Urban Heat and Community Design

BC Lung Association 2022 Air Quality and Health Workshop

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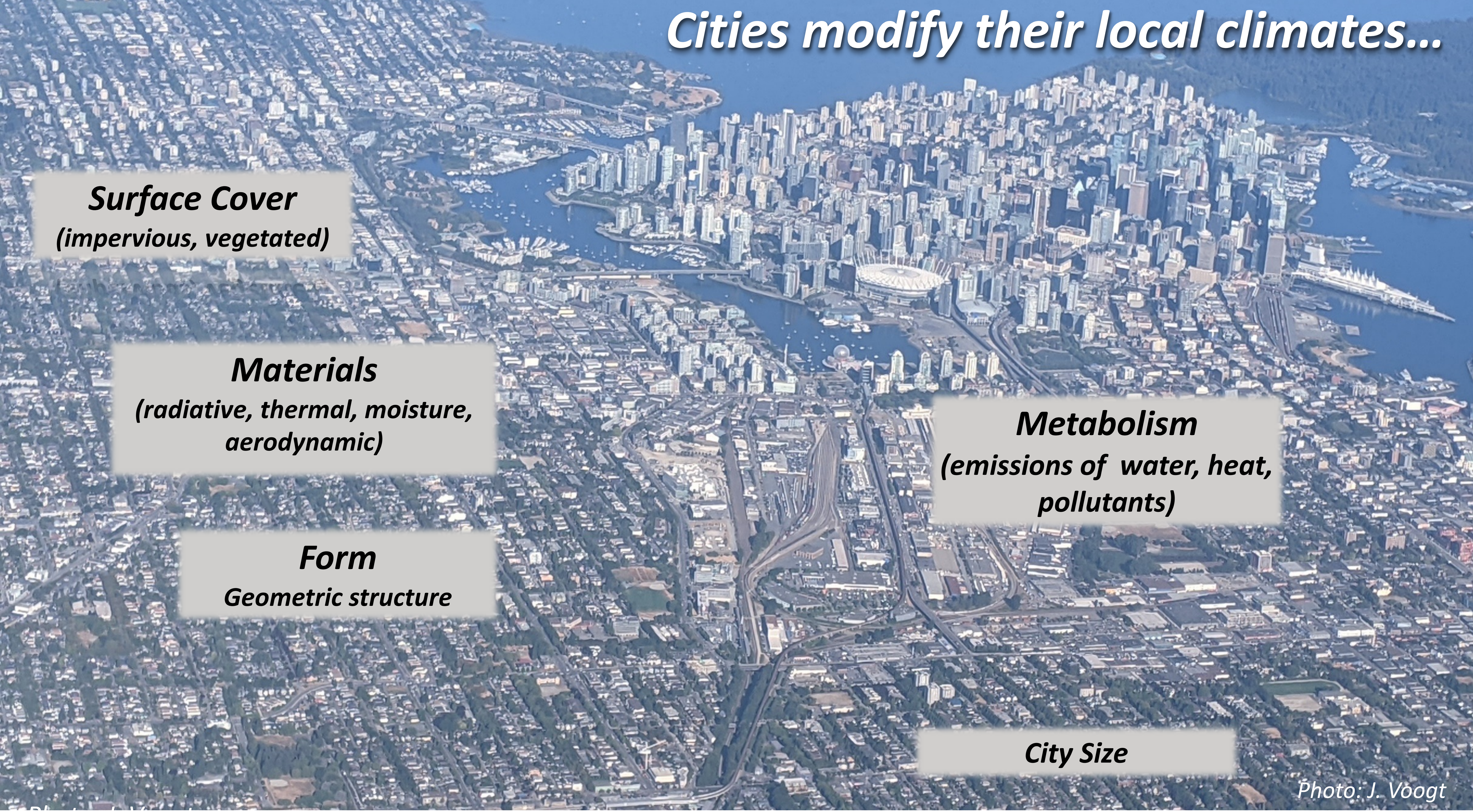
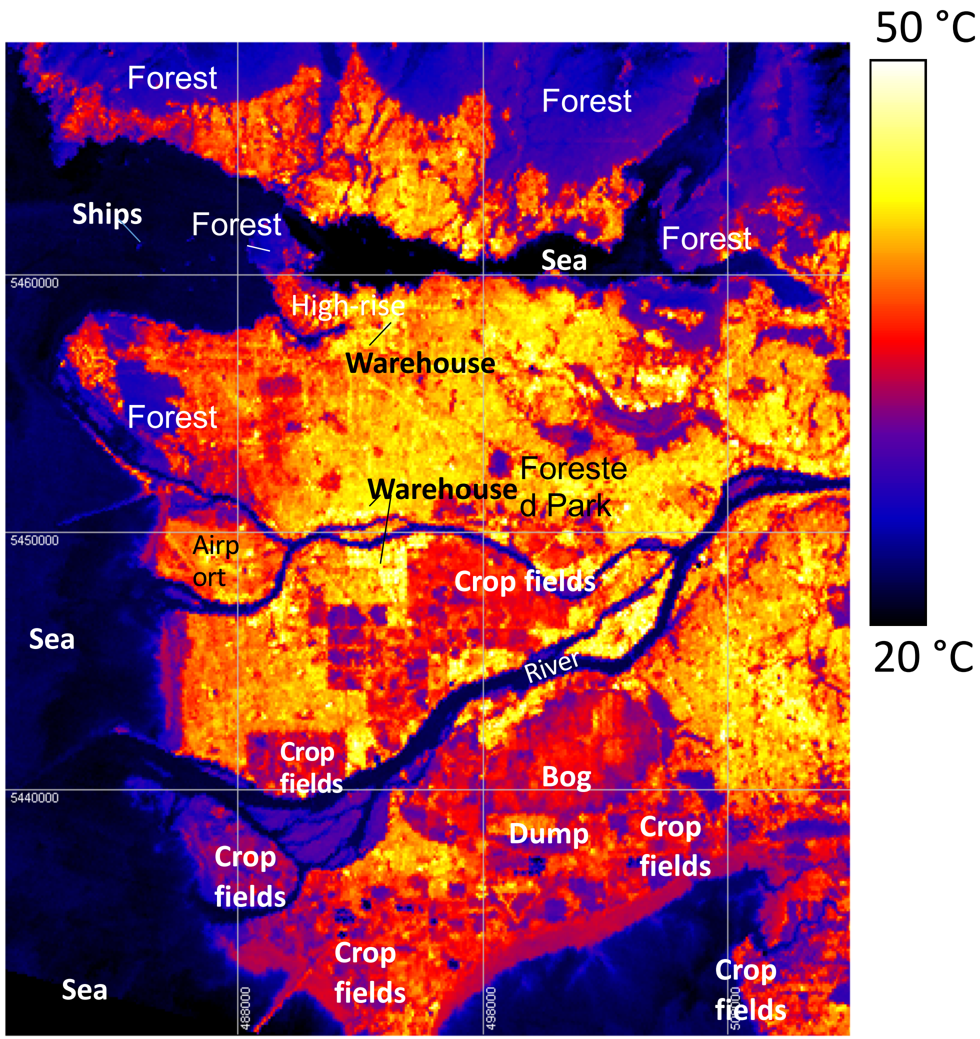
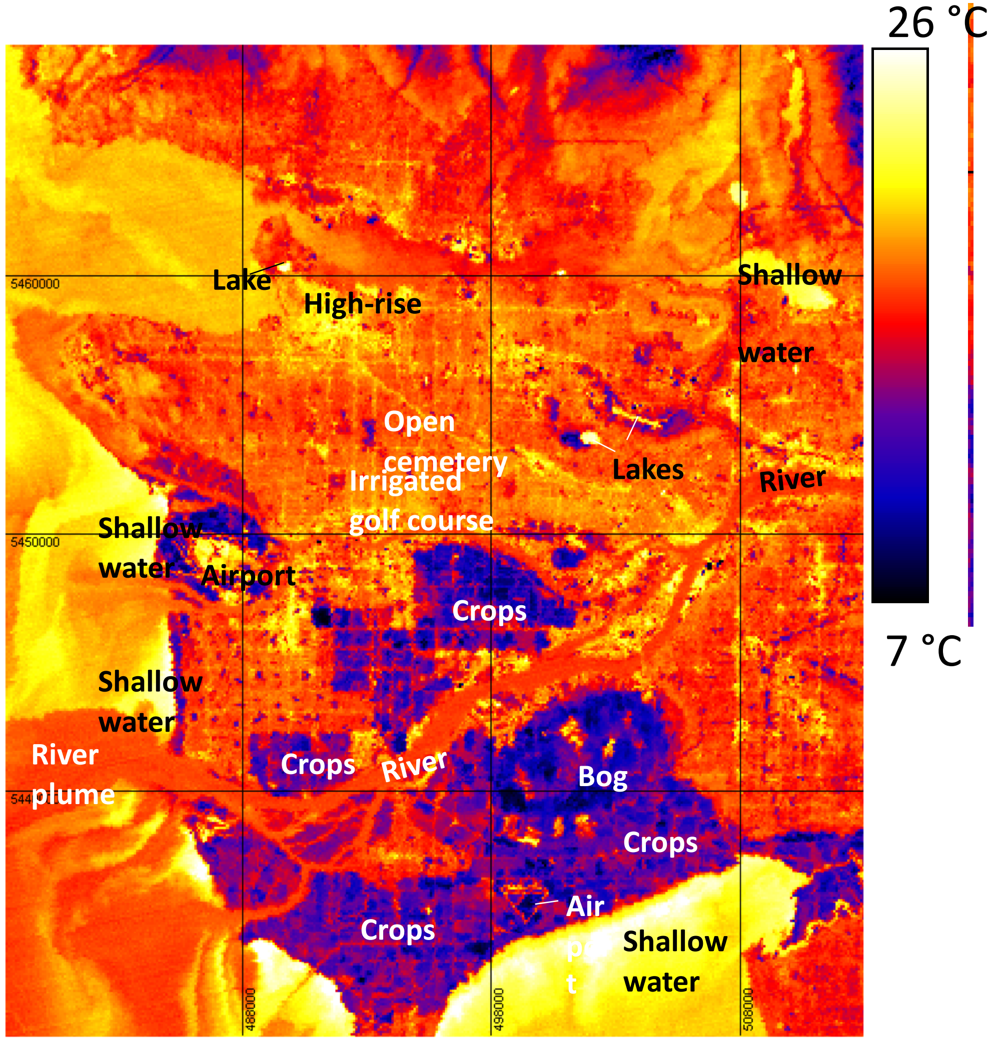

Cities modify their local climates…
Surface Cover
(impervious, vegetated)
Materials
(radiative, thermal, moisture, aerodynamic)
Form
Geometric structure
Metabolism
(emissions of water, heat, pollutants)
City Size
Photo: J. Voogt

Urbanization: altered surface characteristics modify surface temperatures



Summer daytime



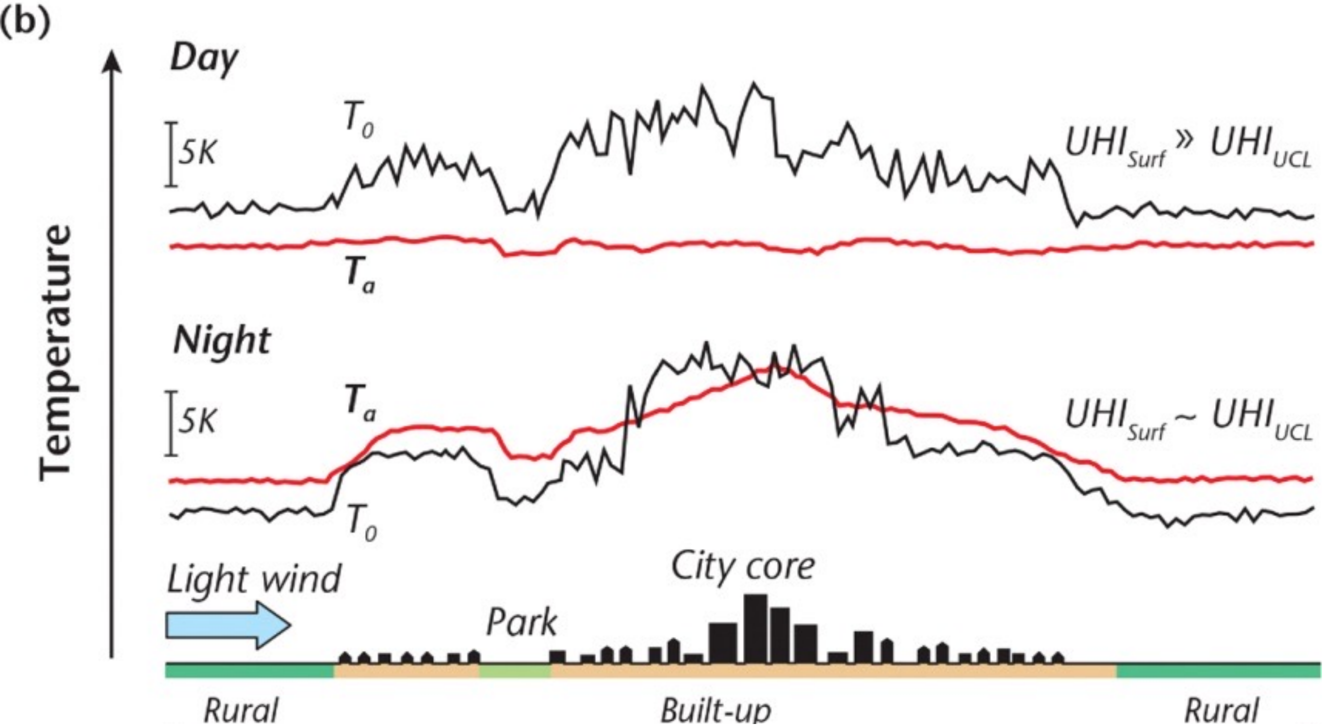
Summer nighttime

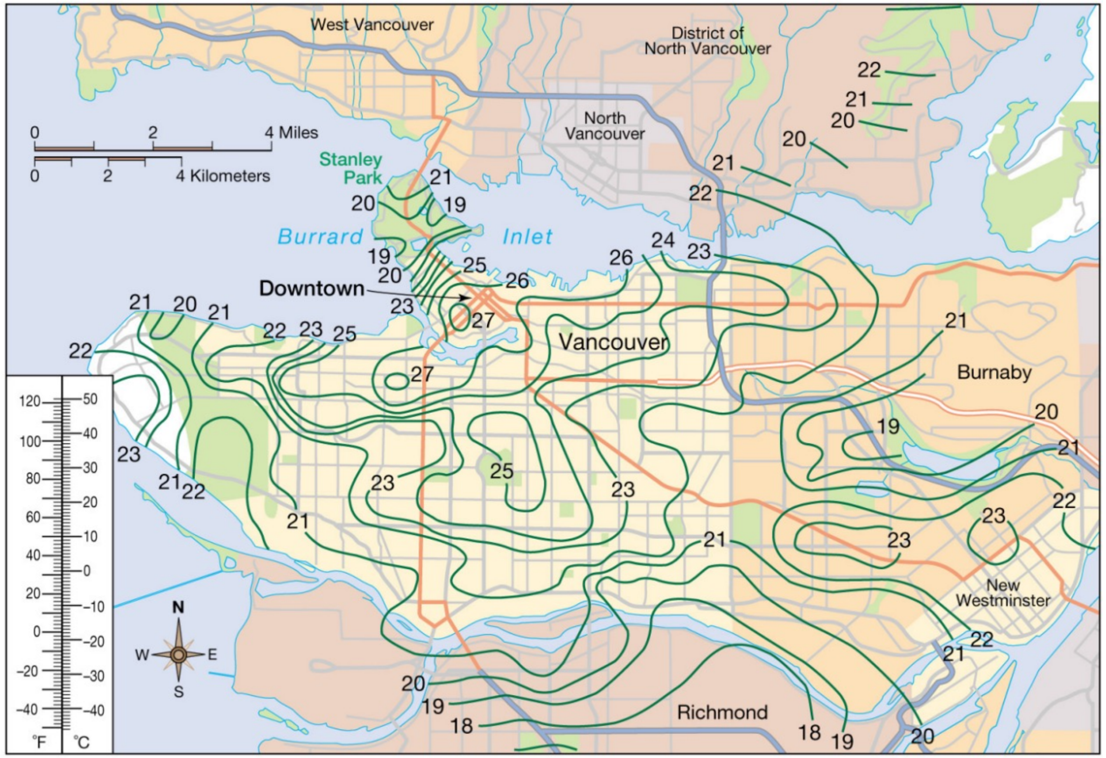
Surface urban heat islands

Oke et al. (2017)

Air Temperature Heat Islands

- A maximum at night, under calm and clear conditions (max 12°C, annual average 1-2°C). May be small or even negative during the day.
- Surface (T_o) and air (T_a) temperatures are very different by day, more similar at night

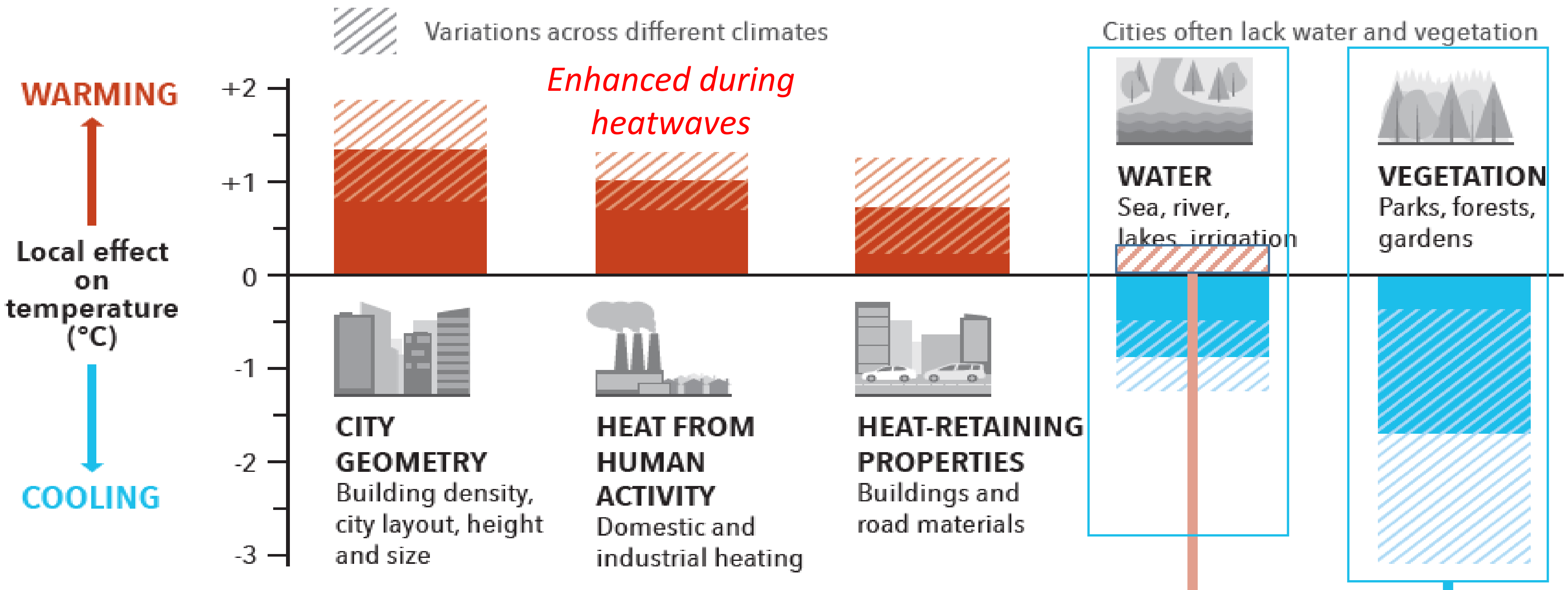




Oke et al. (2017)

Data from Oke in Aguado and Burt (2004)

Forcings on local climates



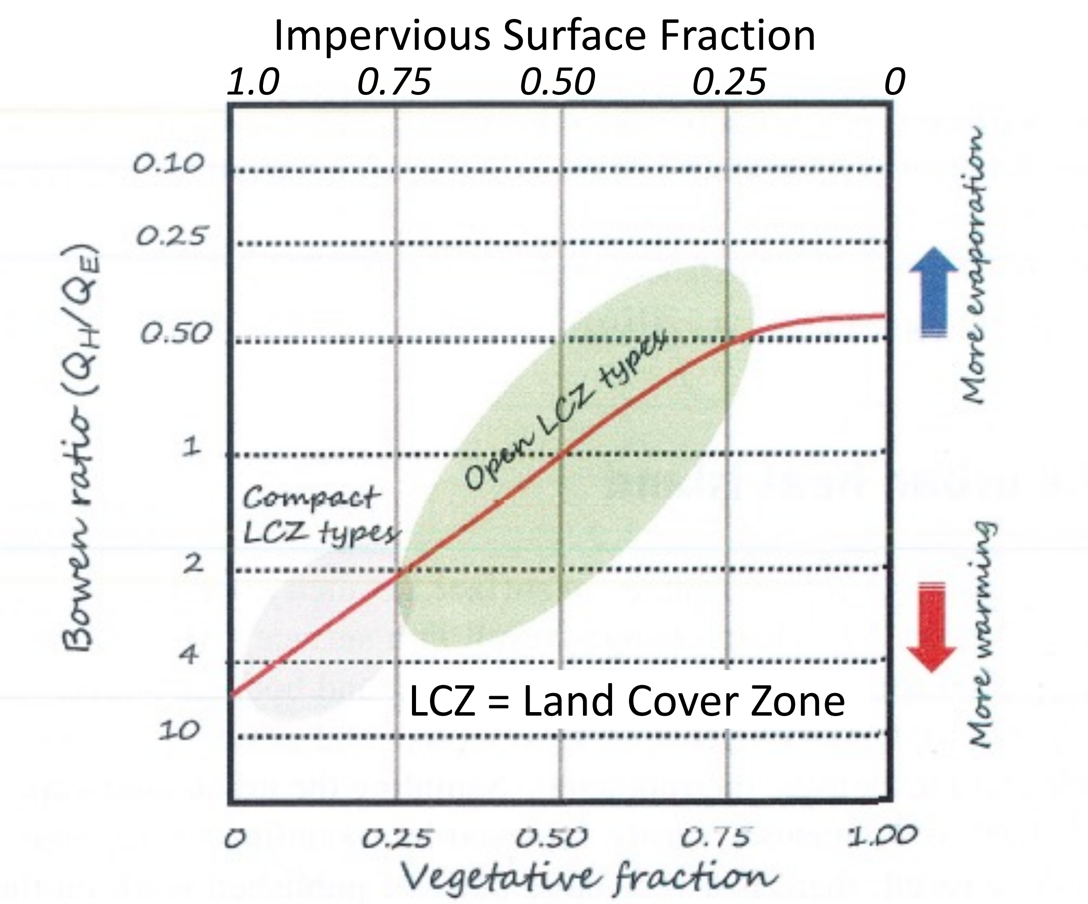
Note: Smaller water bodies with primarily standing water can provide a warming effect at night, especially later in the summer season, so may contribute to excess heat

And see comments about vegetation design – what and where – in this presentation

Eyquem & Feltmate (2022) adapted from IPCC (2021)

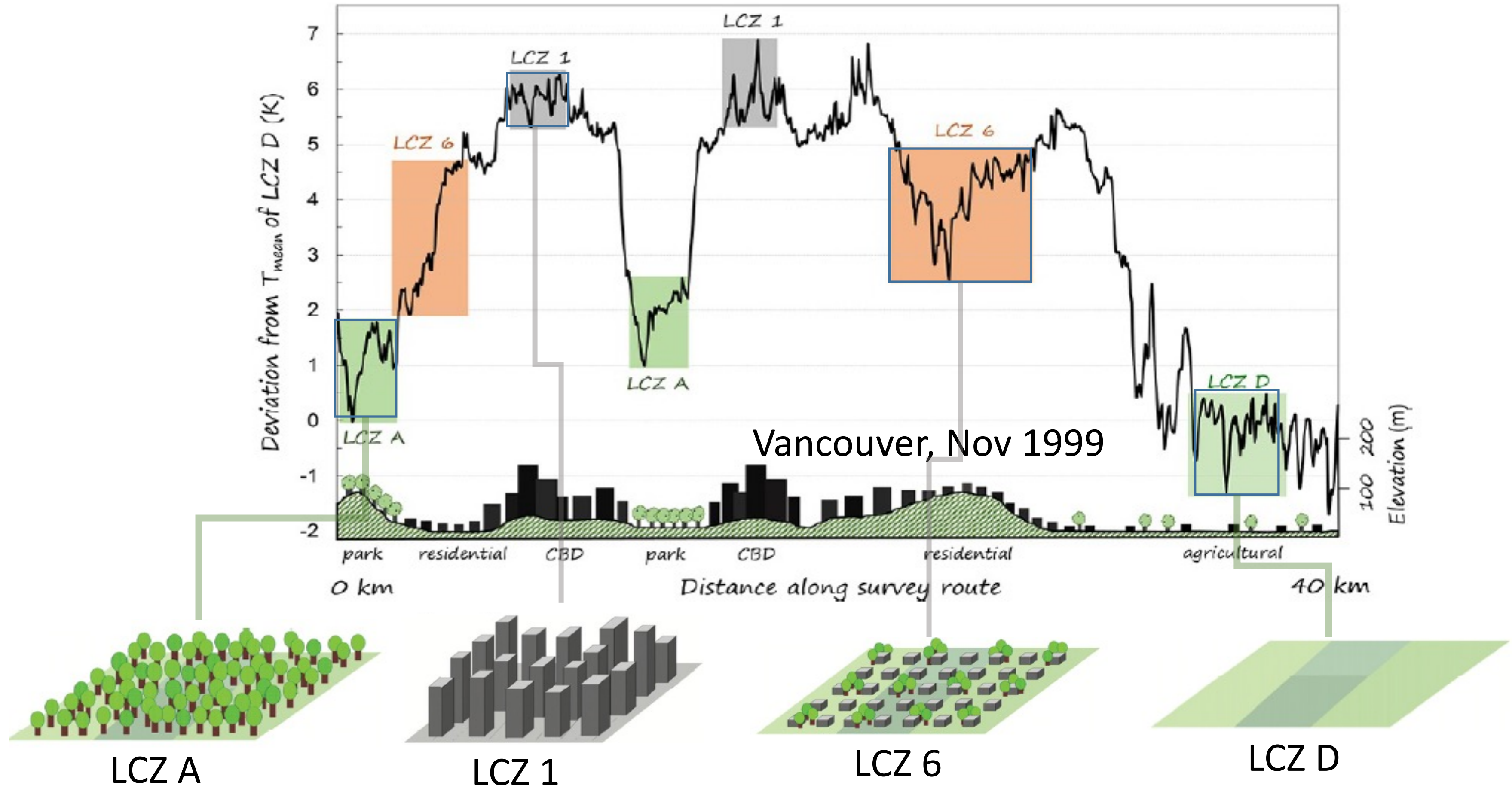
Surface Cover

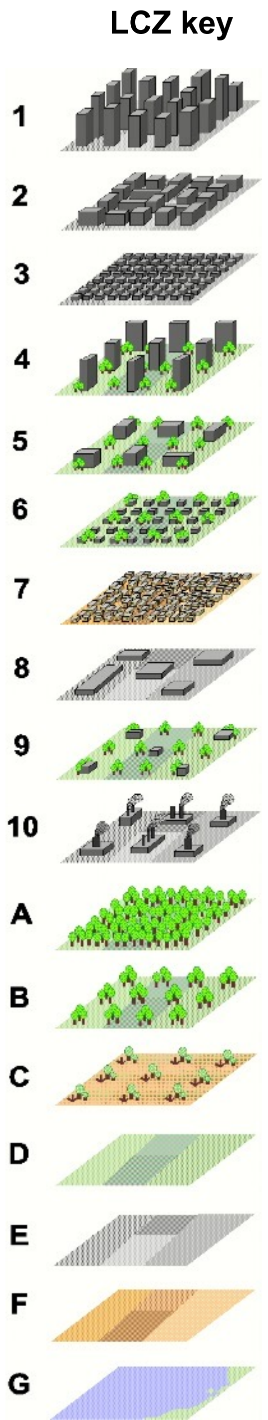
- *At the urban scale, vegetation vs impervious surface cover is an important control on the surface energy balance and how much energy goes into heating the air.*



Stewart and Mills (2021)

Local Climate Zones are linked to the UHI





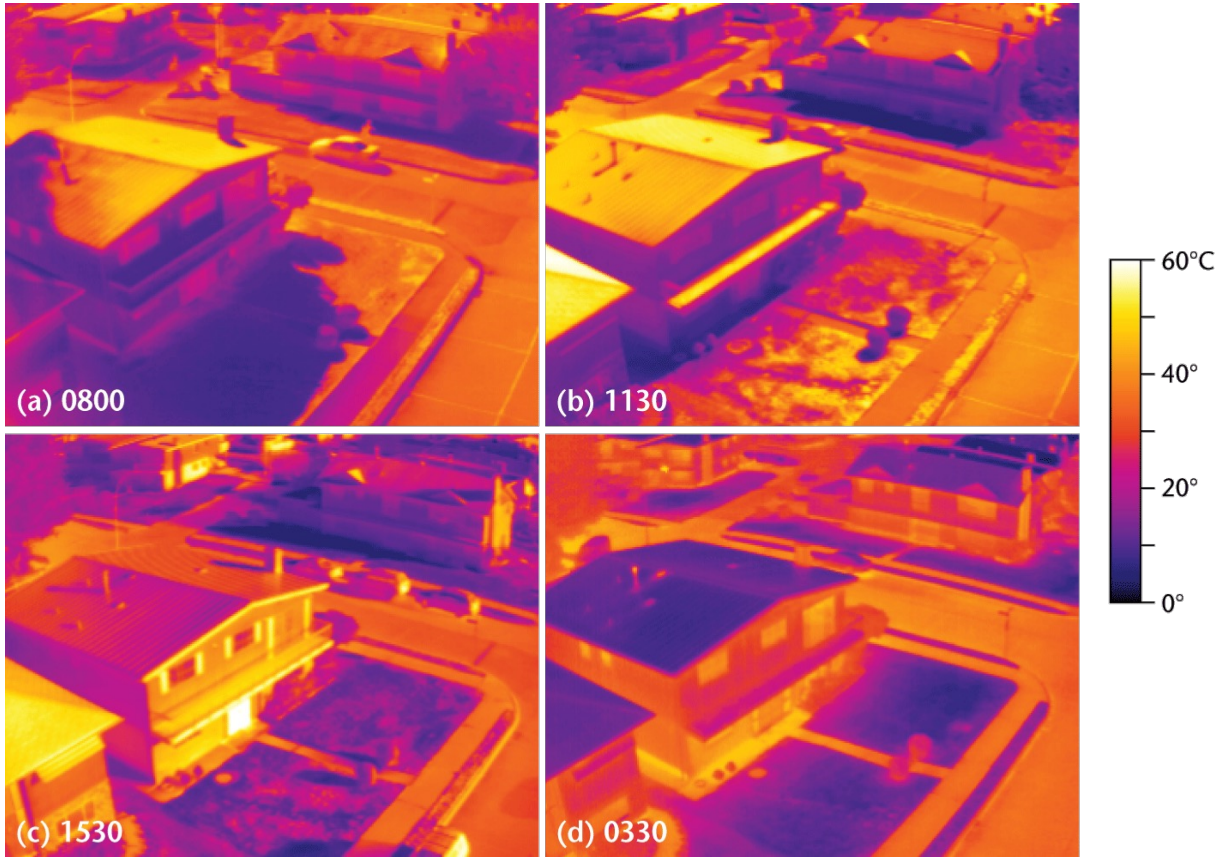
LCZs have been mapped for many Canadian cities by the CANUE project

Stewart and Mills (2021); redrawn from Stewart et al. (2014)

Some basics on the built form

The temperature of every surface depends on its surface energy balance, which is governed by its properties:

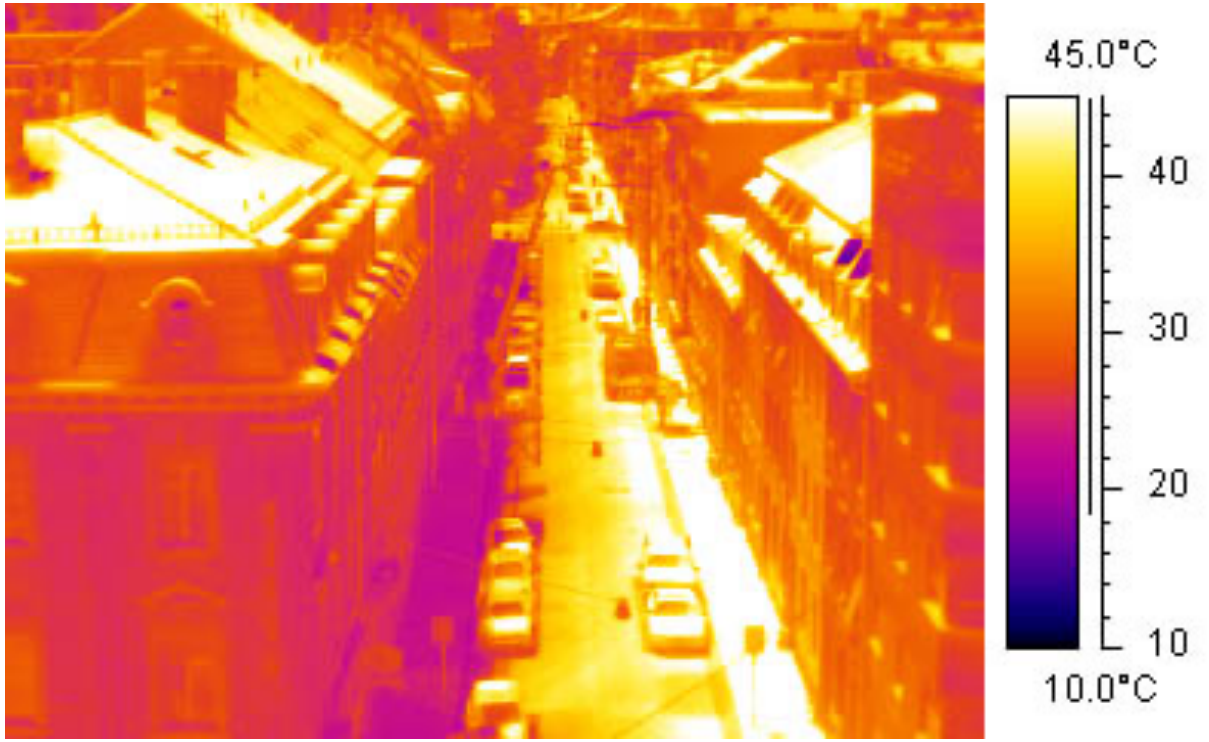
- Orientation and exposure to Sun, sky and wind
- Radiative ability to reflect solar and infrared and to emit infrared
- Availability of surface moisture
- Ability to conduct and diffuse heat
- Roughness



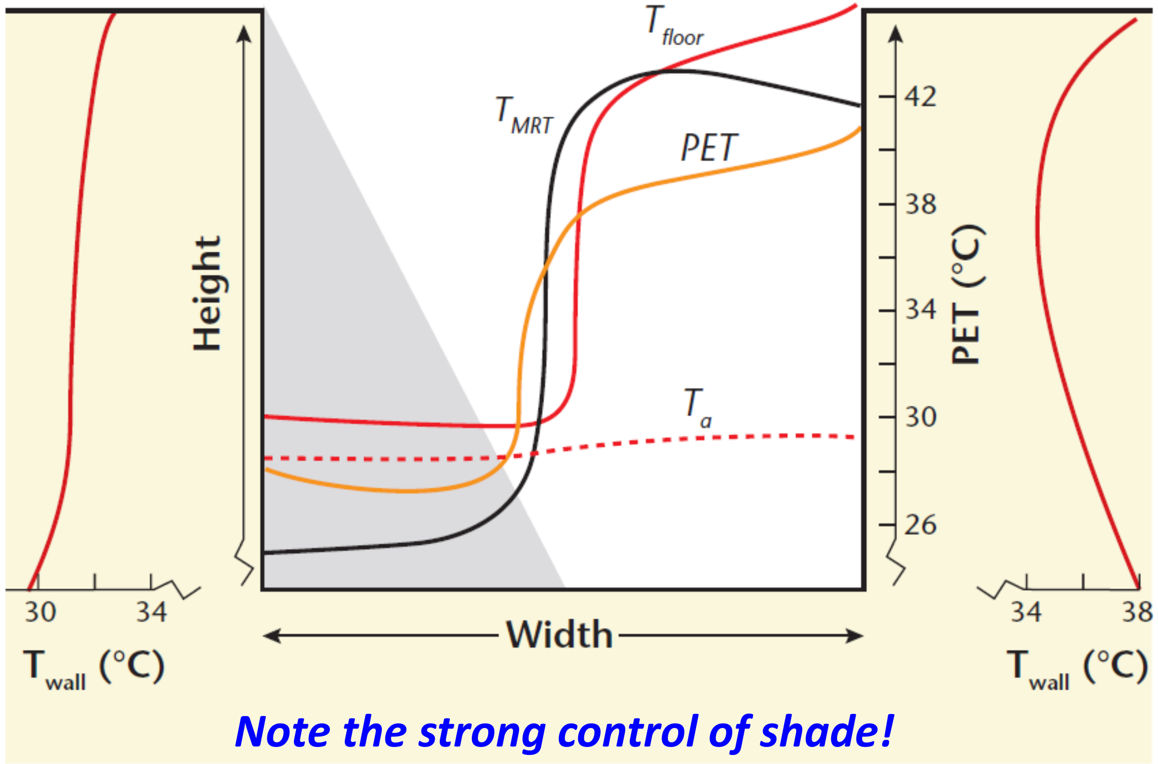
Elgin St., Vancouver

These properties form the basis of possible heat mitigation strategies.

Consider that ‘heat’ is more than ‘temperature’



Urban or street canyon

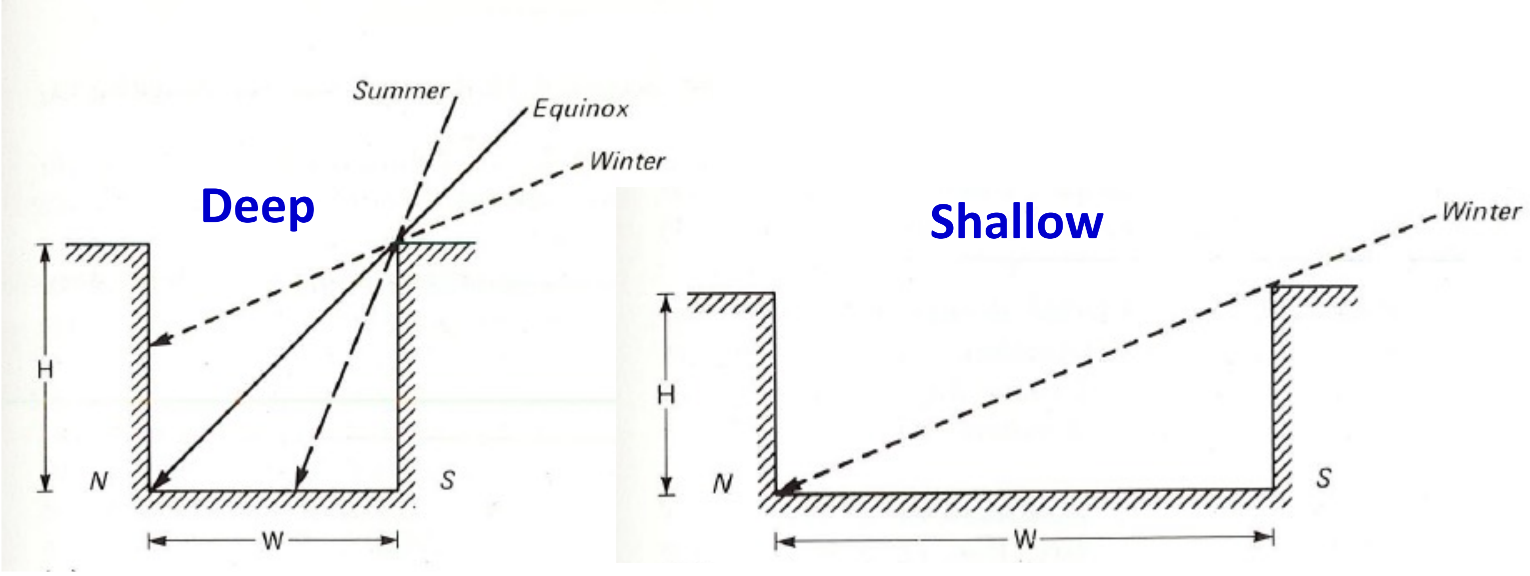


T_{MRT} = Mean Radiant Temperature
PET = Physiologically Equivalent Temperature

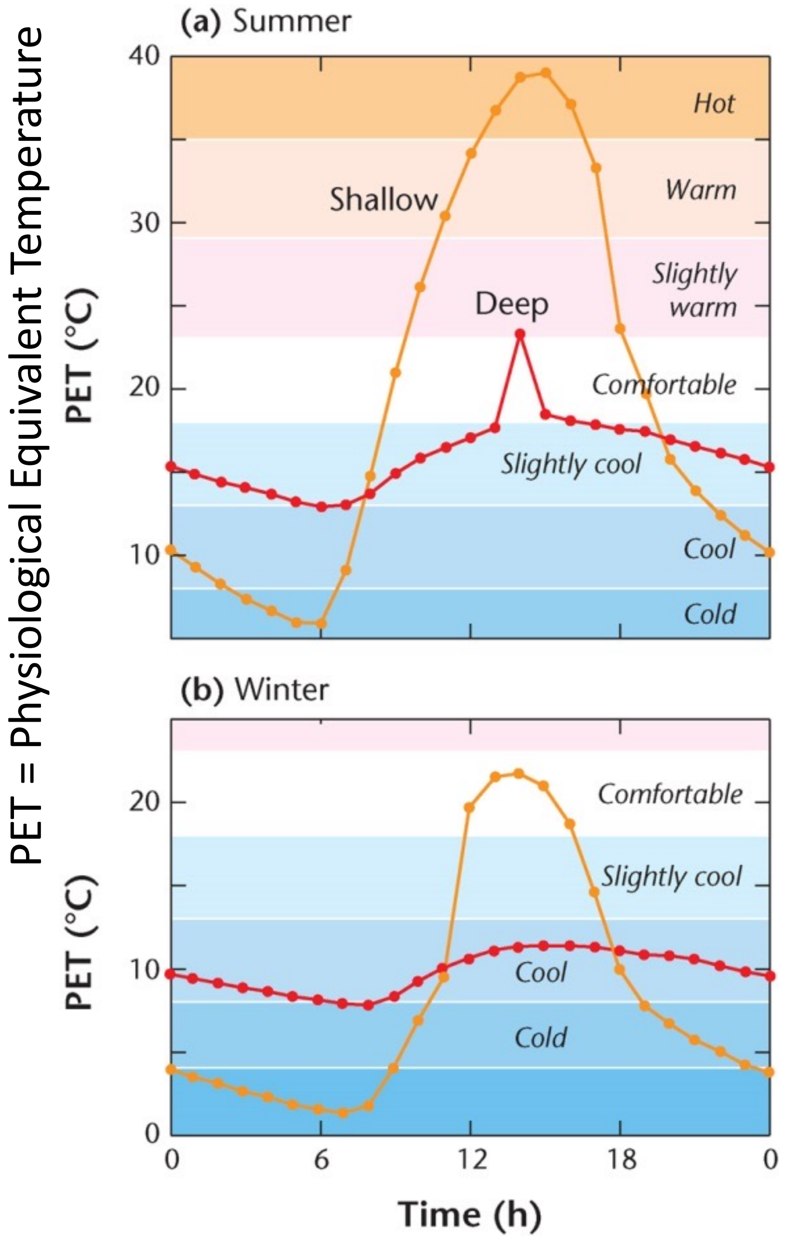
(Credit: Gerd Jenritzky; as shown in Oke et al. 2017)

Street Canyon Geometry

- Building Height (H) to Width (H) ratio controls
  - Solar access
  - Atmospheric dispersion
  - Shelter from winds
  - Retaining warmth at night
- H/W of ~0.4 - 0.6 provides some balance



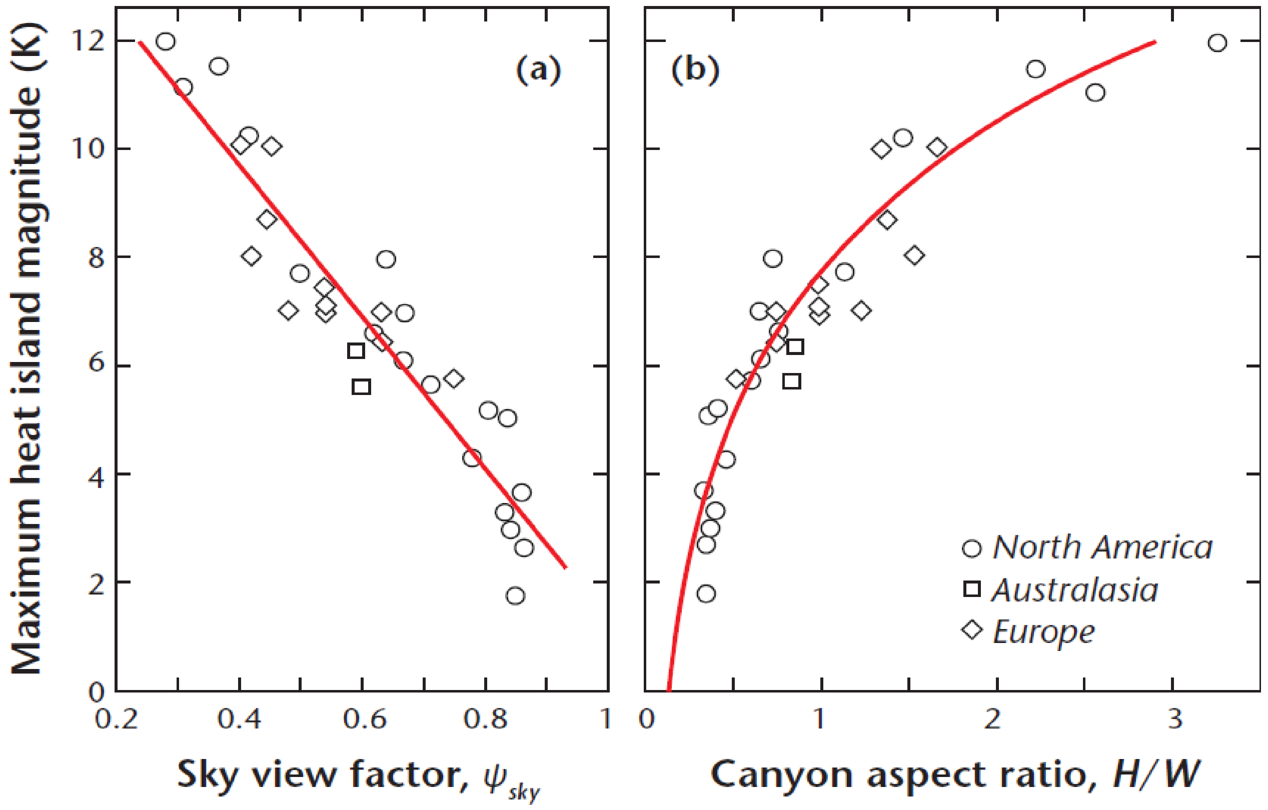
Oke 1988



Johansson 2006 as shown in Oke et al. 2017

Street Canyon Geometry – Night

- As H/W increases (buildings more closely spaced) – more night time warmth – greater night time heat island.



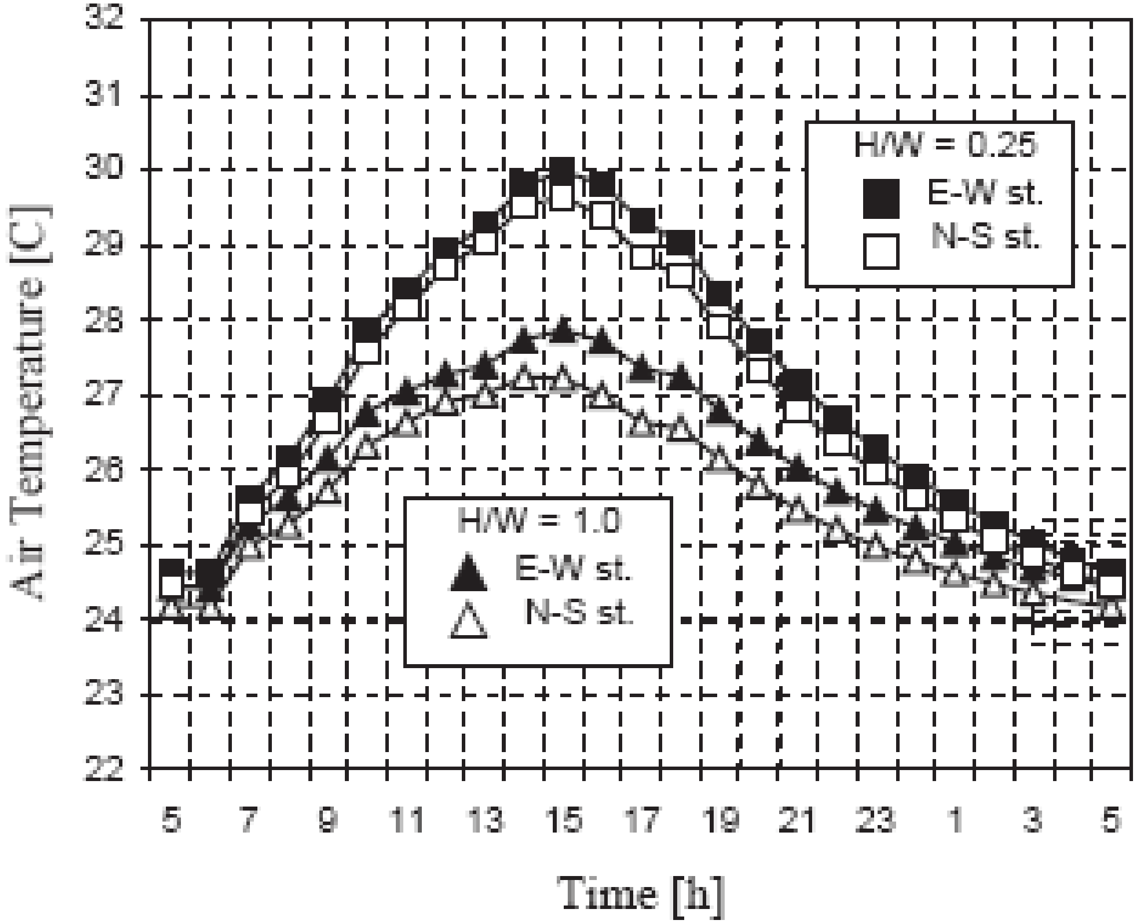
Oke et al. 2017

Cold building roofs – large SVF, low heat storage
Warm streets – low SVF, high heat storage
Car roofs – low heat storage, low emissivity

Street Orientation and Street Width

- For pedestrians, a narrower N-S street is beneficial in warm season, a wider E-W street in cold season, based on solar access
- Consider impacts on ventilation by wind for cooling under humid conditions and dispersion of pollution.

Model simulations



H/W = 0.25: ■ E-W st. with trees □ N-S st. with trees, H/W = 1.0: ▲ E-W st. with trees △ N-S st. with trees

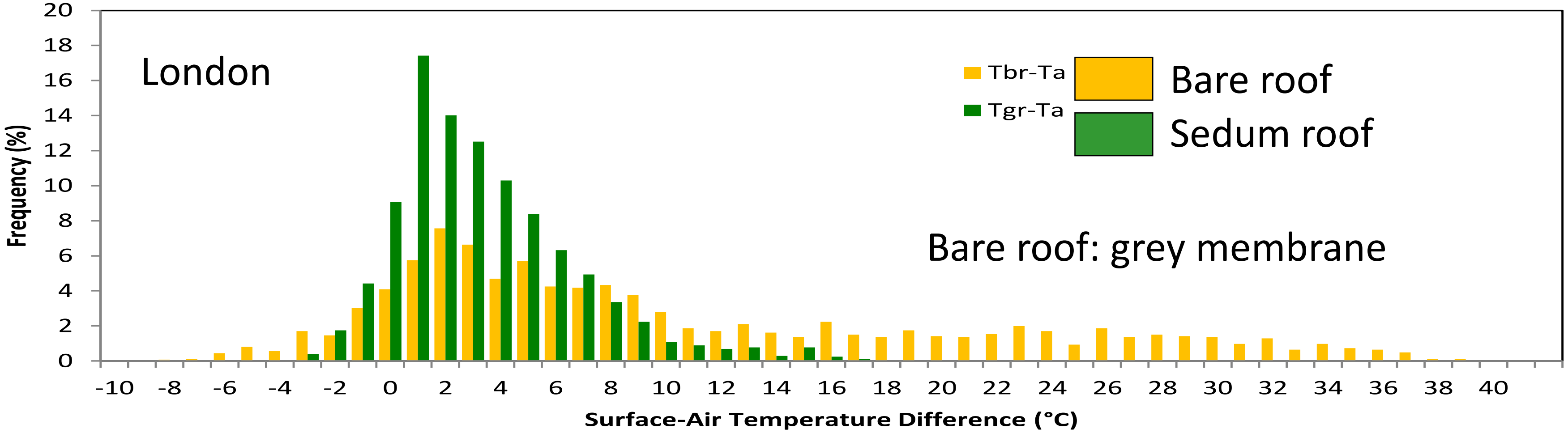
Bar and Hoffman (2004)

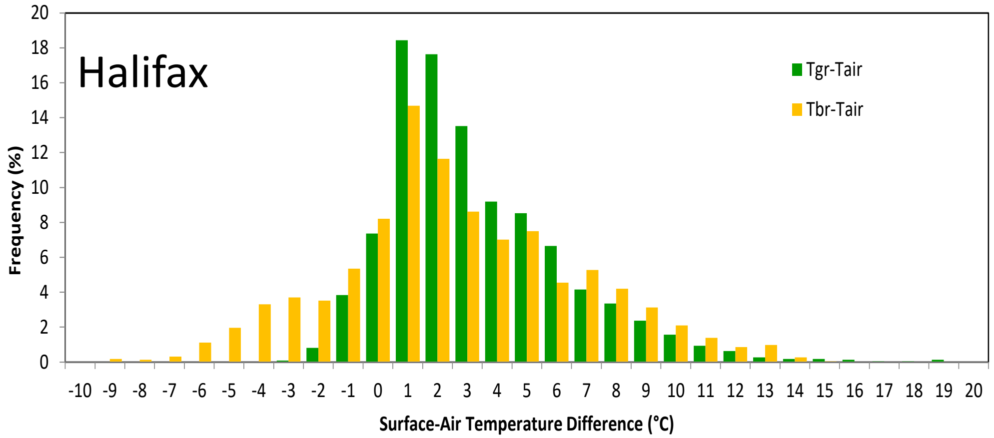
Urban Materials: Roofs

Cool roofs provide potential for reducing urban temperatures (surface & air), especially above roof level.

High albedo typically more effective than green roofs.

Roof materials less effective at providing cooling at pedestrian height.



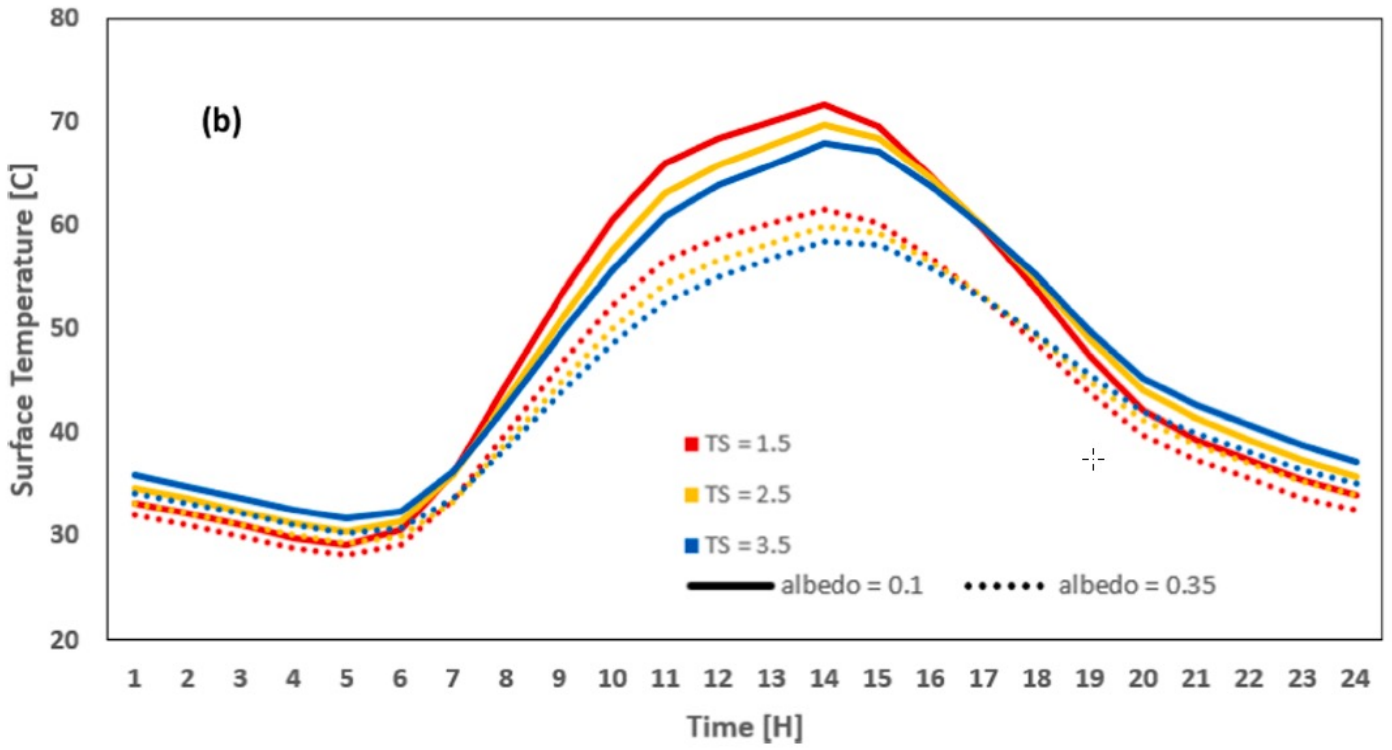


Bare roof: white membrane

Typical roof albedo cooling effectiveness: ~0.2°C – 0.6 °C cooling per 0.10 neighbourhood albedo (daytime summer clear afternoon); based on models Krayenhoff et al. (2021)

Urban Materials: Roads

- Thermal properties provide an ability to store heat by day.
- Higher heat storage reduces surface T_{max} but yields warmer T_{min}
- Can reduce/offset peak day time surface temperature
- Increasing albedo reduces road temperature but potentially adds radiative heat load to pedestrians.



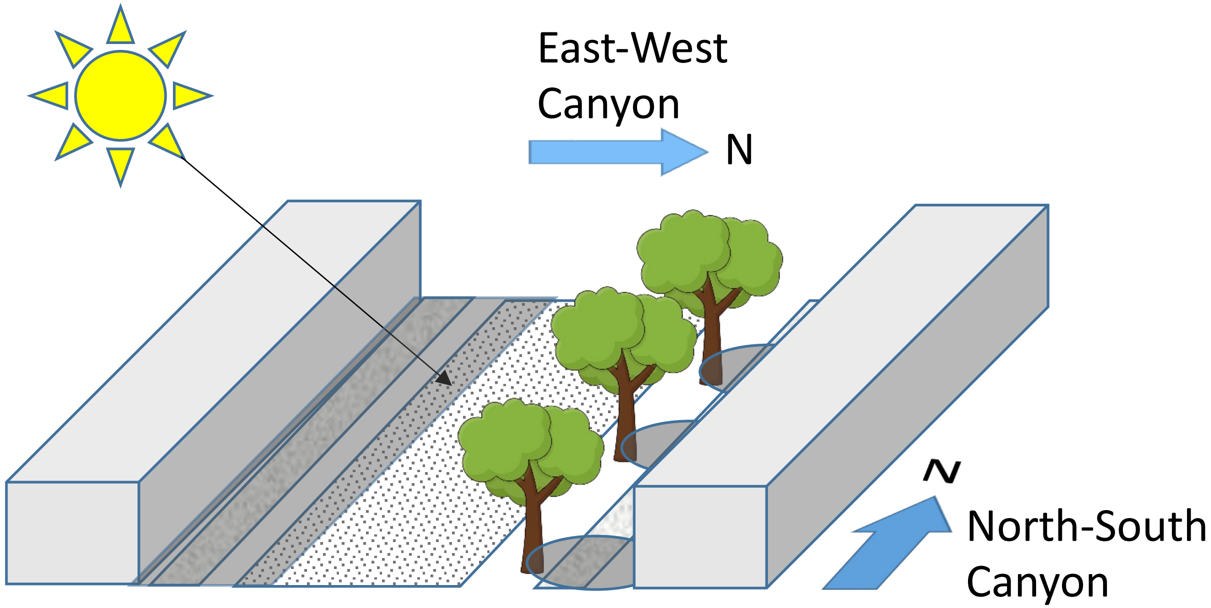
TS = Thermal Storage Capacity

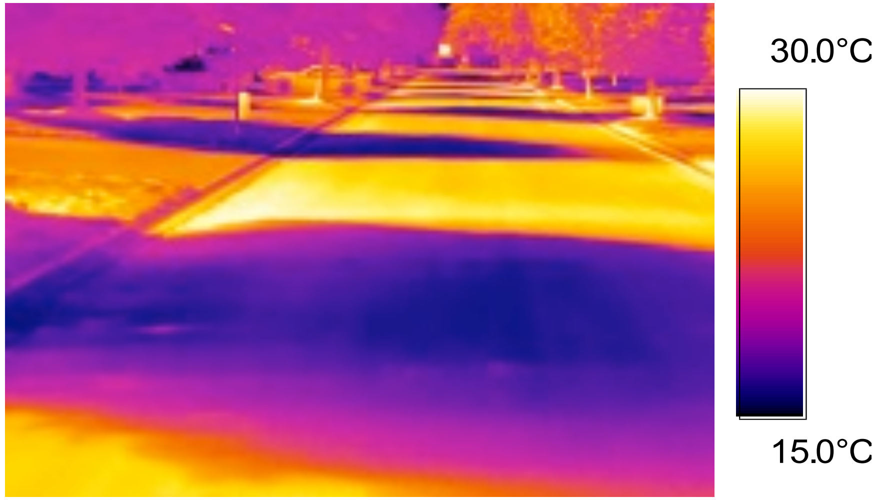
Anand and Sailor (2022)

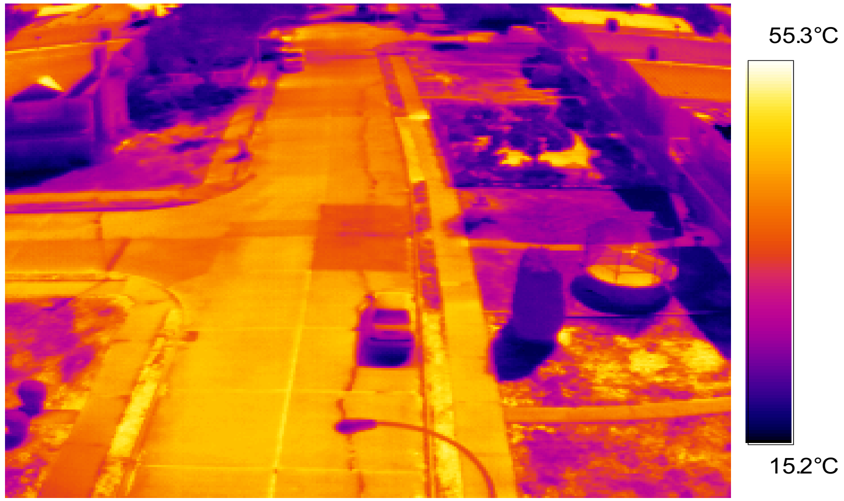

Vegetation provides
• Shade
• Transpiration
• Shelter / Reduced ventilation
• Surfaces for pollutant deposition
Photo: J. Voogt

Street tree placement

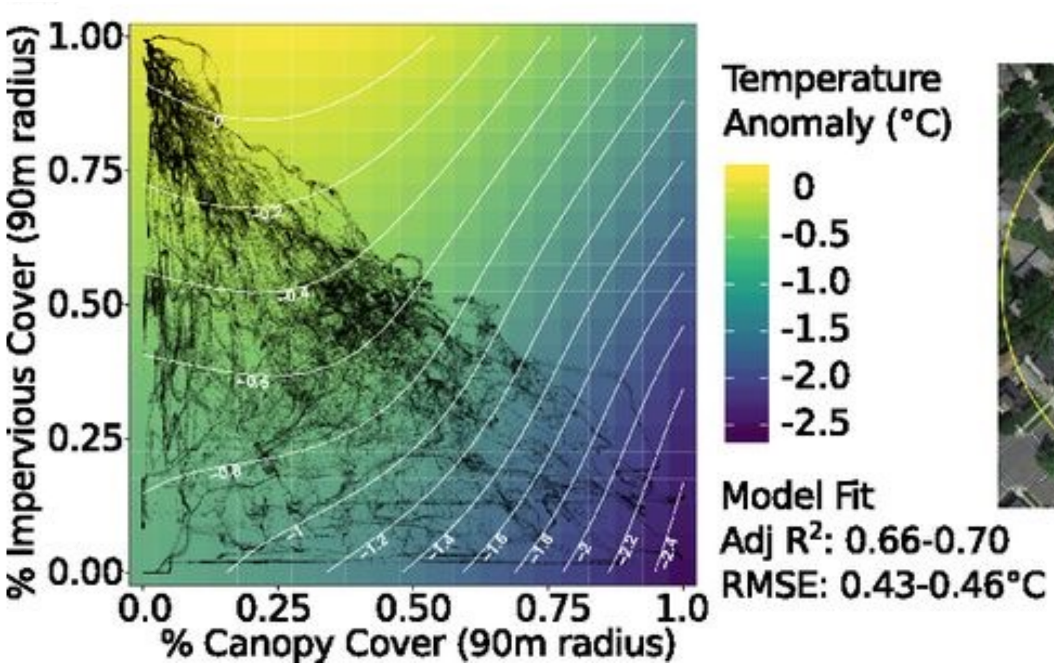
- Cooling benefit of street trees increases as street canyon becomes more open
- Shade south and west facing walls and pedestrians
- Tree density: maximize shade area
  but provide sufficient spacing to allow
  ventilation and nocturnal cooling
- To address daytime heat – more trees;
  To address night time heat – more ground level vegetation

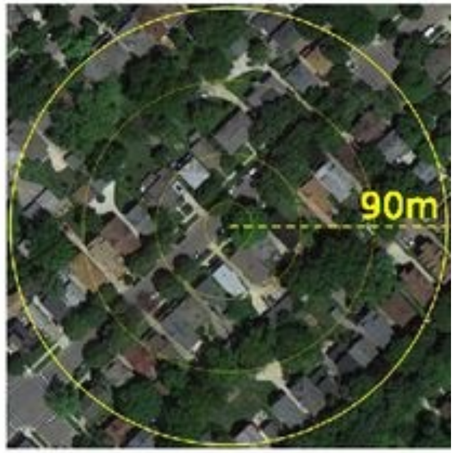




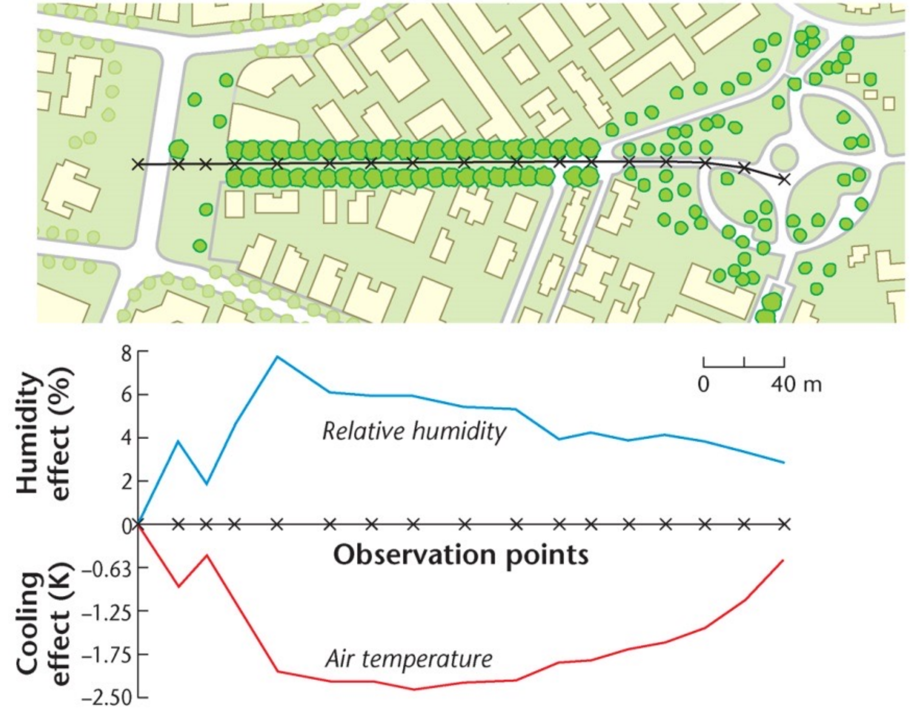


Vegetation air temperature cooling





Ziter et al. (2019)



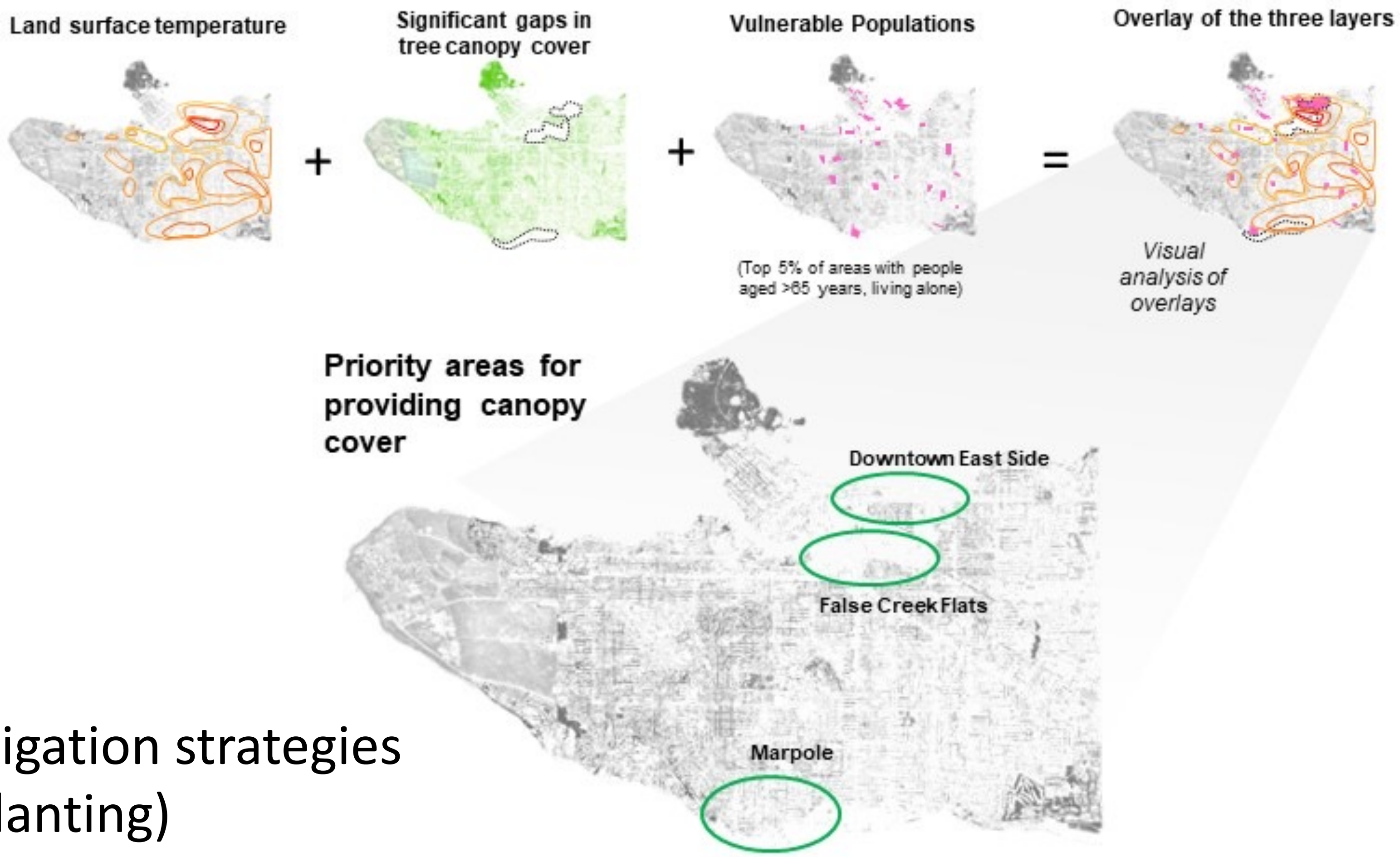
From Shashua-Bar and Hoffman (2000)

- Vegetation Cooling Effectiveness: ~ 0.3°C cooling per 0.10 fractional canopy cover increase for afternoon clear-sky summer conditions
- VCE for low vegetation and green roofs shows large variation (sensitivity to moisture)
- Higher humidities and higher wind speeds dilute the impact

The Role of Greenspace: Not just how much but where

Heat-adaptation programs need to consider vulnerability assessments and adaptation strategies that protect populations at most risk to extreme heat.

Check for spatial coincidence of
- the most heat sensitive people;
- highest population densities;
- greatest opportunity for heat mitigation strategies (e.g. roof area or areas for tree planting)



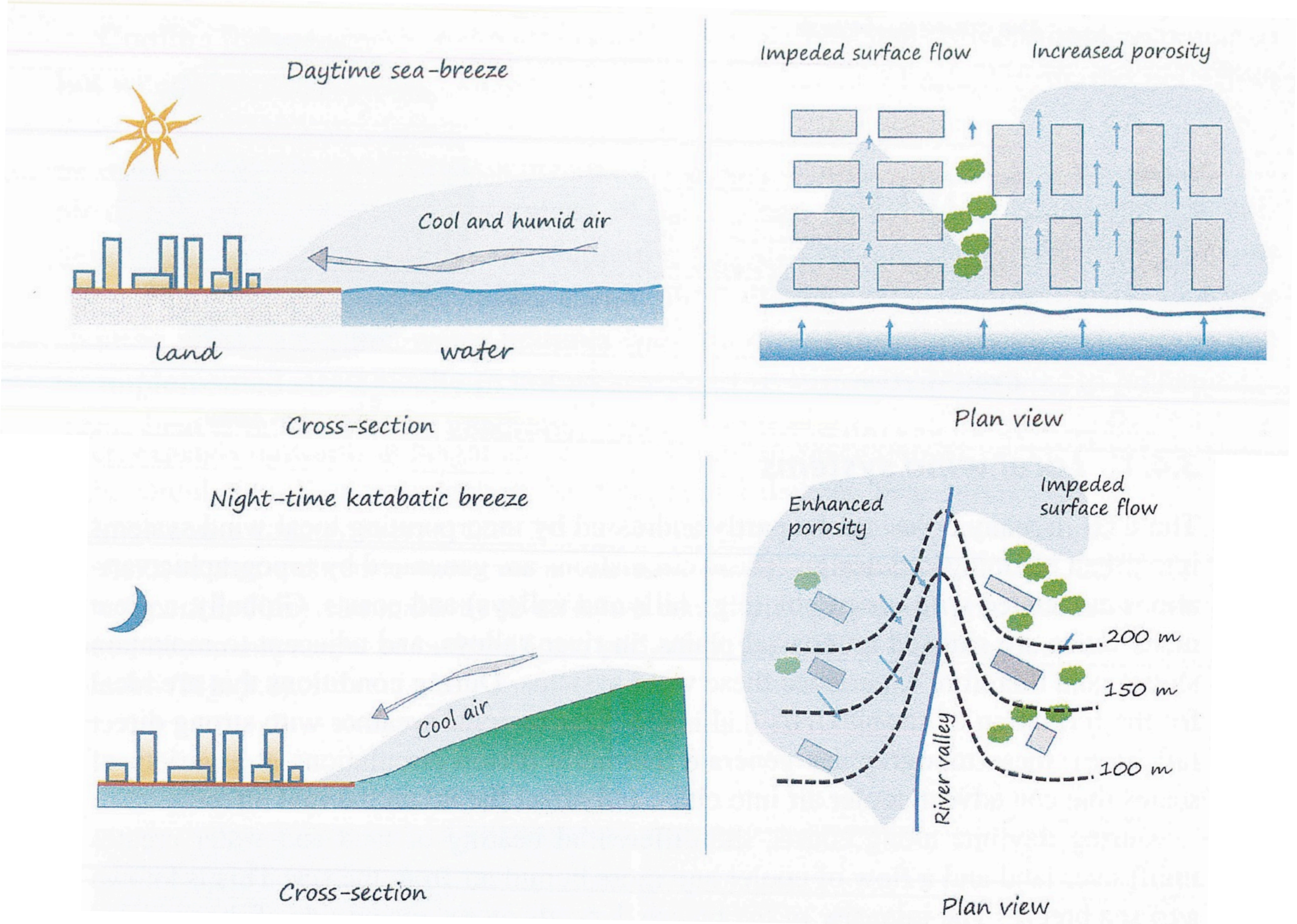
These allow for targeted implementation with maximum benefits

Source: City of Vancouver (2015) as shown in Health Canada (2020)

Urban Climate Design and the local landscape

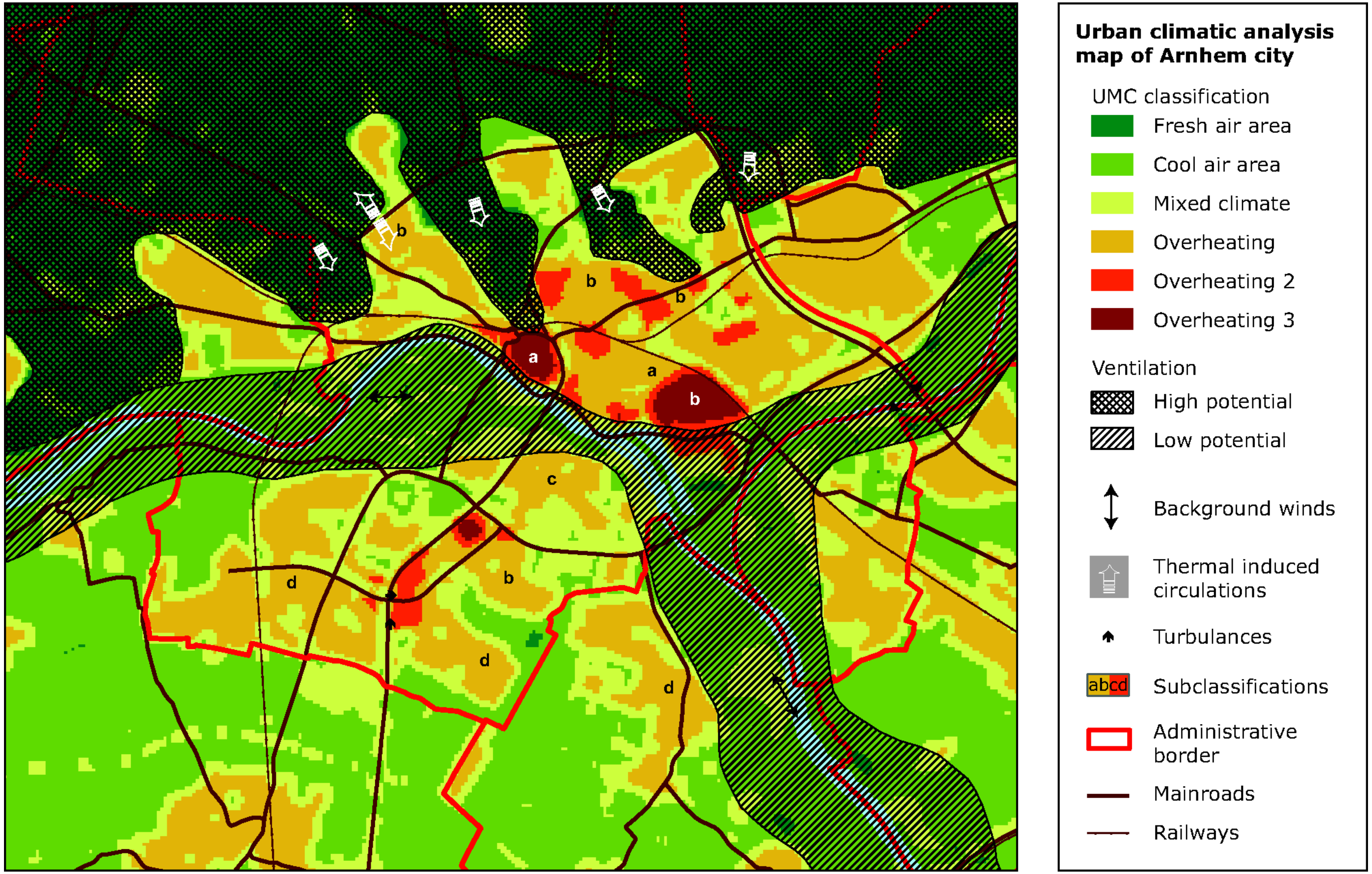
Consider the potential for sources of cool air from lake/sea-breezes, topographically-induced flows, or areas of vegetation

Provide ventilation corridors



Stewart and Mills (2021)

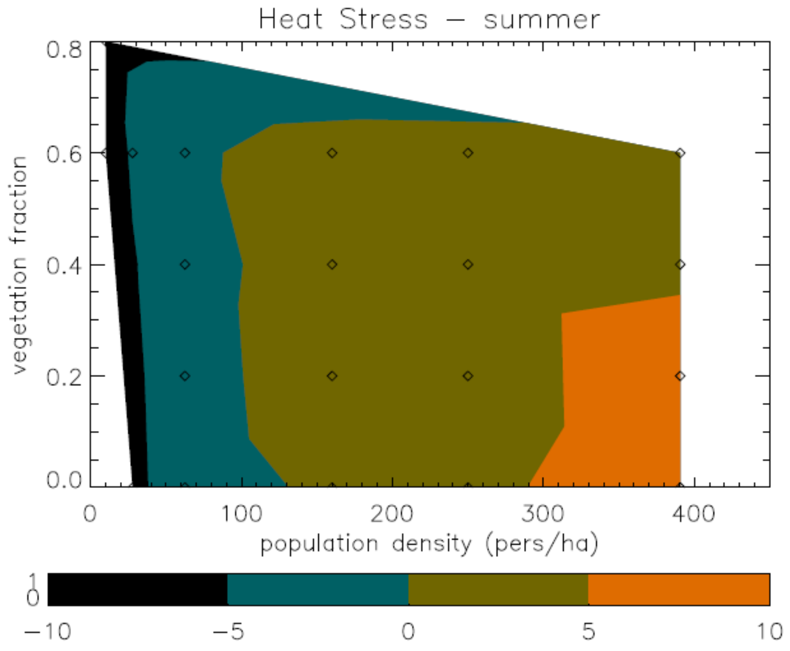
Urban Climatic Map Analysis

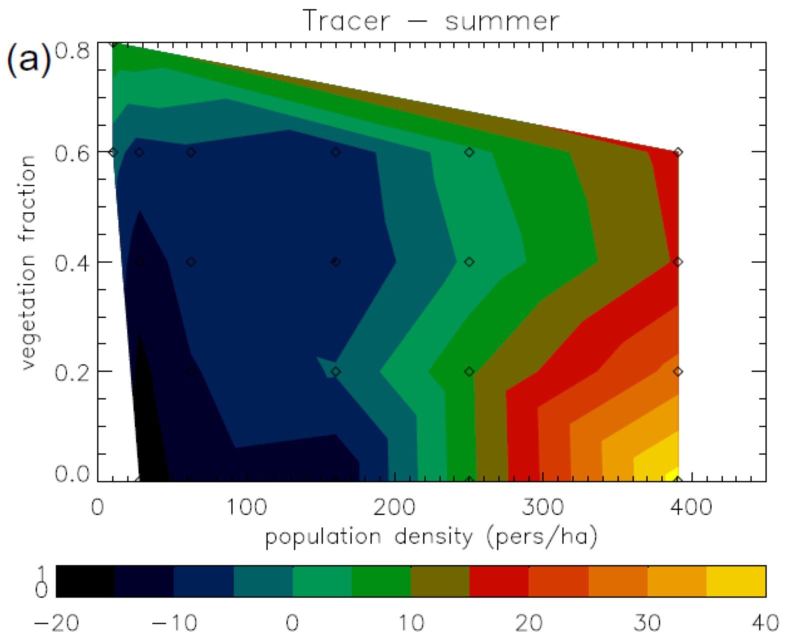


EEA Future Cities (2012) https://www.eea.europa.eu/data-and-maps/figures/urban-climate-analysis-map-for

Paradox of Compact Cities (in a dry hot climate)

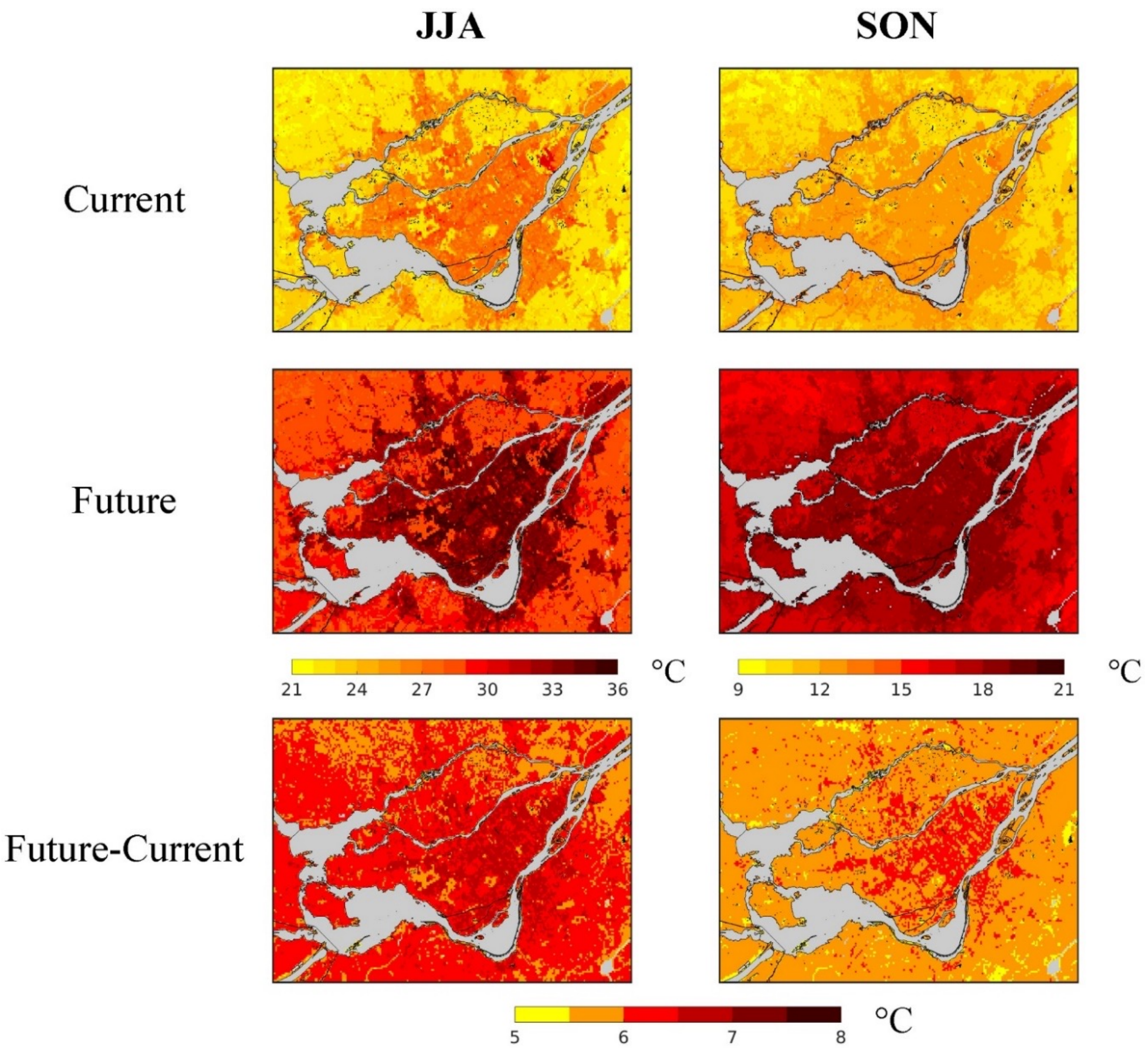
- Very compact cities with no vegetation are the most *uncomfortable* from a heat stress point of view – reduced nocturnal cooling (low sky view factor) and more heat from AC systems.
- Very compact cities also yield higher air pollution emissions per unit surface.
- BUT – compact cities minimize energy consumption and thus CO_2 emissions.
- Consider the H/W 0.4 – 0.6 from earlier



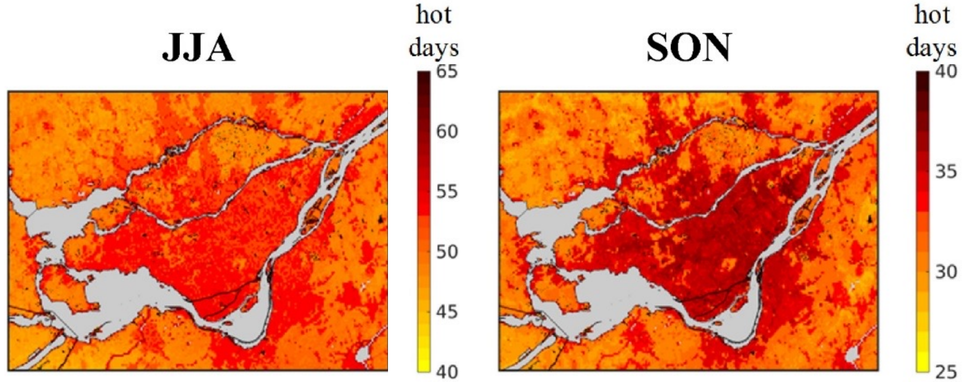


Martilli (2014)

Our future urban climates



Changes to # of hot days for 2071-2100 vs 1981-2010



Hotter but not necessarily a greater UHI
Must also consider development of cities

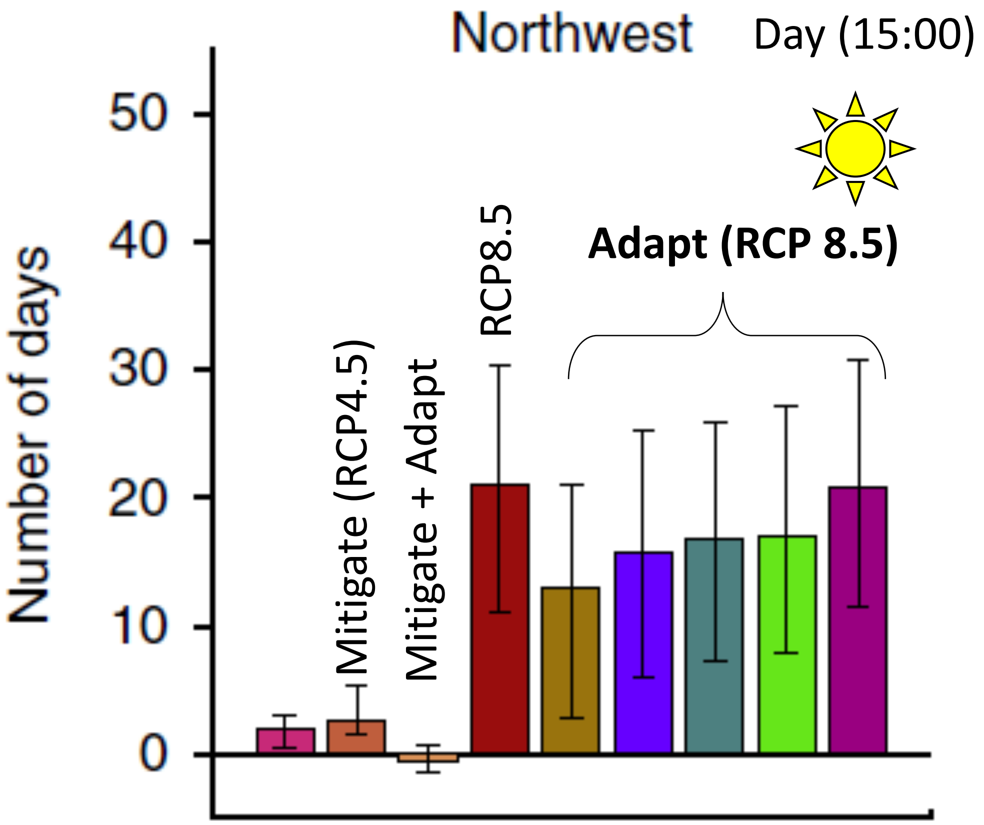
During heat waves, UHI may be synergistically greater

LST. Note that while LST increases, SUHI is weakly affected

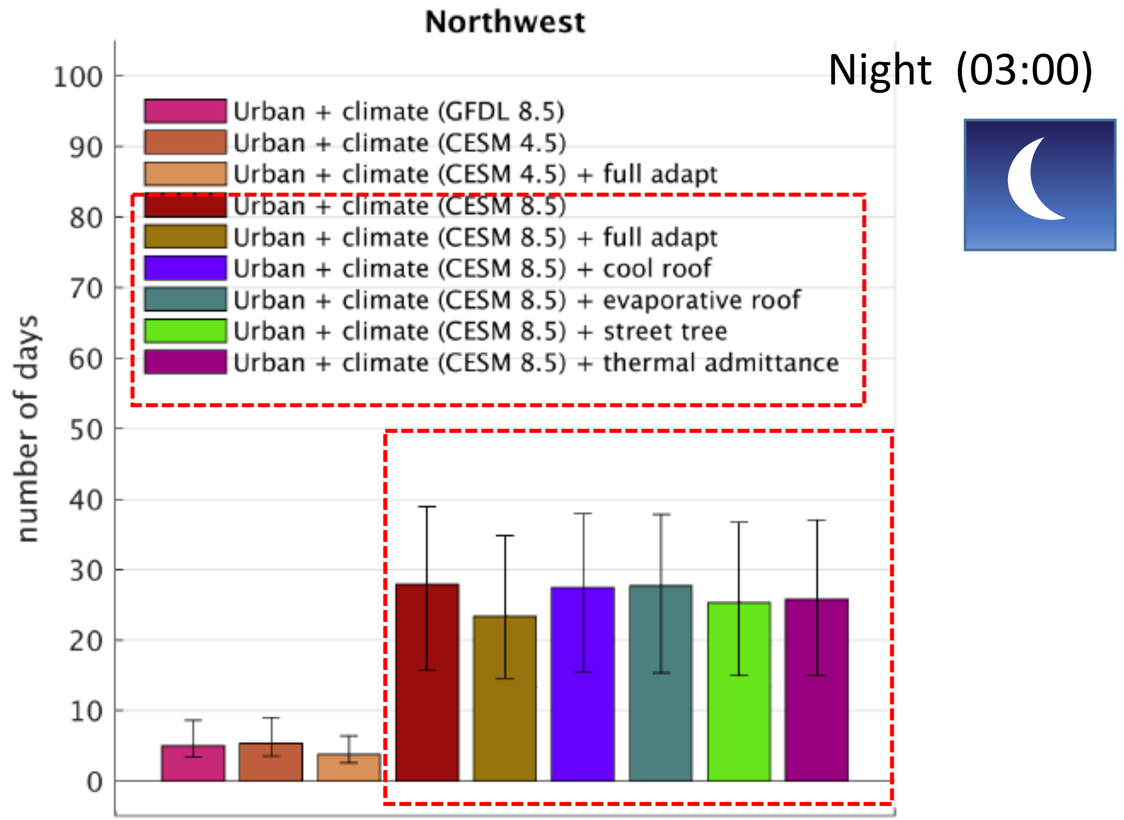
Roberge & Sushama (2018)

Urban adaptation helps, but does not overcome large scale warming (RCP 8.5)

US based modelling study, but Northwest likely representative of southern BC



Increase in extreme heat afternoons by 2100 greater than the 99th percentile of contemporary climate.



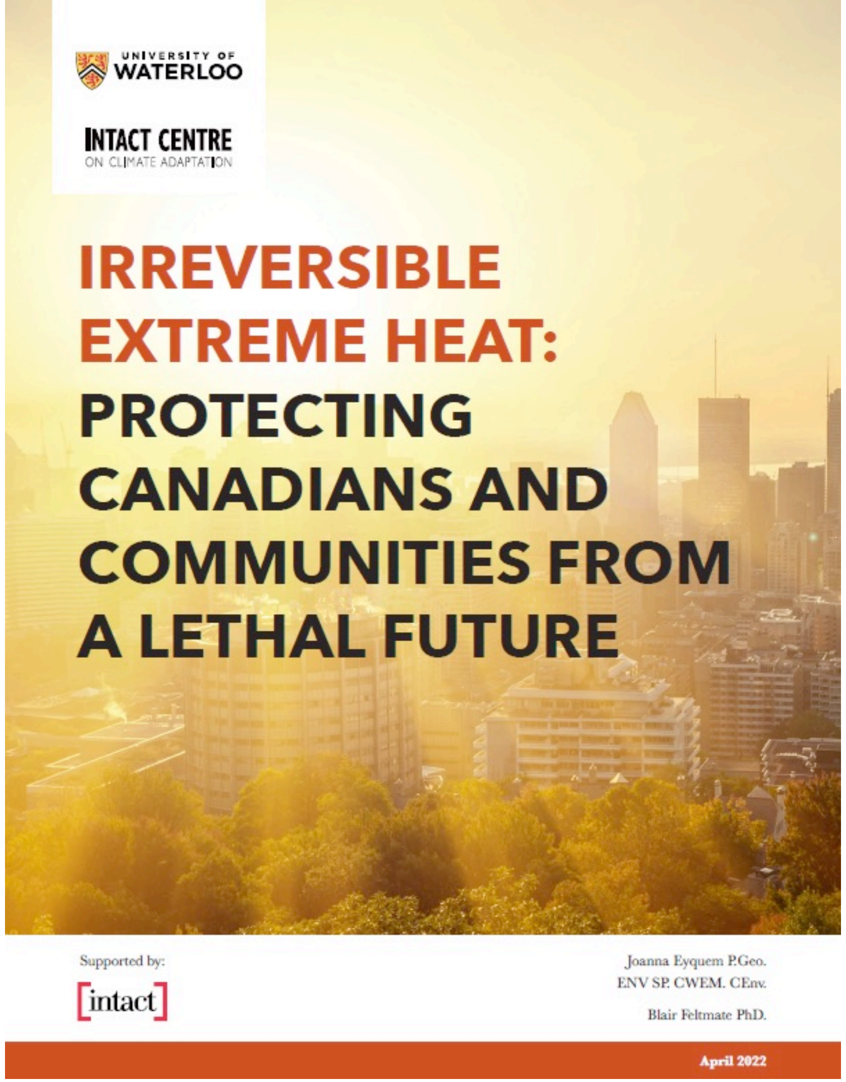
Social Adaptation measures will also be important.

From: Krayenhoff et al. 2018, *Nature Climate Change*

Summary

- Cities create their own microclimates – and are important drivers of large scale climate change through GHG emissions
- Consider a blend of planning and design measures across a range of scales – e.g. the landscape setting of the city through to streetscapes. These provide both adaptive and mitigation benefits – up to 2.5-3°C cooling at the city scale is possible for some climates.
- Optimum design is often locally specific and climate region dependent – is daytime T_{max} the issue or night time T_{min}? Is the climate humid or dry?
- More deciduous trees a nearly universal applicable strategy (consider water availability, maintenance, no blocking of key ventilation, support from residents)
- Be aware of the topographic setting of your community – make use of cool air resources
- Develop an urban climatic map for your community

Resources


UNIVERSITY OF WATERLOO
INTACT CENTRE
ON CLIMATE ADAPTATION
IRREVERSIBLE EXTREME HEAT: PROTECTING CANADIANS AND COMMUNITIES FROM A LETHAL FUTURE
Supported by:
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Joanna Eyquem P.Geo.
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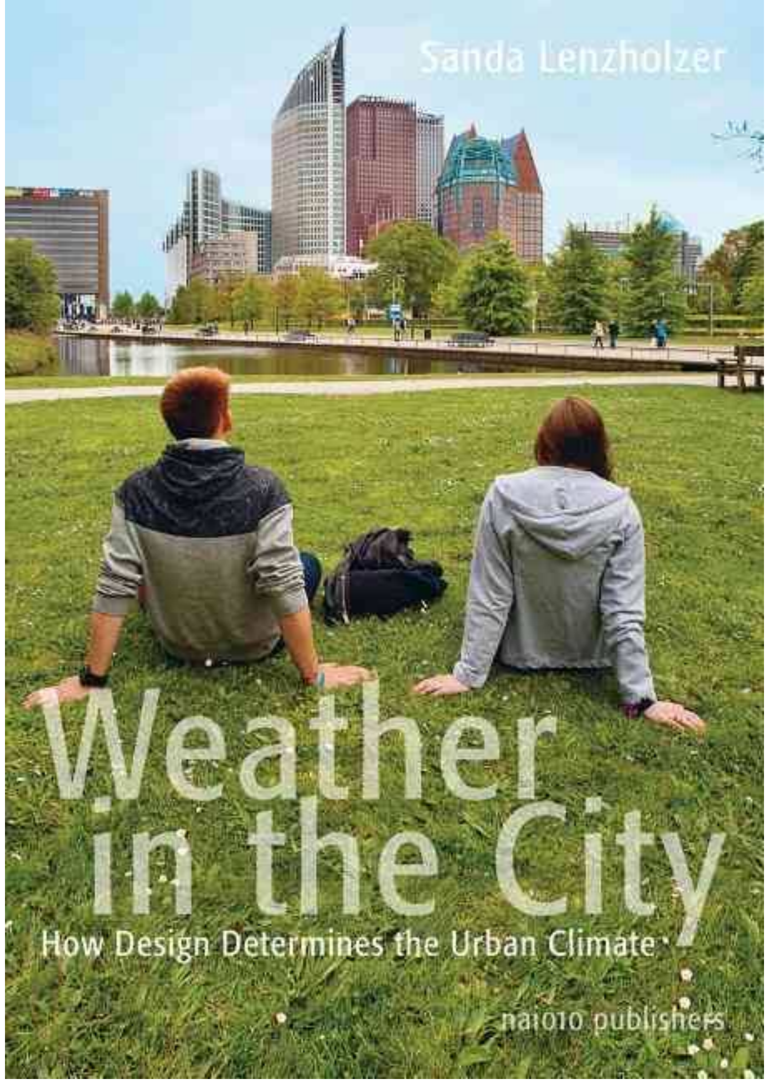
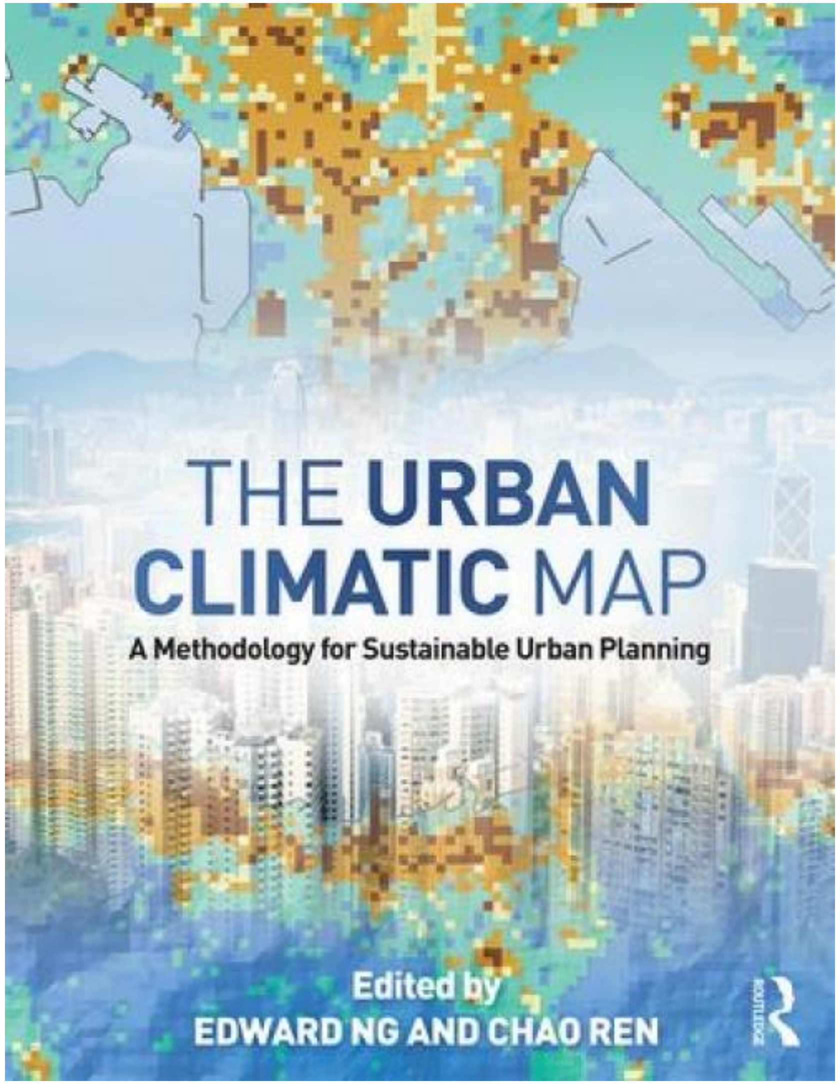
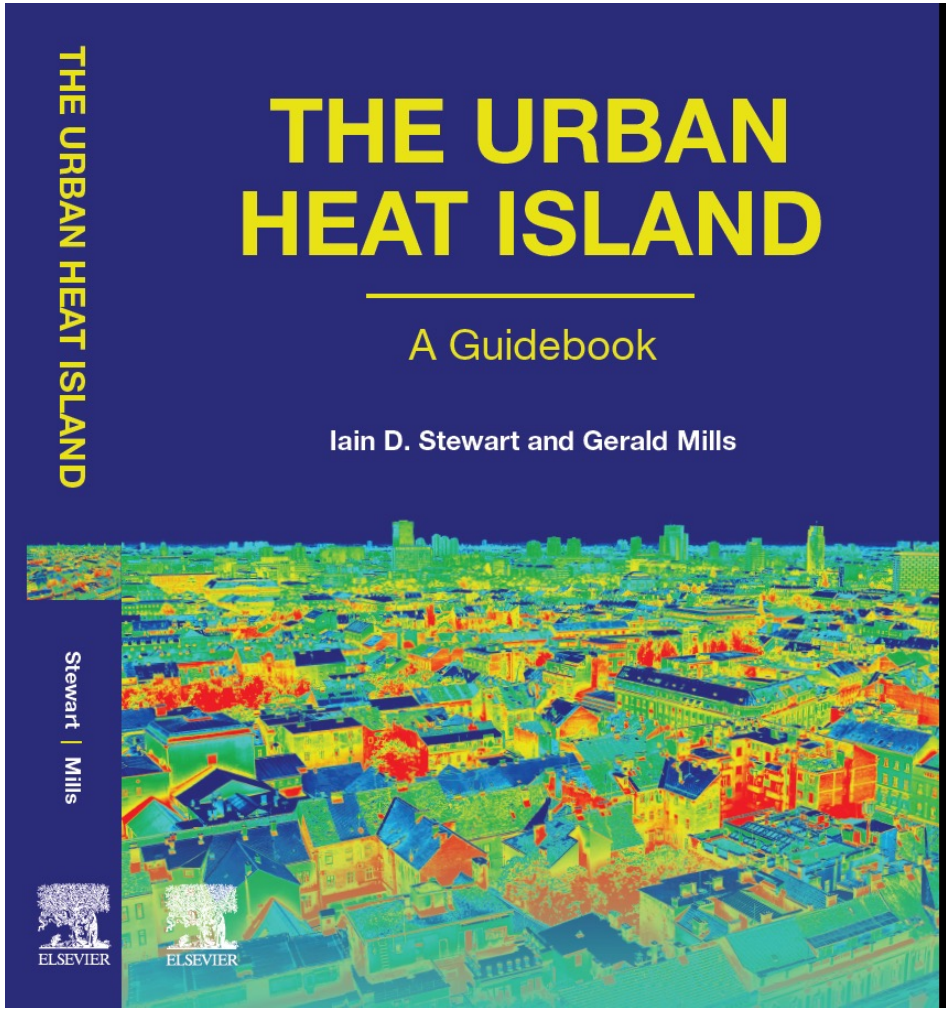
April 2022


Sanda Lenzholzer
Weather in the City
How Design Determines the Urban Climate
nai010 publishers


THE URBAN CLIMATIC MAP
A Methodology for Sustainable Urban Planning
Edited by
EDWARD NG AND CHAO REN

Resources


THE URBAN HEAT ISLAND
THE URBAN HEAT ISLAND
A Guidebook
Iain D. Stewart and Gerald Mills
Stewart | Mills
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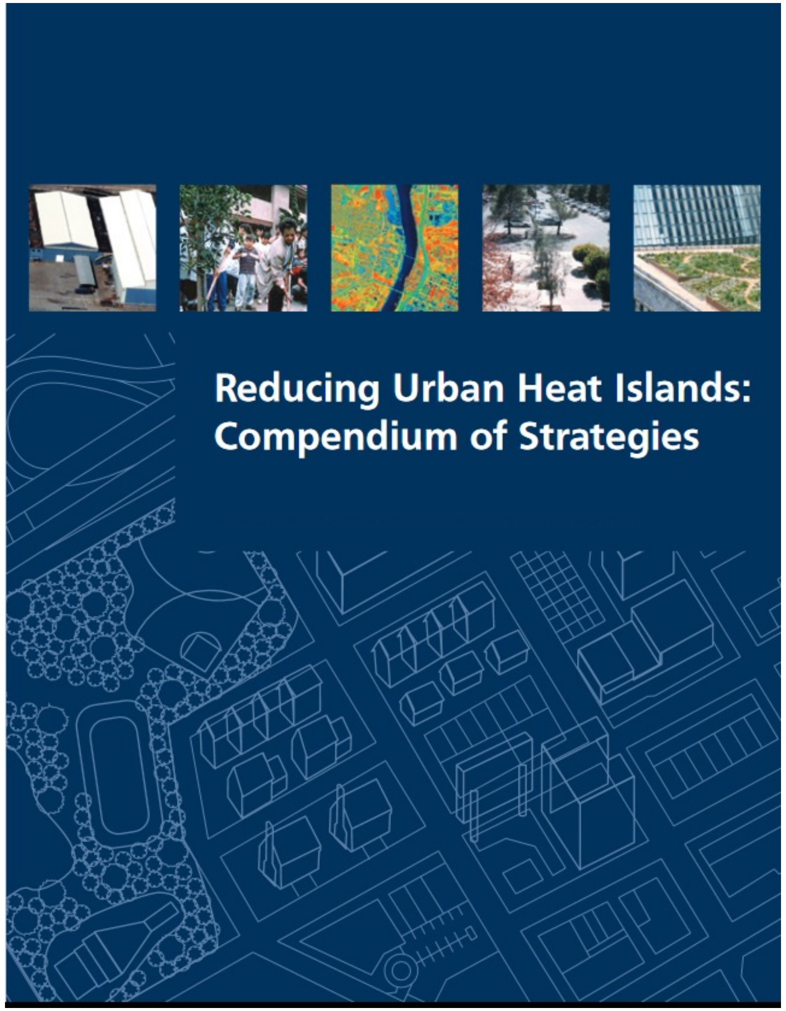
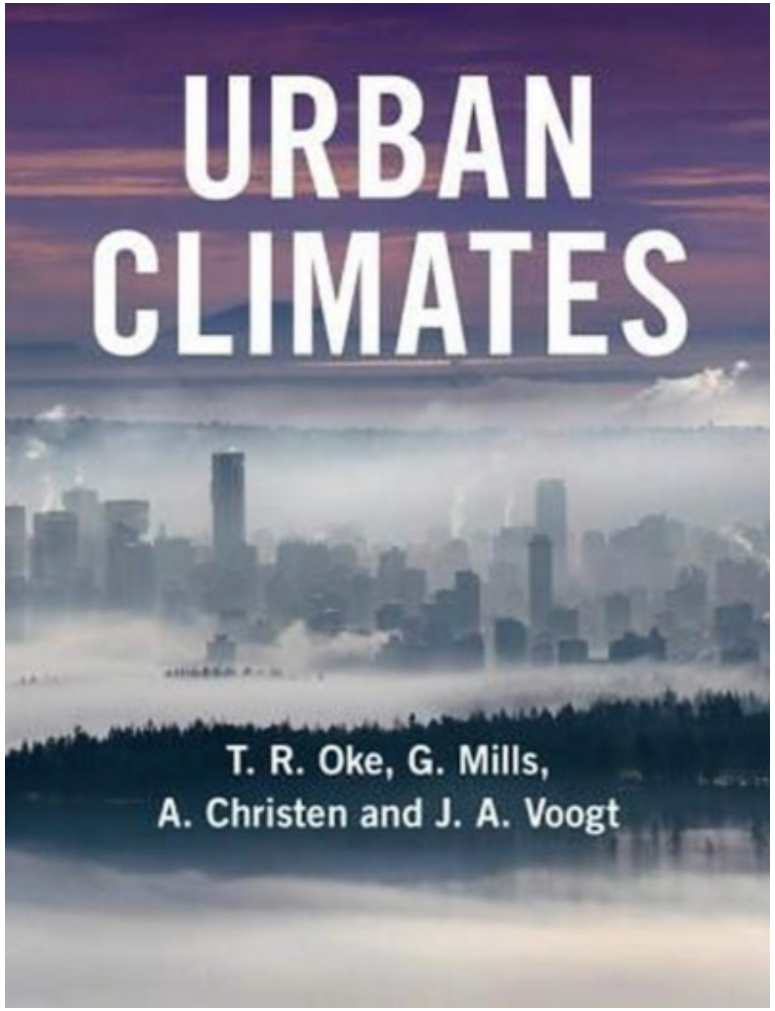
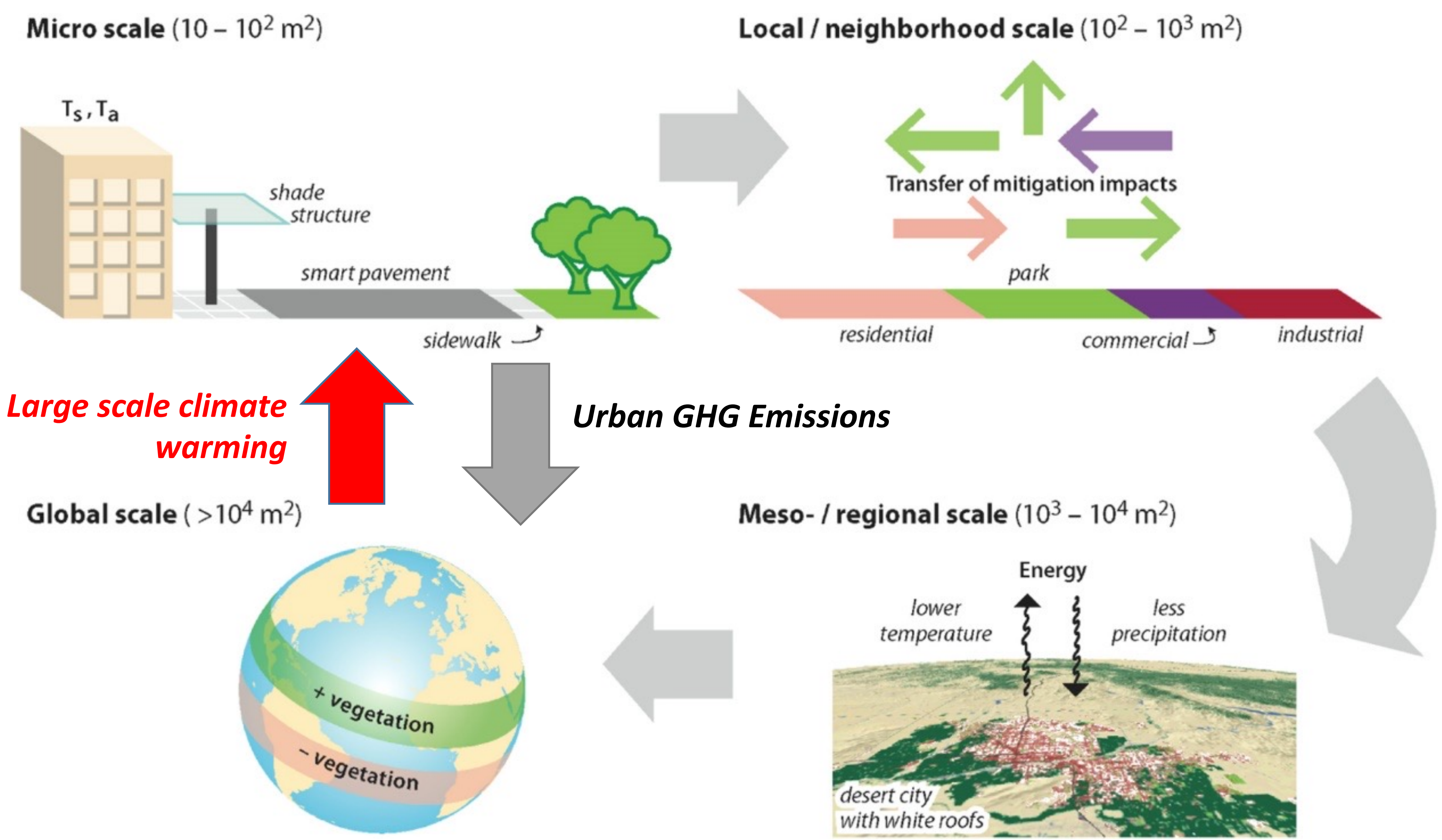

Reducing Urban Heat Islands:
Compendium of Strategies


URBAN
CLIMATES
T. R. Oke, G. Mills,
A. Christen and J. A. Voogt

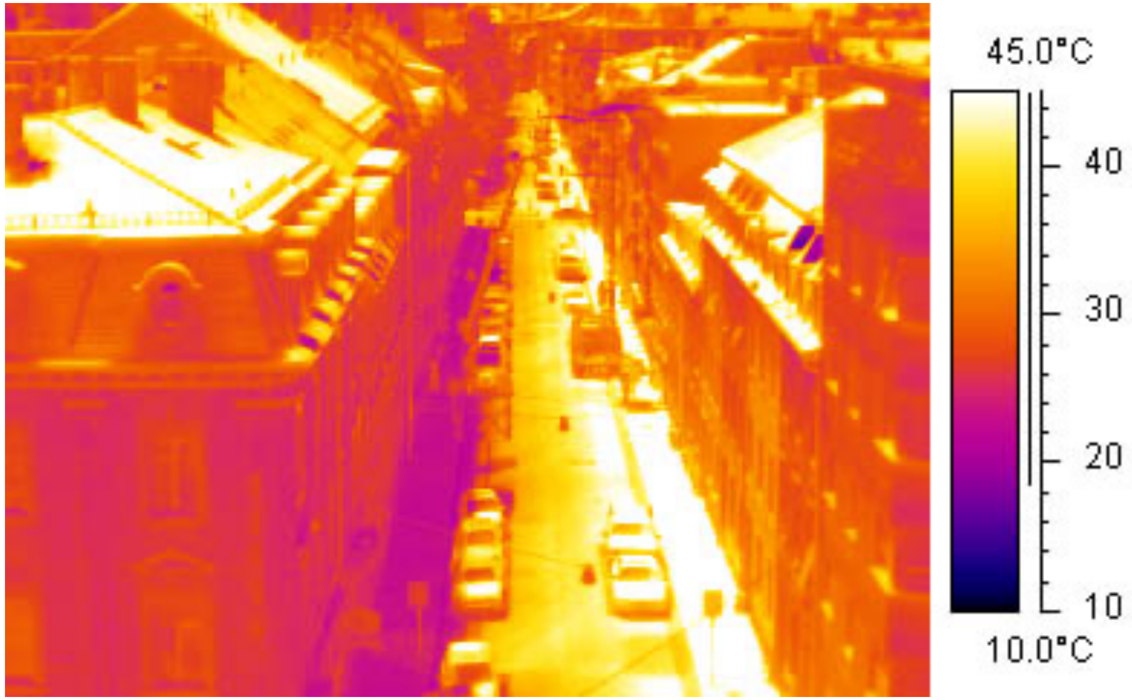
Extras

Scales of Urban Heat

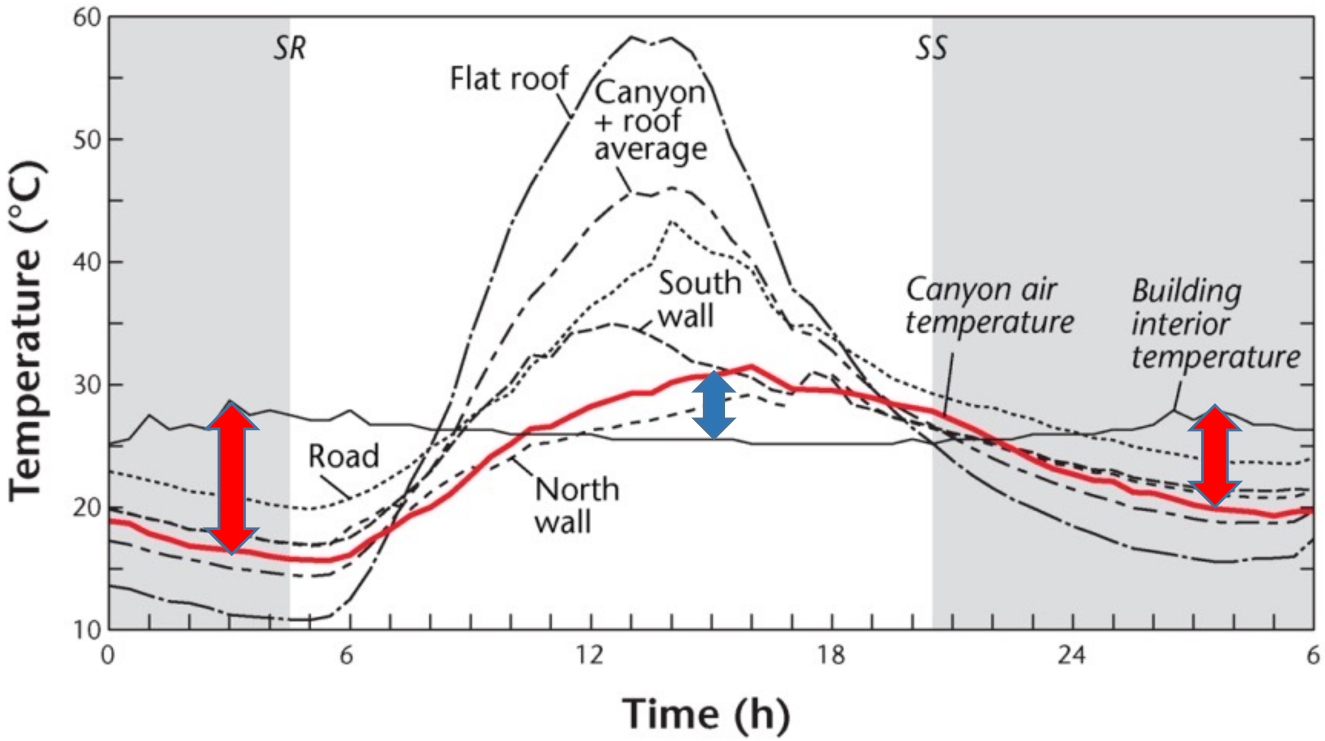


Modified from Georgescu et al. 2015

Microscale Variations and Outdoor vs Indoor Temperatures



Basel, Switzerland (J. Voogt)



Uncontrolled building interior warmer than outdoor T_{air}

Uncontrolled building interior cooler than outdoor T_{air}

Indoor conditions can be very different

Urban climates are a ‘boundary condition’

Oke et al. (2017)

Urban environments: strong spatio-temporal variations

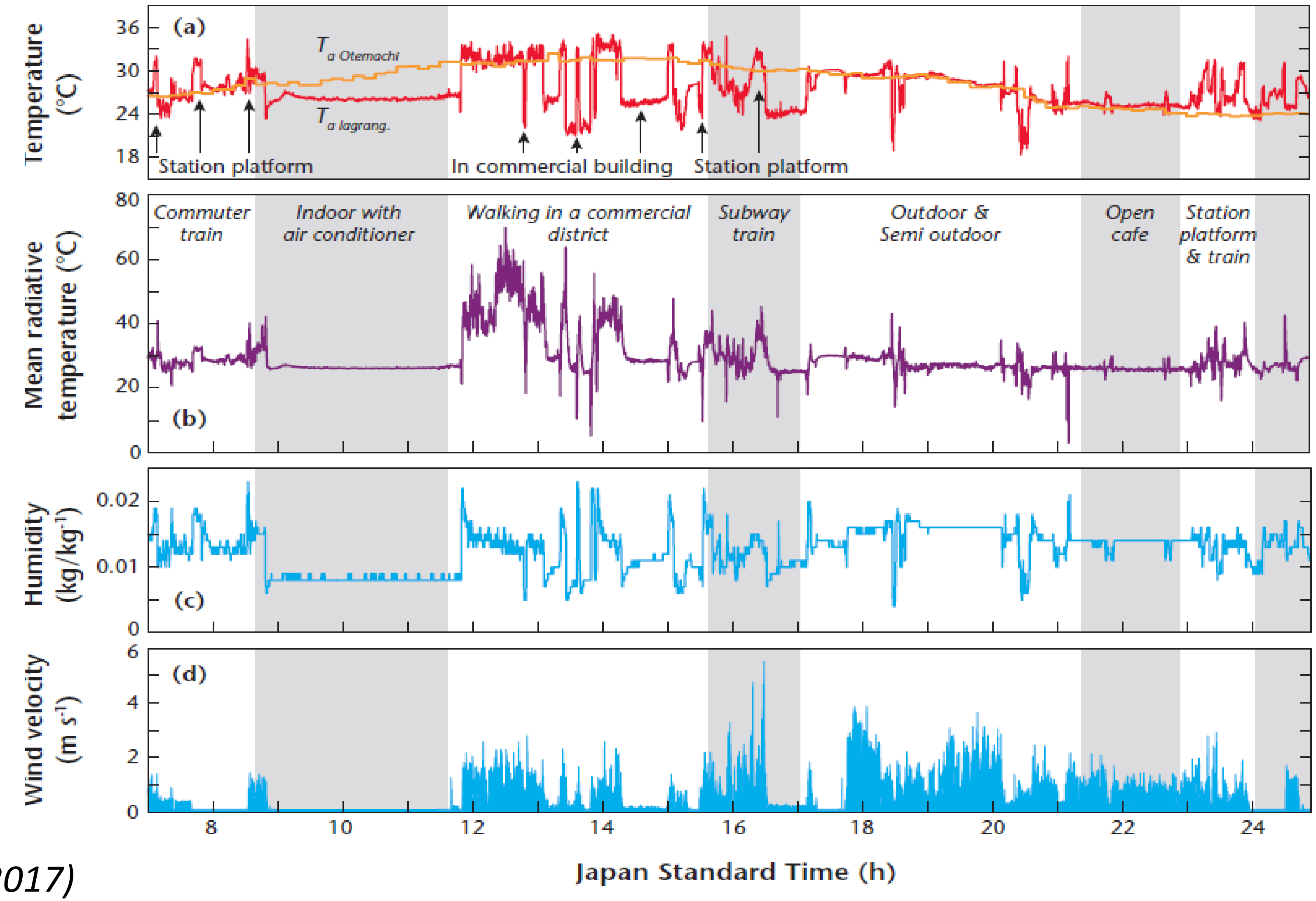
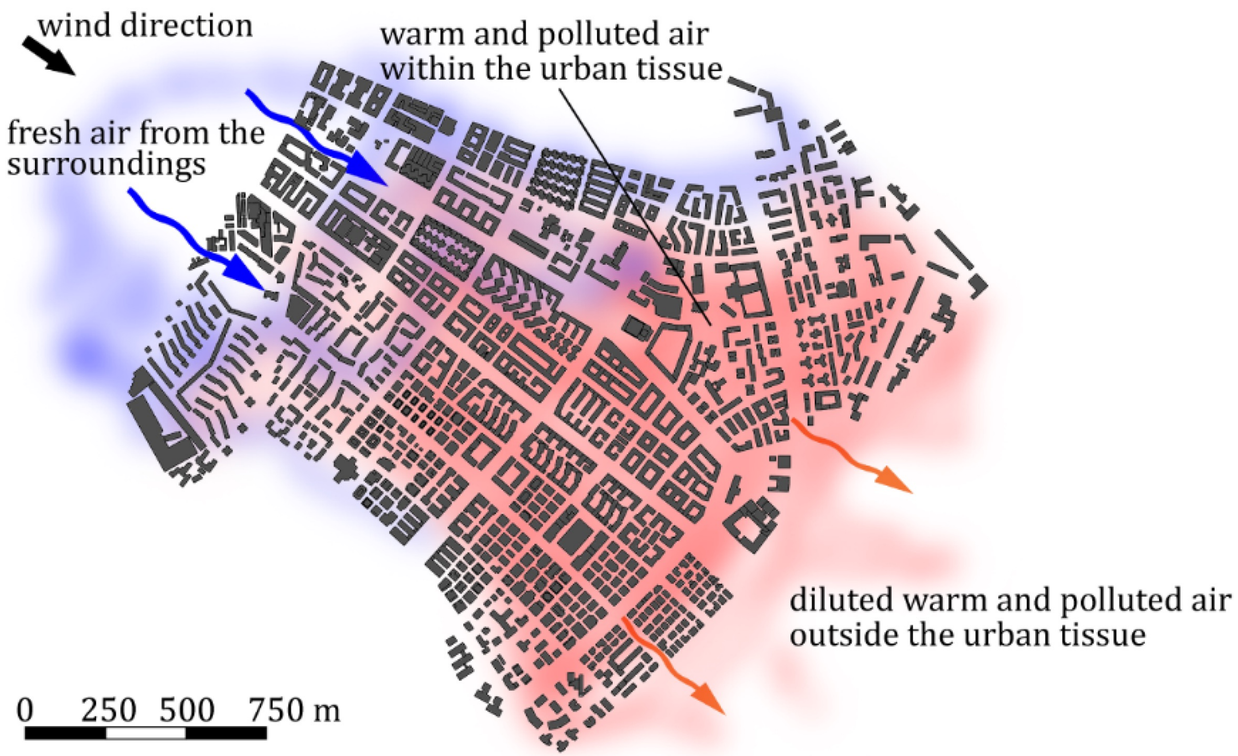
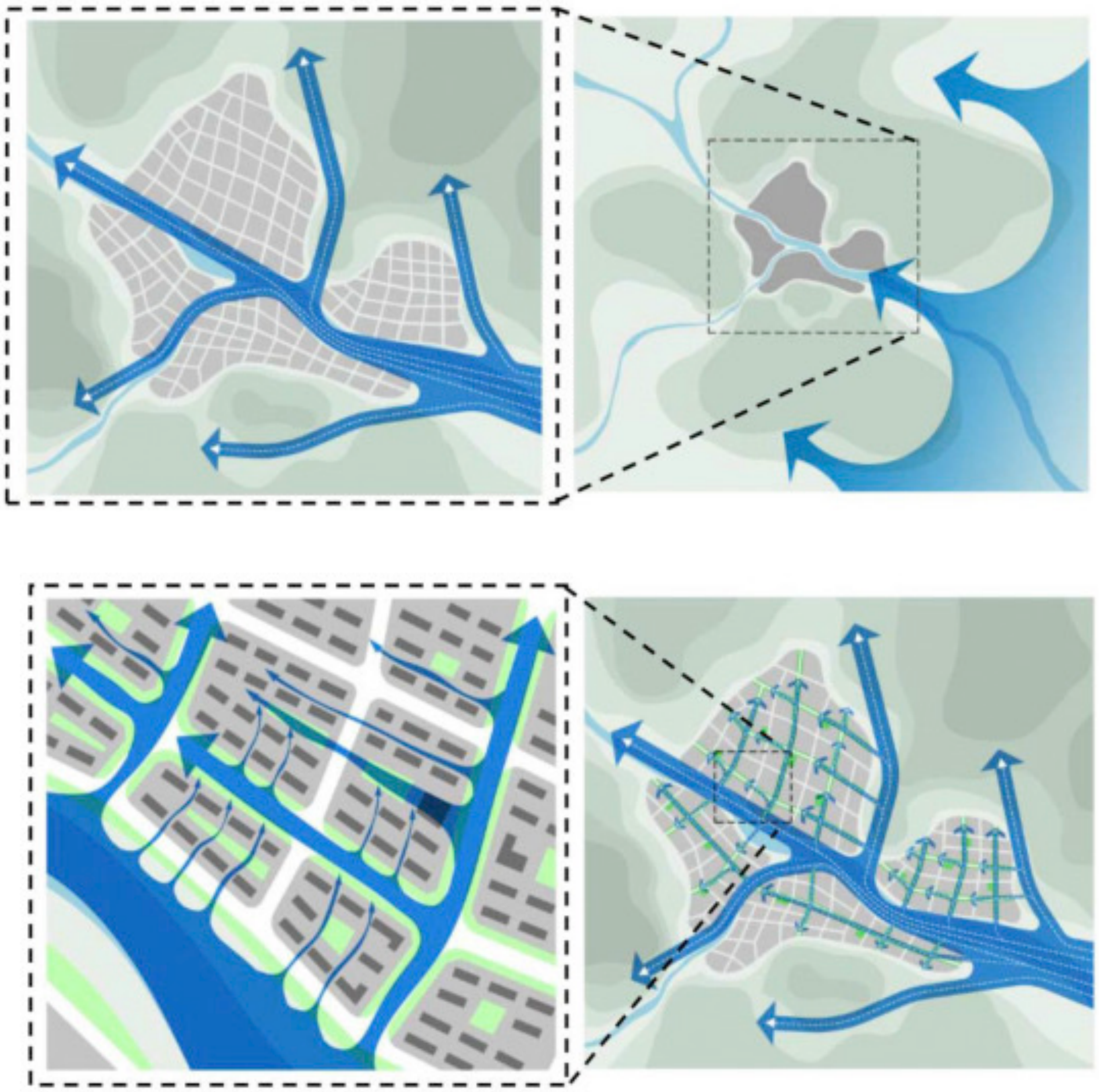


Photo and figure:
M. Nakayoshi (as shown in Oke et al. 2017)

Ventilation Corridors

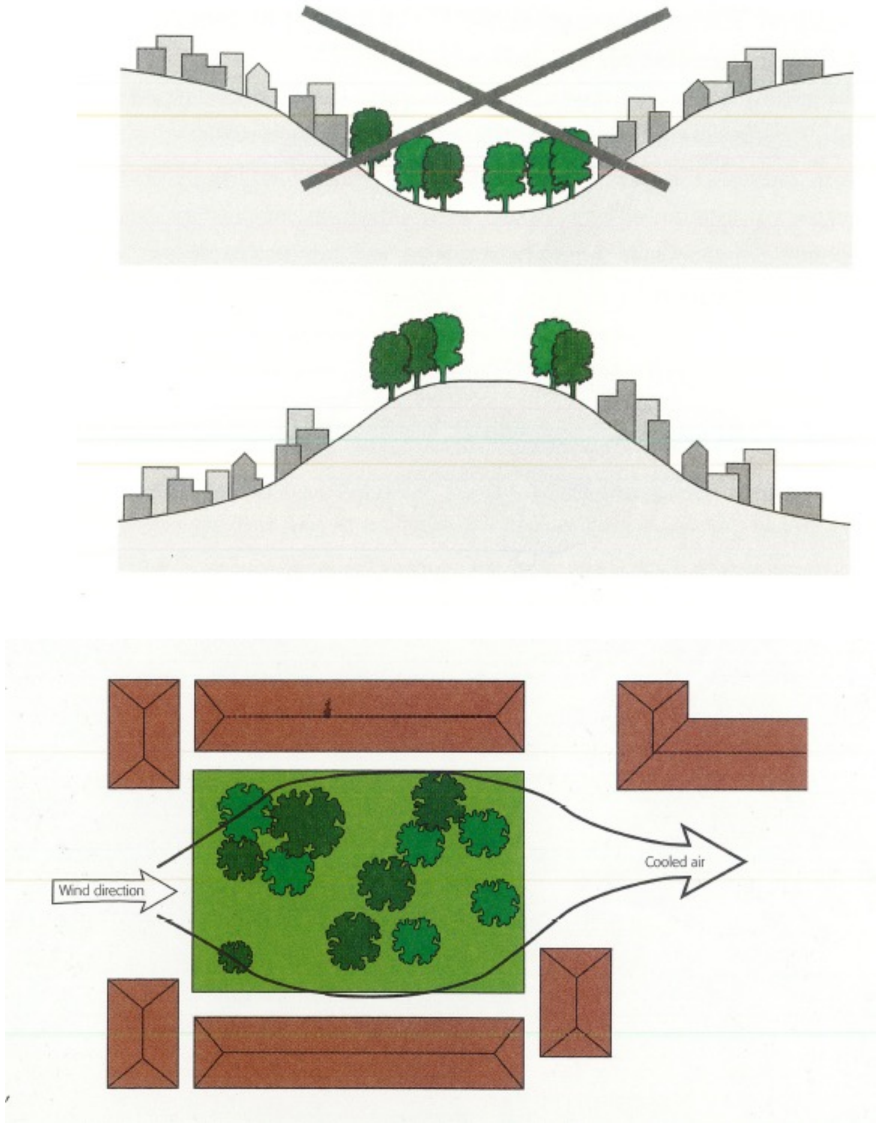


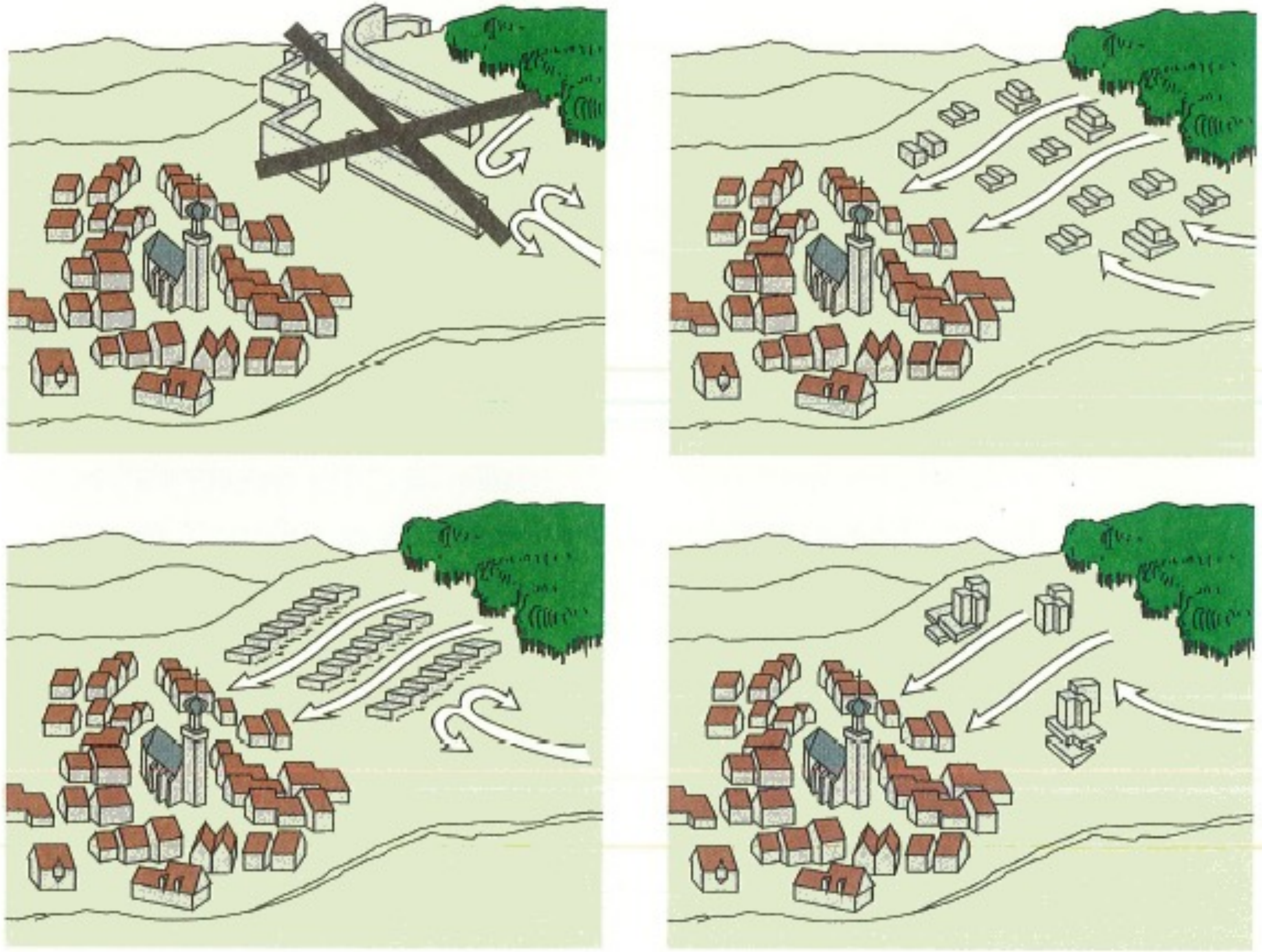
Palusci and Cecere (2022)



Ren et al. 2018

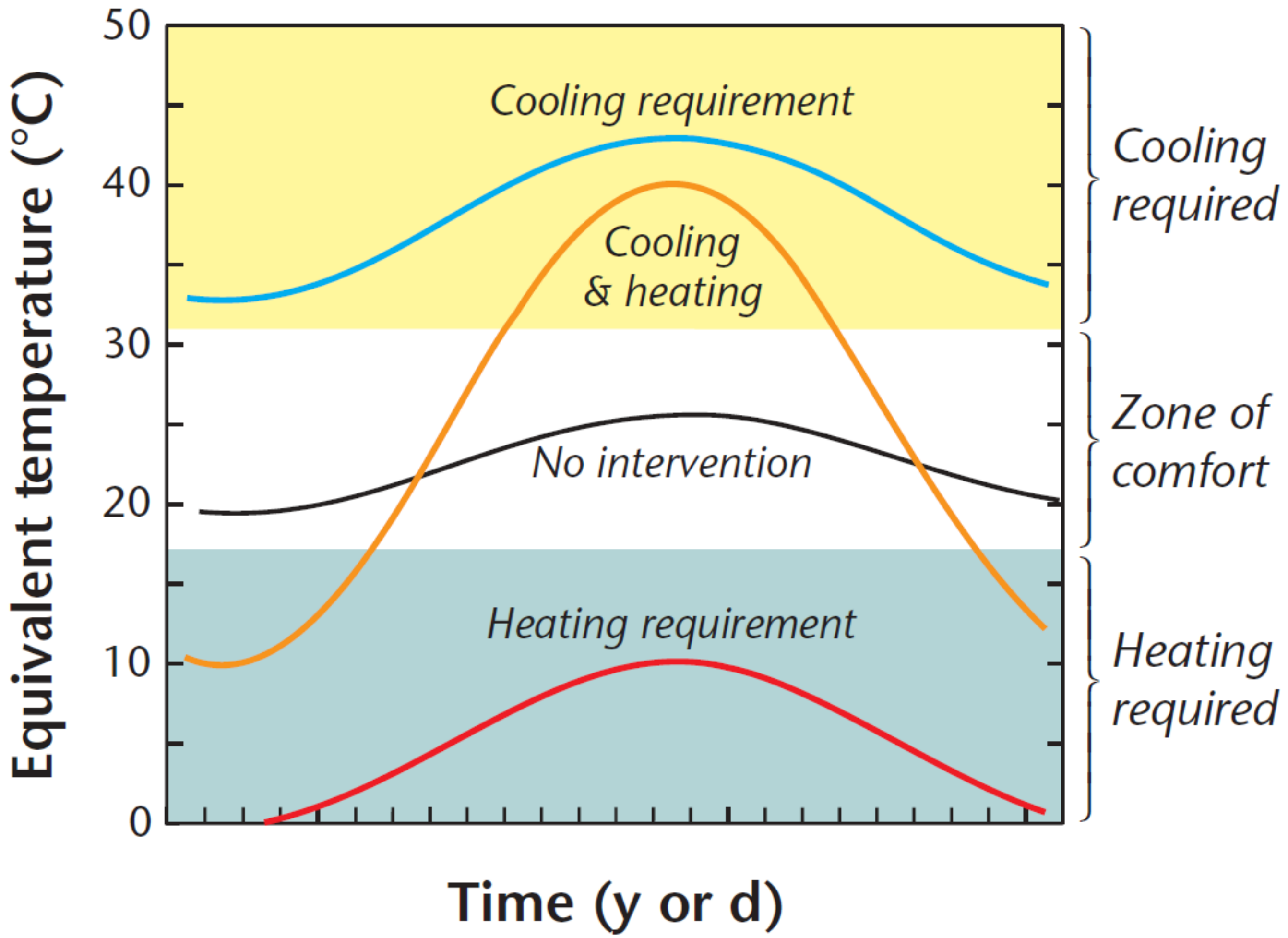
Integration of Vegetation Cooling into Urban Design





Lenzholzer (2015)

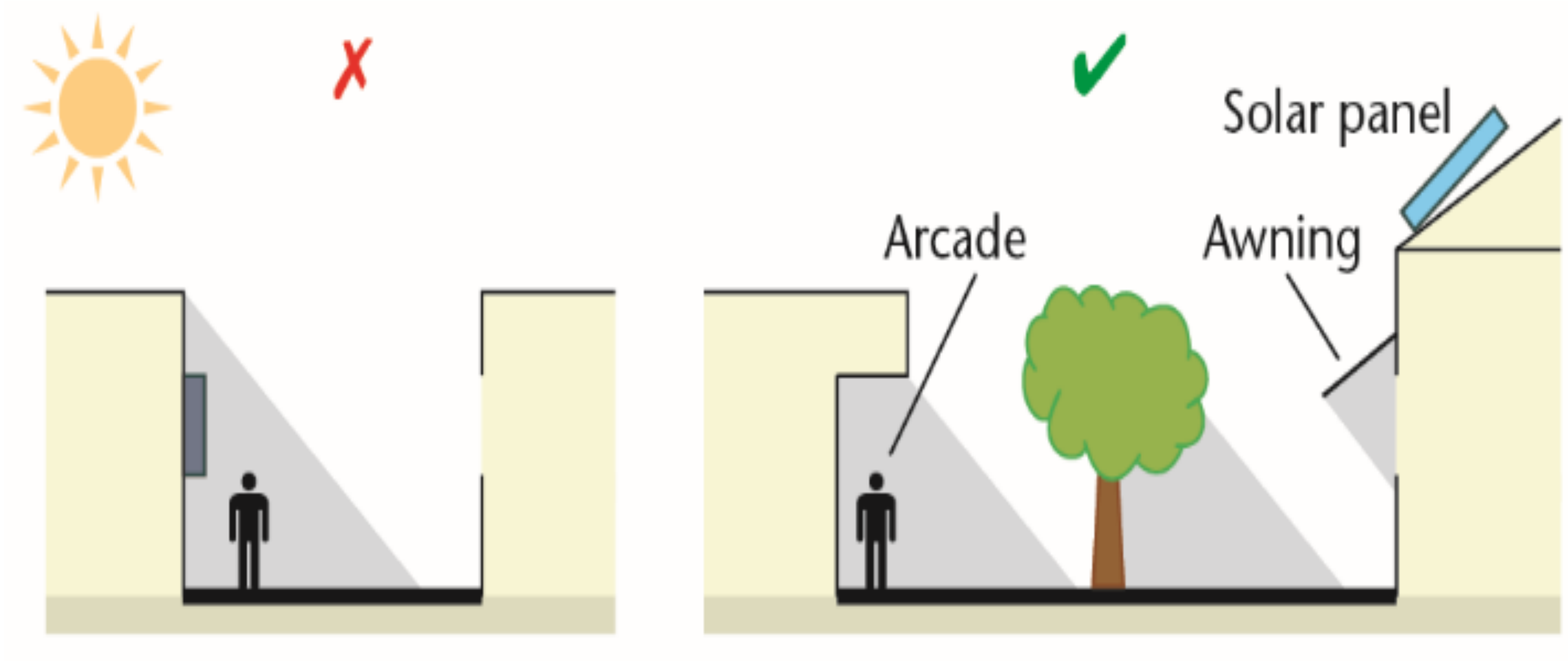
Design Interventions & Climate



- The tricky bit: consider annual variations in climate vs design needs

Source: Oke et al. (2017)

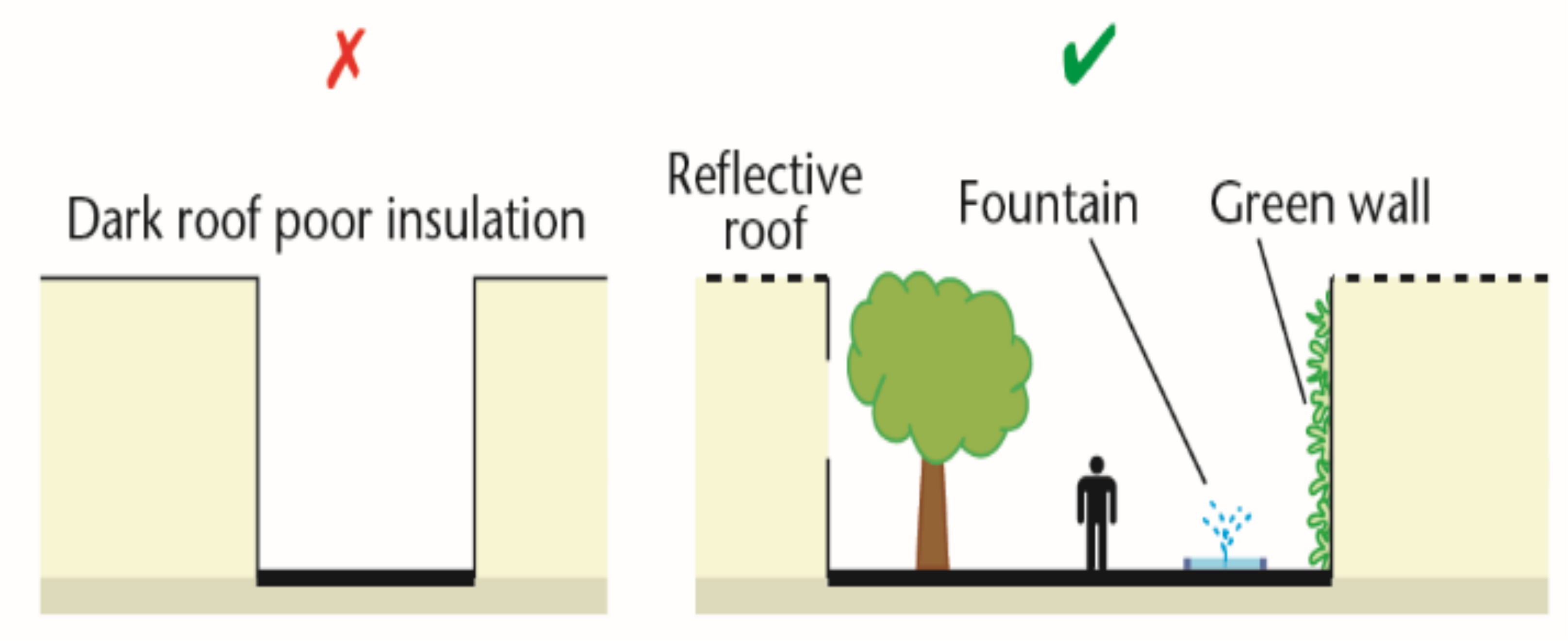
Solar Control



Source: Oke et al. (2017)

Temperature Control

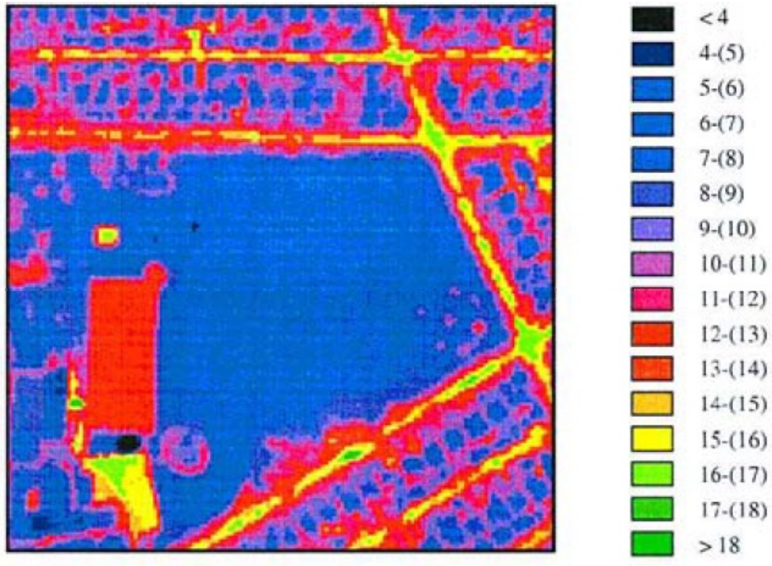
Roof albedo cooling effectiveness:
Summer, midday sunny conditions: ~ 0.6°C per 0.1 increase of neighbourhood albedo
Summer night: less than half of daytime cooling rate
Summer seasonal: half to 2/3 of the summer midday (Krayenhoff et al. 2021)



Source: Oke et al. (2017)

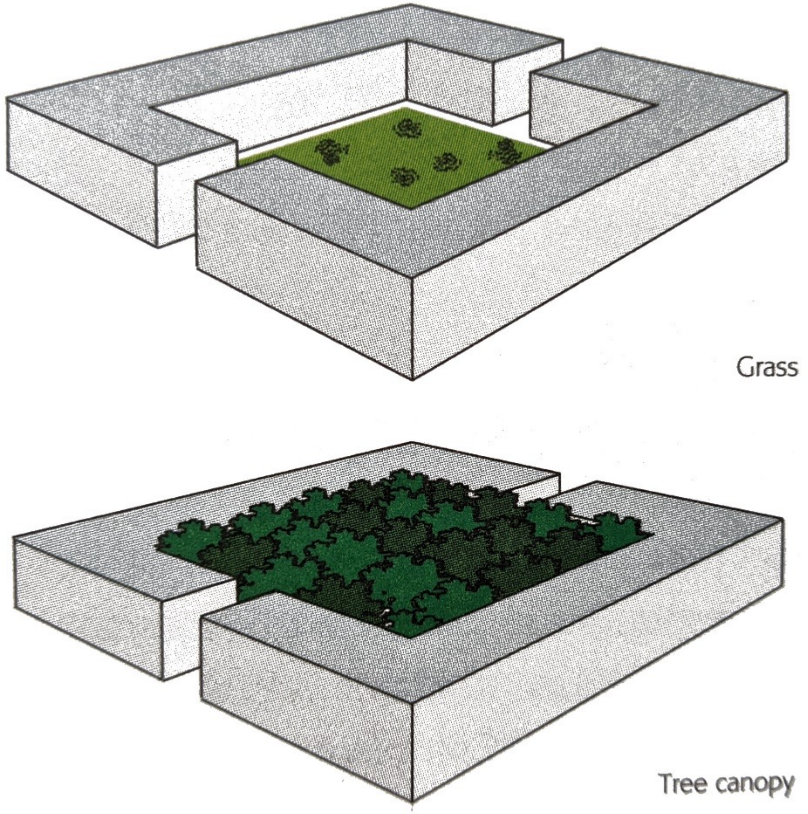
Vegetation and Parks

- More open parks – better night time cooling
- More tree canopy in parks – better day time cooling



Surface Temperature (°C)

Air Temperature (°C)



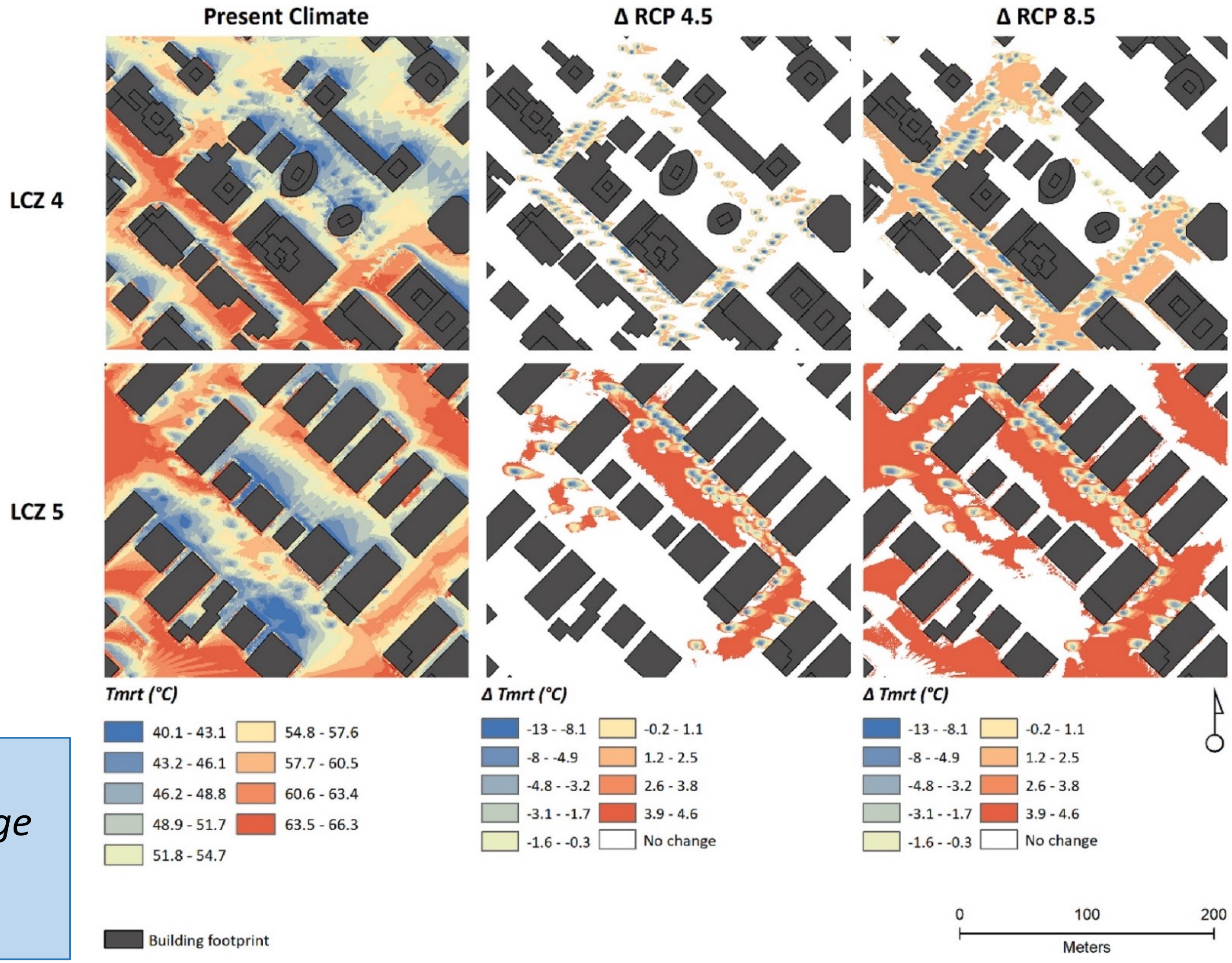
Spronken Smith and Oke (1998) – Trafalgar Park, Vancouver – 11 pm

Lenzholzer (2015)

Urban climate (re)design for Canadian Communities

Heat events in Canadian cities, e.g. Vancouver 2009, have prompted new work on heat risks, adaptation and policy in cities.

High-resolution modeling tools provide capability for adaptation through urban design at the neighbourhood scale.



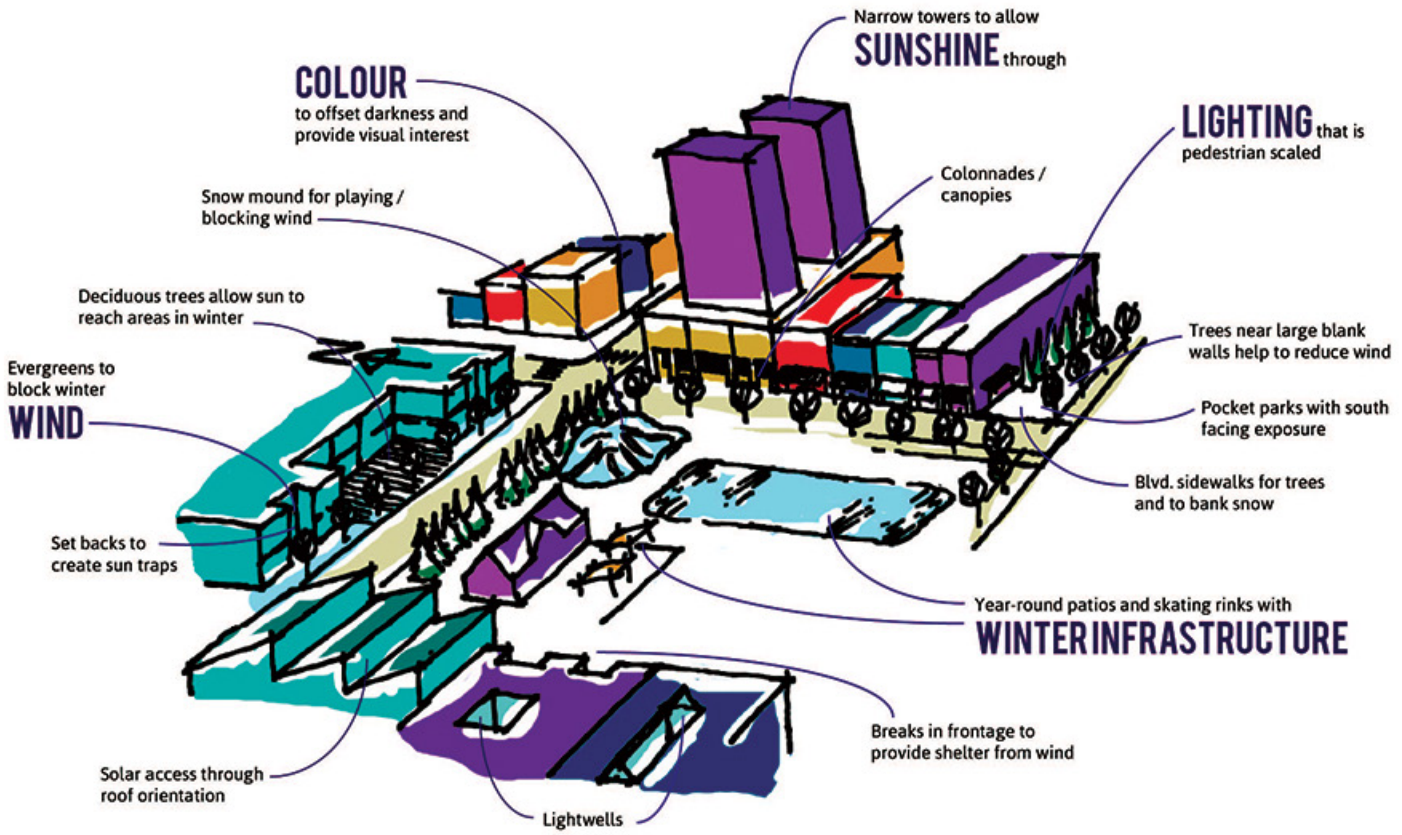
Tmrt (Mean Radiative Temperature) and its change for future climates in a Vancouver neighbourhood

Aminipouri et al. (2019)

Urban climate (re)design for Canadian Communities

- Canadian urban climate design-guidelines should accommodate both warm and cool seasons, aiming to provide a diversity of microclimates to protect citizens from extreme heat and cold year-round

- The *Winter Design Guidelines* for the City of Edmonton (2016) are exemplary of this all-season approach to urban-climate adaptation in Canada.



https://www.edmonton.ca/city_government/initiatives_innovation/winter-design-guidelines.aspx