may have higher surface temperature due to higher thermal emissivity, however, longer period of cooling effect after rainfall can be achieved with improved design of pavement structure (Liu et al., 2018; Ferrari et al., 2020).



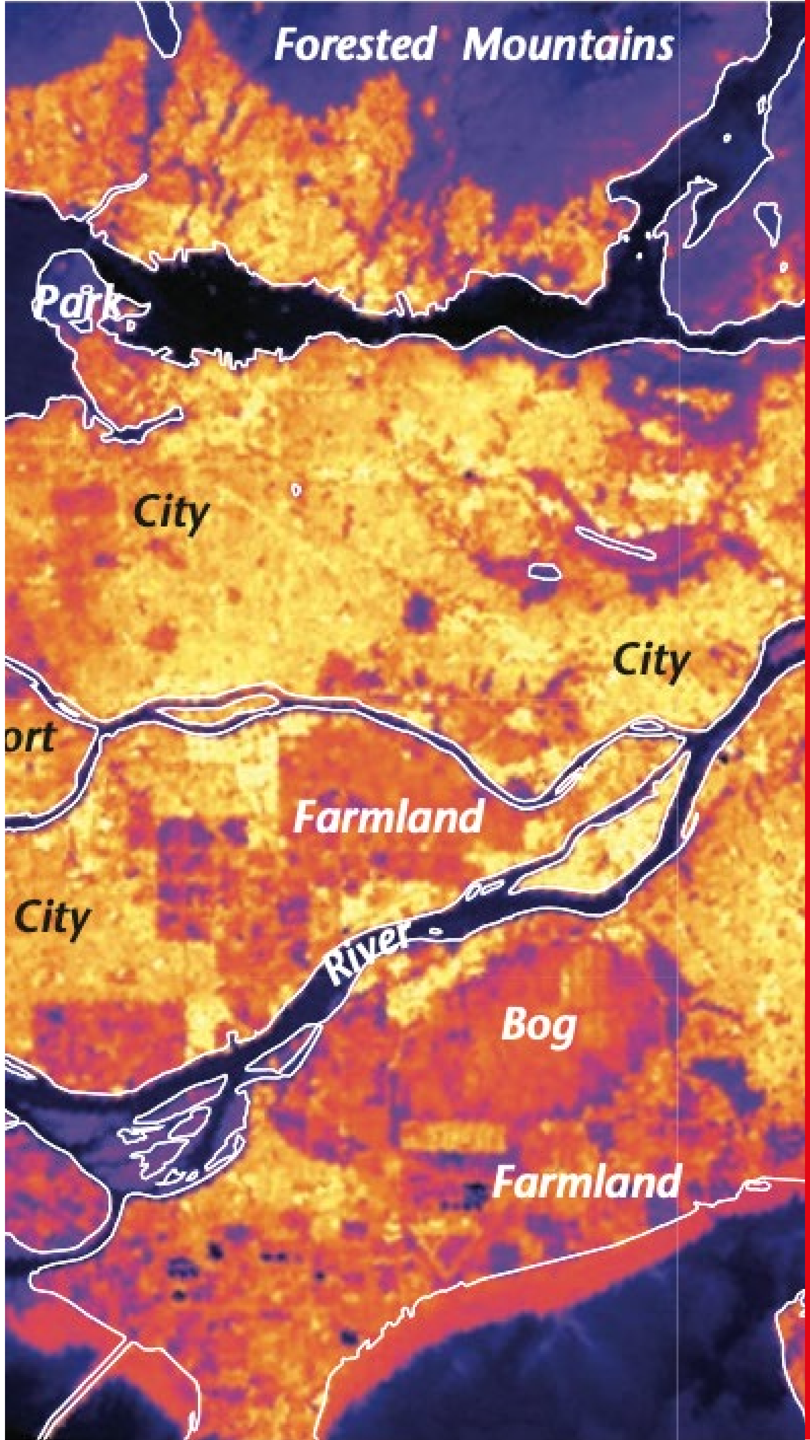
Mitigation strategies: Canyon Aspect Ratio

Dr. Kun Lyu

- The **canyon aspect ratio** λ regulates:
  1. access to sunshine,
  2. radiative heat loss at night,
  3. shelter from the ambient wind
  4. street ventilation and air quality
- Small λ allows access to sunshine and ventilation, promotes night-time cooling and provides little shelter.
- High λ provides shade, limits night-time heat loss, provide shelter and weakens ventilation.
- Values of $0.4 < \lambda < 0.6$ offer comprise from both.



Source: Oke, Urban Climates, p. 433



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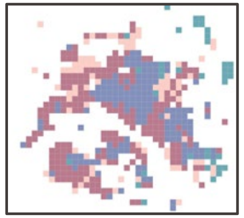
Framework for urban heat intervention

City

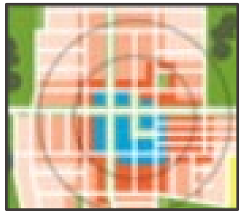


Categorise neighbourhoods
- LCZ
- Data driven neighbourhood typology
- Neighbourhood morphology

City

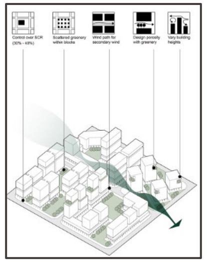
Prioritise neighbourhood
- Thermal imagery
- Social vulnerability
- Activity map

Neighbourhood



Analyse neighbourhood
- Mitigation potentials
- Existing green & blue infrastructure
- Climatic characteristics

Neighbourhood



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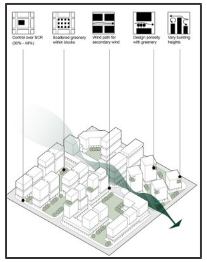
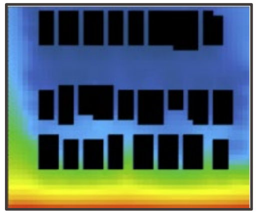


Mitigation Scenarios

Neighbourhood



Assessment
- Performance metrics
- Multi-objective assessment
- UHI intensity, outdoor thermal comfort, energy performance, heat risk etc.
- Best performance UHI mitigation scenarios

Informing urban planning policy and design practice

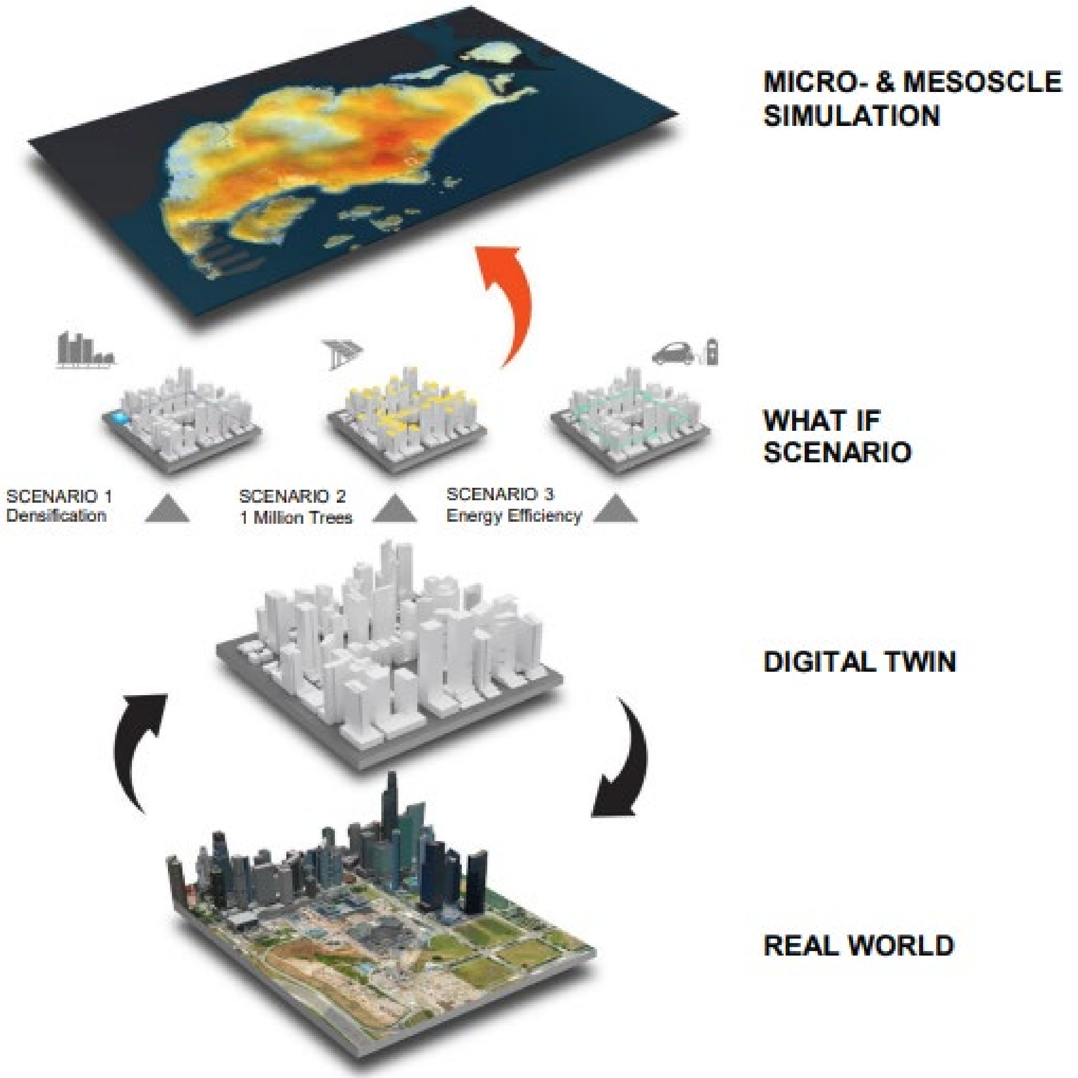
Urban block/ building plot level intervention

Emerging research and practice – Cooling Singapore

- Cooling Singapore 1.0 (youtube.com)
- How Singapore Uses Science to Stay Cool (youtube.com)
- **Digital Urban Climate Twin (DUCT):**

Digital representation of the city that integrates computational models of all relevant urban elements (e.g., land-use and vegetation, buildings, industry, transport) as well as urban climate.

Dynamic behaviour of urban elements for the purpose of simulating cause and effect (e.g., traffic, air conditioning, microclimate).

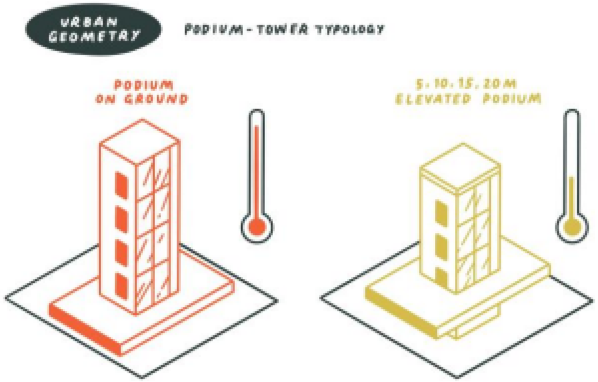


Source: Oke, Urban Climates, p. 440

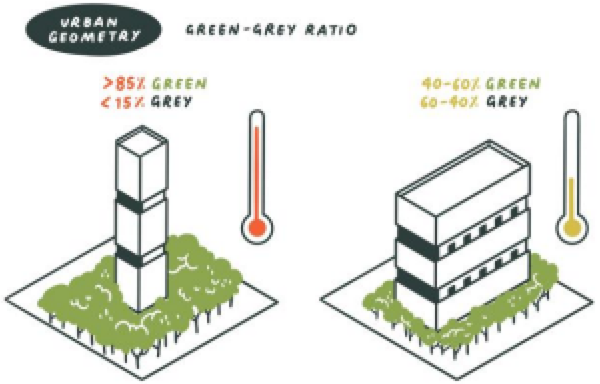
Emerging research and practice – Cooling Singapore

What-if scenarios

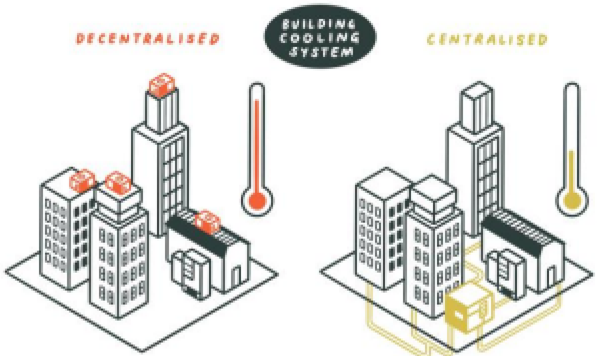
What is the urban geometry impact on Outer Thermal Comfort (OTC)?



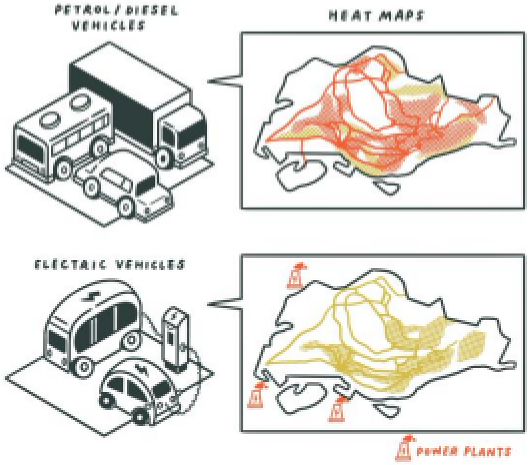
What is the impact of greenery on Urban Heat Island (UHI)?



What is the impact of District Cooling implementation on Energy Efficiency (EE)?



What is the impact of electric vehicle adoption on Anthropogenic Heat (AH) emissions?



Source: H. Aydt (2020). Cooling Singapore – Towards Urban Climate Design and Management in Indicia 03, editors: S. Cairns and D. Tunas
Image: Idea Ink (2020)

Multidomain Neighbourhood Typology

Conventional LCZ:
- Generic system and does not account for individual urban context
- Homogeneous zones, in actual city, the urban structure and fabric are often mixed (new type)
- Does not consider multidomain environmental quality other than thermal aspects

CRITERIA

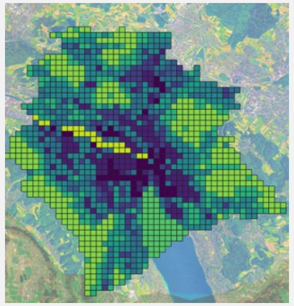
Morphology
- Building height
- Building height variability
- Sky view factor
- Frontal area index

Land cover
- Building
- Pervious surface
- Impervious surface
- Water

Road Network
- Road hierarchy
- Canyon intersection density
- Orientation
- Aspect ratio
- Road length

K-means

Multidomain Neighbourhood Typology



TARGET

Urban temperature
- Land surface temperature

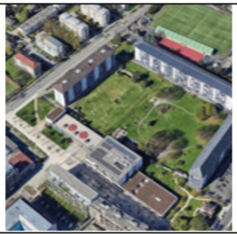
Air Pollution
- PM 2.5
- PM 10
- NO_2

Noise
- Daytime traffic noise
- Night-time traffic noise

Daylighting
- Direct solar radiation on building walls

Source: Oke, Urban Climates, p. 440

Neighbourhood typology in Swiss Cities

G-A	*G-B*	*G-C*	*G-D*	*G-E*
				
Very high density urban area (building cover = 45%),midrise buildings, both primary and secondary road.	*Very high density urban area (building cover = 40%),midrise buildings, secondary road network, orient mostly towards N-S and E-W directions.*	*High density urban area (building cover = 30%), highly impervious surface cover (60%), midrise buildings, very dense primary road network, orient mostly towards NE-SW and SE-NW directions.*	*Mid-density urban area (building cover = 20%), presence of vegetation (30%), midrise building, primary road network.*	*Low density urban area with abandunt vegetation cover, midrise building, secondary road network.*
G-F	*S-A*	*S-B*	*S-C*	*S-D*
				
Urban neighbourhood near water body.	*High density urban area (30%), mid-rise buidlings, seconary road network, orient mostly towards NE-SW and SE-NW directions.*	*High density urban area (30%), mostly impervious surface with limited pervious land cover (20%), mid-rise buidlings, primary road network.*	*Mid-density urban area, mid to lowrise buildings (14m), presence of vegetation (30%), secondary road network.*	*Low-density urban area, lowrise buildings (10m), low-density road network, abandunt natural features (70%).*
S-E	*Z-A*	*Z-B*	*Z-C*	*Z-D*
				
Water body.	*Mid-density urban area, low rise buildings, secondary road network.*	*Mid-density neighbourhood adjacent to railway.*	*Low density urban area, lowrise building, next to highway.*	*Forrested area.*

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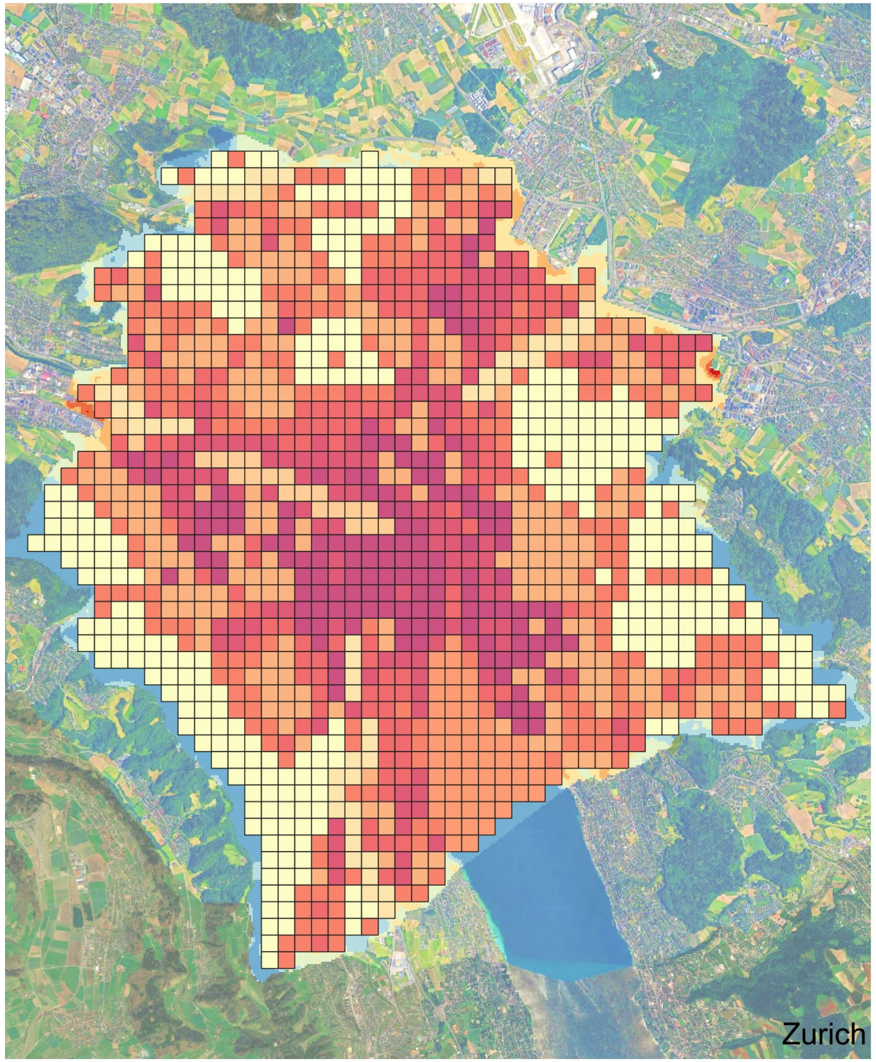
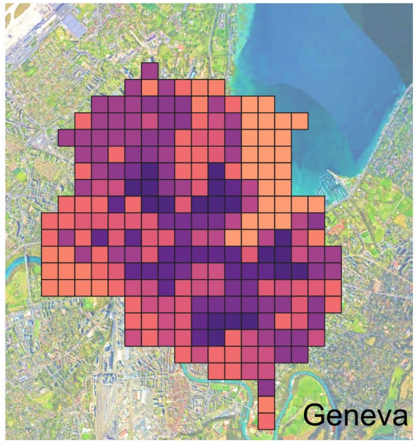
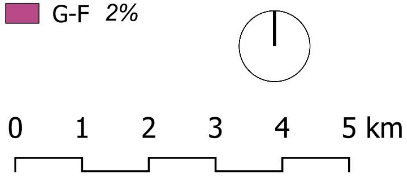
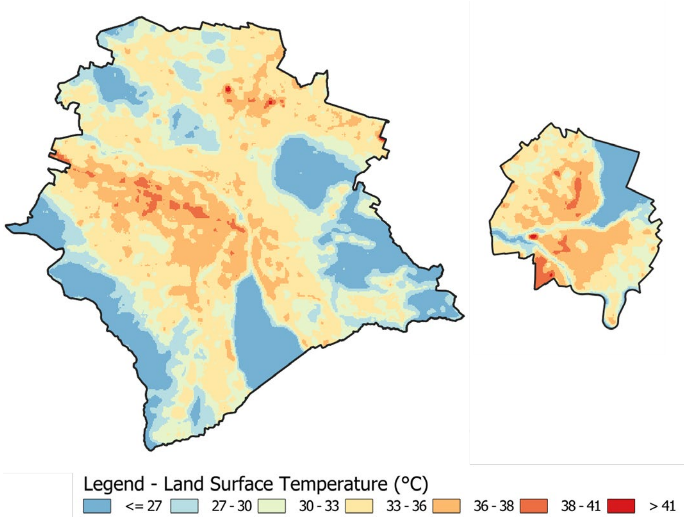
Neighbourhood typology in Swiss Cities

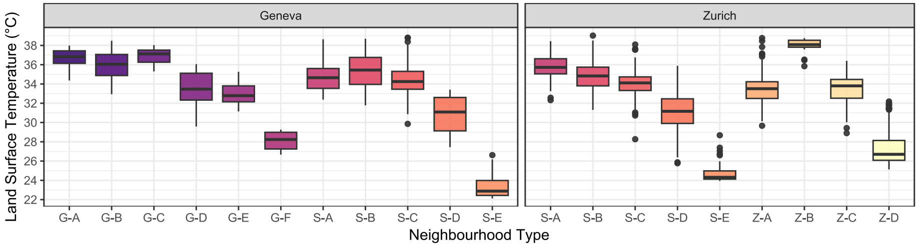




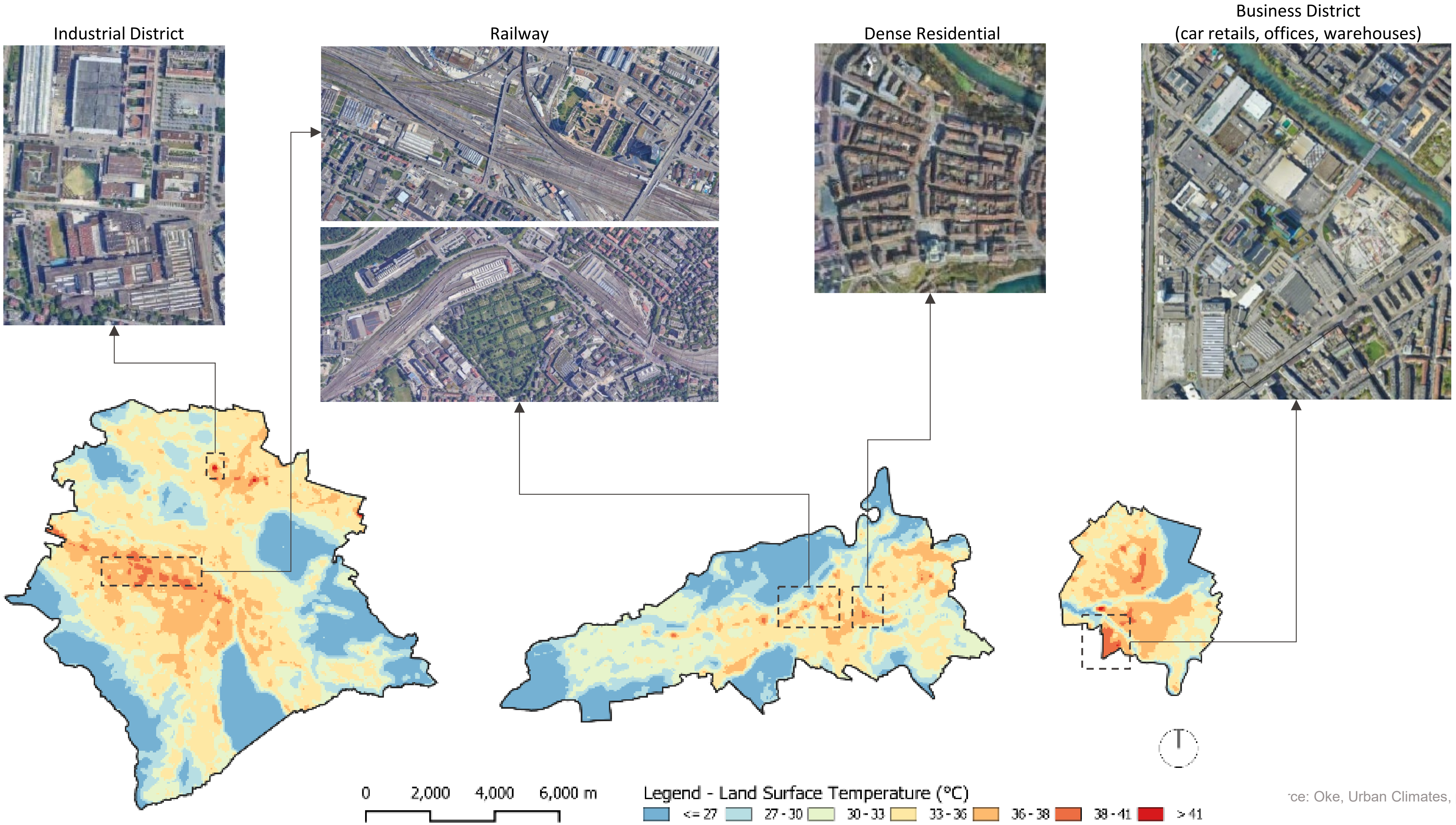
Geneva	Proportion	Zurich	Proportion
S-A	*11%*	S-A	*11%*
S-B	*10%*	S-B	*11%*
S-C	*15%*	S-C	*10%*
S-D	*6%*	S-D	*18%*
S-E	*11%*	S-E	*4%*
G-A	*8%*	Z-A	*18%*
G-B	*7%*	Z-B	*1%*
G-C	*5%*	Z-C	*4%*
G-D	*10%*	Z-D	*23%*
G-E	*13%*		
G-F	*2%*		





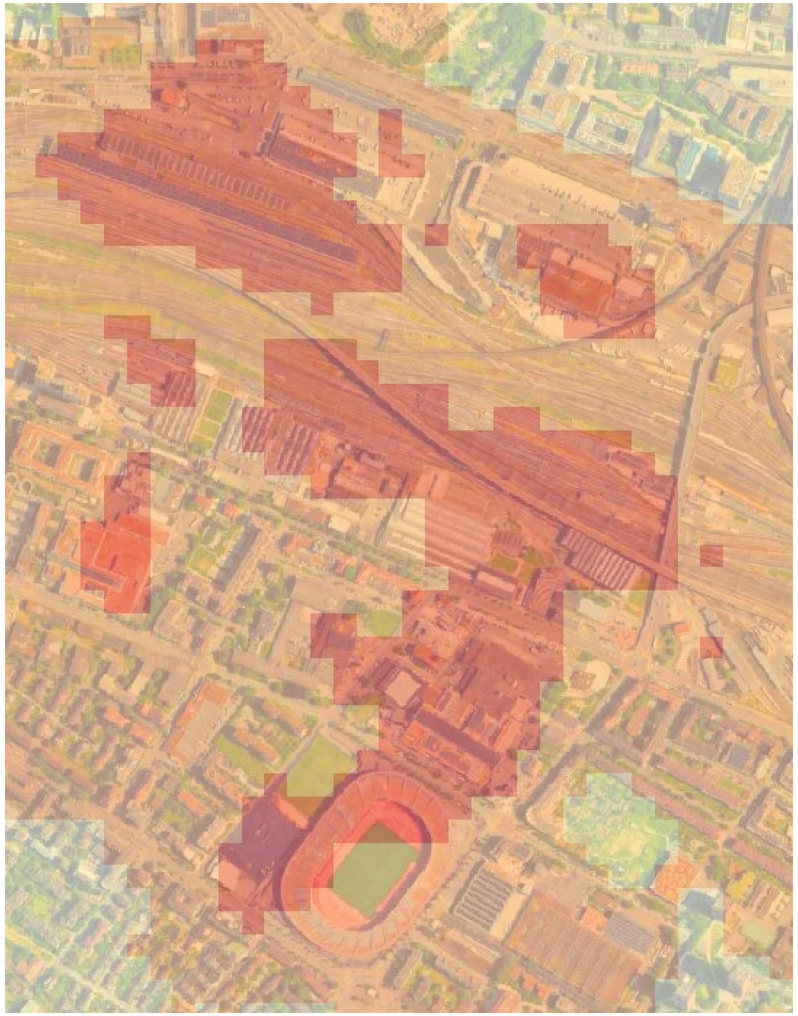


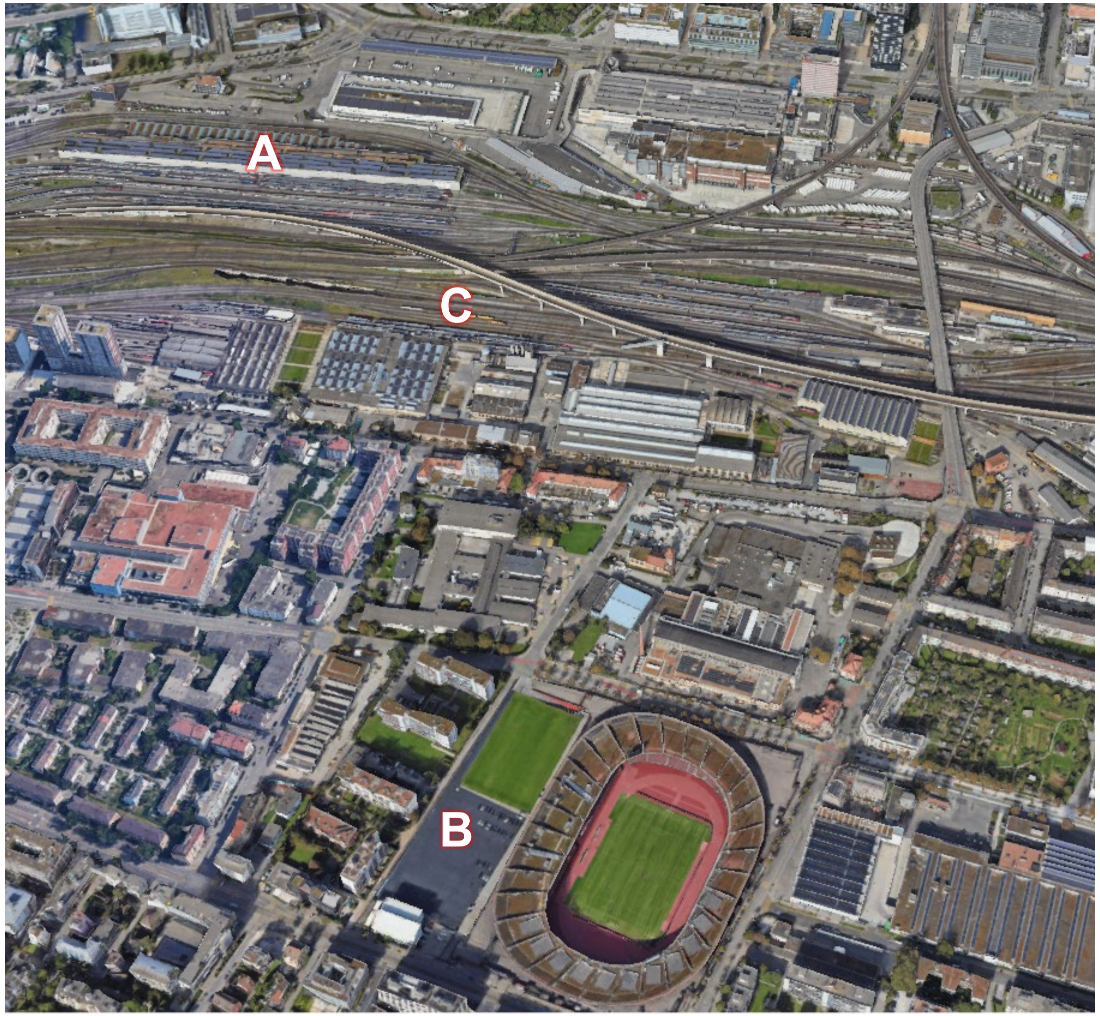
Surface Urban Heat Island Identification



ce: Oke, Urban Climates, p. 440

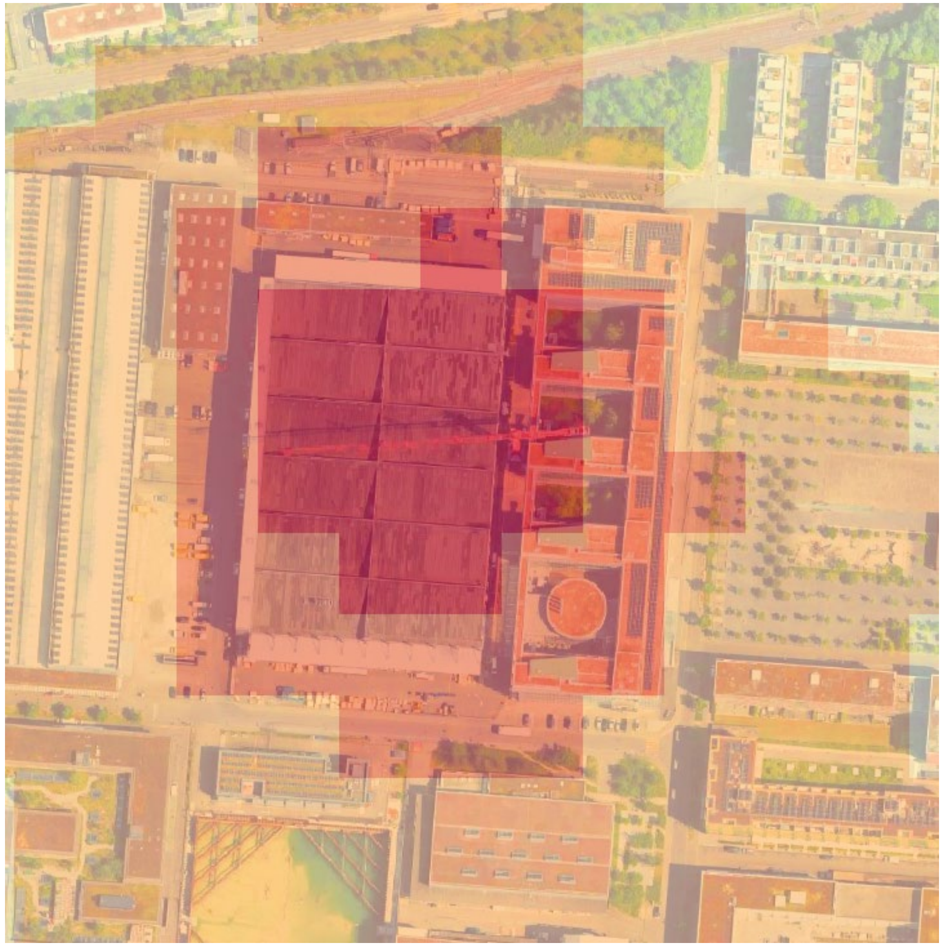
Surface Urban Heat Island Identification





What are the causes for urban heat island at location A, B, and C?
How can we mitigate urban heat at these locations?

Surface Urban Heat Island Identification



What are the causes for urban heat island?
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Surface Urban Heat Island Identification

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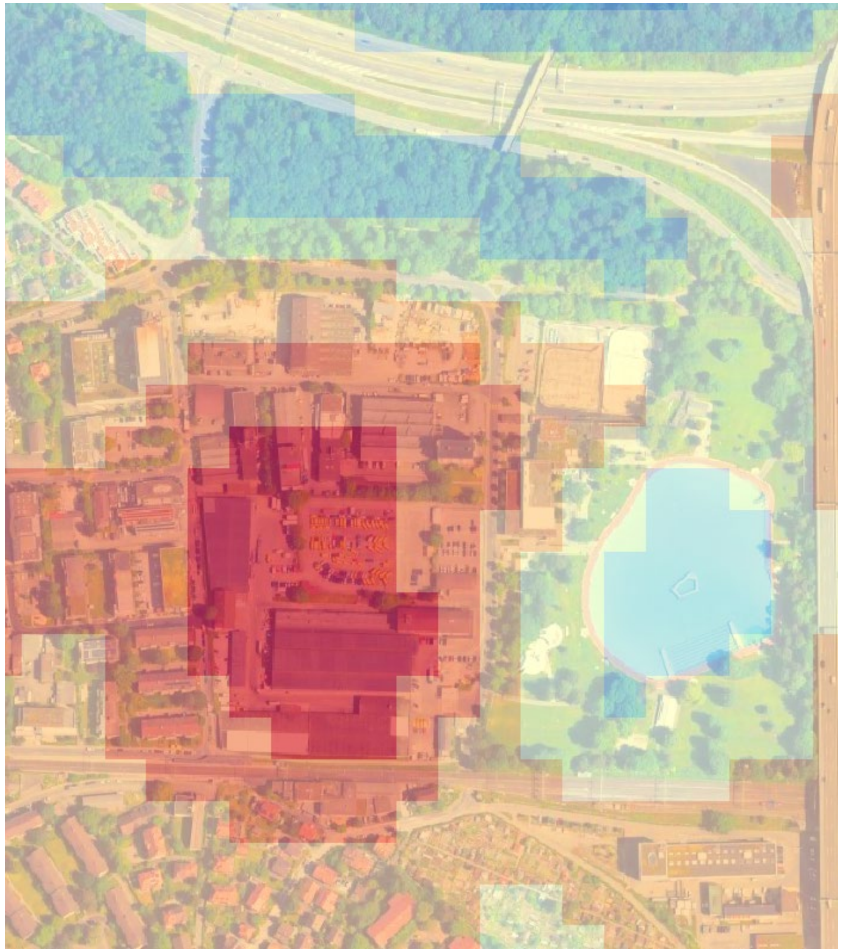
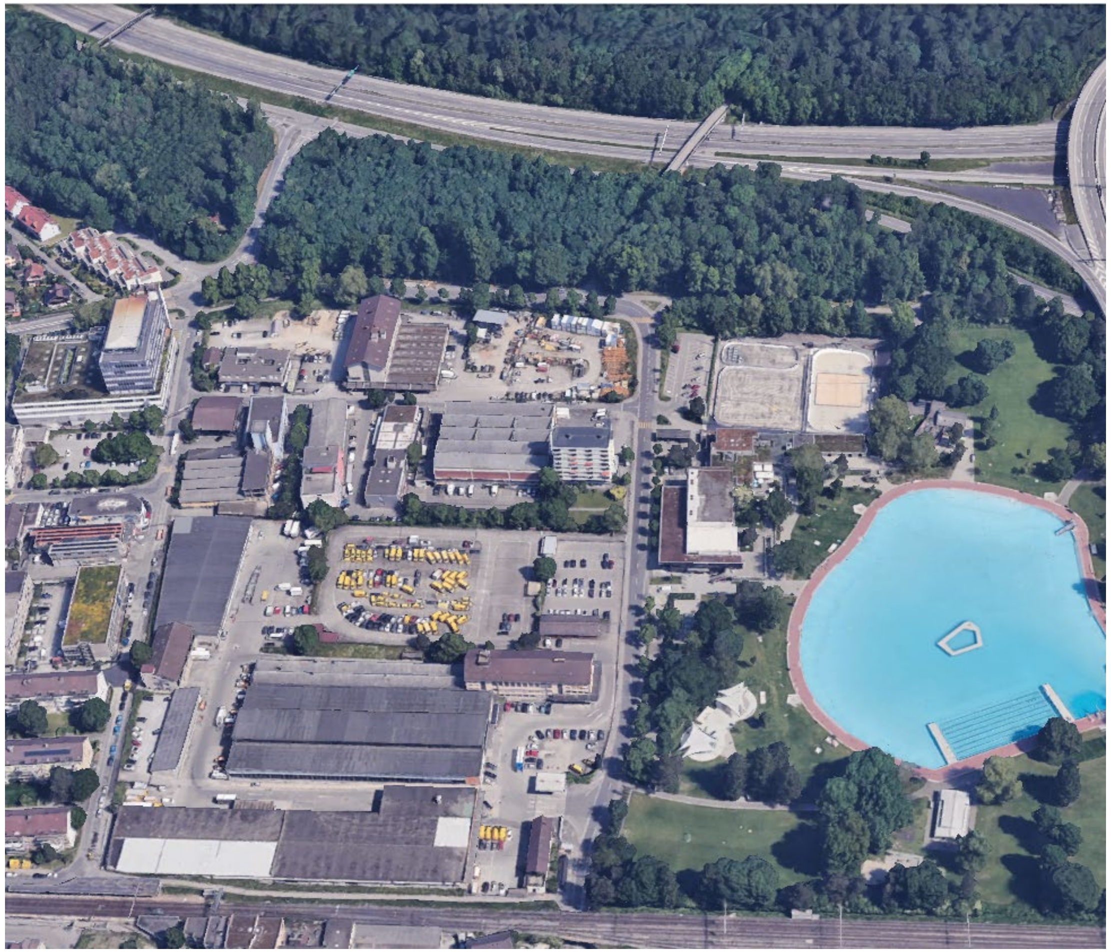
Surface Urban Heat Island Identification





What are the causes for urban heat island?
How can we mitigate urban heat at these locations?

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Thank you for your attention

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