Participatory LAB - Laboratory of Spatial, Urban and Environmental Participatory Planning for Climate Change Adaptation

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Practical session

Understanding Urban Heat Island: modeling, assessing and adapting

Carmela Apreda

REgional Models and geo-Hydrological Impacts (REMHI) Division, CMCC Foundation

commonspace

PARTICIPATORY LAB

cmcc Centro Euro-Mediterraneo sui Cambiamenti Climatici

Overview

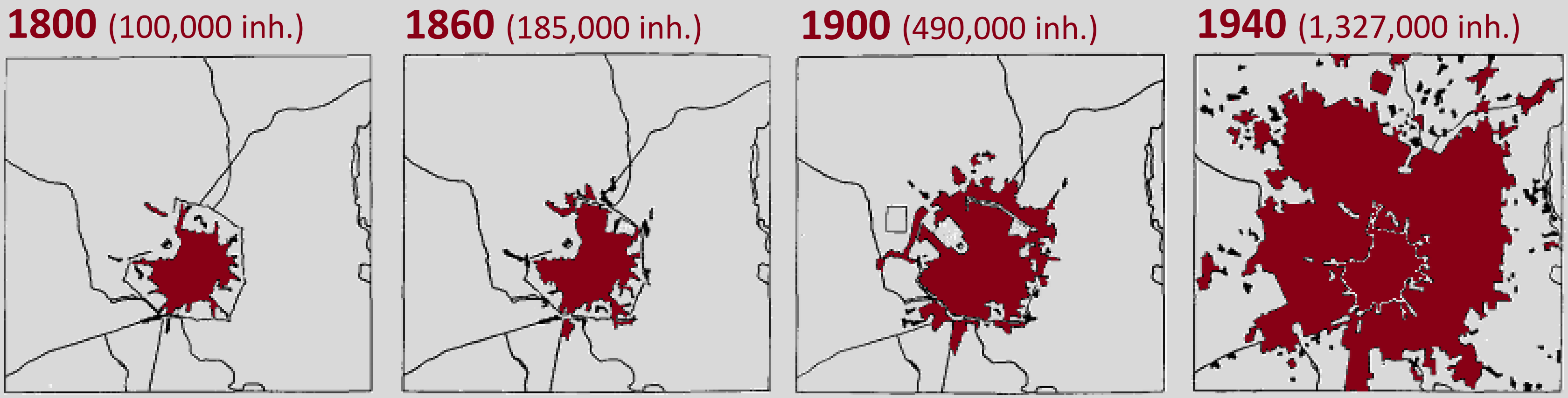
1. **Urban climate fundamentals and concepts**
   + Satellite analysis of SUHI intensity
2. **Methods and modelling approaches**
   + Measurements with thermal imaging camera
   + Microclimate modelling with ENVI-met
3. **Application of climatology in urban planning and design: Climate-sensitive urban design**
4. **Outdoor thermal comfort: metrics and indices**
   + Microclimate analysis

Q&A

Background: urban population growth

In the last centuries, the global population growth and the increasing process of urbanization have led to a strong modification of the land use.

Milan (Italy)



(modified after Bacci & Maugeri, 1992)

This transformation may cause a huge impact on the climate at the urban scale returning a significant variation of the temperature and air humidity, as well as profile and structure of the wind circulation patterns compared to those expected in non-urban areas.

Background: impacts of climate change in urban context

The impacts of climate changes are expected to be different according to geographical areas, local features and socio-economic conditions affecting in more significant way the poorest countries and needier sections of the population.

At present, cities are experiencing a significant alteration in climate patterns compared to their surroundings. Such an alteration is returning an increment in:

- **warming**
- **poor air quality**
- **extreme weather and climate events such as heat waves, floods, droughts, storms**

These impacts are exacerbated by the urban geometries/features and high exposure!

Urban climate fundamentals and concepts

Heat wave

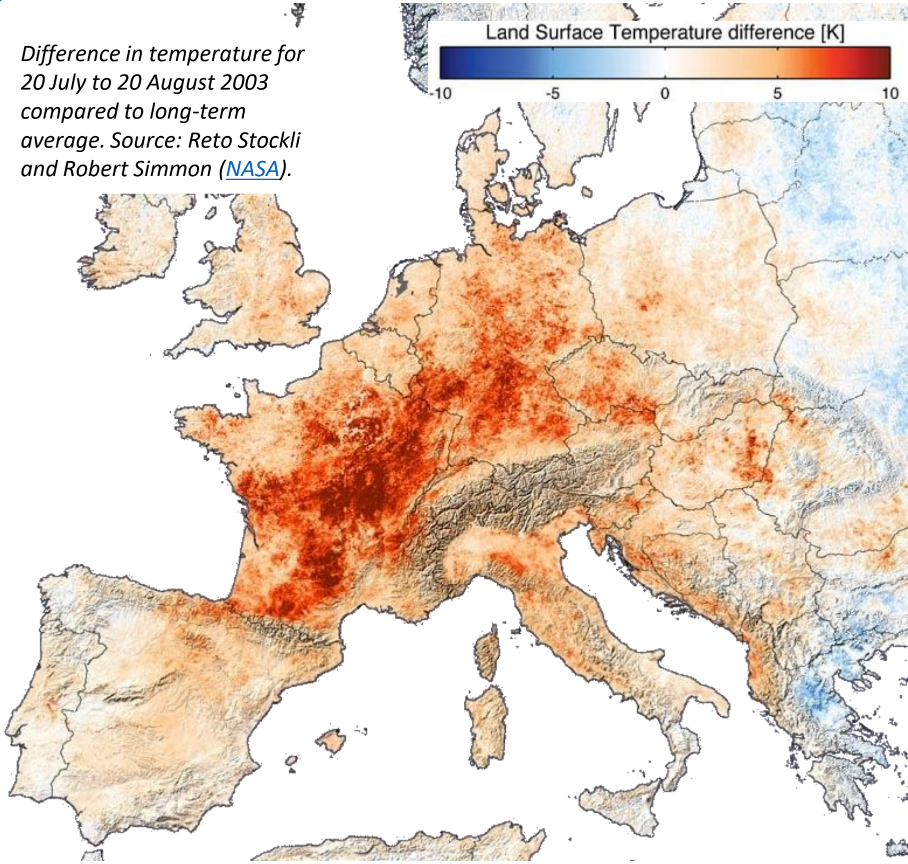
There is no universal definition for a heat wave as it is relative to a specific area and to a certain time of year!

Heat wave is defined as summertime weather that is substantially **hotter** and/or **more humid** than average for a location at that time of year.

US EPA, 2006

A marked unusual **hot weather** over a region persisting at **least two consecutive days** during the hot period of the year based on **local climatological** conditions, with thermal conditions recorded above given thresholds.

WMO, 2015



Difference in temperature for 20 July to 20 August 2003 compared to long-term average. Source: Reto Stockli and Robert Simmon (NASA).

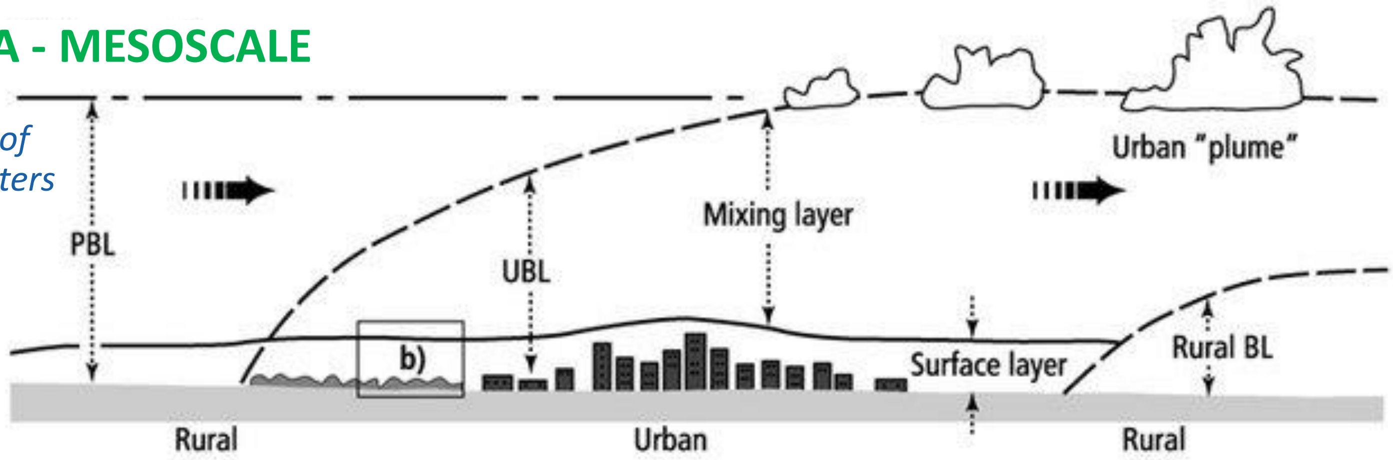
During the summer of 2003, in Europe, heat wave claimed about **70,000** lives with overall losses evaluated at **13,800** US$M (MunichRe data)

Urban climate fundamentals and concepts

The scales of climatic studies

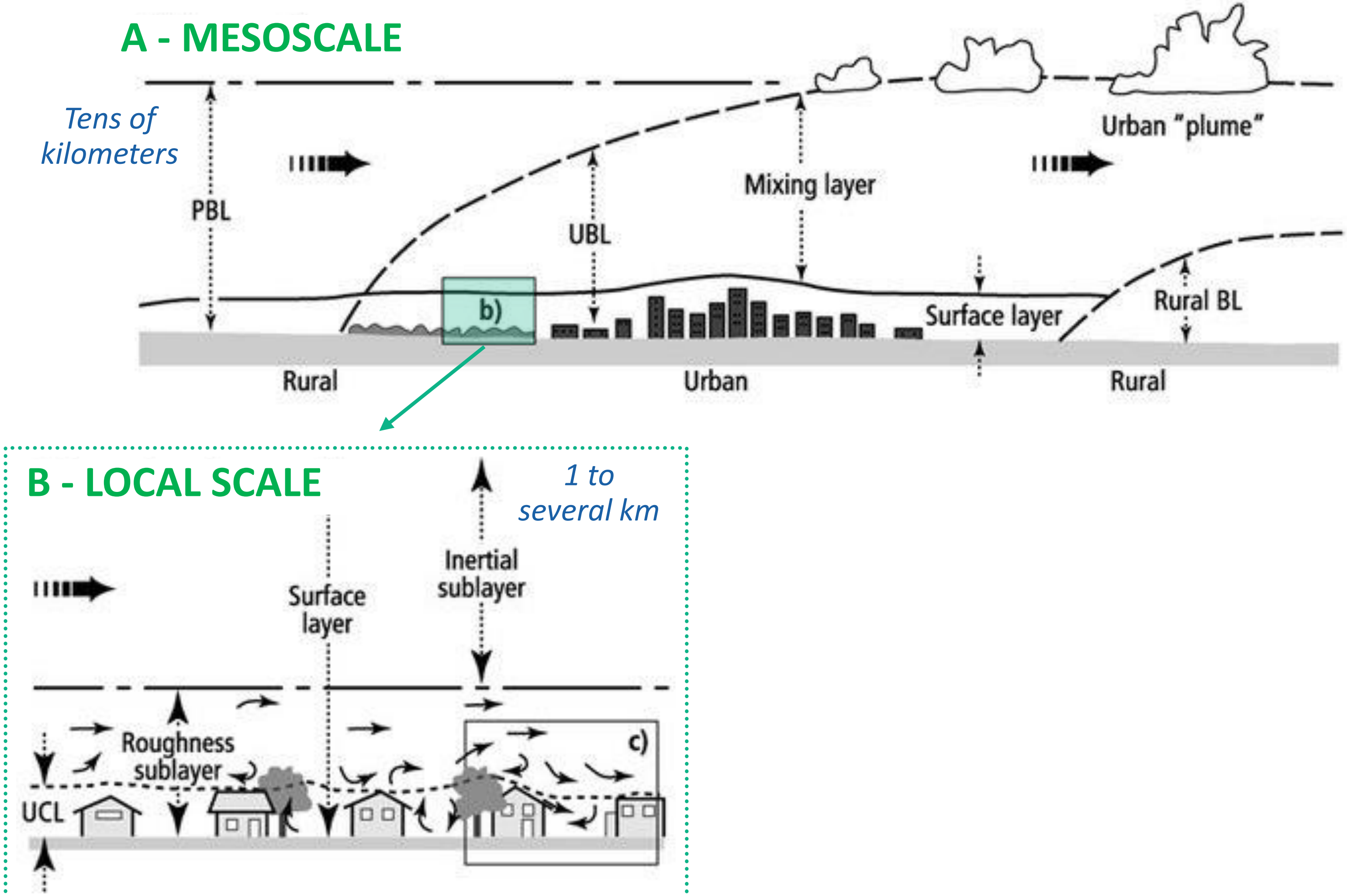
A - MESOSCALE

Tens of kilometers



Oke, T., 2006. *Initial guidance to obtain a representative meteorological observation at urban sites.* Instruments and observing methods, REPORT no. 81, World Meteorological Association.

The scales of climatic studies



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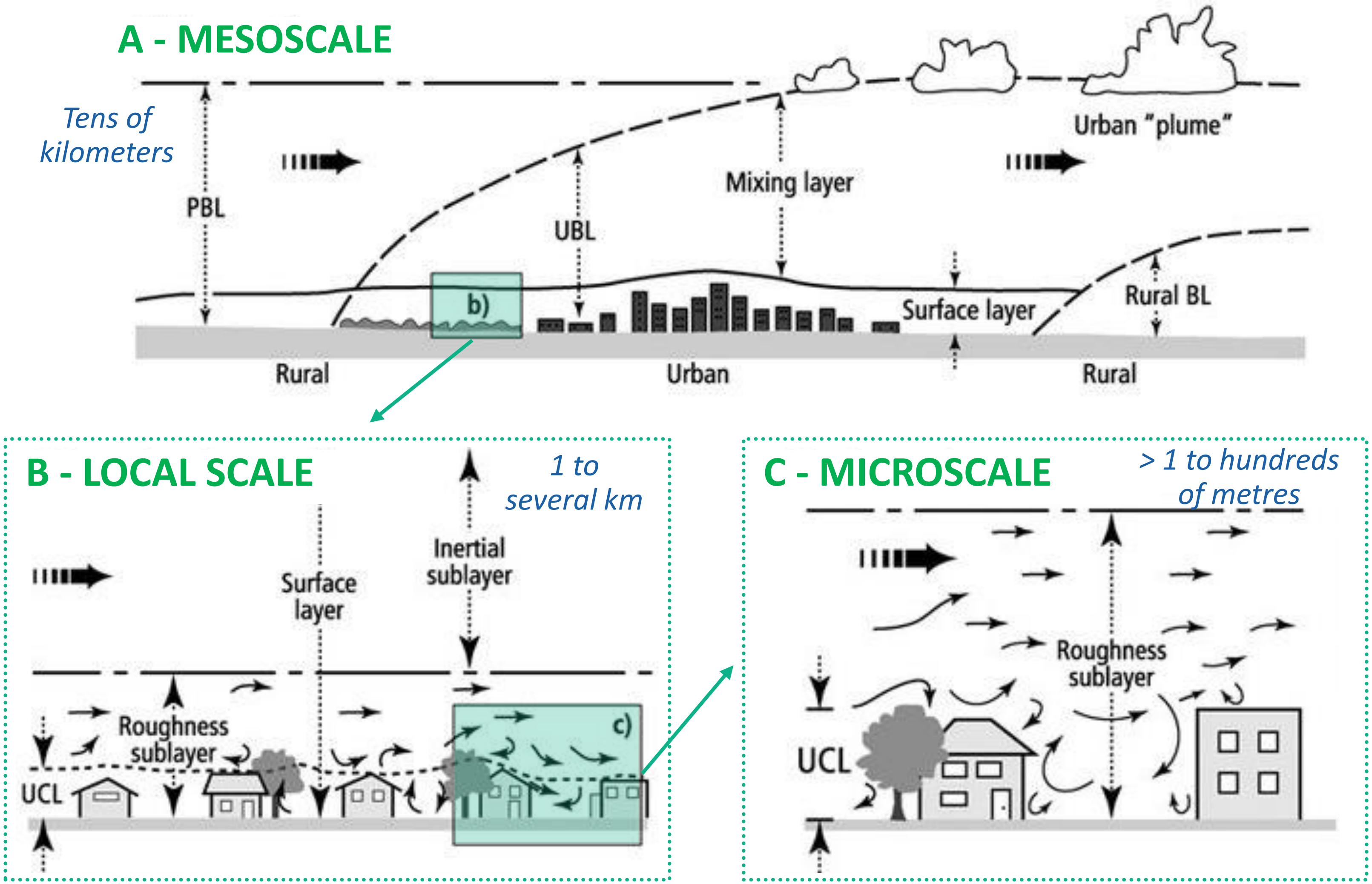
The scales of climatic studies



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What is Urban Climate?

Any set of **climatic conditions that prevails in a large metropolitan area and that differs from the climate of its rural surroundings**.

Urban climates are distinguished from those of less built-up areas by differences of air temperature, humidity, wind speed and direction, and amount of precipitation. These differences are attributable in large part to the altering of the natural terrain through the **construction of artificial structures and surfaces**. For example, tall buildings, paved streets, and parking lots affect wind flow, precipitation runoff, and the energy balance of a locale (Britannica, 1998).

Local climate that differs from its surrounding climate due to effects of buildings and emissions. This relates to both, the meteorological parameters of air temperature, air humidity, radiation and wind as well as to emission factors, such as air quality and noise (WMO, https://bit.ly/3l4kiYJ).

Urban climate fundamentals and concepts

Urban Climate

Climate variables

- Radiation
- Temperature
- Pressure
- Wind
- Humidity
- …

Urban features

- **Urban fabric** (geometry, orientation, heat storage ability, albedo, etc.)
- **Urban land cover** (imperviousness, lack of greenery)
- **Urban metabolism** (anthropogenic heat emissions, pollutants)

Changes in "natural" surface energy and humidity budget. Values of wind, temperature, humidity in urban areas differ from surrounding values.

What is an Urban Heat Island (UHI)?

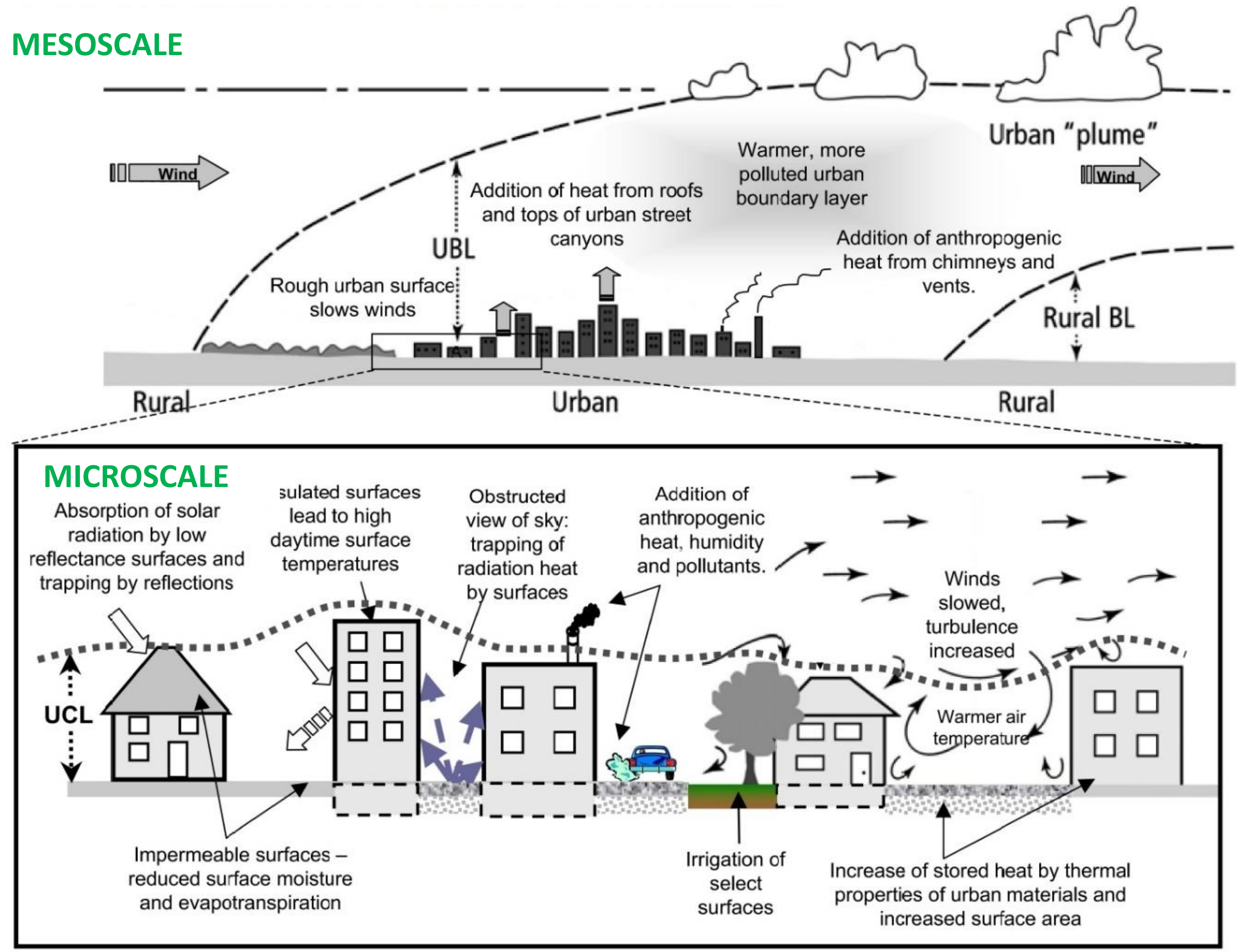
Urban Heat Islands (UHI) is a phenomenon of **higher temperatures in urban areas than in their surroundings**. Its intensity is usually defined as urban-rural difference in 2m-height air temperature ($UHII^{2m}$) or in radiative surface temperature ($UHII^{s}$) (Zhao et al., 2018)

http://www.extension.org/pages/66920/urban-heat-island#.VcC8WfntlBc

Analogy: as a '**warm island**' in a '**cool sea**' of the surrounding natural environment

Met Office, 2012

Why Urban Heat Island (UHI)? What are the UHI processes?

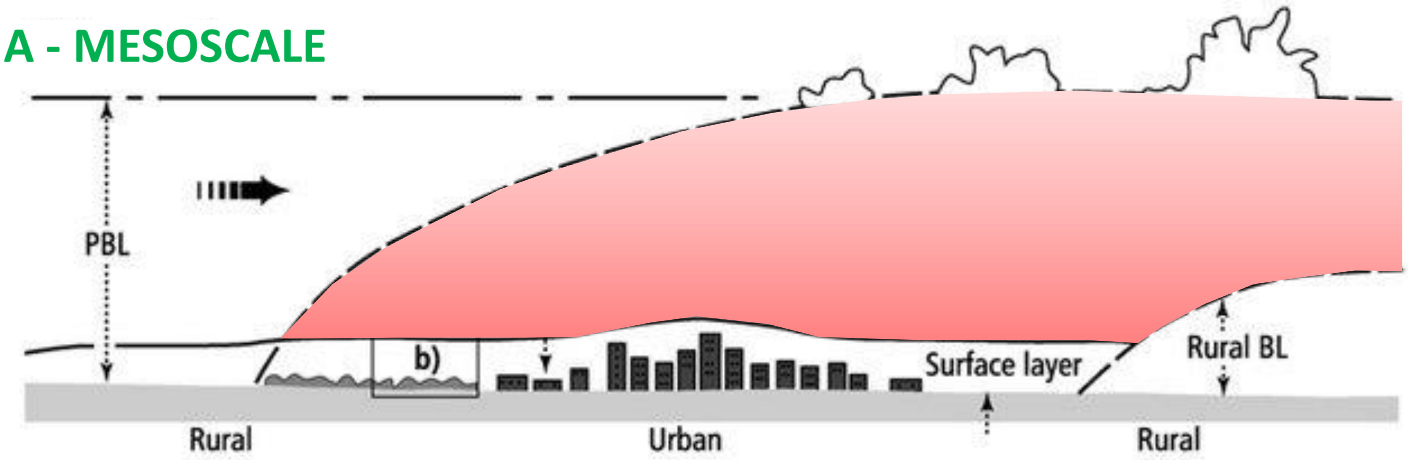


Voogt, J.A., 2006. *How researchers measure Urban Heat Islands*. https://bit.ly/3l6a4qJ. Accessed 9 September 2021.

Types of UHI

BOUNDARY LAYER HEAT ISLAND - BLUHI

A - MESOSCALE



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Types of UHI

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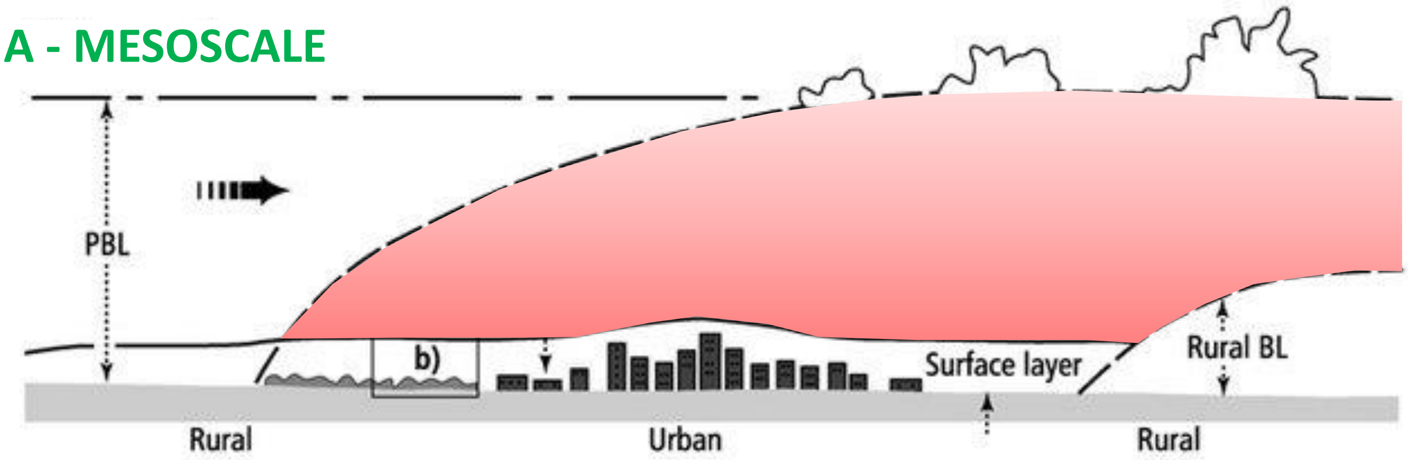
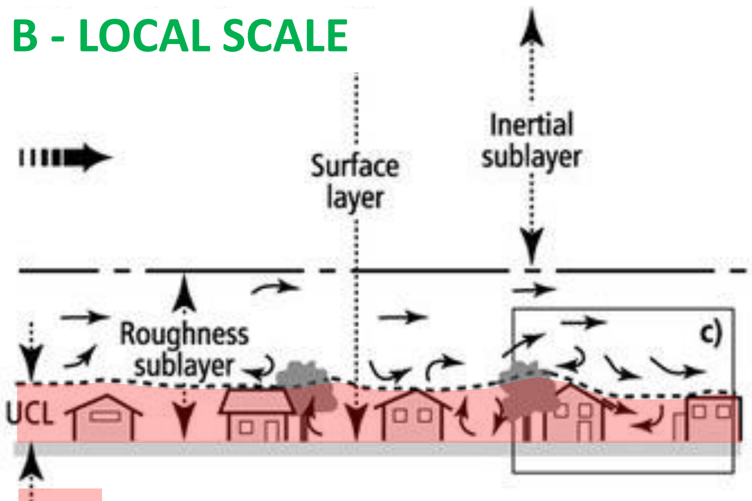


B - LOCAL SCALE

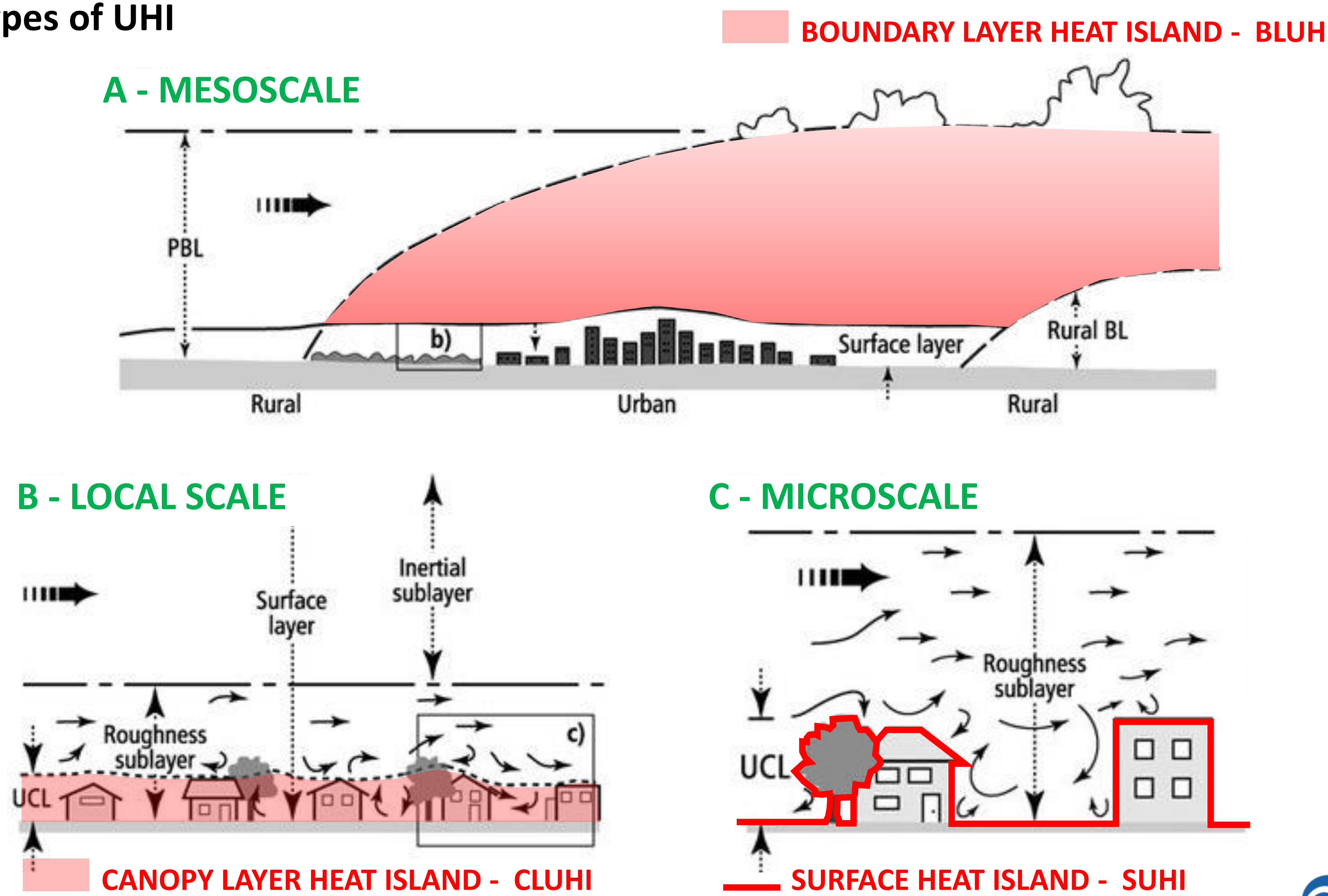


CANOPY LAYER HEAT ISLAND - CLUHI

Oke, T., 2006. *Initial guidance to obtain a representative meteorological observation at urban sites.* Instruments and observing methods, REPORT no. 81, World Meteorological Association.

Urban climate fundamentals and concepts

Types of UHI



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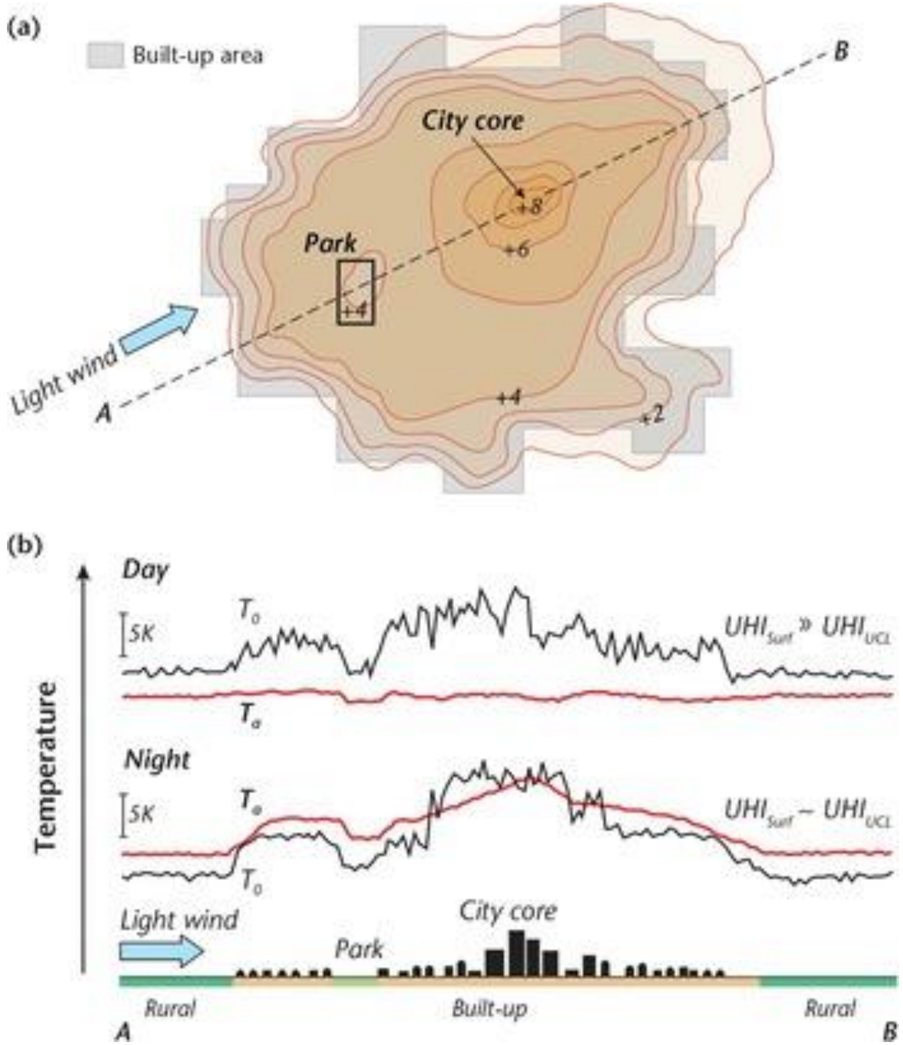
Urban climate fundamentals and concepts

Typical UHI – Difference between CLHUI and SUHI

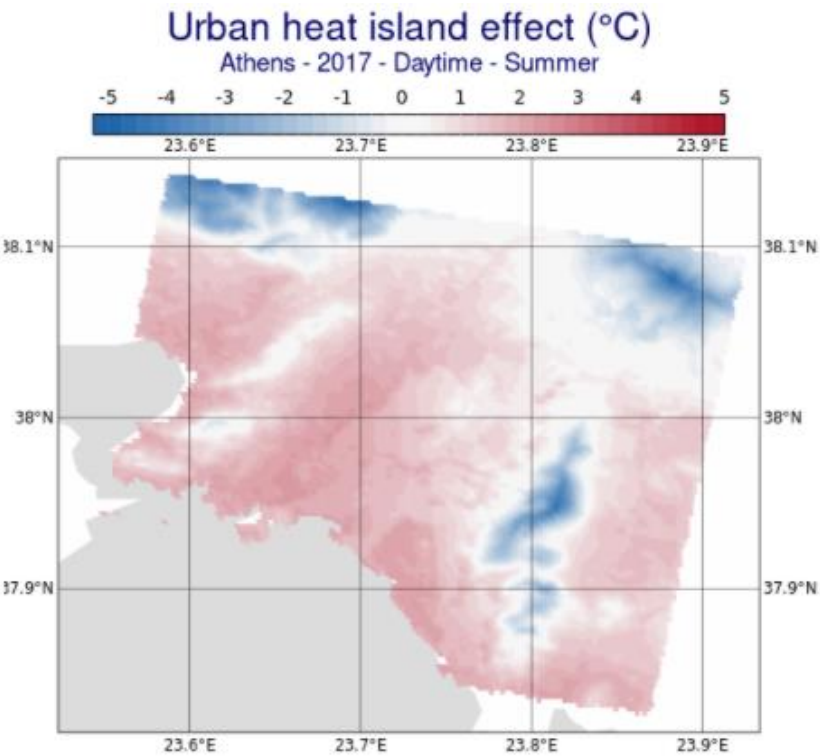


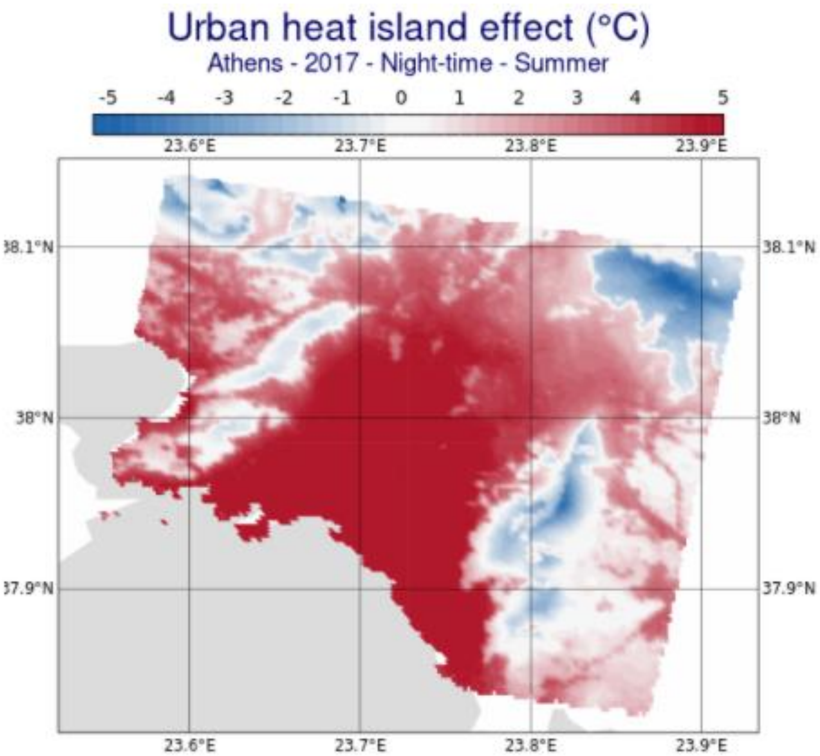
- Greater variability in surface temperature (T_0) compared to air temperature (T_a) in response to large variability in surface properties (especially during daytime).
- During daytime T_0 of all surface facets > T_a in UCL, except water bodies or wet surfaces; at night T_0 of roofs < T_a in UCL (e.g. industrial area)
- SUHI represents an immediate temperature response at the scale of facets to inputs and outputs of energy
- CL-UHI response is slower blending contributions of nearby surfaces + anthropogenic heat within the UCL + advected contributions from the neighbourhood

Oke et al., 2017

Urban climate fundamentals and concepts

UHI intensity in Athens (summer 2017)





C3S, Urban heat island intensity for European cities from 2008 to 2017 derived from reanalysis, https://bit.ly/2Z9lbI5.

UHI and climate change: complexities and challenges

- **Downscaling Regional Climate Models** (RCMs) can provide useful information to understand the microclimate at the urban level

↓↓↓↓↓

Obtaining **reliable and representative information of urban microclimate** and differences with its surroundings

- Developing a **detailed and representative 3D city model**, which include all relevant urban features, such as geometry, vegetation and surface materials, by adopting high resolution dataset (e.g. LIDAR, Landsat, Copernicus Land Monitoring Service, etc.)

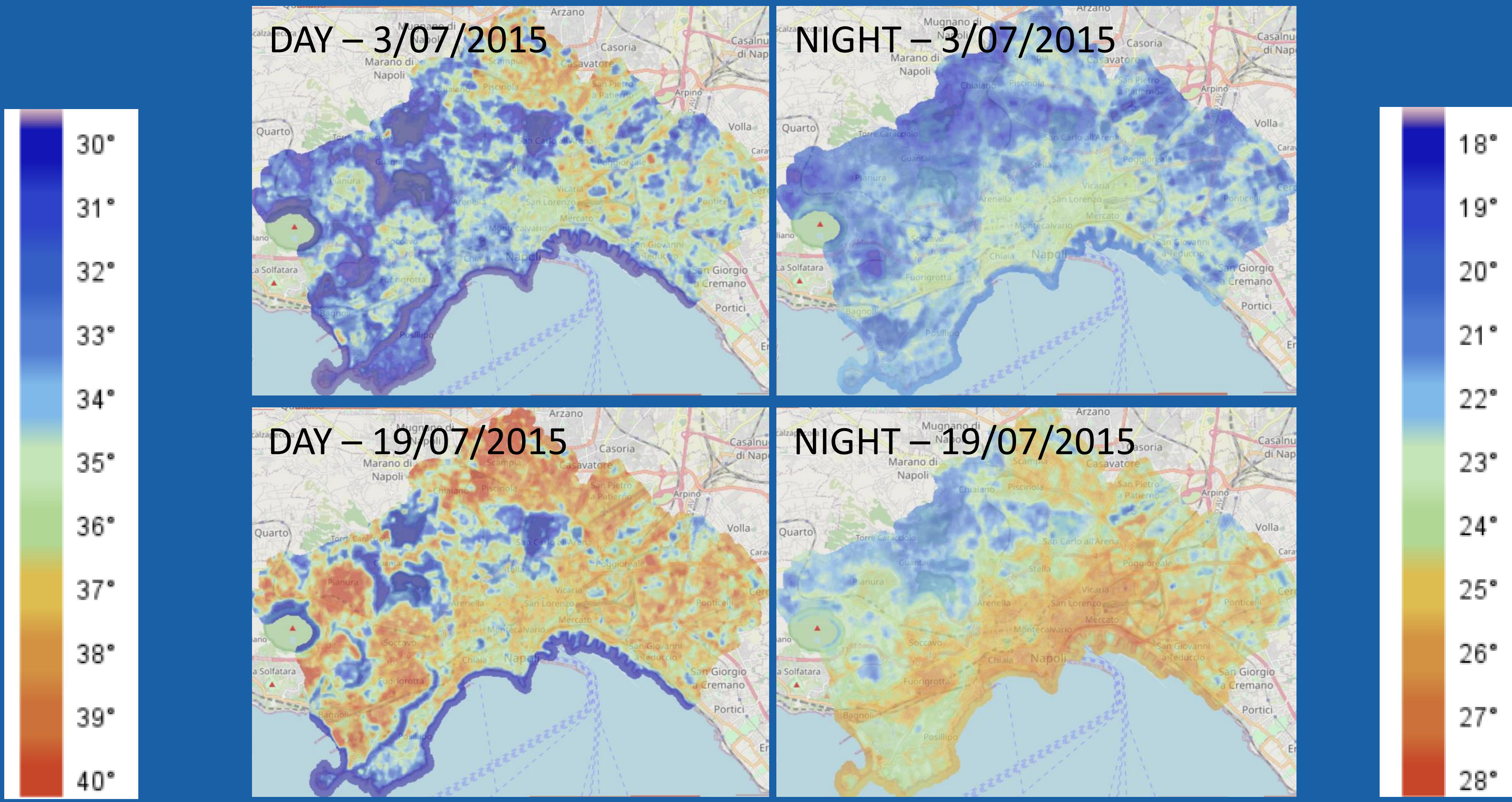
↓↓↓↓↓

Developing **spatially and computationally efficient models** also adopting supercomputing facilities

FOCUS: Satellite analysis of SUHI intensity

1

Surface temperature in Naples (from Landsat_8, band 11)



METROPOLIS project, http://webgis.progetto-metropolis.it/.

Methods and modelling approaches

A successful study of urban climates is founded on clearly stated scientific and/or applied objectives that stipulate the:

- **properties** and **processes** of interest (such as air temperature or turbulent fluxes)
- physical extent (**domain**) of the system under consideration
- strategy for capturing the **horizontal**, **vertical** and **temporal variation** within the system.

The main methods used in urban climatology are:

1. **Field observations**
2. **Numerical modelling – Urban high-resolution modelling**

Oke et al., 2017

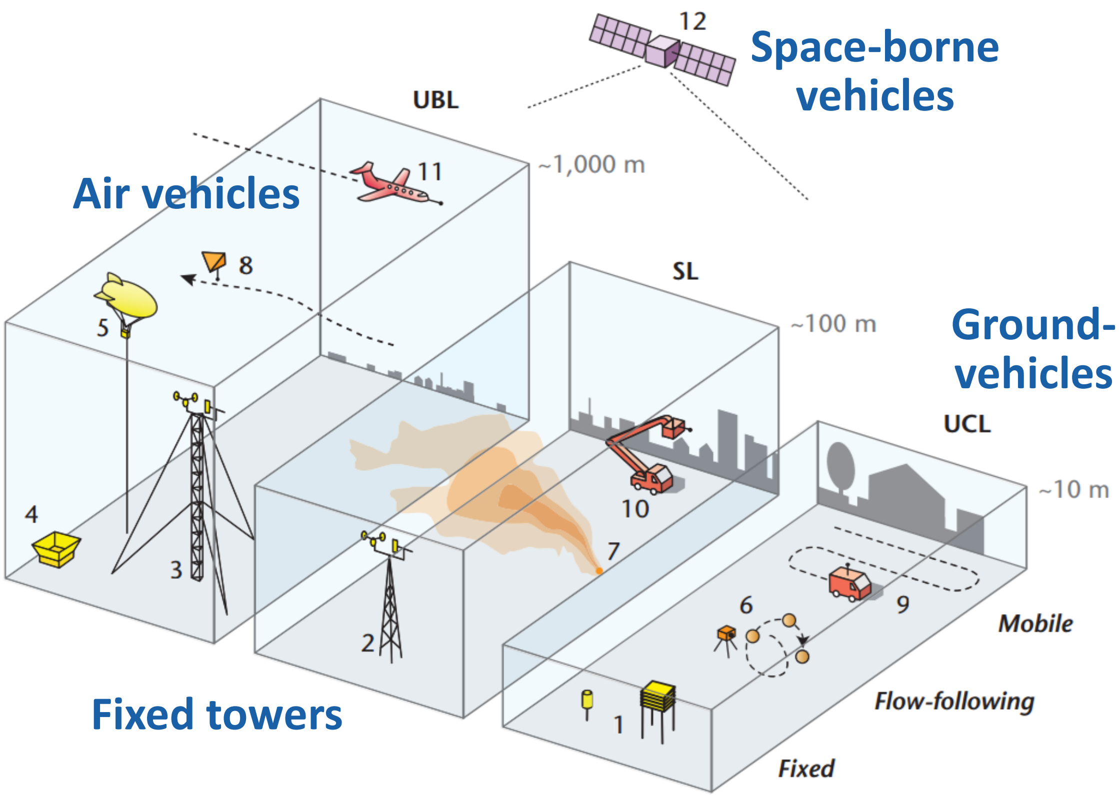
Methods and modelling approaches

Field observations

Observations play a central role in the evaluation of urban climate effects and in the development of understanding of the processes responsible. Given the growth in the number and size of cities and the paucity of urban meteorological stations, the need for regular observations of the atmosphere in cities is probably greater now than ever.

Observations can be:

- **Written records** of events and phenomena
- Measurements made by **physical devices** (sensors) or **instrumented stations**



Oke et al., 2017

Methods and modelling approaches

Urban high-resolution modelling

Numerical models simulate real-world phenomena using a **set of equations that link properties** (e.g. air temperature) to **processes** (e.g. sensible heat flux density).
Similar to physical models, they can be used to conduct quasi-controlled experiments. A variety of models of varying sophistication have been employed to understand exchanges of energy, mass and momentum within the UBL or at the urban surface.

Two groups of numerical models with different horizontal resolution can be found:

- **Energy-Based (EB) models**
- **Computational Fluid Dynamics (CFD) models**

Oke et al., 2017

Methods and modelling approaches

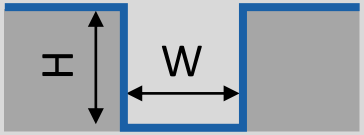
Urban high-resolution modelling: **Energy-Based (EB) models**

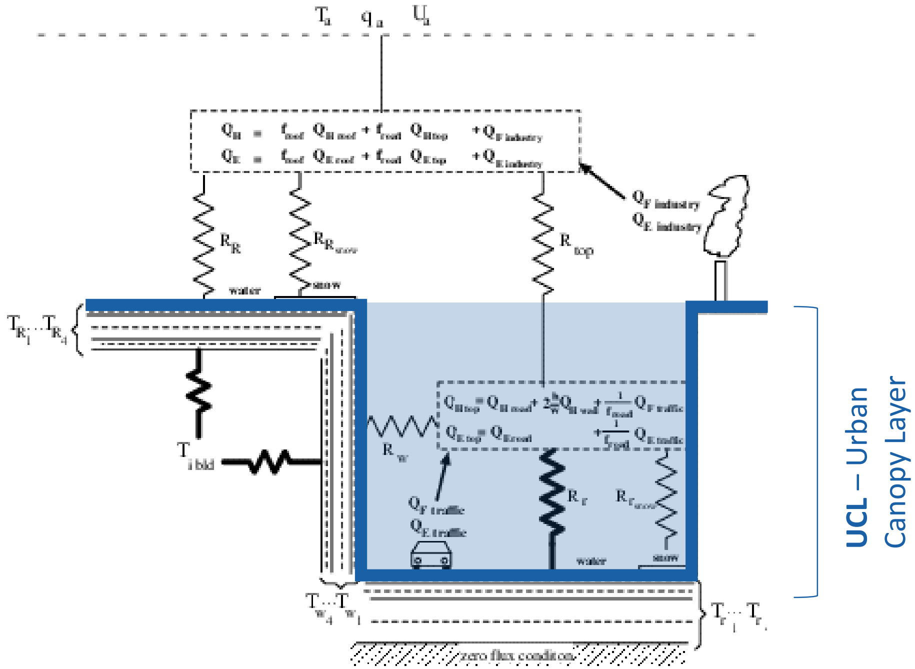
EB includes models based on the resolution of the **energy balance on a target control volume**. Each urban element is featured by a single temperature and surface energy balance and interacts with the other elements.

Horizontal resolution ranging from the **mesoscale to the microscale**. These models were developed to be embedded in mesoscale atmospheric models.

Town Energy Balance (TEB) model

The 2D canyon form represent the basis for many Energy-Based models, such as the Town Energy Balance (TEB) model (Masson, 2000).





Oke et al., 2017

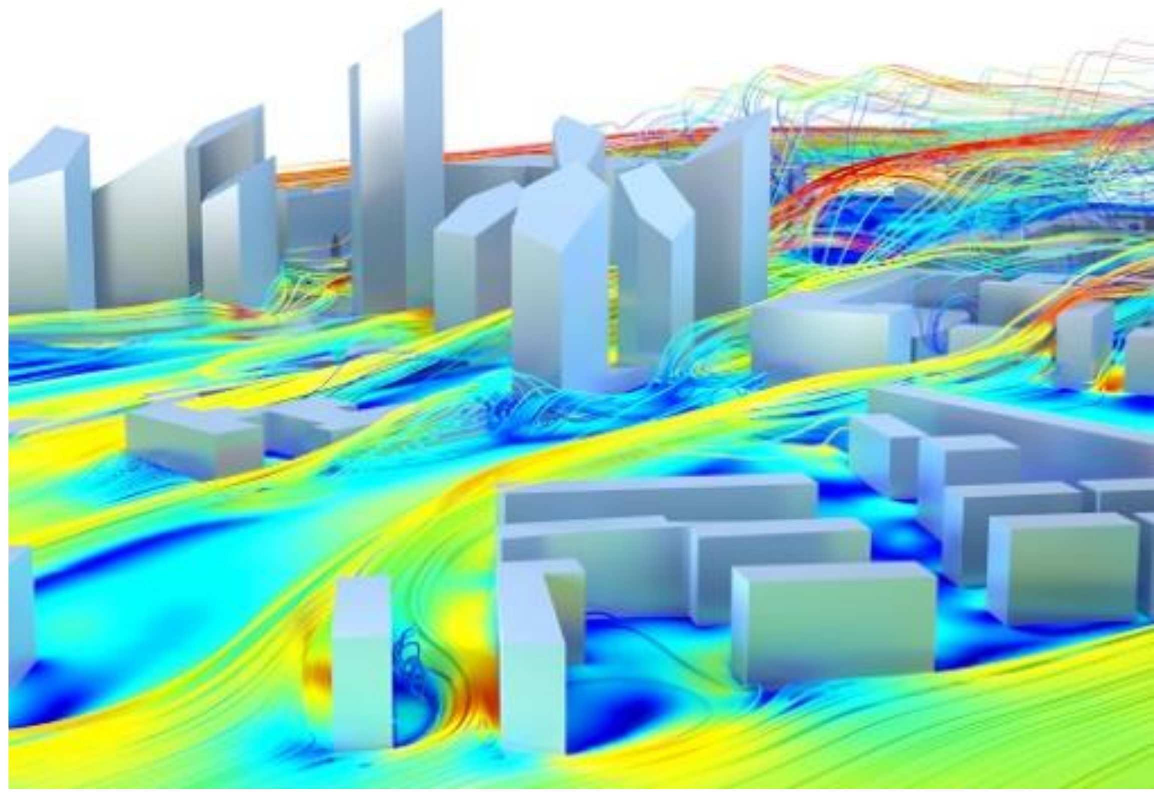
Methods and modelling approaches

Urban high-resolution modelling: Computational Fluid Dynamics (CFD) models

Models able to simulate airflow around obstacles are usually classed as computational fluid dynamics (CFD) models. CFD includes models coupling **velocity**, **temperature** and **pollution** fields.

They are **very high resolution models**: individual buildings with horizontal resolution of 100 m; building indoor environment with horizontal resolution of 10 m or even human scale.

These models require a **high-resolution representation of urban geometry**, accuracy in boundary conditions for all relevant flow variables and adequate computational resources.



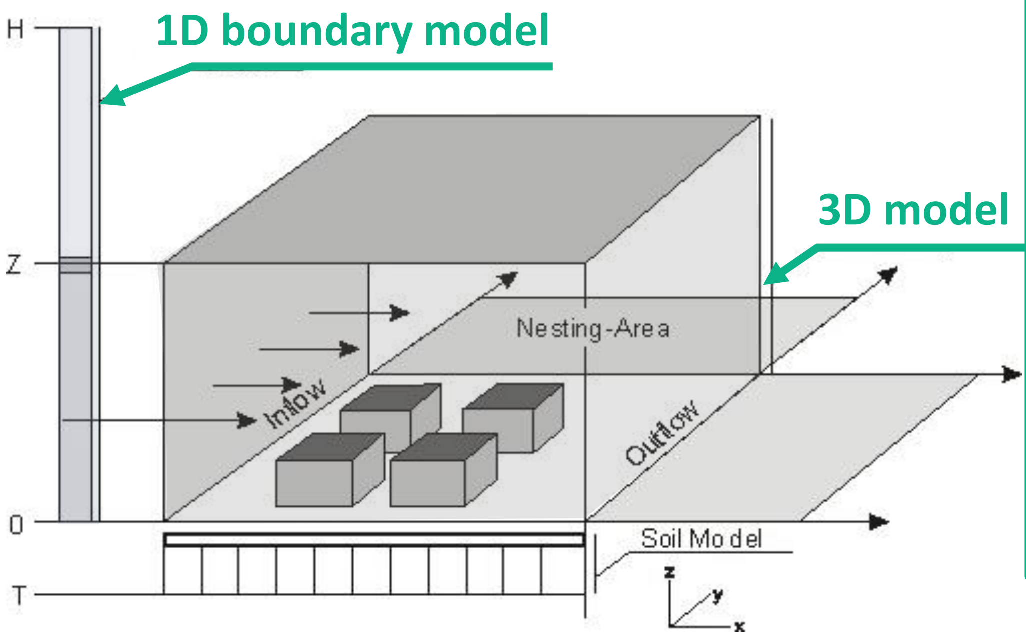
Oke et al., 2017

Methods and modelling approaches

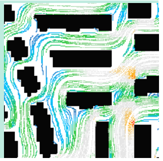
Urbanl high-resolution modelling: ENVI-met CFD model

ENVI-met is a holistic **three-dimensional** non-hydrostatic model for the simulation of surface-plant-air interactions not only limited to, but very often used to simulate urban environments and to asses the effects of green architecture visions.

It is designed for microscale with a **typical horizontal resolution from 0.5 to 10 m** and a typical **time frame of 24 to 48 hours** with a time step of 1 to 5 seconds. This resolution allows to analyze small-scale interactions between individual buildings, surfaces and plants.

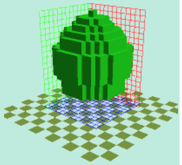


Atmospheric model



Soil model

Vegetation model



Methods and modelling approaches

ENVI_MET 2

What we can simulate with ENVI-met?

Solar Analysis

- Sun & shade hours
- Glazing analysis
- Shadow casting
- Solar energy gain

Building Physics

- Façade temperatures
- Exchange processes with vegetated walls
- Interaction of outdoor microclimate with indoor climate
- Water and energy balance of living wall systems

Green & Blue Technologies

- Benefits of façade & rooftop greening
- Impact of green spaces and bodies of water
- Simulation of living wall
- Air cooling through water spray

Air Pollutant Dispersion

- Emission and transport of particles and gases
- Chemical reactions between NOx, Ozone and (B)VOC
- Includes deposition on plants and surfaces
- Integrated tools to calculate traffic emission profiles

Wind Flow

- Wind patterns in complex environments
- Wind speed around buildings and trees
- Wind comfort

Outdoor Thermal Comfort

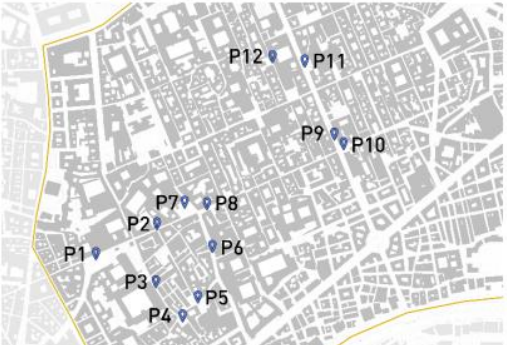
- Air temperature
- Radiant temperature of surrounding surfaces
- Air movement in the vicinity of the body
- Relative Humidity

FOCUS: Measurements with thermal imaging camera

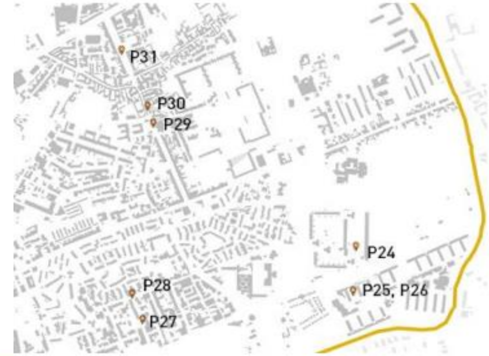
1

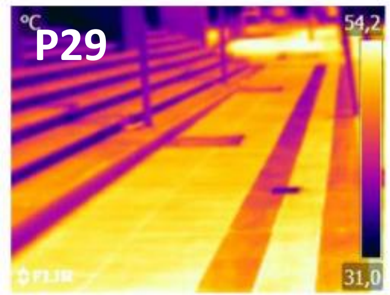
Surface temperature in Naples with thermal imaging camera (FLIR E40 BX)

Historical centre



East Naples





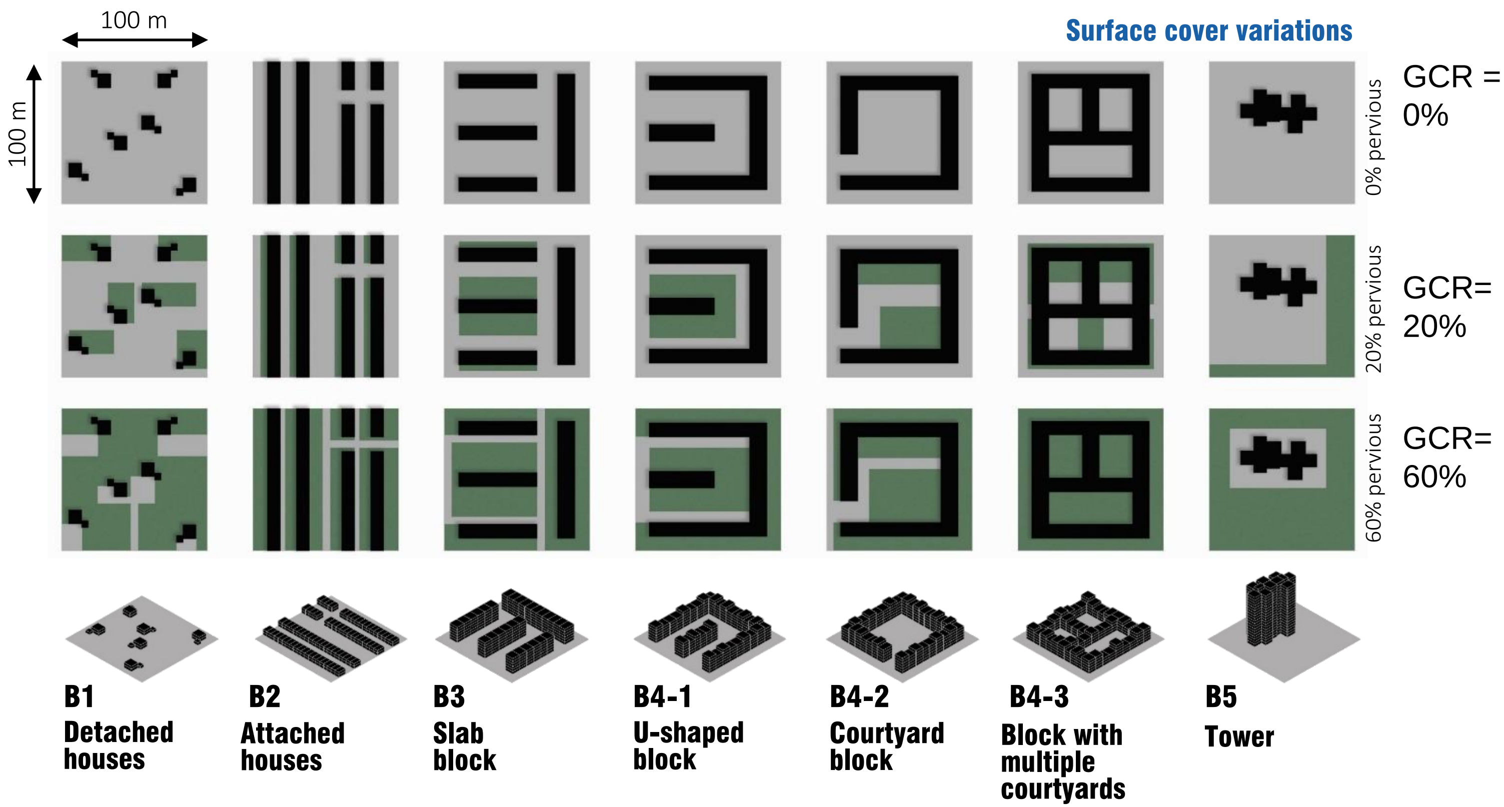
3/07/2015

Bassolino, E., 2016. Climate adaptive design strategies for the Built Environment. PhD dissertation, https://bit.ly/2XLeuLZ.

FOCUS: Microclimate modelling with ENVI-met

2

Effects of urban morphology on microclimate



Surface coverage
BCR - Building Coverage Ratio
ICR - Impervious Coverage Ratio
GCR - Green Coverage Ratio

Density
FAR- Floor Area Ratio

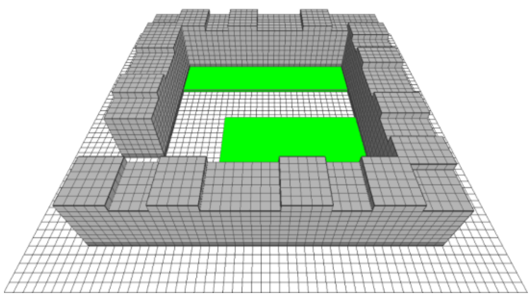
Canyon geometry
Street canyon ratio – Height-to-Width Ratio

Apreda et al., 2020. doi:10.1016/j.enbuild.2020.110171

FOCUS: Microclimate modelling with ENVI-met

Built environment modelling

B4-2 Courtyard block

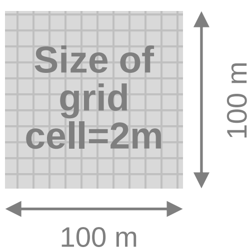


Buildings

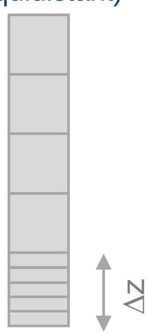
Roads

Green areas

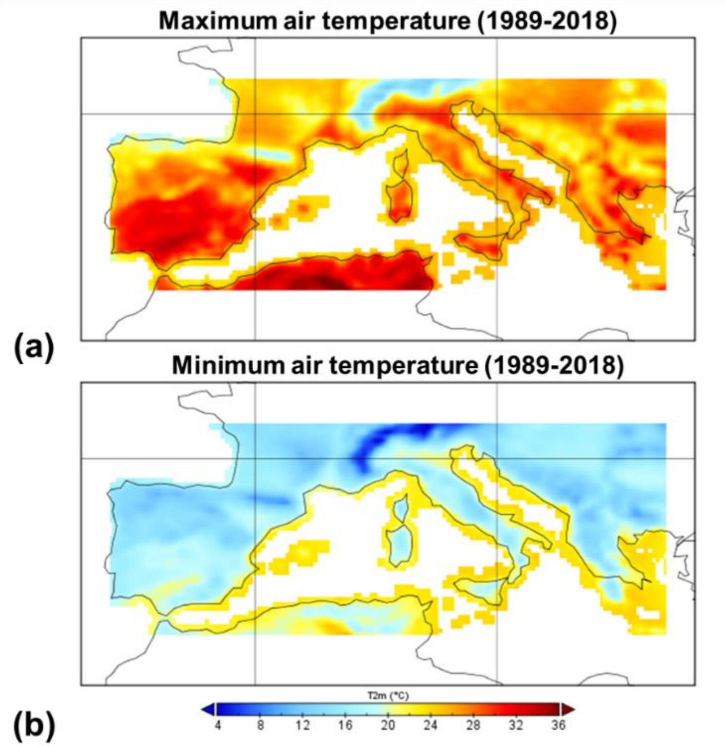
Horizontal grid



Vertical grid (equidistant)



Input data



Mean JJA values for TA in the daytime (a) and night-time (b) in the Euro-Mediterranean region.*

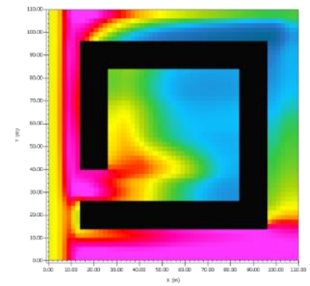
Air temperature (ERA5)*: T_{Amin}=16°C; T_{Amax}=28°C

Relative humidity: RH_{min}=50%; RH_{max}=70%

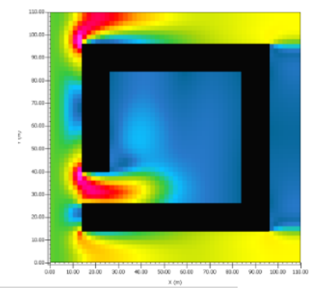
Wind speed (10 m): 3 m/s

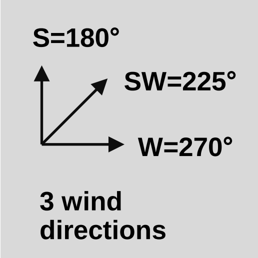
Output

Air Temperature (°C)



Wind Speed (m/s)





Apreda et al., 2020. doi:10.1016/j.enbuild.2020.110171

Methods and modelling approaches

What method/model type to use

Method	Advantages	Disadvantages
Field observation	• Records ‘real-world’ urban conditions including all scales of influence • Provides data to test models	• Lack of experimental control. • Vagaries of weather may limit measurement period or otherwise constrain planned study. Measurement errors always present • Equipment can be costly
Physical modelling	• Provides experimental control • Allows detailed observation of urban effects	• Requires careful design to ensure similitude • Requires access to specialized facilities, e.g. flume, wind tunnel • Expensive • Requires testing against field observations or numerical results
Numerical modelling	• Gives complete experimental control and can account for all scales of climate • Can give predictions that possess practical utility	• Assumptions can be restrictive, unrealistic or too theoretical • Requires testing against field observations to establish confidence • Output can be voluminous • High computational resources • High computation time

Modified from Oke et al., 2017

Climate-sensitive urban design

What makes a well-planned and designed city from a climatic perspective?

- The city is **efficient** in its **use of resources** (land, energy materials, water, etc.) so as to minimize its global and regional impact (e.g. emission of air pollutants and greenhouse gases, water degradation, waste generation)
- City neighborhoods are designed to **improve the microclimates** surrounding buildings and their environments (or at least not worsen them)
- People and infrastructure are **protected from extreme weather events** by considering current and future climate variability and extremes

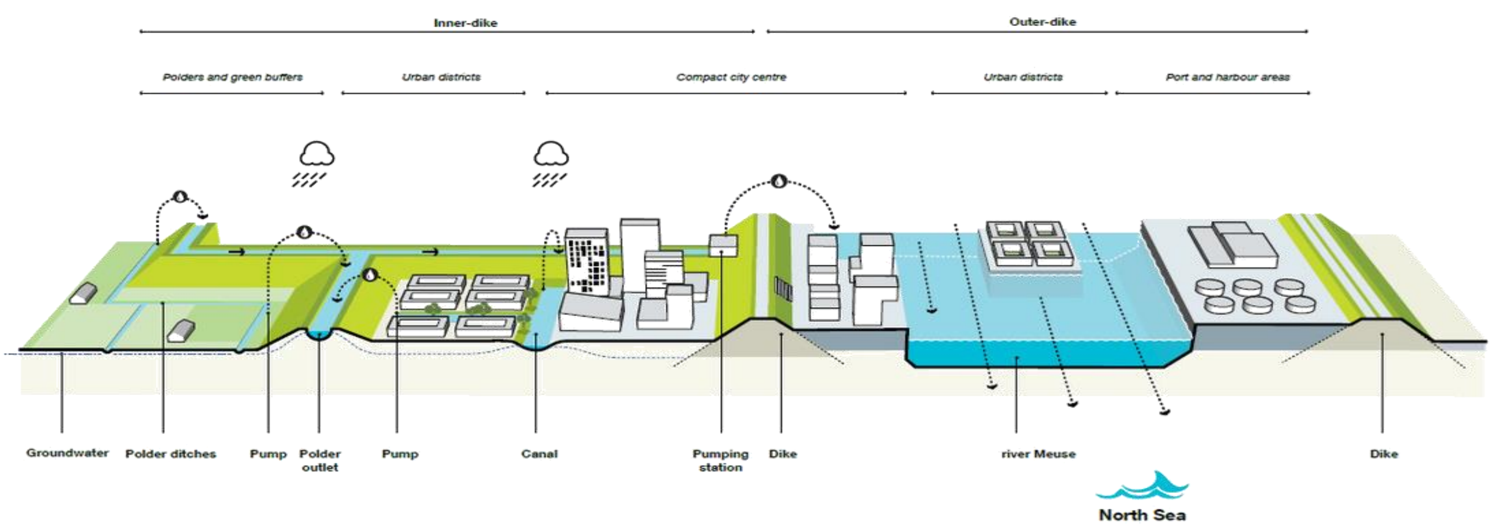
© SCAPE/City of Boston

Oke et al., 2017

Climate-sensitive urban design

Climate-sensitive urban design is defined as a process that considers the fundamental elements of microclimates (e.g., sun, wind, temperature) for design purposes (Tapias and Schmitt, 2014).

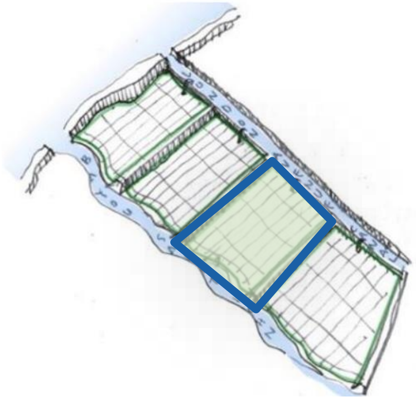
This approach is important because it uses the microclimate for the benefit of planning climate sensitive urban environments. Climate sensitive urban design aims to use passive design strategies to create human comfort conditions in the built environment and urban green infrastructure to design outdoor spaces that encourage residents to venture out and also help in retention and absorption of rain water which helps in reducing the Urban Heat Island effect (Bhoge, 2019).



Rotterdam Climate Initiative, 2013

Climate-sensitive urban design

City/District

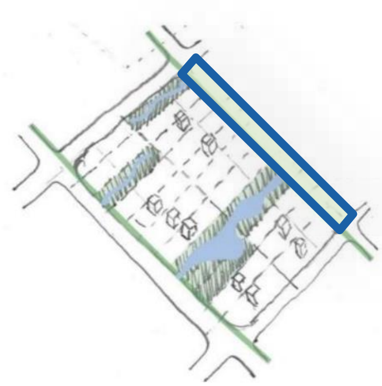


- Compact city (building and population density)
- Use of renewable energy
- Ventilation pathways (e.g. greenways)
- Provision of mass transit
- Green infrastructure

Neighbourhood

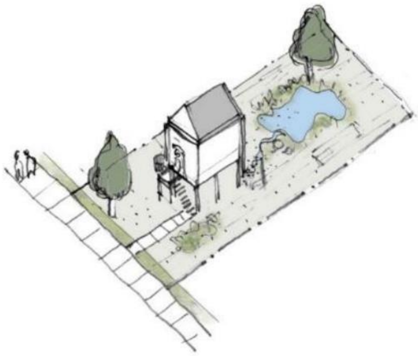
- Compact city (building and population density)
- Street length and connectivity
- Height variation
- Permable paving
- Green infrastructure

Street



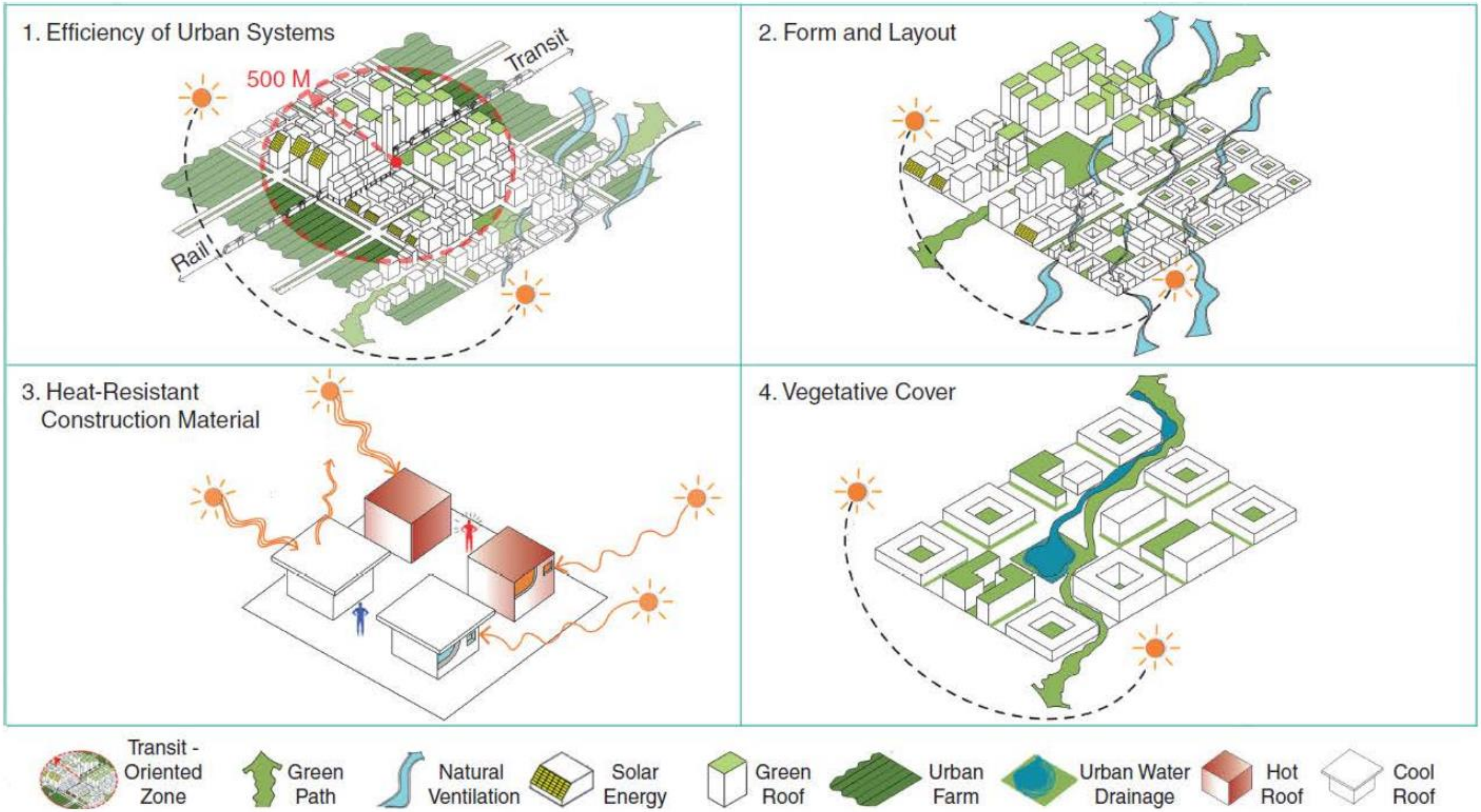
- Shading (street dimensions and orientation, trees)
- Permeable paving
- Rain gardens

Building



- Orientation
- Reflectivity (cool roofs, cool paving)
- Green roofs, green walls

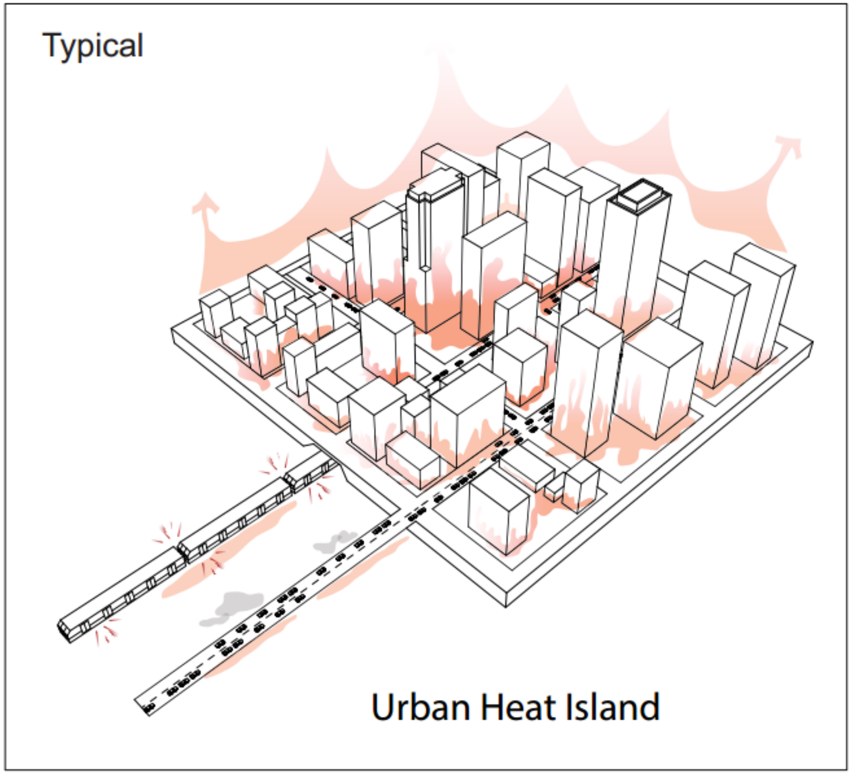
Climate-sensitive urban design

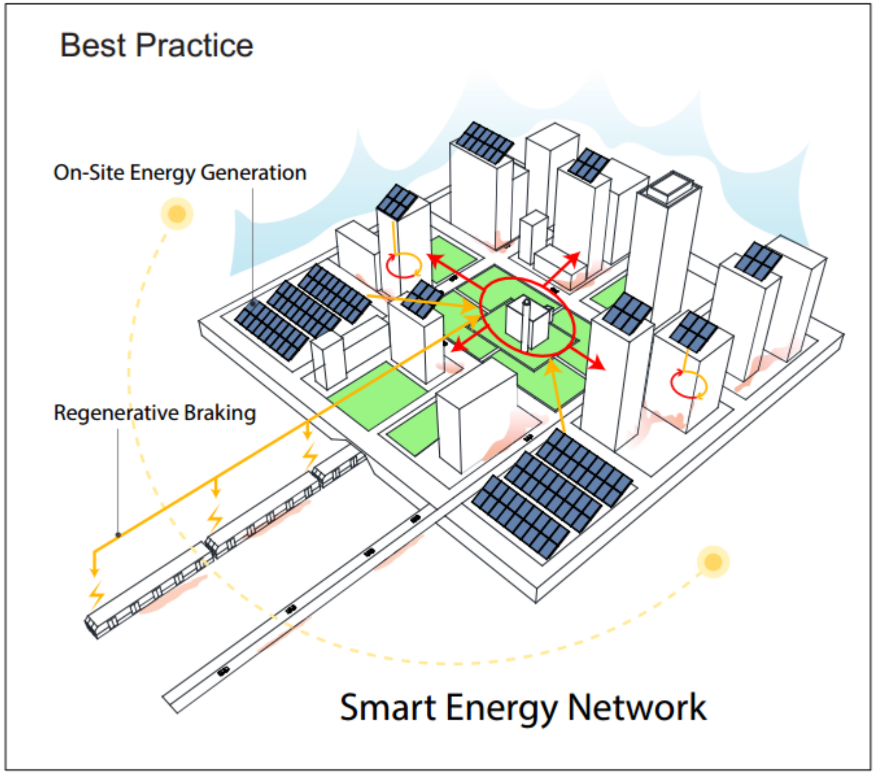


Urban Climate Lab, Graduate Program in Urban & Regional Design, NYIT, 2017. https://bit.ly/3CgFDFl. Accessed 16 September 2021.

Climate-sensitive urban design

Efficiency of urban system: **Smart energy network**

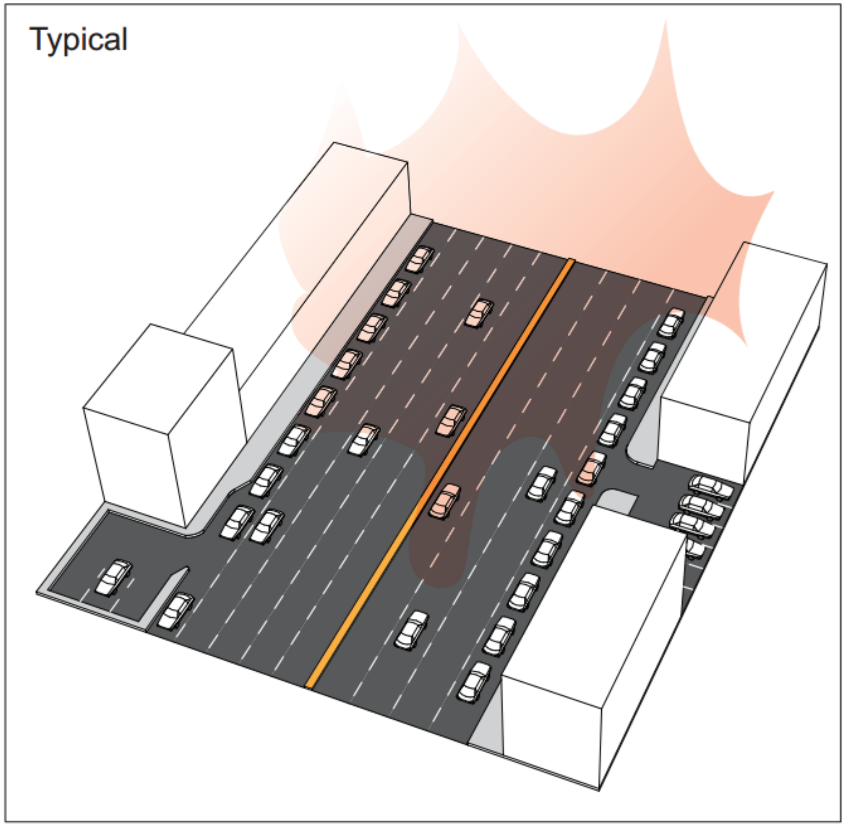


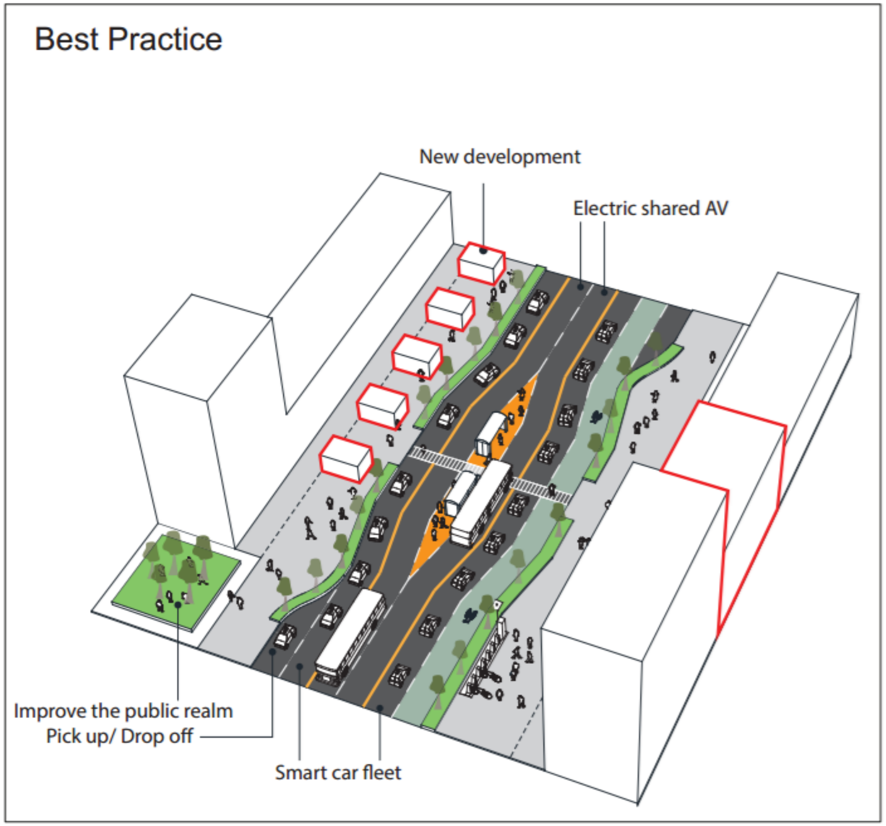


Urban Climate Lab, Graduate Program in Urban & Regional Design, NYIT, 2017. https://bit.ly/3CgFDFl. Accessed 16 September 2021.

Climate-sensitive urban design

Efficiency of urban system: Transportation efficiency

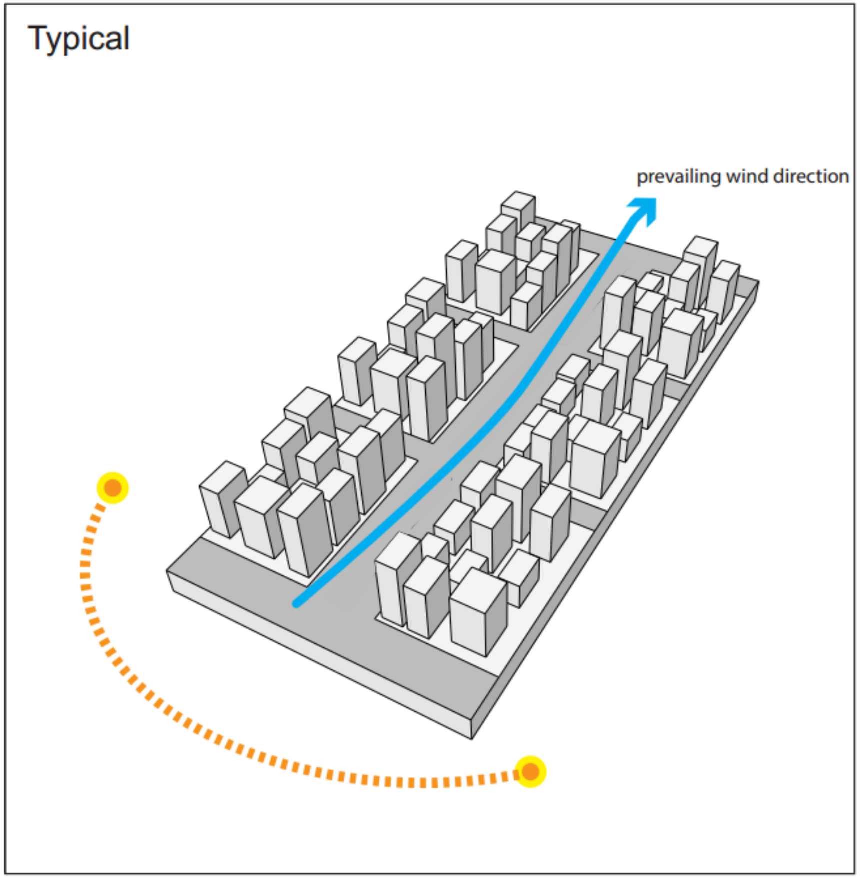


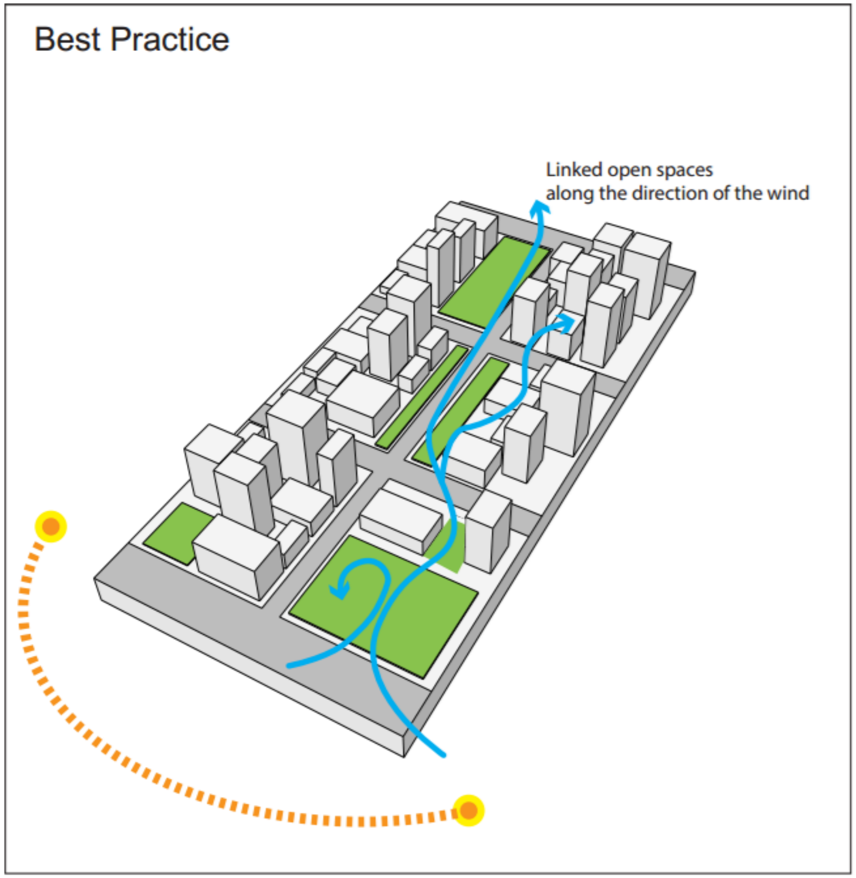


Urban Climate Lab, Graduate Program in Urban & Regional Design, NYIT, 2017. https://bit.ly/3CgFDFl. Accessed 16 September 2021.

Climate-sensitive urban design

Form and layout: Wind corridor





Urban Climate Lab, Graduate Program in Urban & Regional Design, NYIT, 2017. https://bit.ly/3CgFDFl. Accessed 16 September 2021.

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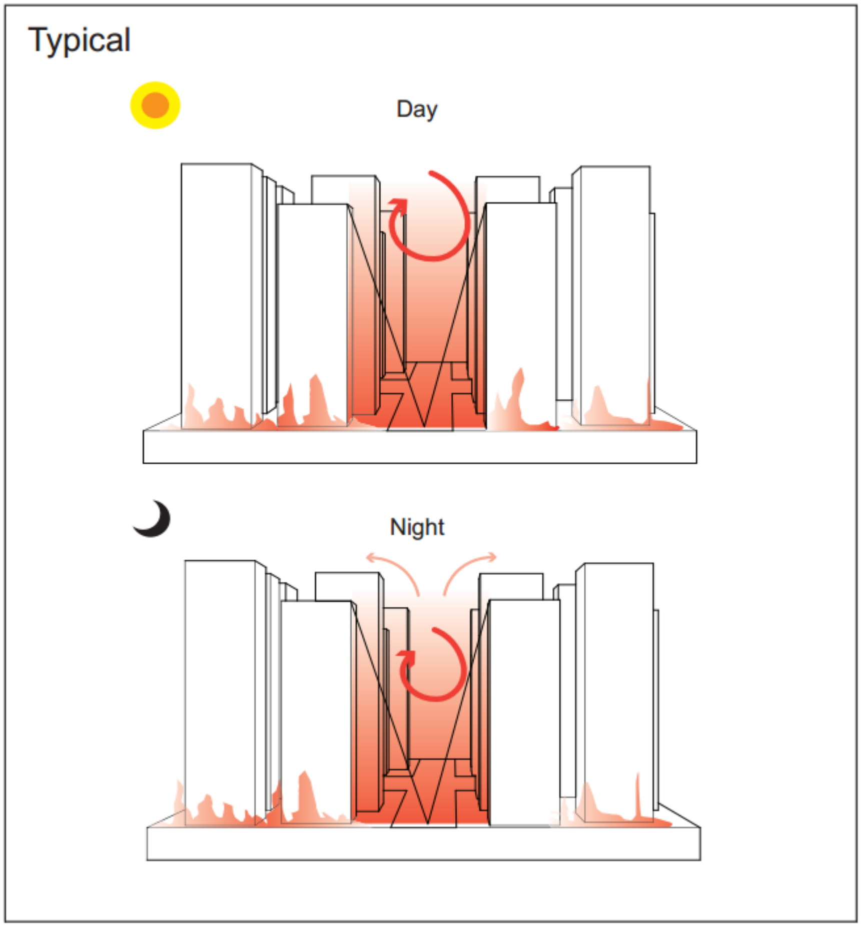
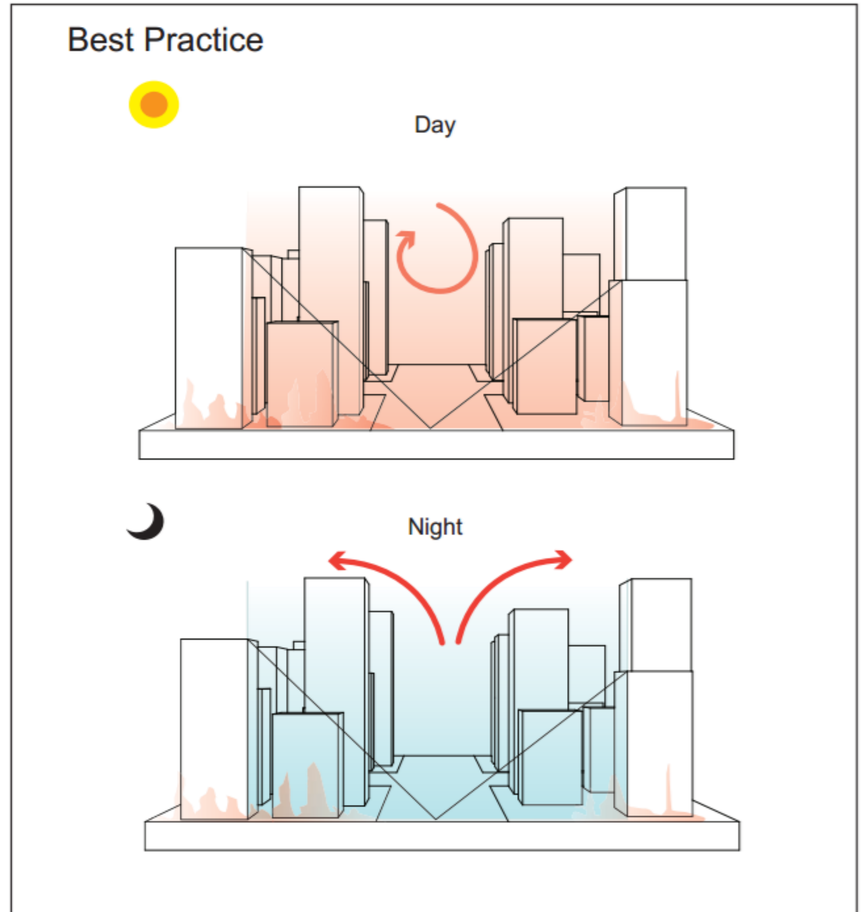
Form and layout: Sky View Factor

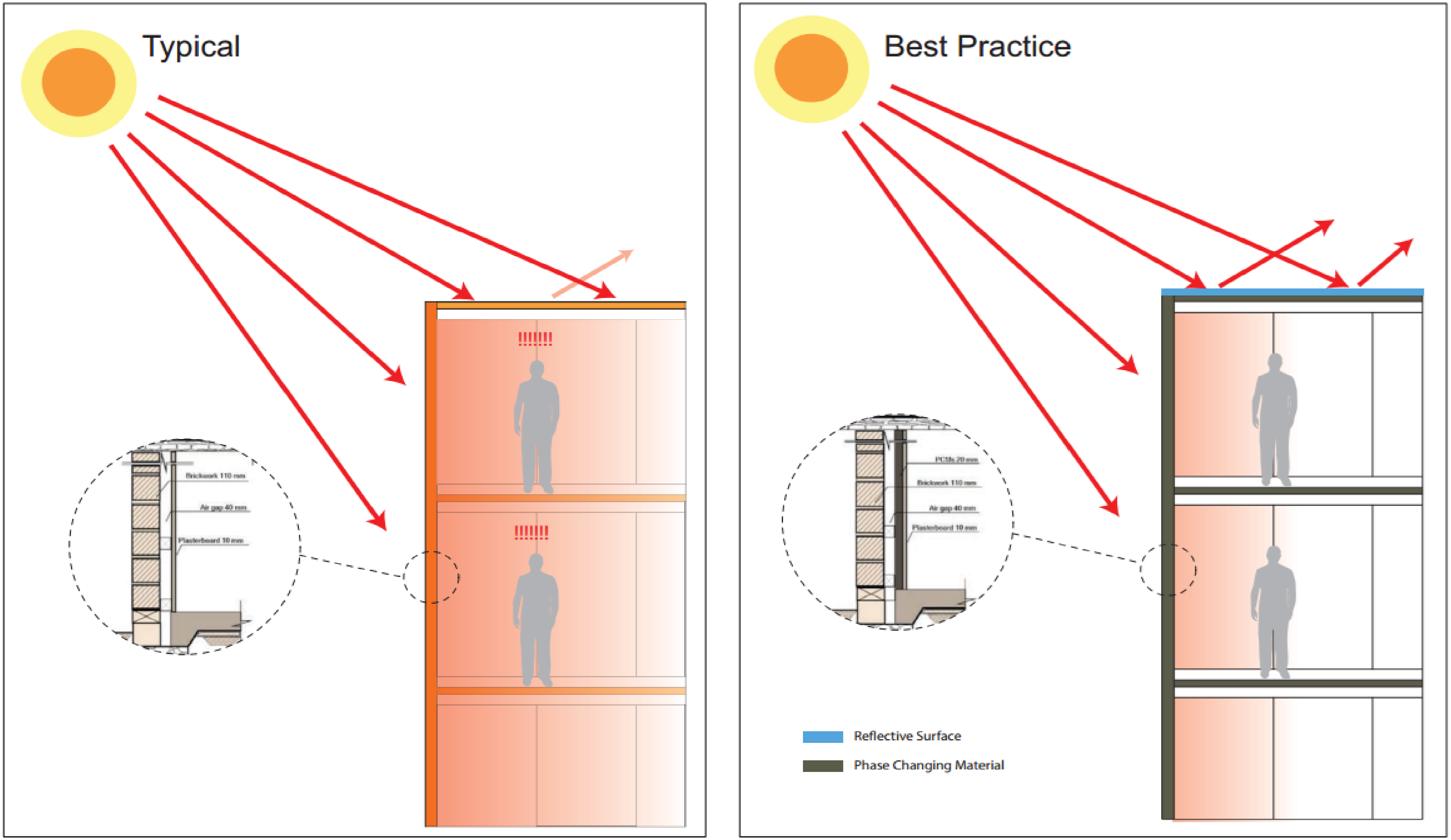




Urban Climate Lab, Graduate Program in Urban & Regional Design, NYIT, 2017. https://bit.ly/3CgFDFl. Accessed 16 September 2021.

Climate-sensitive urban design

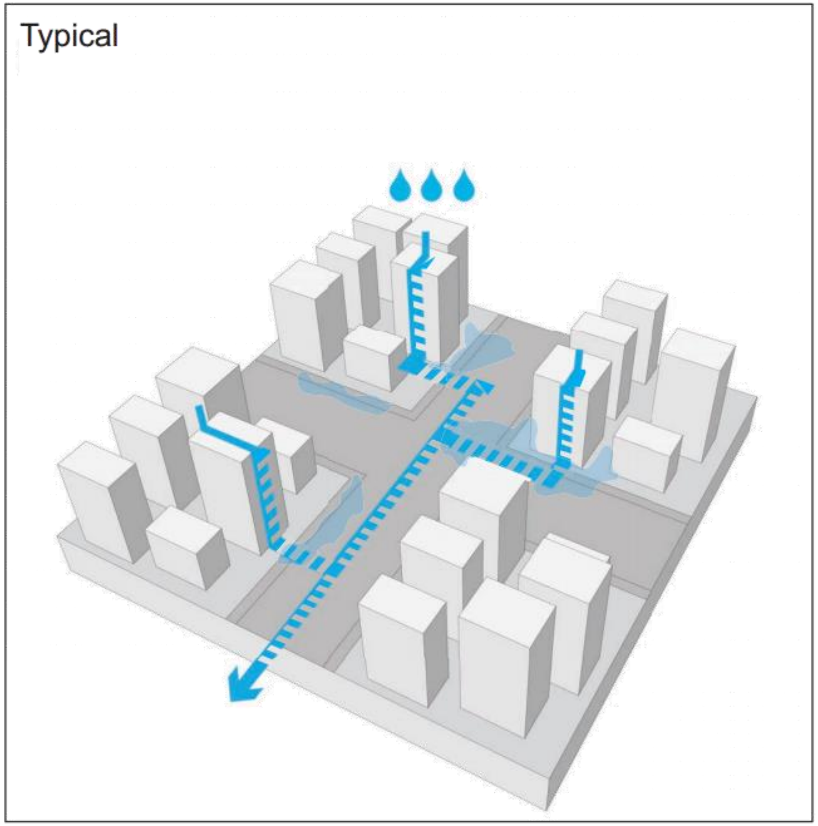
Heat-Resistant Construction Materials: Albedo and Phase Change Material



Urban Climate Lab, Graduate Program in Urban & Regional Design, NYIT, 2017. https://bit.ly/3CgFDFl. Accessed 16 September 2021.

Climate-sensitive urban design

Vegetative cover: **Stormwater Management**



Urban Climate Lab, Graduate Program in Urban & Regional Design, NYIT, 2017. https://bit.ly/3CgFDFl. Accessed 16 September 2021.

Outdoor thermal comfort: metrics and indices

What are the factors that impact outdoor thermal comfort?

Thermal comfort is defined as the **condition of mind that expresses satisfaction with the thermal environment ad is assessed by subjective evaluation** (ANSI/ASHRAE standard 55-2010).

Thermal comfort depends on many factors:

Climate factors	Behavioral factors	Psychological factors	Other/ Personal factors
Air temperature	Clothing	Expectations	Sex
Wind speed	Activity	Experience	Acclimatization
Radiation		Perception	Age
Humidity			

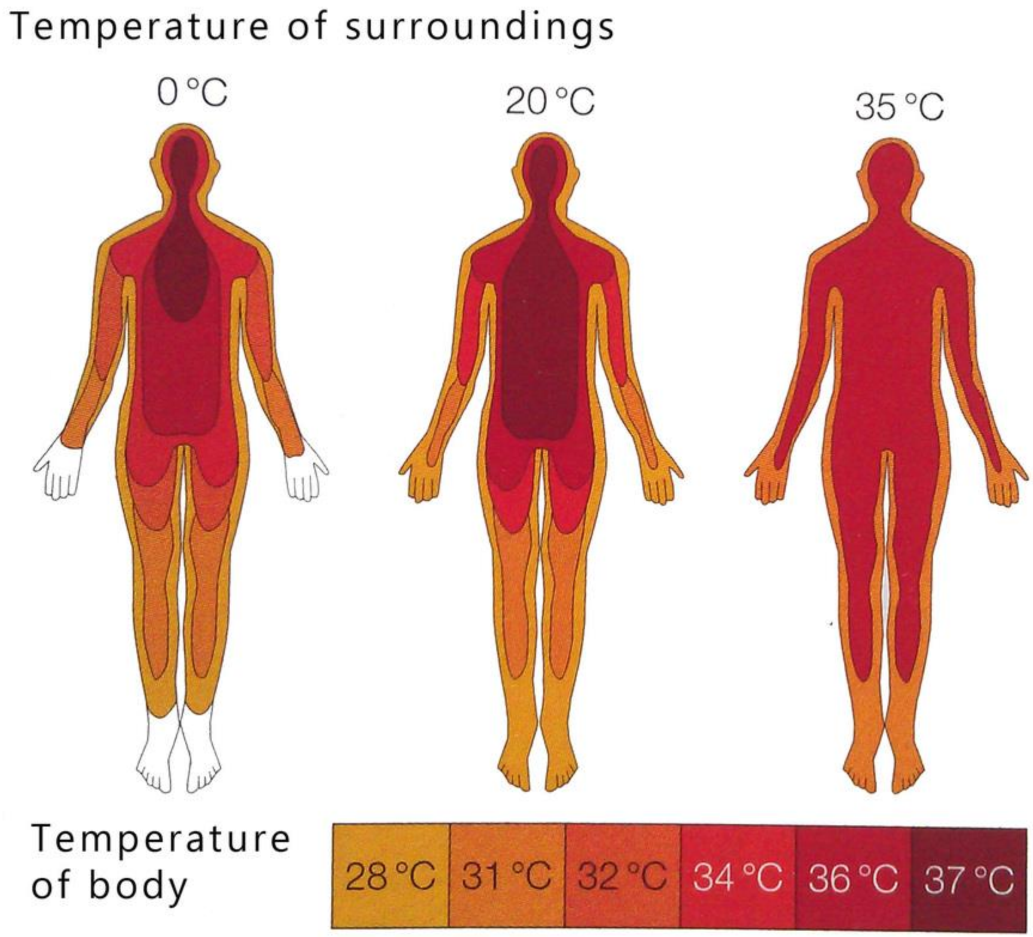
Outdoor thermal comfort: metrics and indices

Human heat balance

The **body's heat balance** can be expressed as:

$$M \pm R \pm Cv \pm Cd - E = \Delta S \; (W)$$

M = metabolic rate
Cv = convection
R = net radiation
Cd = conduction
E = evaporation heat loss
ΔS = change in heat stored



Hegger et al., 2008. *Energy manual - Sustainable architecture*. Berlin: DETAIL.

What are thermal indices?

Thermal indices are criteria used for the determination of the combined effects of climatic factors (such as air temperature, humidity, air speed and radiation) from the viewpoint of body comfort (Givoni, 1960).

The study of the relationship between the human body and thermal environment can be carried out by adopting two types of indices:

- **Single indices**
- **Indices from heat budget**

Outdoor thermal comfort: metrics and indices

Main heat metrics	When to use which metric?
Single Indices	
• **Air temperature** (T_A) Measure of how hot or cold the air is	→ Building energy use, UHI quantification
• **Surface temperature** (T_S) Temperature of a surface	→ Surface UHI
• **Heat Index** (HI) Human-perceived temperature	→ Human thermal comfort
Indices derived from heat budget models	
• **Mean Radiant temperature** (T_{MRT}) Synthetic parameter that summarizes the heat load on a person's body	→ Human thermal comfort and exposure
• **Physiological Equivalent Temperature** (PET) Equivalent temperature	→ Human thermal comfort and exposure
• **Predicted Mean Vote** (PMV) Thermal sensation and physiological stress level	→ Human thermal sensation

Outdoor thermal comfort: metrics and indices

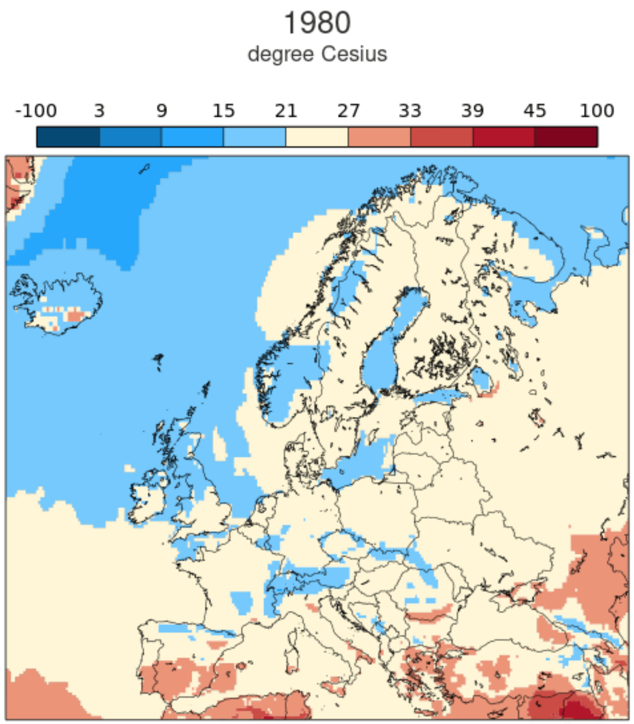
Copernicus Climate Change Service, C3S – Thermal comfort indices

Variables	Mean radiant temperature Universal Thermal Climate Index
Horizontal resolution	0.25° x 0.25°
Temporal coverage	1979-01-01 to near real time for the most recent version
Temporal resolution	Hourly data
File format	NetCDF

Copernicus Europe's eyes on Earth — Climate Change Service

MEAN RADIANT TEMPERATURE FOR EUROPE

Seasonal mean (Jun-Aug) – 1981-2020 (°C)



Climate Adapt - European Climate and Health Observatory, https://bit.ly/2ZepfHf

C3S, Thermal comfort indices derived from ERA5 reanalysis, https://bit.ly/3lzml7e.

Heat Index -HI

The Heat Index is a measure of how hot it really feels when relative humidity is factored in with the actual air temperature.

$$
\begin{aligned}
HI = & -8.784695 + 1.61139411 \cdot T + 2.338549 \cdot RH \\
& -0.14611605 \cdot T \cdot RH - 1.2308094 \cdot 10^{-2} \cdot T^2 \\
& -1.6424828 \cdot 10^{-2} \cdot RH^2 + 2.211732 \cdot 10^{-3} \cdot T^2 \cdot RH \\
& +7.2546 \cdot 10^{-4} \cdot T \cdot RH^2 - 3.582 \cdot 10^{-6} \cdot T^2 \cdot RH^2
\end{aligned}
$$

Input variables

T = air temperature (°C)
RH = relative humidity (%)

Classification	Heat Index	Effect on the body
Caution	80°F - 90°F	Fatigue possible with prolonged exposure and/or physical activity
Extreme Caution	90°F - 103°F	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	103°F - 124°F	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger	125°F or higher	Heat stroke highly likely

NOAA-NWS, https://bit.ly/2Z4Bfea

Rothfusz LP (1990). The heat index equation. NWS Southern Region, Technical Attachment, SR/SSD 90–23, Fort Worth, Texas.

Heat Index

The Heat Index is a measure of how hot it really feels when relative humidity is factored in with the actual air temperature.

NWS Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution · Extreme Caution · Danger · Extreme Danger

NOAA-NWS, https://bit.ly/2Z4Bfea

Rothfusz LP (1990). The heat index equation. NWS Southern RegionTechnical Attachment, SR/SSD 90–23, Fort Worth, Texas

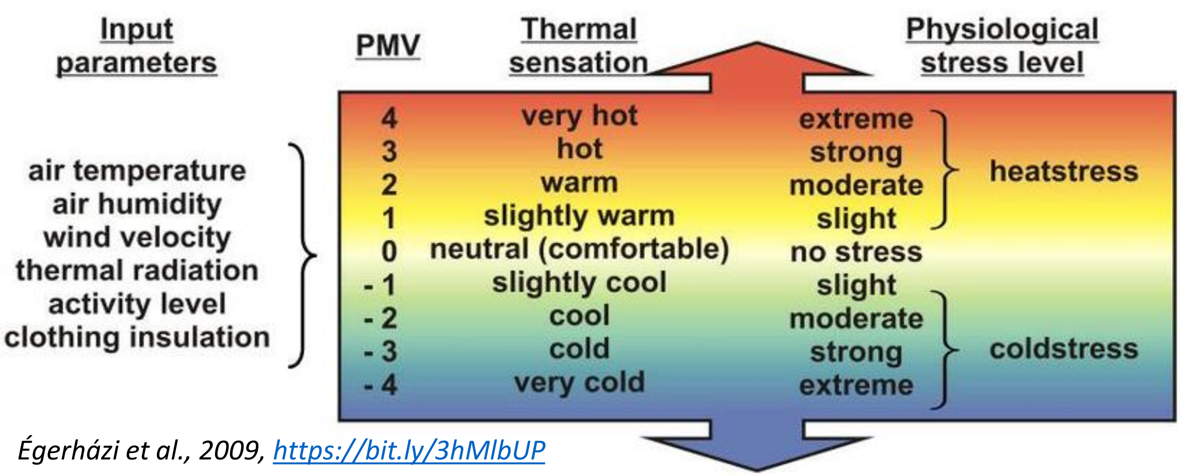
Outdoor thermal comfort: metrics and indices

Predicted Mean Vote (PMV)

PMV is the difference between the internal heat production and the heat loss to the actual environment for a person kept at the comfort values for skin temperature and sweat production at the actual activity level (Fanger, 1970).

$$PMV = [0.028 + 0.303 \cdot \exp(-0.036 \cdot M/A_{Du})] \cdot (H/A_{Du} - E_d - E_{sw} - E_{re} - L - R - C)$$

ENVI-met equation



Égerházi et al., 2009, *https://bit.ly/3hMlbUP*

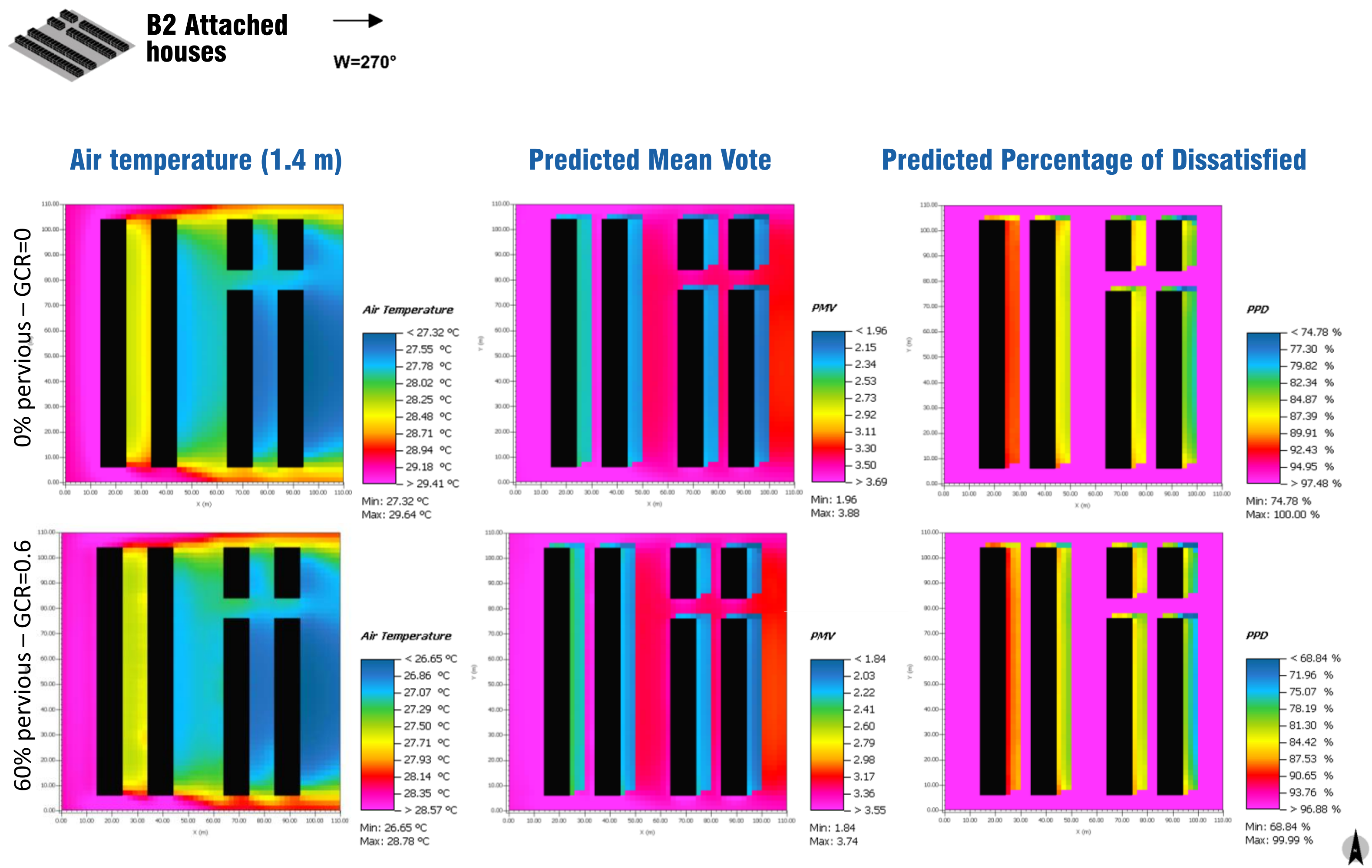
Predicted Percentage of Dissatisfied (PPD)

PPD establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm.

Fanger PO (1970) Thermal Comfort. Analysis and Application in Environment Engineering. Danish Technical Press, Copenhagen.

FOCUS: Microclimate analysis

Effects of urban morphology on microclimate – AIR TEMPERATURE, PMV/PPD



Conclusions

The formation of Urban Heat Island can worsen the impacts related to climate change and the extreme heat events

for this reason is necessary to

1. **Downscale Regional Climate Models** (RCMs) to provide useful information to understand the microclimate at the urban level
2. **Develop a detailed 3D city model**, which include all relevant urban features
3. Develop **spatially and computationally efficient models**

Furthermore, a proper planning and design approach to urban climate adaptation should take into account 4 steps:

- Climate analysis mapping
- Public space evaluation
- Planning and design intervention with climate-sensitive design
- Post intervention evaluation

References

Apreda C., Reder A., Mercogliano P., 2020. Urban morphology parameterization for assessing the effects of housing blocks layouts on air temperature in the Euro-Mediterranean context. *Energy and Buildings*, 223: 110171. doi:10.1016/j.enbuild.2020.110171

Bhoge, R., 2019. *Climate sensitive urban design: A comparison between Brisbane (Australia) and Nagpur (India).* Thesis for the Mphil, University of Queensland. https://bit.ly/3hTaboH

Britannica, The Editors of Encyclopaedia, 1998. Urban climate. *Encyclopedia Britannica*, 20 Jul. 1998, https://www.britannica.com/science/urban-climate. Accessed 8 September 2021.

Erell, E., Pearlmutter, D., & Williamson, T., 2010. *Urban Microclimate: Designing the Spaces Between Buildings* (1st ed.). Routledge. https://doi.org/10.4324/9781849775397

Masson, V., Lemonsu, A., Hidalgo, J., Voogt, J. (2020). Urban Climates and Climate Change, *Annual Review of Environment and Resources,* 45,1: 411-444. https://doi.org/10.1146/annurev-environ-012320-083623

MetOffice, 2019. *Microclimates*, National Meteorological Library and Archive, Fact sheet 14, https://bit.ly/3l5slok. Accessed 9 September 2021.

Oke, T.R., 2006. *Initial guidance to obtain a representative meteorological observation at urban sites.* Instruments and observing methods, REPORT no. 81, World Meteorological Association.

Oke, T.R., Mills G., Christen, A., Voogt, J., 2017. *Urban Climates*, Cambridge University Press, UK.

Roth, M., 2021. *Essential elements of urban climatology for understading the urban heat island effect*. Webinar | GHHIN Masterclass 5.1 - Understanding Urban Heat: Urban Climate Science Background, 17 and 18 Feb, 2021, https://bit.ly/3hQARqh. Accessed 9 September 2021.

Tapias, E., Schmitt, G., 2014. Climate-sensitive urban growth: Outdoor thermal comfort as an indicator for the design of urban spaces. *The Sustainable City*, 1, 12.

Voogt, J.A., 2006. *How researchers measure Urban Heat Islands*. https://bit.ly/3l6a4qJ. Accessed 9 September 2021

U.S. E.P.A., 2006. *Excessive Heat Events Guidebook*, EPA 430-B-06-005. U.S. Environmental Protection Agency, Washington, U.S.A.

Zhao, L., Oppenheimer, M., Zhu, Q., Baldwin, J. W., Ebi, K. L., Bou-Zeid, E., Guan, K., & Liu, X., 2018. Interactions between urban heat islands and heat waves. *Environmental Research Letters*, *13*(3), [034003]. https://doi.org/10.1088/1748-9326/aa9f73

Thank you!

carmela.apreda@cmcc.it

Centro Euro-Mediterraneo sui Cambiamenti Climatici