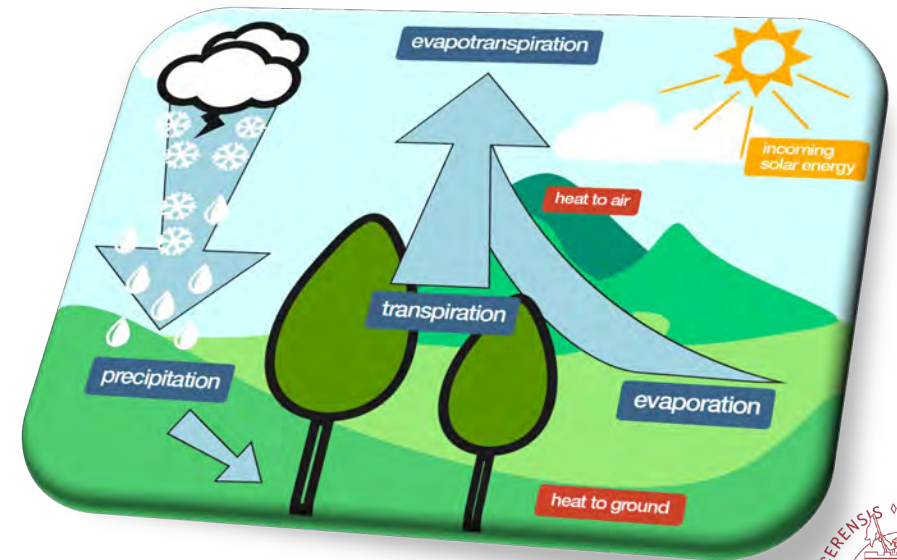


Cooling Cities with Nature: From Ecological Principles to Urban Design and adaptive management

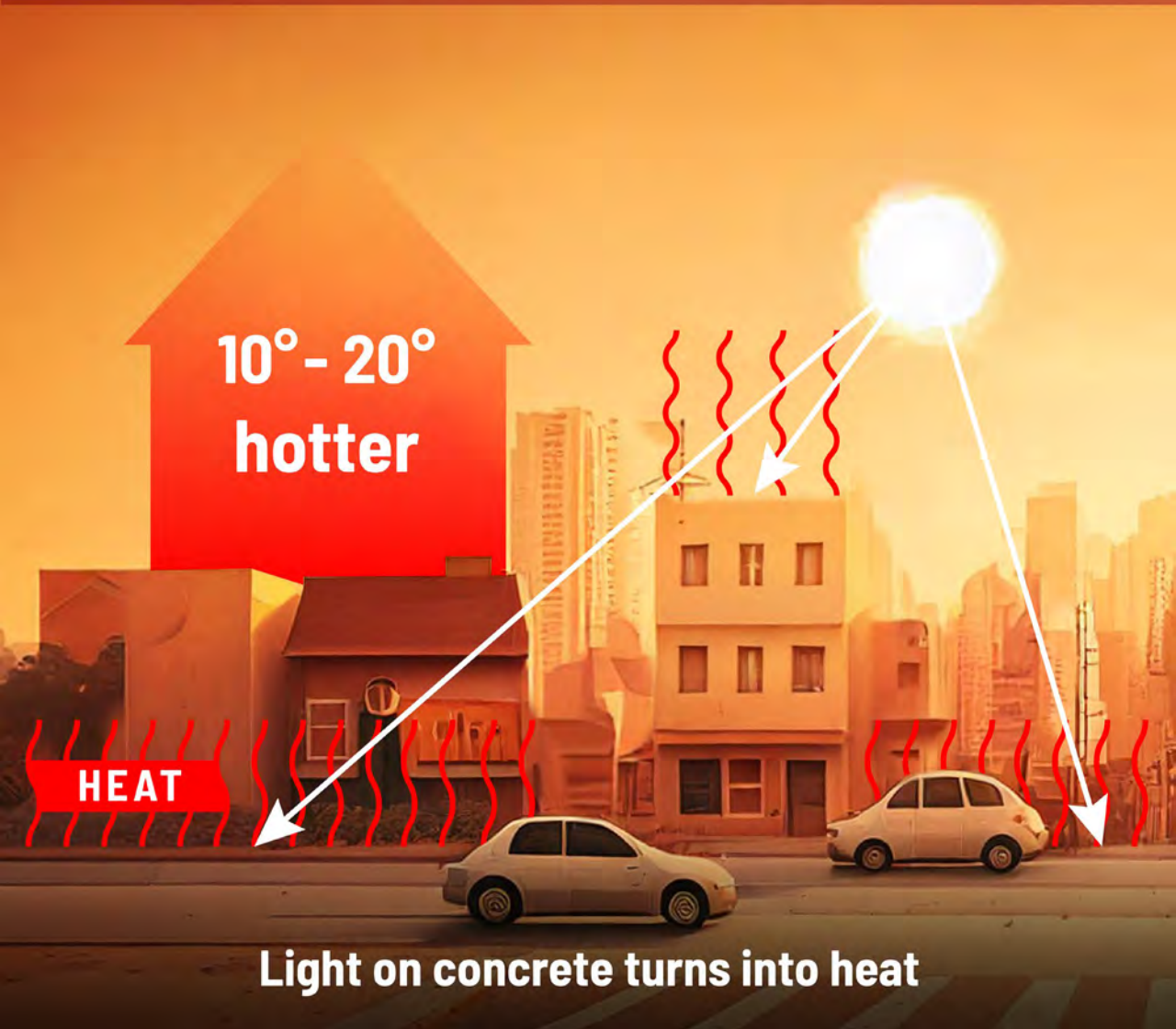


Fabio Salbitano
PhD Forest Ecology
University of Sassari

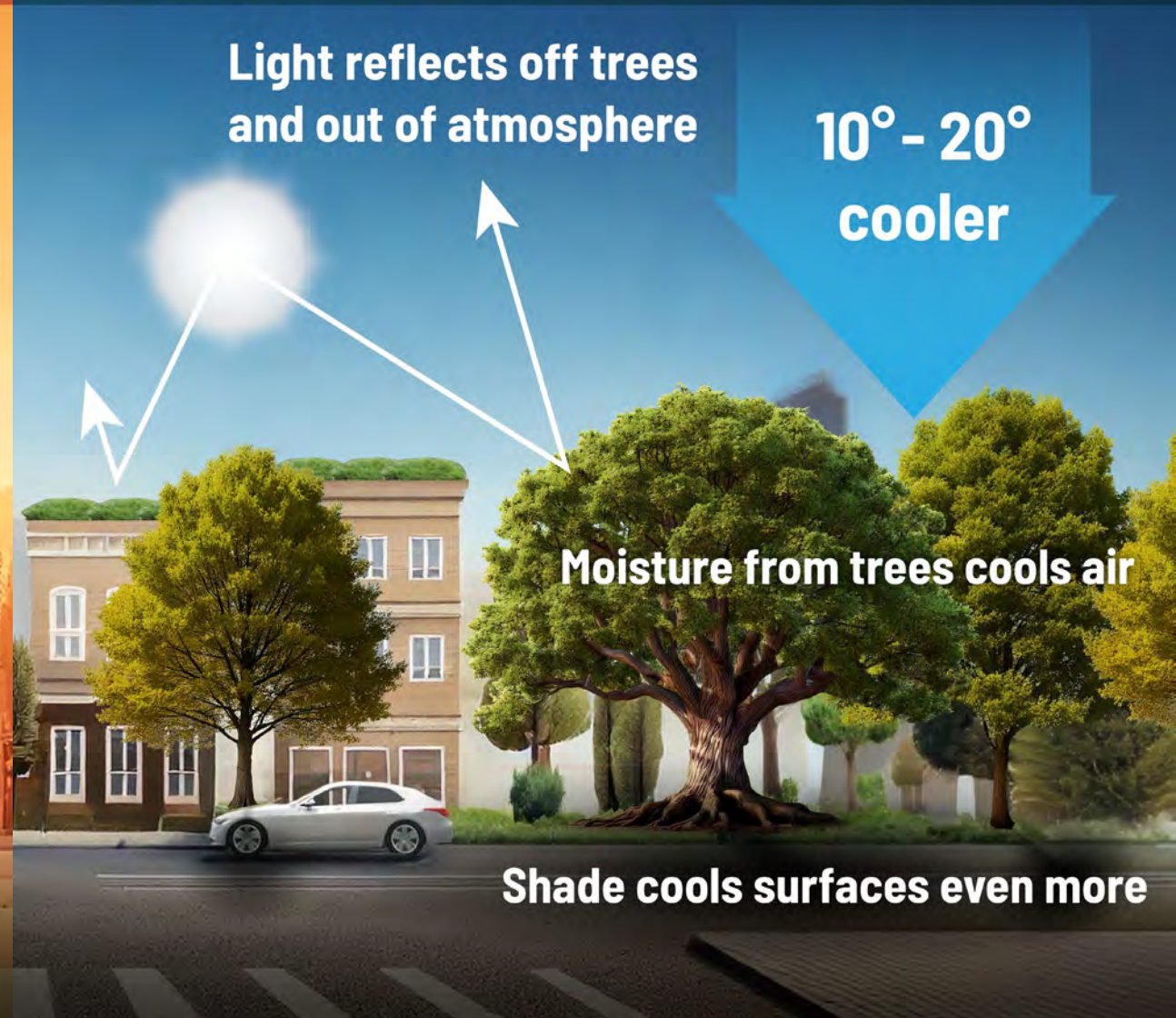


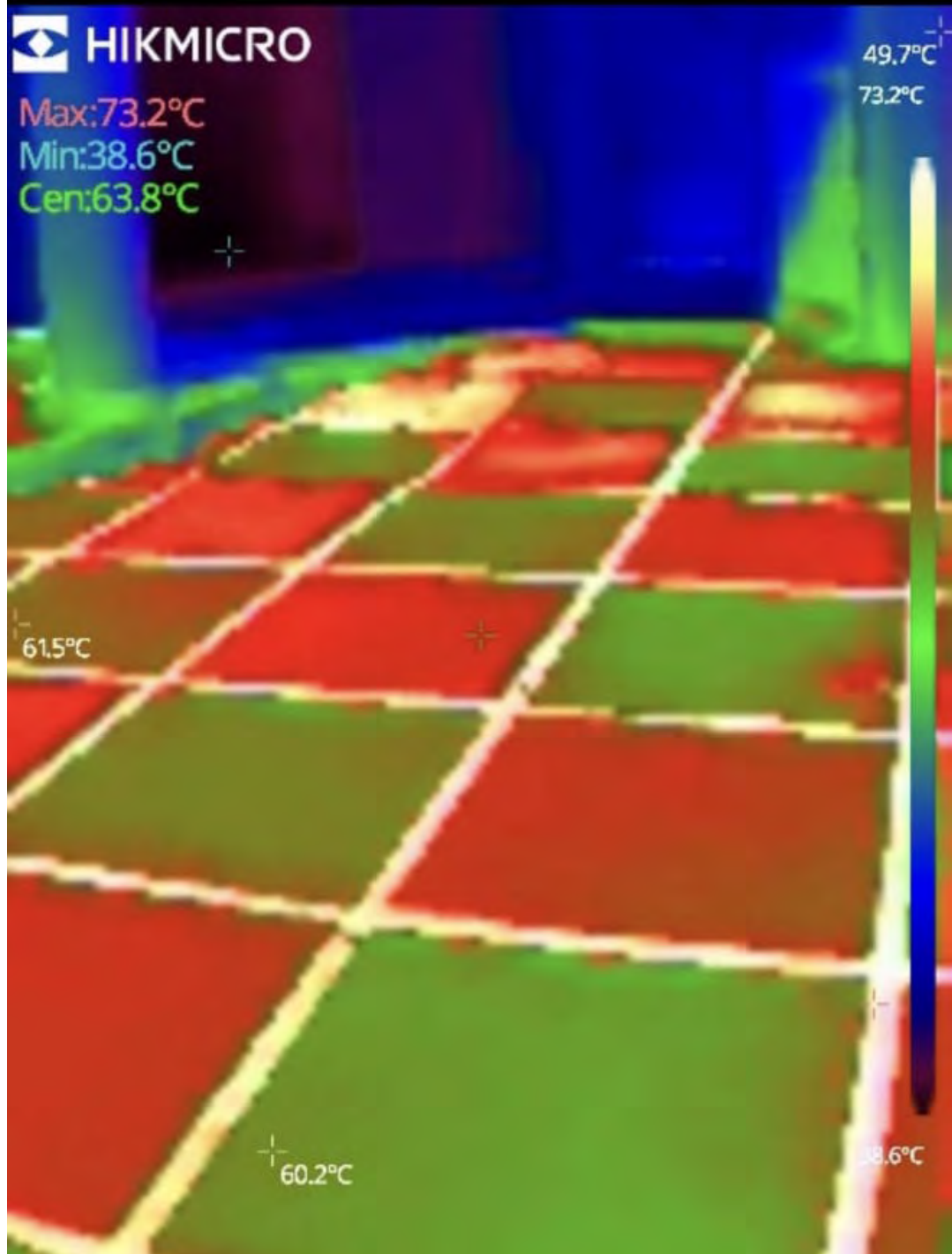
UNISS
UNIVERSITÀ
DEGLI STUDI
DI SASSARI

Urban heat island effect



Green canopy cooling effect





HIKMICRO

Max: 62.4°C
Min: 3.3°C
Cen: 54.7°C

62.4°C

43.8°C
42.5°C
43.9°C

3.3°C



Influencing factors of pavement temperature

Environmental factors

Air temperature

Total solar radiation

Wind speed; Humidity; Latitude

Atmospheric counter radiation

Material Factors

Absorption and reflection of total solar radiation

Heat conduction; Heat convection; Heat radiation

Regulating pavement temperature by changing heat transfer process

Heat radiation

Heat conduction;
Heat convection

Reflection enhancement

Increase thermal resistance

Evaporative cooling

Regulating pavement temperature based on heat harvesting, storage, and conversion

Heat exchange system

Energy storage

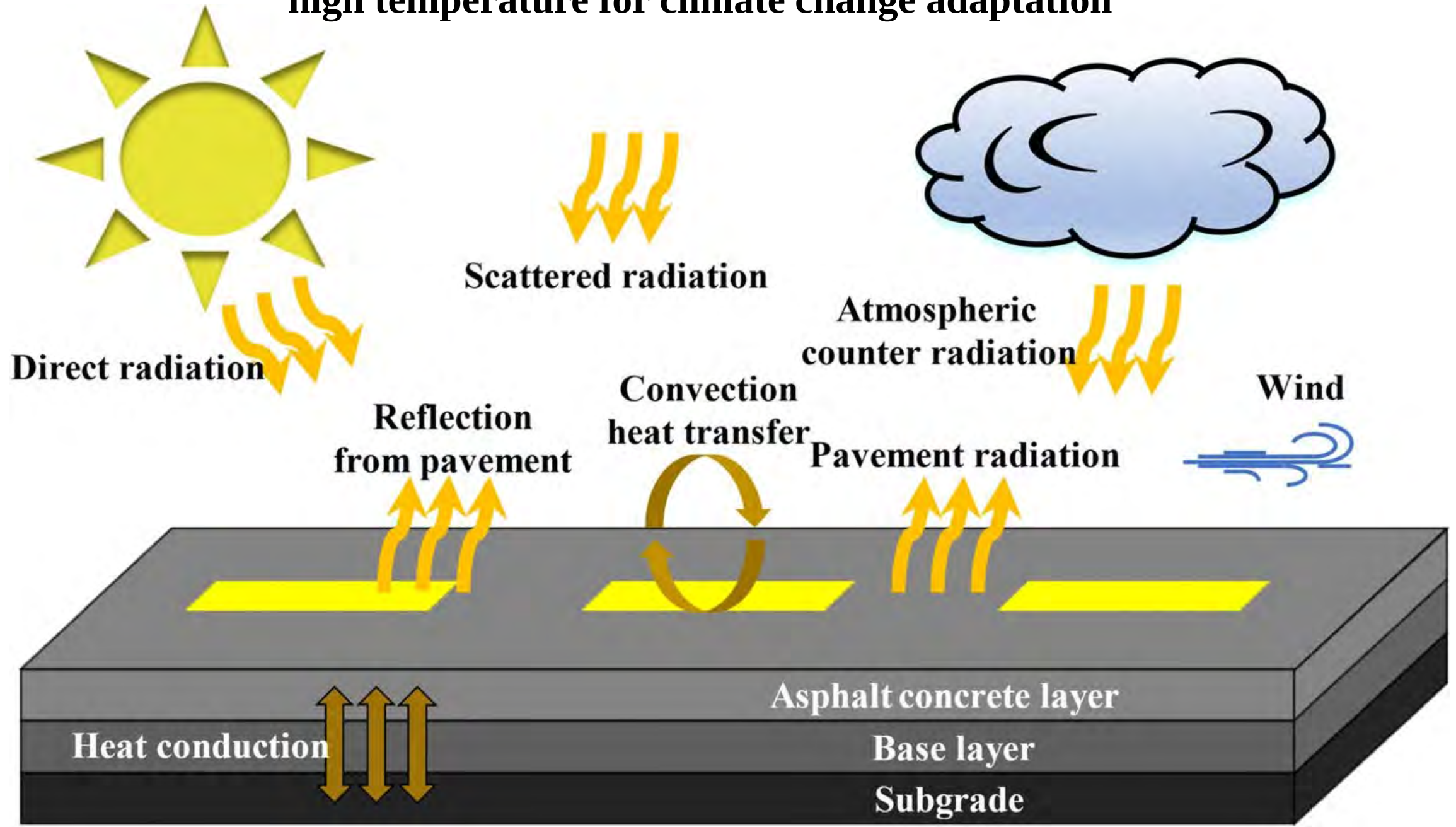
Energy conversion

Solar collector asphalt pavement

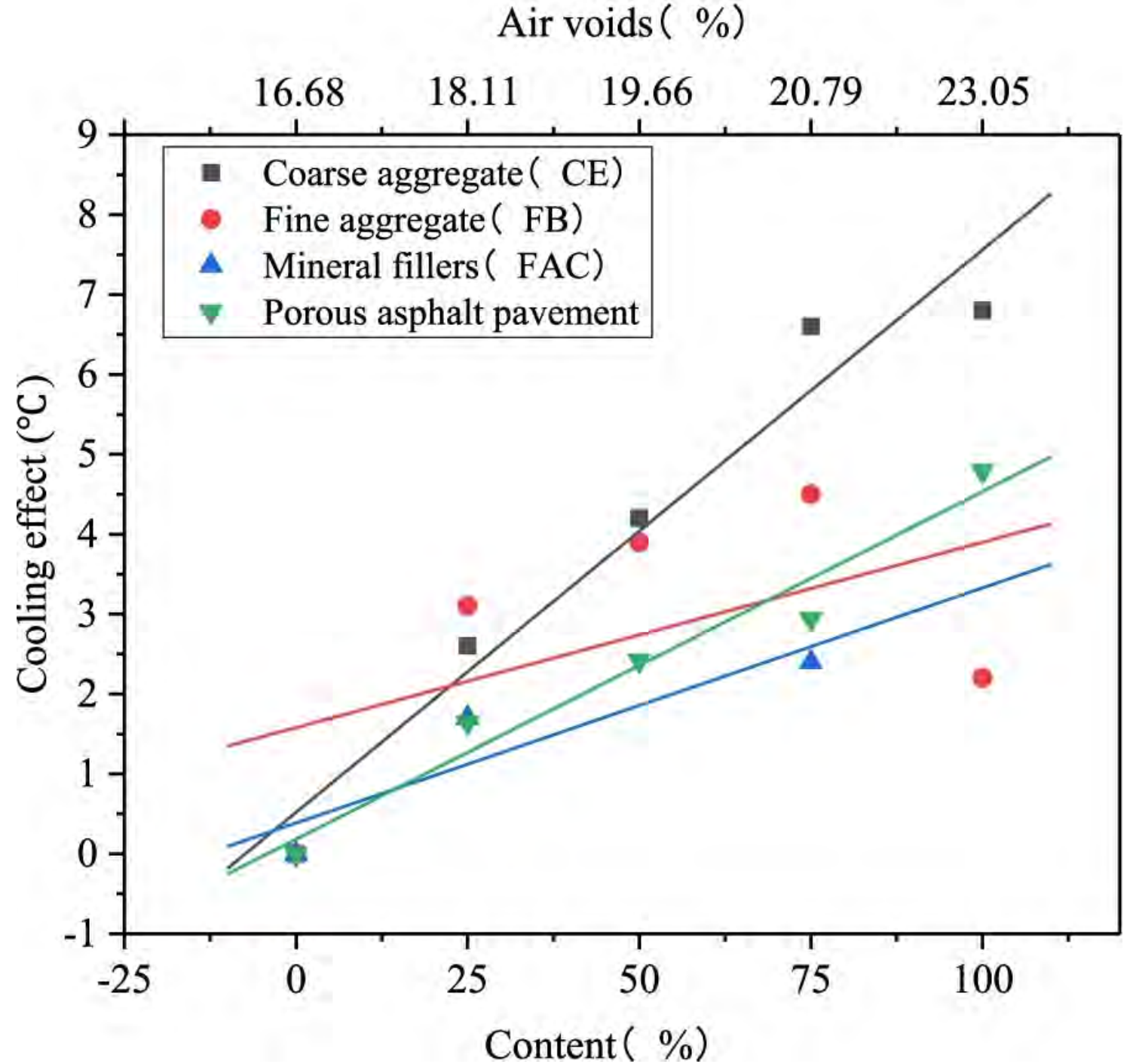
Phase change asphalt pavement

Thermoelectric asphalt pavement

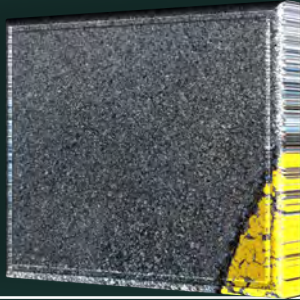
Review of regulation techniques of asphalt pavement high temperature for climate change adaptation



Cooling effect of different thermal resistant pavements



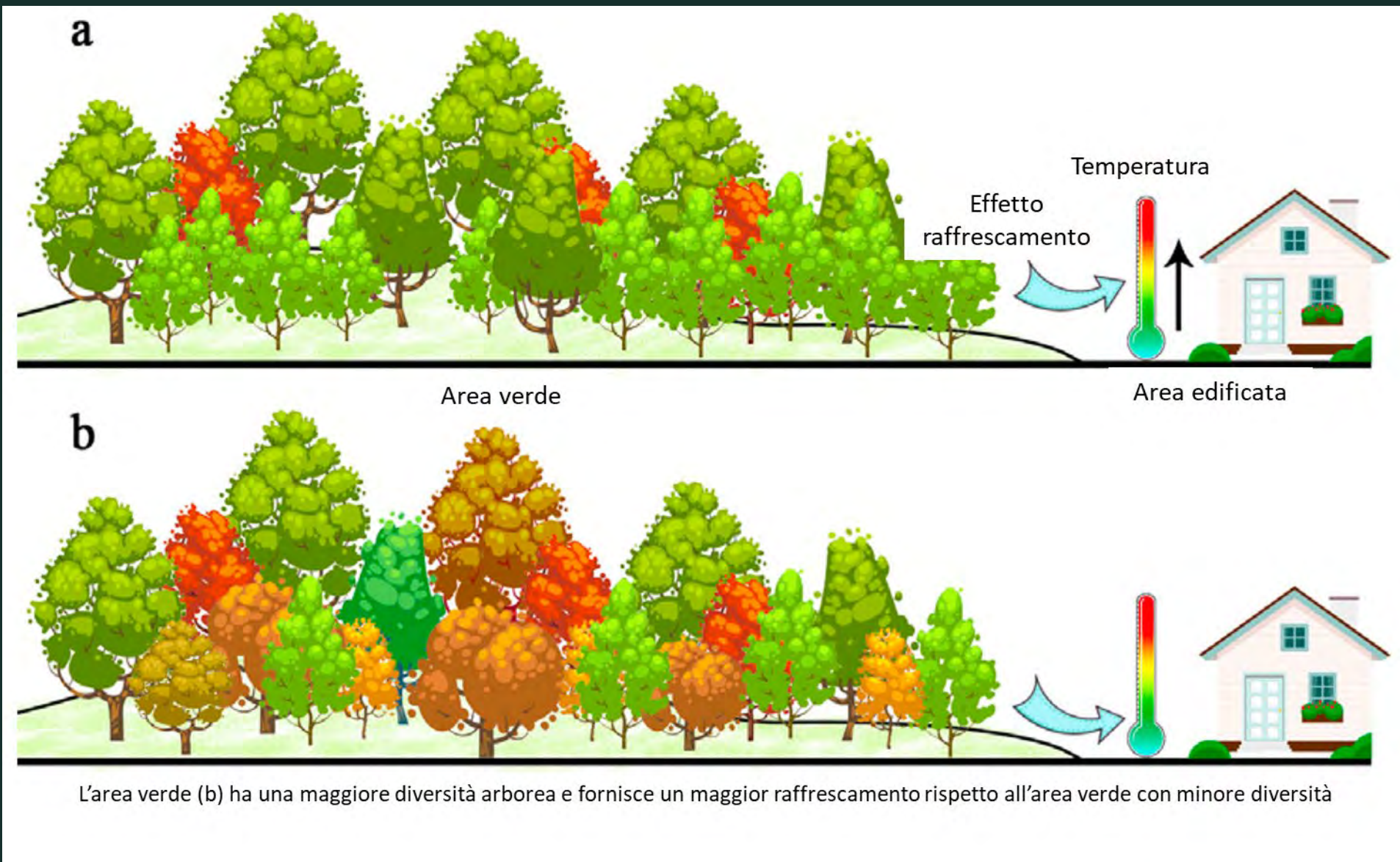
Thermal behaviour of different permeable and impervious land covers in Florence, Italy



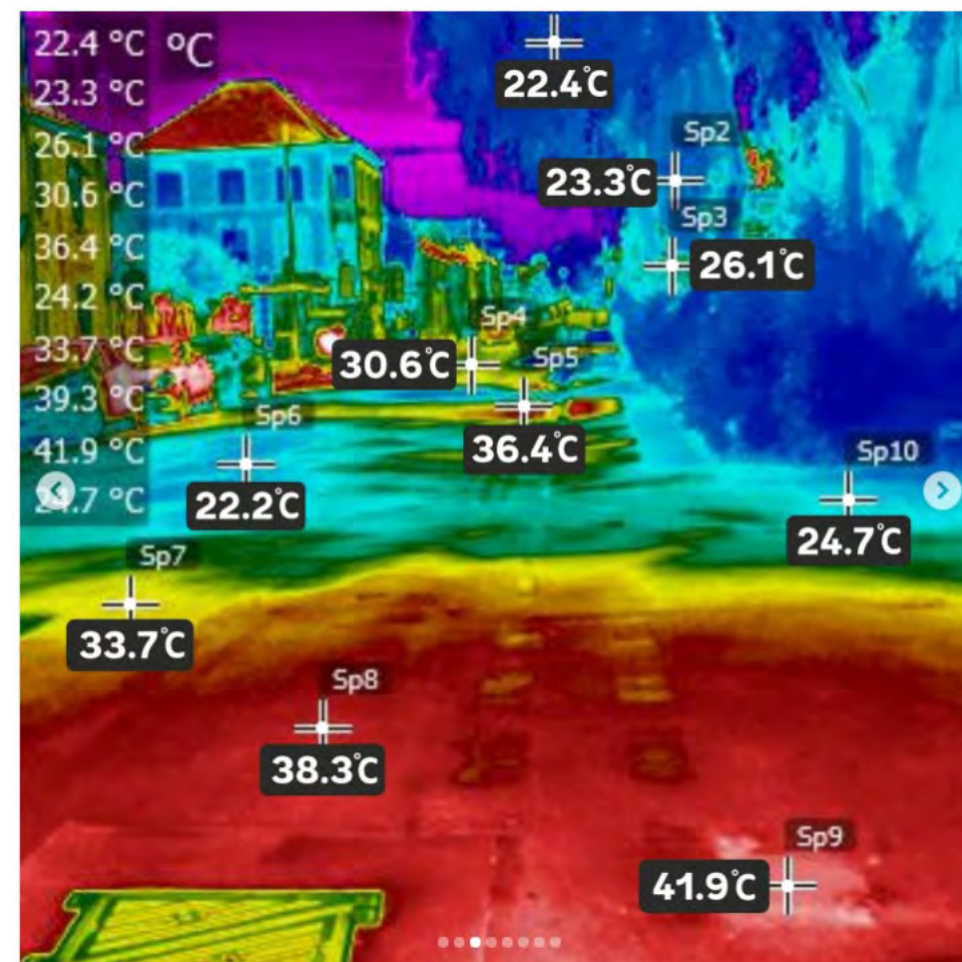
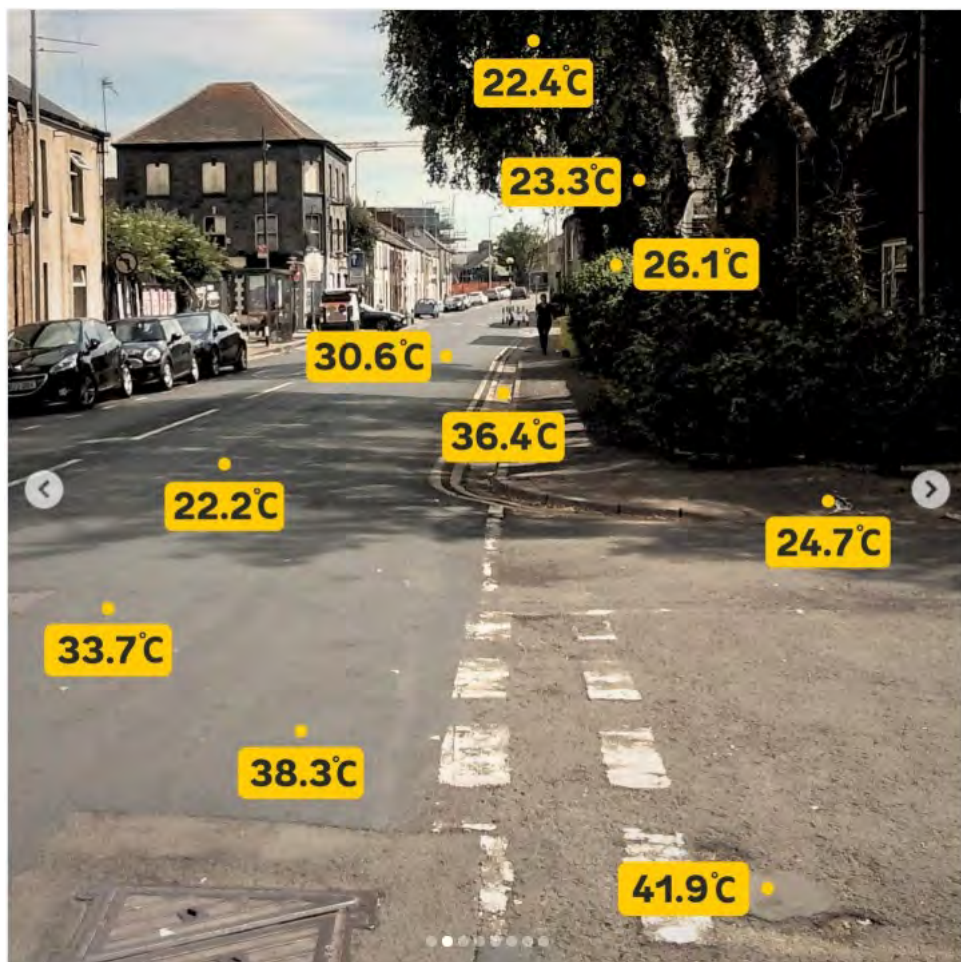
The shading effect of trees (S = shading) proved decisive even for the surface material with the poorest thermal performance.

Petralli et al. 2020 UTCI field measurements in an urban park in Florence (Italy). Miscellanea Geographica. 24, 3 • DOI: 10.2478/mgrsd-2020-0017

		Ref	Exp Grass	Exp Asphalt	S Asphalt	Exp Gravel
Ta	Mean	26.1	26.3	27.4	25.9	27.5
	Max	32.5	32.9	35.0	31.0	35.1
	Min	18.3	18.5	19.4	19.6	18.9
MRT	Mean		36.9	39.5	26.0	40.0
	Max		66.1	67.2	38.8	63.8
	Min		17.4	18.4	19.4	17.7
UTCI	Mean		27.8	29.5	25.4	29.7
	max		41.7	44.6	32.6	44.1
	min		17.4	18.4	18.8	18.0



Tree canopy cover and biodiversity are positively correlated with the magnitude of cooling (adapted from Wang et al., 2021).

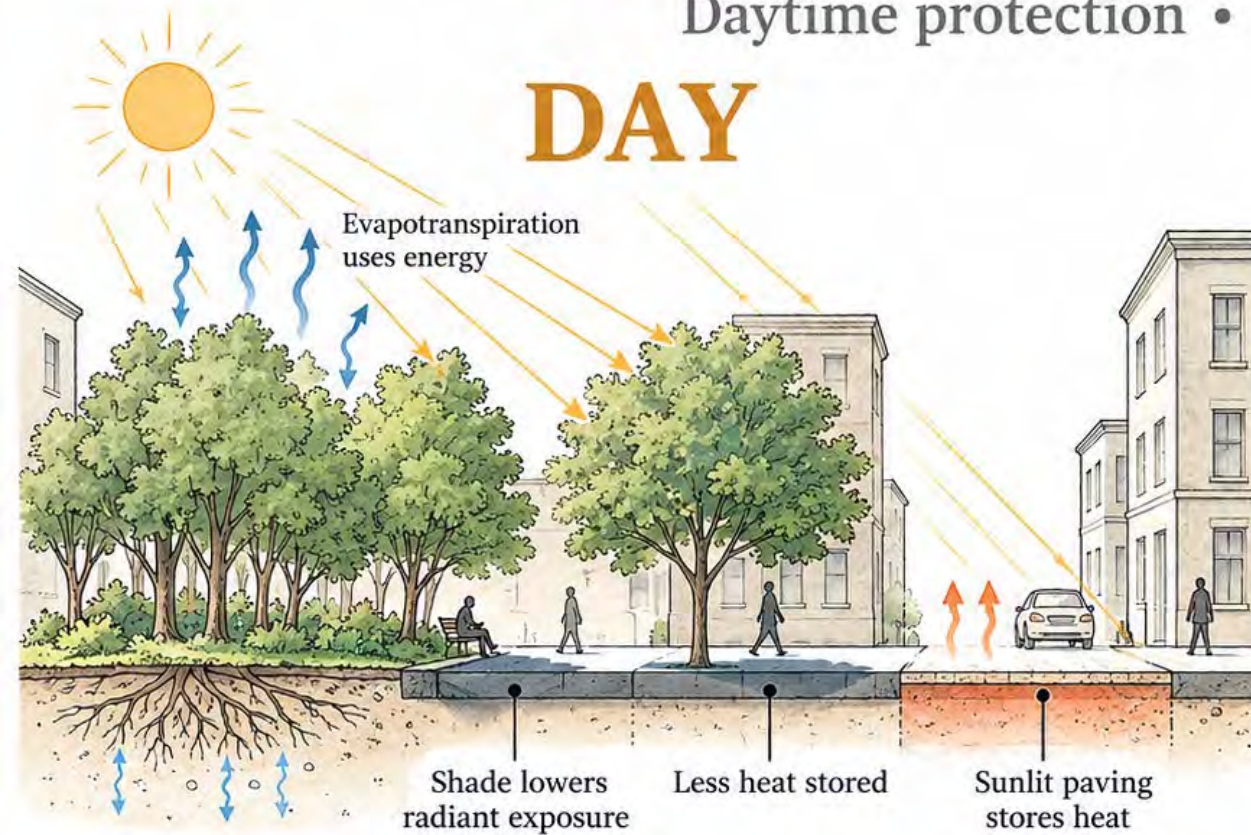




HOW TREES COOL A CITY

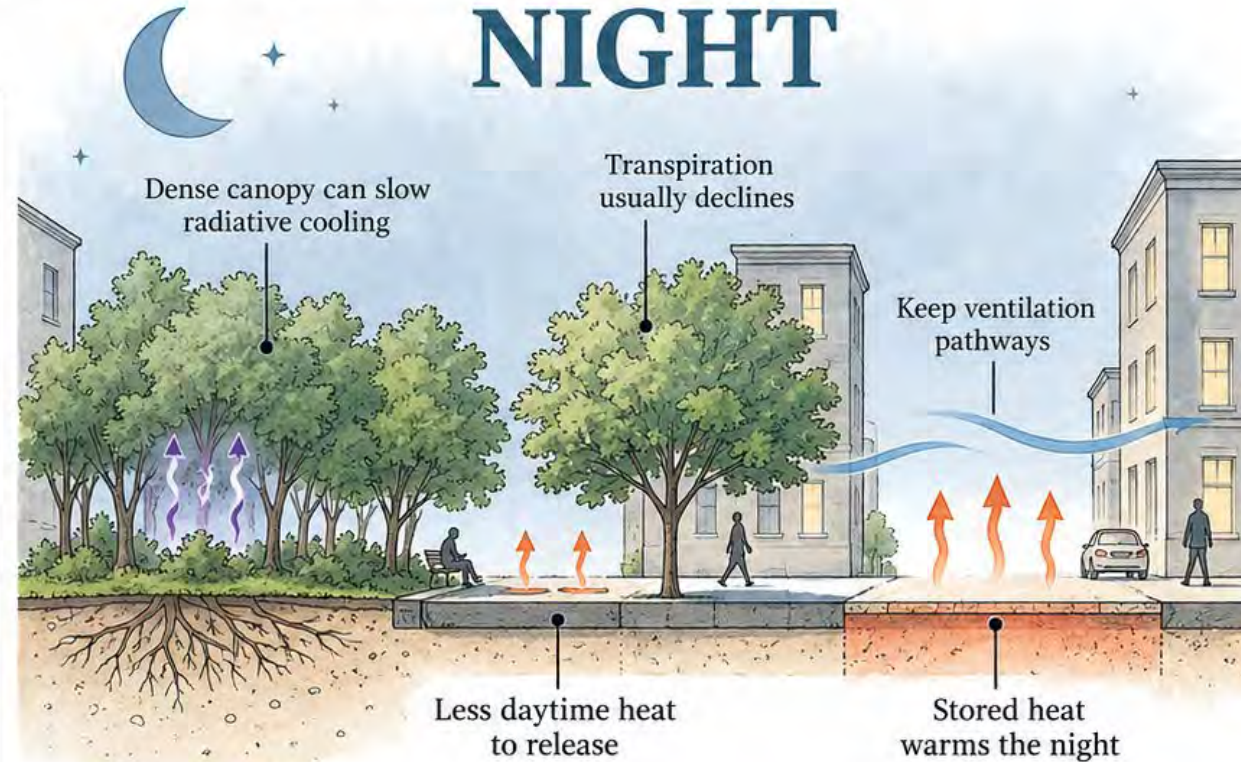
Daytime protection • Nighttime heat balance

DAY



Shade + evapotranspiration reduce daytime heat exposure.

NIGHT

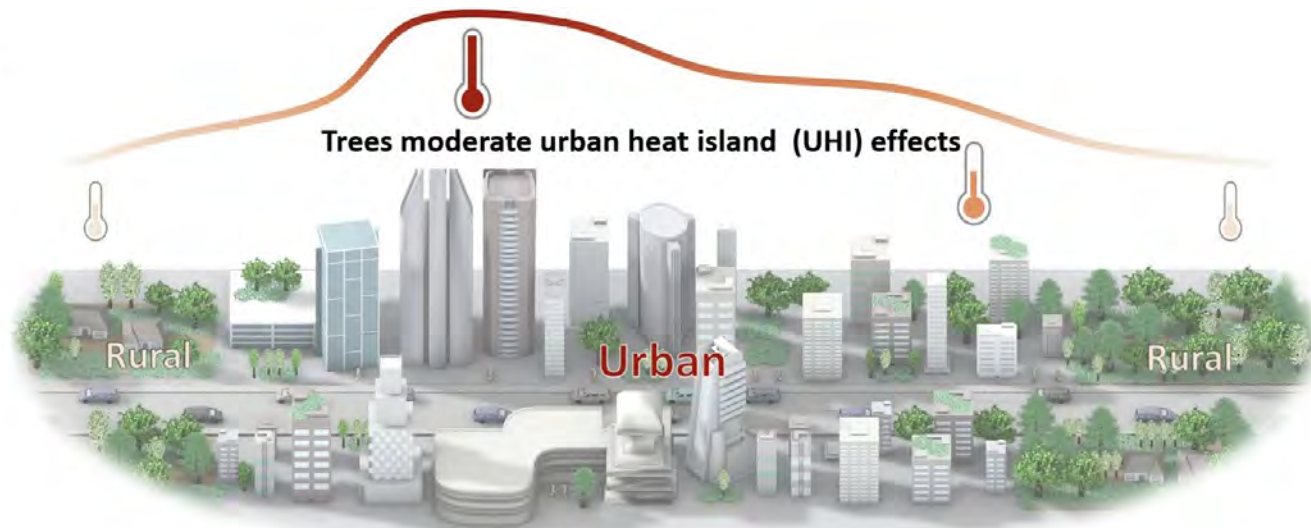


Benefits depend on stored heat, sky exposure and airflow.

Combine healthy trees, permeable soils and ventilation. Trees do not guarantee cooler air at every hour.

Conceptual sketch • Air temperature, surface temperature and thermal comfort are different measures.

(a)



(b)

How to harness cooling benefits of urban trees?



a Urban trees mitigate the urban heat island effect. **b** Cooling benefits are maximized by optimizing tree species selection and spatial placement in relation to three key components: climate, tree functional traits, and urban morphology. The cooling effect results from a combination of mechanisms, including shading (interception of incoming shortwave radiation) and transpiration. At the leaf and stomatal scales, the leaf energy balance can be expressed as follows:

$$q_{\text{sen}} \text{ (Sensible heat flux)} + q_{\text{lat}} \text{ (Latent heat flux)} = q_{\text{rad},l} \text{ (Net longwave radiation)} + q_{\text{rad},s} \text{ (Net shortwave radiation)}.$$

WHAT DOES COOLING MEAN?



Cooler surfaces

Less solar heating and heat storage



Cooler air

Shade and evapotranspiration



Lower human heat exposure

Reduce radiant heat where people spend time



Better indoor conditions

Coordinate trees and building design

Surface temperature, air temperature and thermal comfort are different outcomes.



START WITH PEOPLE AND PLACES



Prioritise everyday routes, schools, care facilities and underserved neighbourhoods

BUILD THE ECOLOGICAL FOUNDATIONS

Protect mature canopy



Provide connected rooting space



Plan a seasonal water budget



Design useful shade



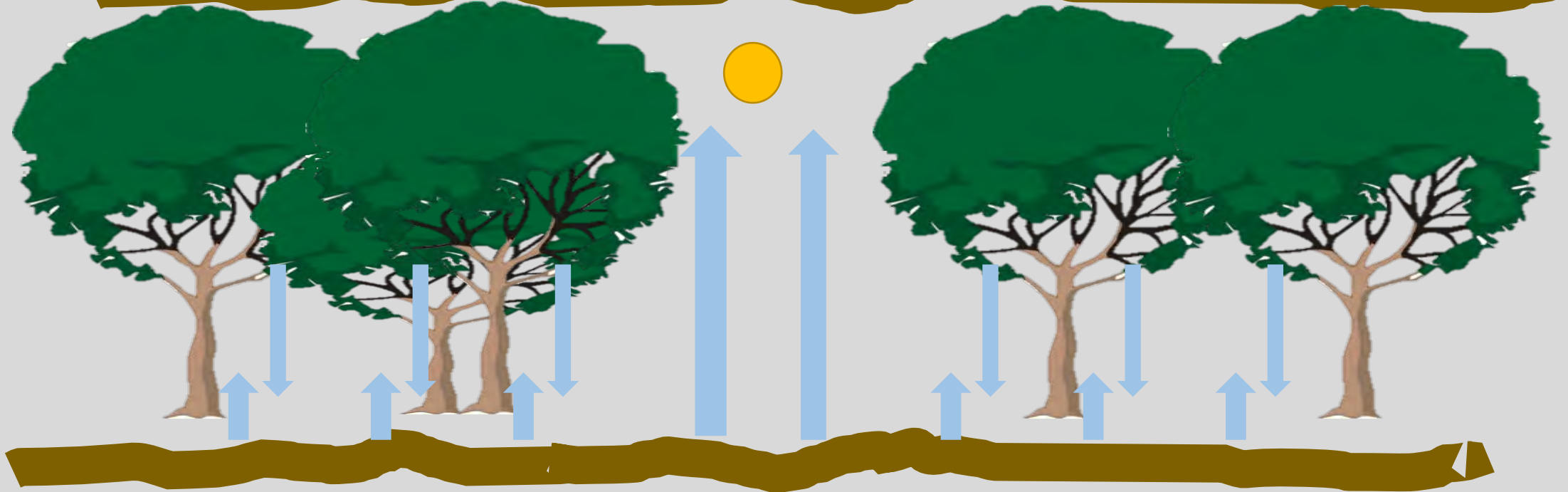
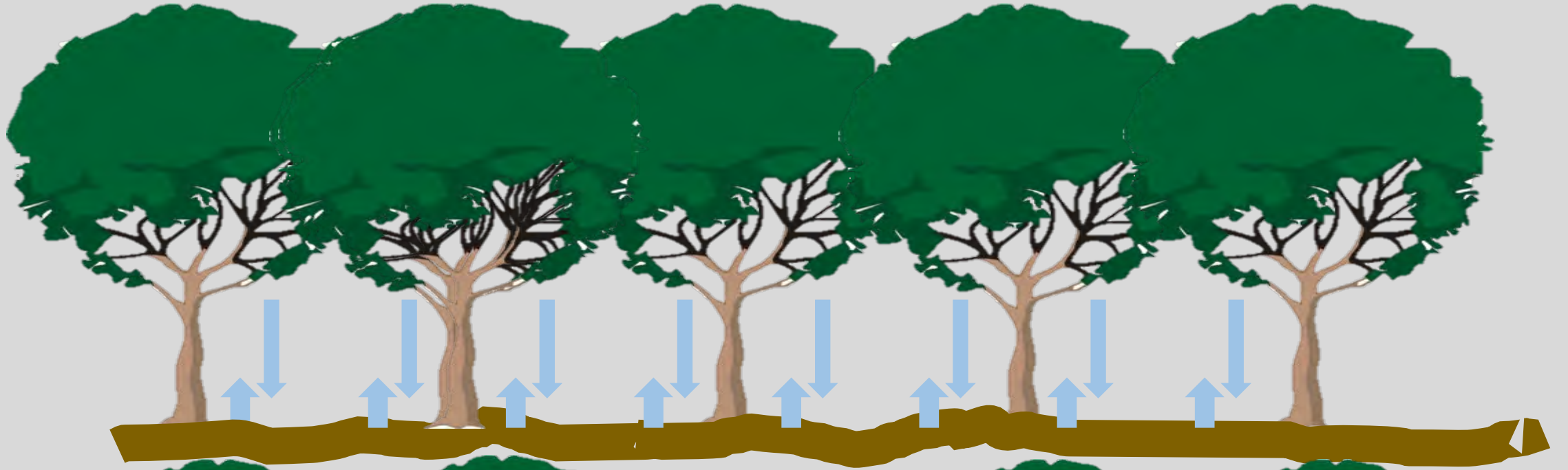
Restore permeable soil

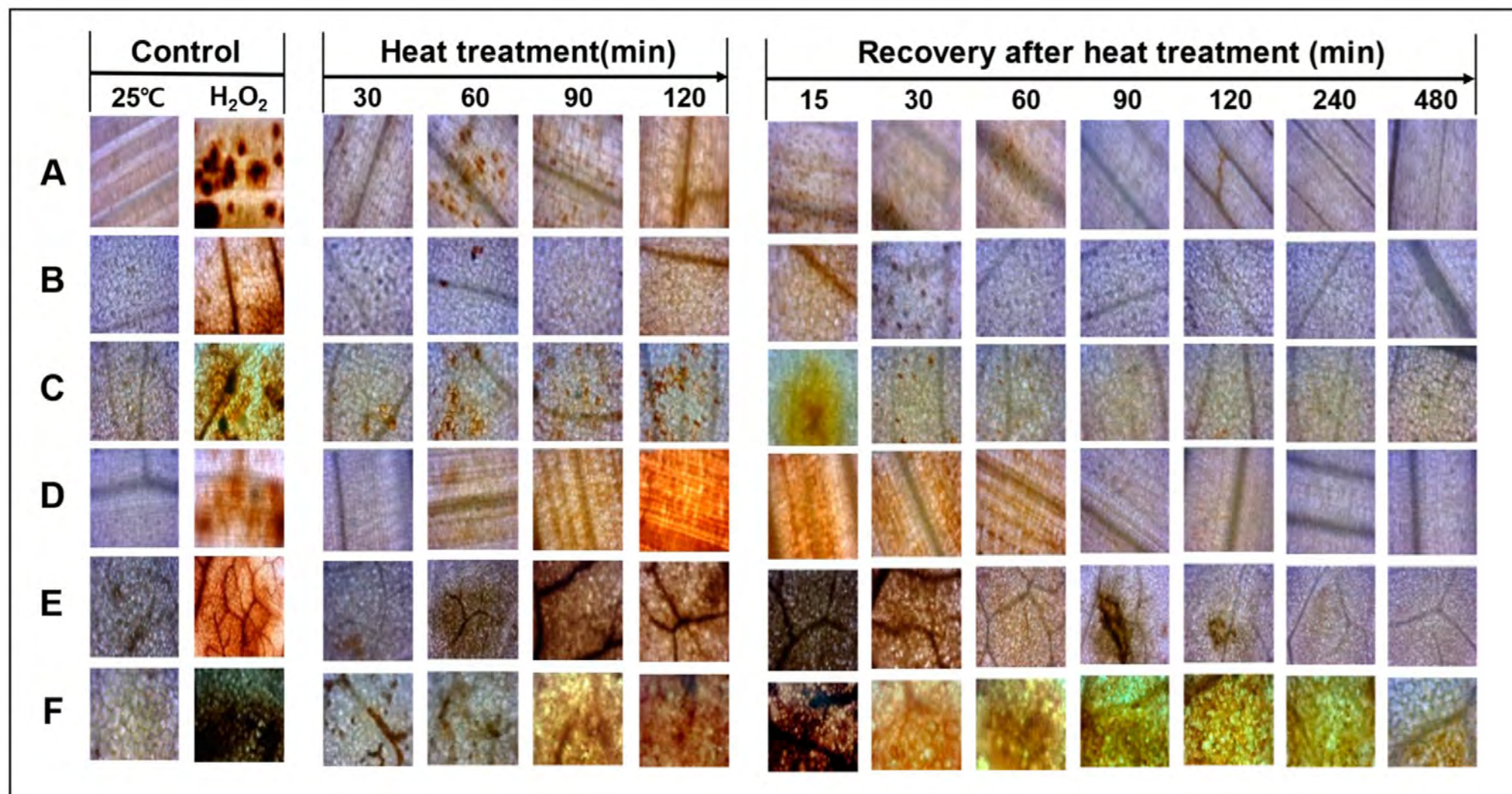


Diversify for future conditions



Drought survival does not guarantee sustained evaporative cooling.
Plan for establishment, growth and long-term care.





Development of in situ hydrogen peroxide in the selected heat-tolerant and sensitive plant species by DAB staining. Heat treatment was performed at 50 °C for 120 min. In situ hydrogen peroxide induced by heat stress was detected in the form of brown precipitates. (A): *H. fulva*, (B) *H. longipes*, (C) *H. plantaginea*, (D) *S. scilloides*, (E) *A. scaber*, and (F) *C. cyanus*.

Park, D.-J. et al. 2024. Establishment of Efficient Method for Evaluation of Heat Stress Tolerance of Herbaceous Plant Species and Selection of Heat-Tolerant Plants. *Horticulturae*, 10(12), 1290. <https://doi.org/10.3390/horticulturae10121290>

CONNECT THE SCALES



TREE & PERSON
Shade where people pause



STREET & BLOCK
Connect everyday shaded routes



PARK & NEIGHBOURHOOD
Provide accessible cool refuges



DISTRICT & CITY
Distribute benefits across neighbourhoods

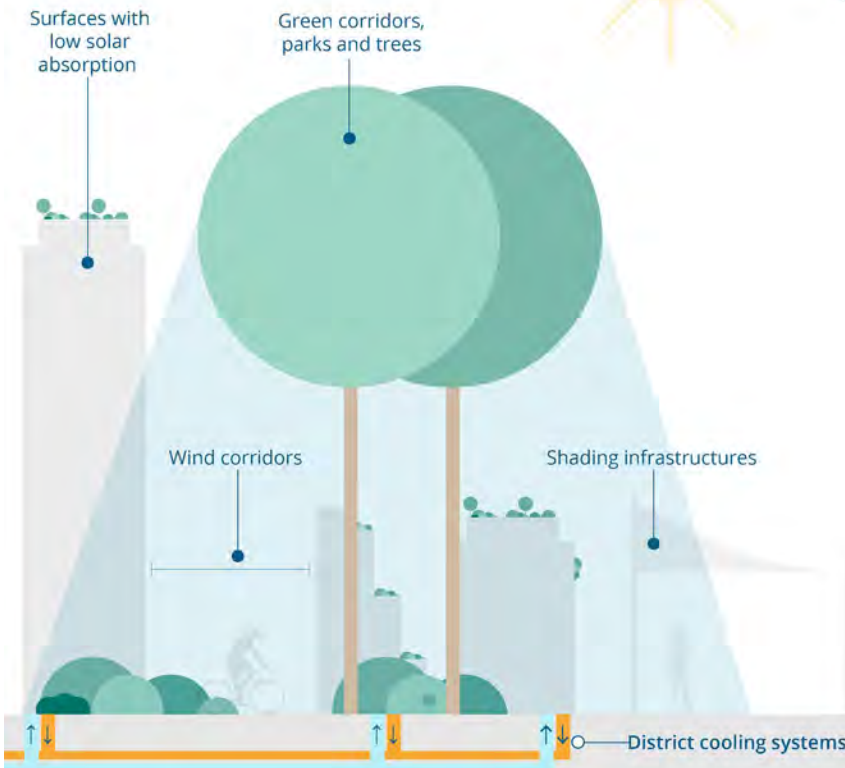


URBAN-PERI-URBAN LANDSCAPE
Protect water systems and relevant airflow pathways

Sustainably cooling buildings is about prioritising and combining all practices that reduce energy needs at **city, building, individual and technological level**, while also considering the local context and future climate change.

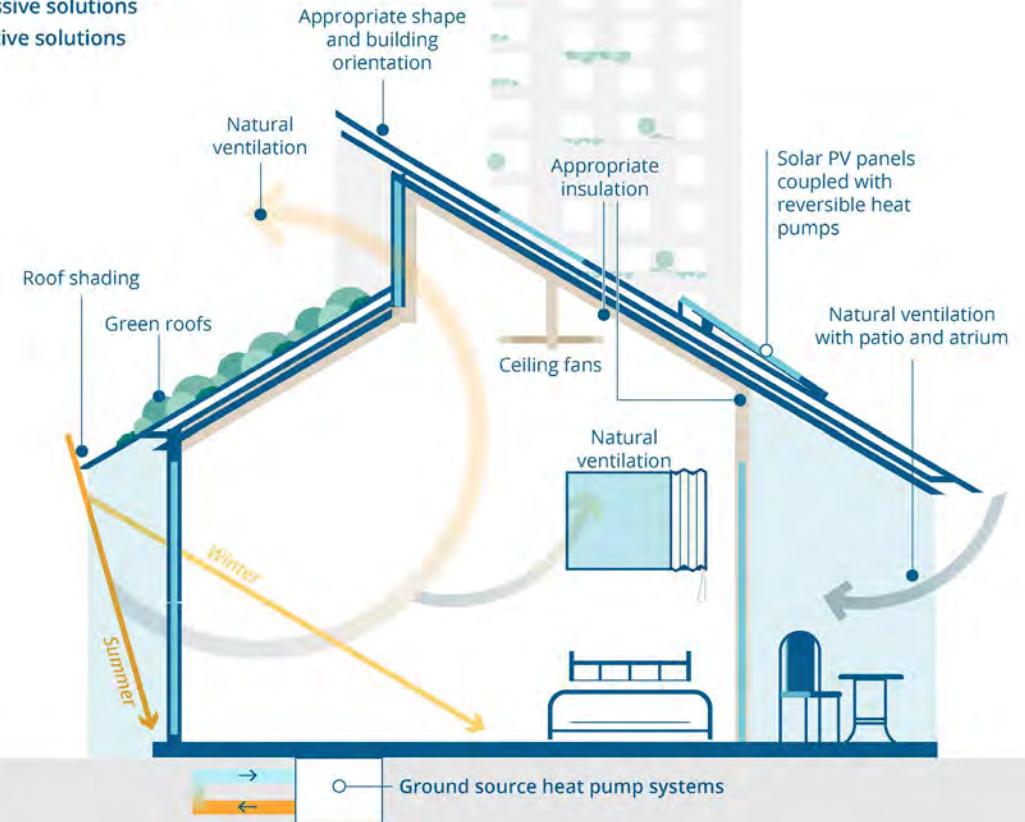
There is no one-size-fits-all solution and incorporating equitable access to cooling for the most vulnerable is part of the strategy. This visual offers non-exhaustive examples of options that can be combined and adopted.

1 City-area design



2 Building renovation and design

- Passive solutions
- Active solutions



3 Individual awareness, behaviour and good practices: non-exhaustive examples



Opening windows at night and close blinds during the day



Use of active cooling systems only if needed



Rational use of AC: e.g. set thermostat to 25°C



Targeting of tailored communication and awareness raising to the more vulnerable



Creating solidarity networks to help people look after each other



Developing low energy efficient cooling technology for extreme temperatures

4 Innovation to be considered

07. MEASURE, LEARN AND ADAPT

1. ESTABLISH THE BASELINE



Map heat, canopy, soils and exposure

2. SET LOCAL OBJECTIVES



Define people, places and critical hours

3. COMPARE DESIGNS



Test shade, water, soil and spatial options

4. VALIDATE PREDICTIONS



Check models against local measurements

5. MONITOR CHANGE



Compare before, after and reference sites

6. ADAPT MANAGEMENT



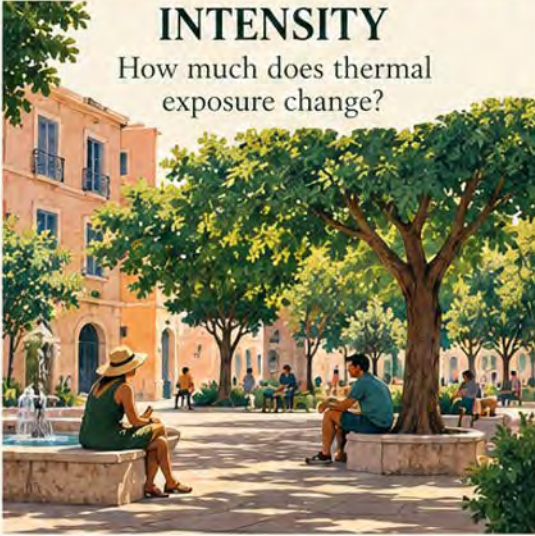
Respond to canopy loss and performance decline

Combine surface observations with pedestrian-level air, wind, humidity and radiation measurements.

08 | ASSESS THE BENEFITS THAT MATTER

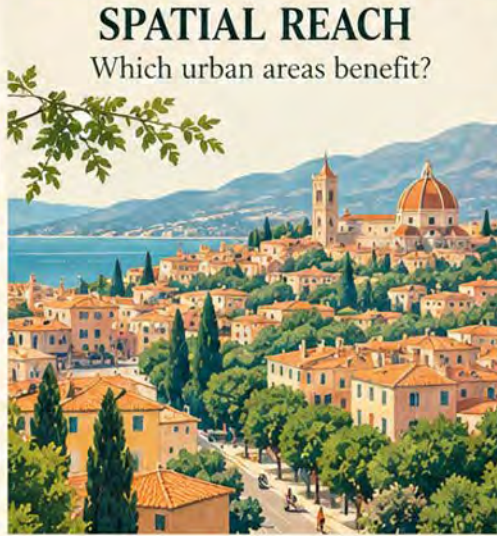
INTENSITY

How much does thermal exposure change?



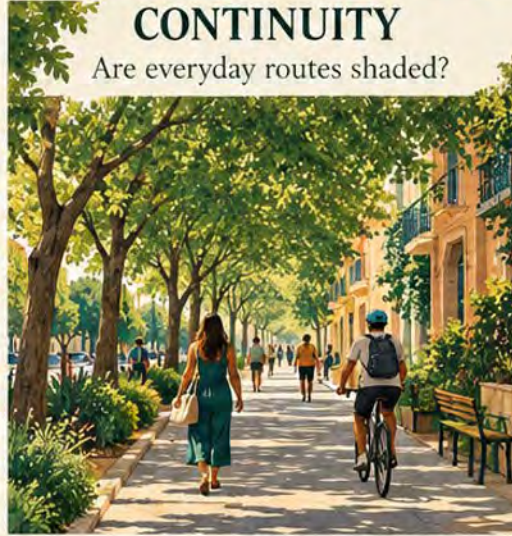
SPATIAL REACH

Which urban areas benefit?



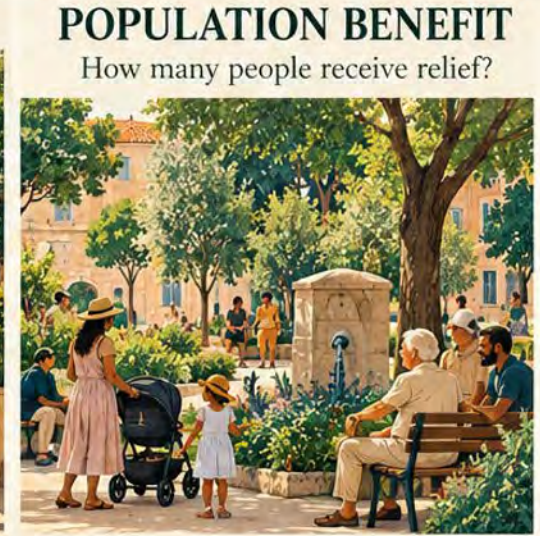
CONTINUITY

Are everyday routes shaded?



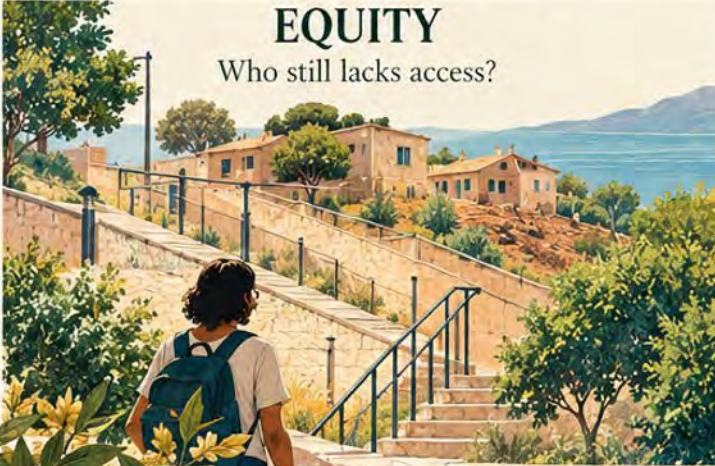
POPULATION BENEFIT

How many people receive relief?



EQUITY

Who still lacks access?



RELIABILITY

Do benefits persist during extremes?



RESOURCE DEMAND

What care, water and funding are needed?



Set local criteria, report uncertainty and keep each outcome visible.

ECOLOGICAL DESIGN
FOR COOLING CITIES

PANEL 09

MAKE COOLING LAST



COORDINATE

Urban forestry • Health • Water •
Housing • Mobility

RESOURCE THE WHOLE LIFE CYCLE

Soil preparation • Establishment •
Care • Replacement

KEEP LEARNING

Monitor outcomes • Share evidence •
Revise decisions

**Sustained reductions in heat exposure,
with priority to those facing the greatest need.**



ADAPTIVE MANAGEMENT: OBSERVE, ACT, CHECK



Monitor hot days and hot nights



OBSERVE

Track shade, soil moisture, canopy health and thermal exposure



ACT

Adjust water, soil care and replacement planting



CHECK

Repeat measurements and revise management

SUSTAIN COOLING THROUGH HEAT AND DROUGHT

ADAPTIVE MANAGEMENT OF URBAN FORESTS AND PUBLIC GREENSPACES



CARE FOR SOIL

Protect roots, reduce compaction and retain moisture.



MANAGE WATER

Use soil moisture and tree condition to guide irrigation.



RENEW THE CANOPY

Retain useful shade and plan succession.



Drought survival does not guarantee sustained evaporative cooling.



Reassess performance during heatwaves.

Adapted from: <https://www.berkeleyca.gov>



A SHADED STREET FOR EVERYDAY JOURNEYS

Tree shade • Connected planting beds • Accessible walking routes



A NEIGHBOURHOOD PARK CONNECTED TO DAILY LIFE

Cool refuges • Shaded approaches • Diverse vegetation



A SCHOOLYARD DESIGNED FOR SUMMER COMFORT

Retained mature trees • Depaving • Shaded learning and play



A COOLER SHARED RESIDENTIAL COURTYARD

Shaded façades • Restored soil • Space for air movement

COOLING CITIES WITH NATURE

Forest-based and other nature-based solutions

Protect existing trees. Restore living soils. Connect cool, accessible places.

1 MATURE TREES & URBAN WOODLANDS

Retain canopy; restore diverse, climate-adapted tree cover.

5 GREEN ROOFS & VEGETATED FACADES

Reduce building heat gains; street-level benefits vary.

6 RIPARIAN BUFFERS & RESTORED WETLANDS

Combine vegetation and water; assess local humidity and airflow.

3 PARKS, POCKET PARKS & SCHOOLYARDS

Create nearby thermal refuges where people need them.

4 DEPAVING & RAIN GARDENS

Restore permeable soil; retain runoff to support vegetation.

2 SHADED STREETS & GREEN CORRIDORS

Connect homes, schools and transport with shaded routes.

SHADE

Less solar radiation reaches people and surfaces.



EVAPOTRANSPIRATION

Water evaporation uses energy; cooling depends on available water.



SOIL-WATER SUPPORT

Healthy soils sustain roots, canopy and transpiration.

DESIGN FOR LASTING, EQUITABLE COOLING



Prioritize heat-exposed, underserved neighbourhoods.



Provide rooting space, drought planning and long-term care.



Match species and canopy layout to climate, biodiversity and ventilation.



Co-design with communities; fund maintenance and adapt.

MEASURE WHAT PEOPLE EXPERIENCE



Monitor shade, tree survival, air temperature and thermal comfort.



Surface temperature $\neq$ air temperature $\neq$ human heat stress.



Cooling varies with climate, water, urban form, canopy maturity and time of day.



Cooling Pavilion for Hot Cities

All mad about Nature Based Solutions



The need of integration of NBS in urban planning, design and management



Urban green strategies

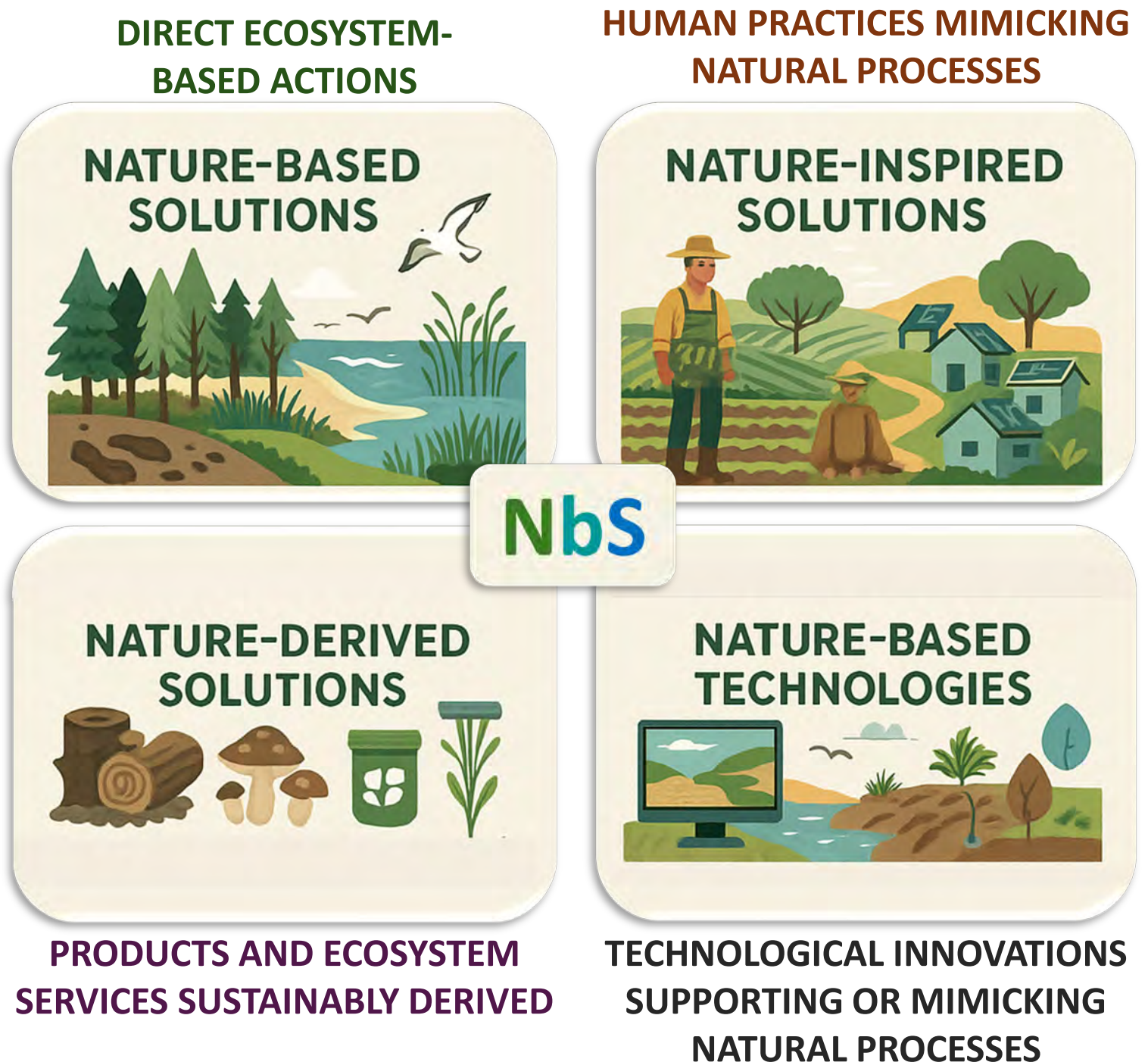
Nature Based Solutions

Co-planning, co-design

Governance, social justice

Nature Based Thinking

NBS beyond NBS





POLITECNICO
MILANO 1863

CATALOGUE OF NATURE-BASED SOLUTIONS FOR URBAN REGENERATION



**E &
UP**

ENERGY & URBAN PLANNING WORKSHOP

Fall semesters 2018 & 2019

School of Architecture Urban Planning and Construction Engineering

Master of Science in Urban Planning and Policy Design

Instructors: Eugenio Morello, Stefano Pareglio

Teaching Assistants: Nicola Colaninno, Israa Mahmoud, Mattia A. Rudini, Ahmed ElDesoky, Federica Rotondo

Graphical Editor: Zeynep Ann Ilhan

Final Report

Version 4 - 24 September 2019

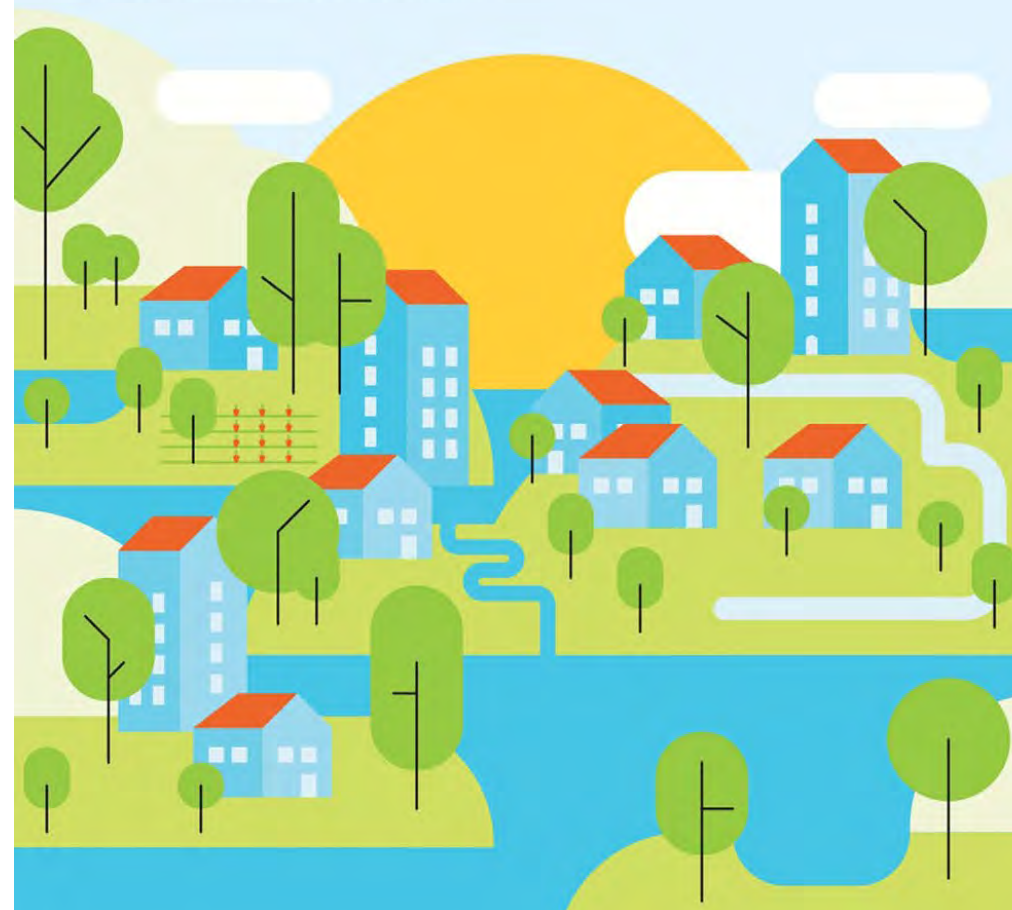
UN 
environment
programme

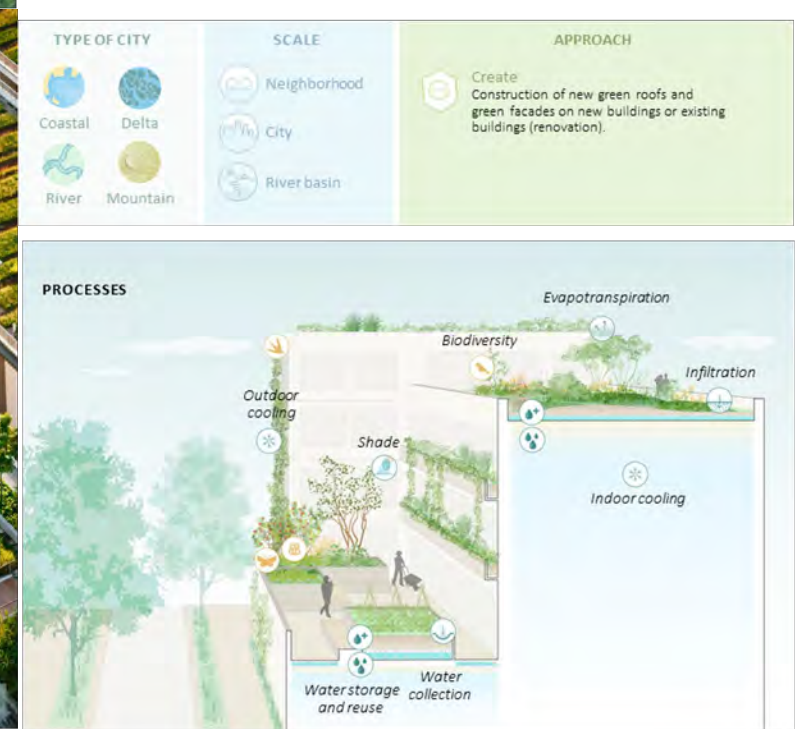
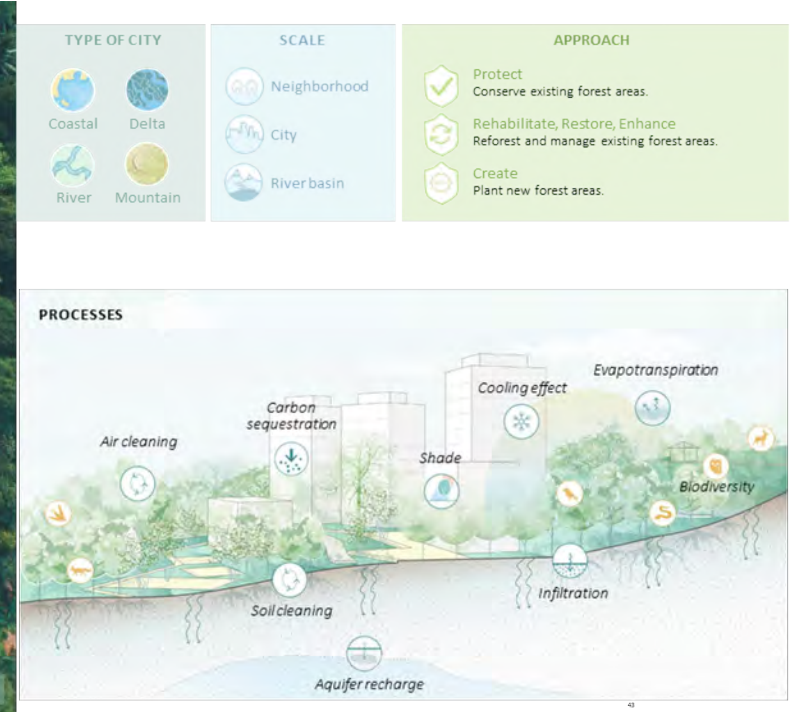
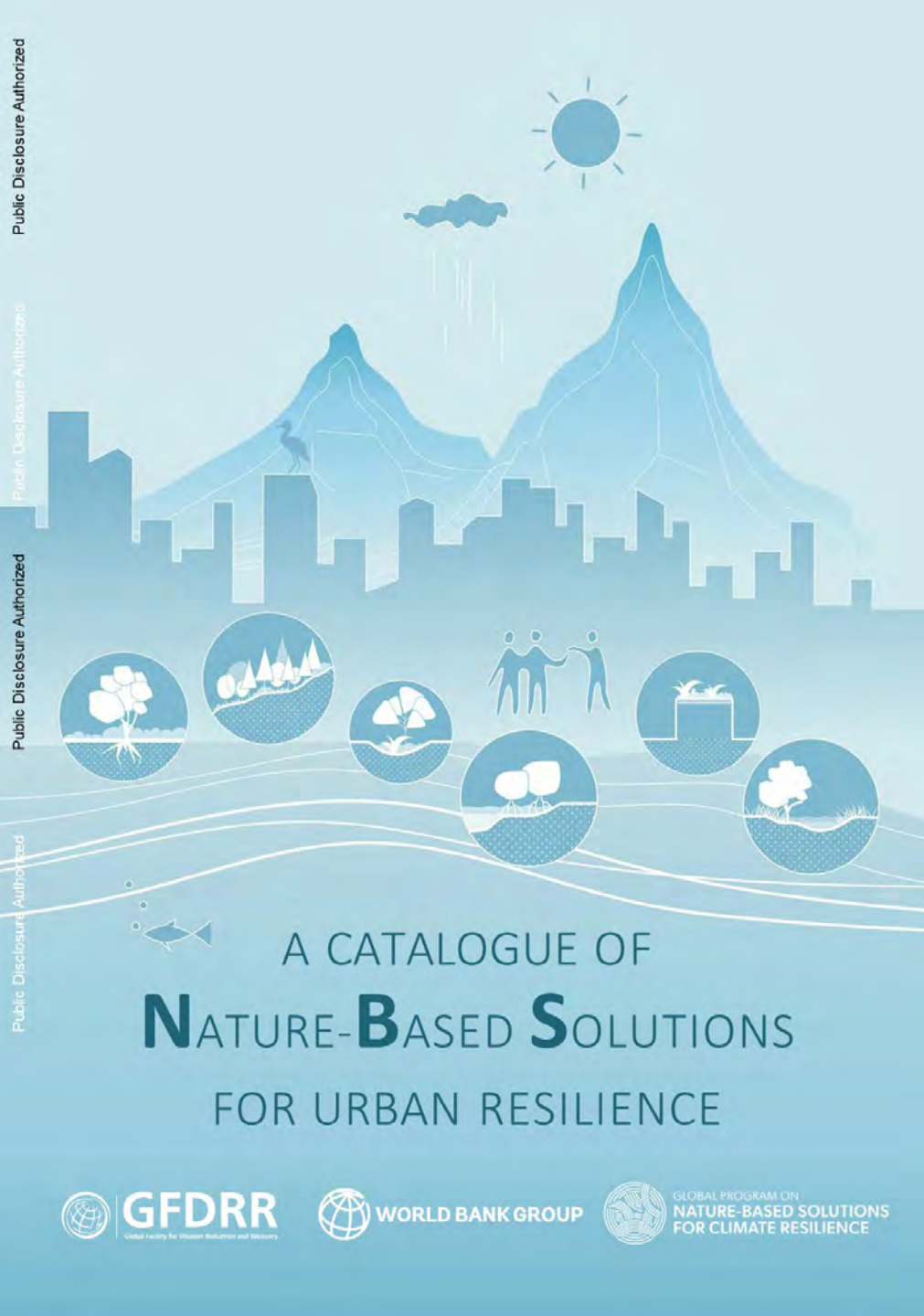
 **UNOPS**



NATURE-BASED INFRASTRUCTURE

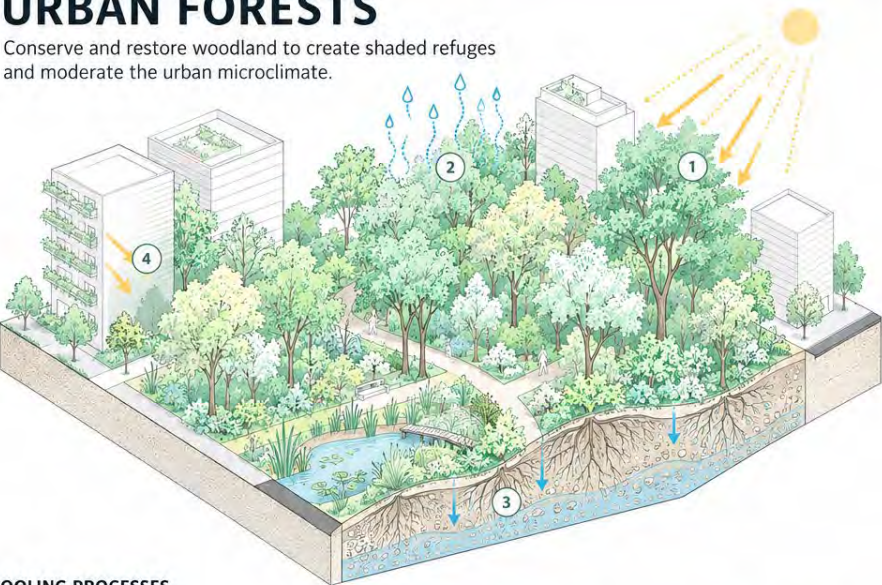
How natural infrastructure solutions
can address sustainable development
challenges and the triple planetary crisis





URBAN FORESTS

Conserve and restore woodland to create shaded refuges and moderate the urban microclimate.



COOLING PROCESSES

1

Canopy shade reduces radiant heat exposure and surface heating.

2

Evapotranspiration transfers energy into water vapour.

3

Permeable, rooted soils retain water that supports transpiration.

4

Cooler shaded surroundings can reduce building heat gains.

DESIGN & SUITABILITY

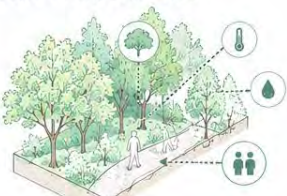


- Protect mature trees.
- Diversify locally suitable species.
- Provide connected rooting space and drought-resilient water management.
- Balance shade with ventilation.

BENEFITS

- Thermal refuge for people and wildlife.
- Biodiversity and habitat provision.
- Runoff regulation and water infiltration.
- Recreation and improved quality of life.

VERIFY PERFORMANCE



- Measure canopy cover and shaded route length.
- Monitor air and surface temperature.
- Assess soil moisture.
- Evaluate pedestrian thermal comfort against a comparable unshaded site.

EVIDENCE

Cooling is well established, but its magnitude and reach depend on canopy, water, weather and urban form. Surface cooling is not the same as air cooling.

OPEN GREEN SPACES

Create accessible parks and gardens that combine shade, living soils and vegetation as everyday heat refuges.



COOLING PROCESSES

1

Tree canopy reduces radiant exposure.
Trees and vegetation provide shade, reducing direct sunlight and radiant heat for people in parks and gardens.

2

Vegetation and moist soils provide evapotranspiration.
Plants release water through their leaves and moist soils evaporate, using heat from the surroundings and cooling the local environment.

3

Replacing sealed surfaces changes heat storage and water balance.
Permeable soils and vegetation store less heat than sealed surfaces and allow rainwater to infiltrate, maintaining soil moisture for ongoing cooling.

4

Airflow may extend cooling beyond the park edge.
Cooler air generated within the park can be transported by local winds, providing cooling benefits in adjacent streets and neighbourhoods.

DESIGN & SUITABILITY



- Prioritize heat-exposed neighbourhoods.
- Combine tree canopy with permeable ground and diverse vegetation (trees, shrubs, meadows).
- Shade entrances, seating and play areas.
- Secure a sustainable summer water supply.

BENEFITS

- Improved thermal comfort for everyday use and outdoor activities.
- Recreation and social wellbeing.
- Health benefits through cooler, greener environments.
- Biodiversity and habitat for urban wildlife.
- Runoff regulation through greater infiltration and soil water storage.

VERIFY PERFORMANCE



- Compare conditions in shaded and open areas within the park.
- Assess air temperature along edge transects.
- Monitor soil moisture to ensure continued cooling from vegetation.
- Map access to usable shade for the local community.

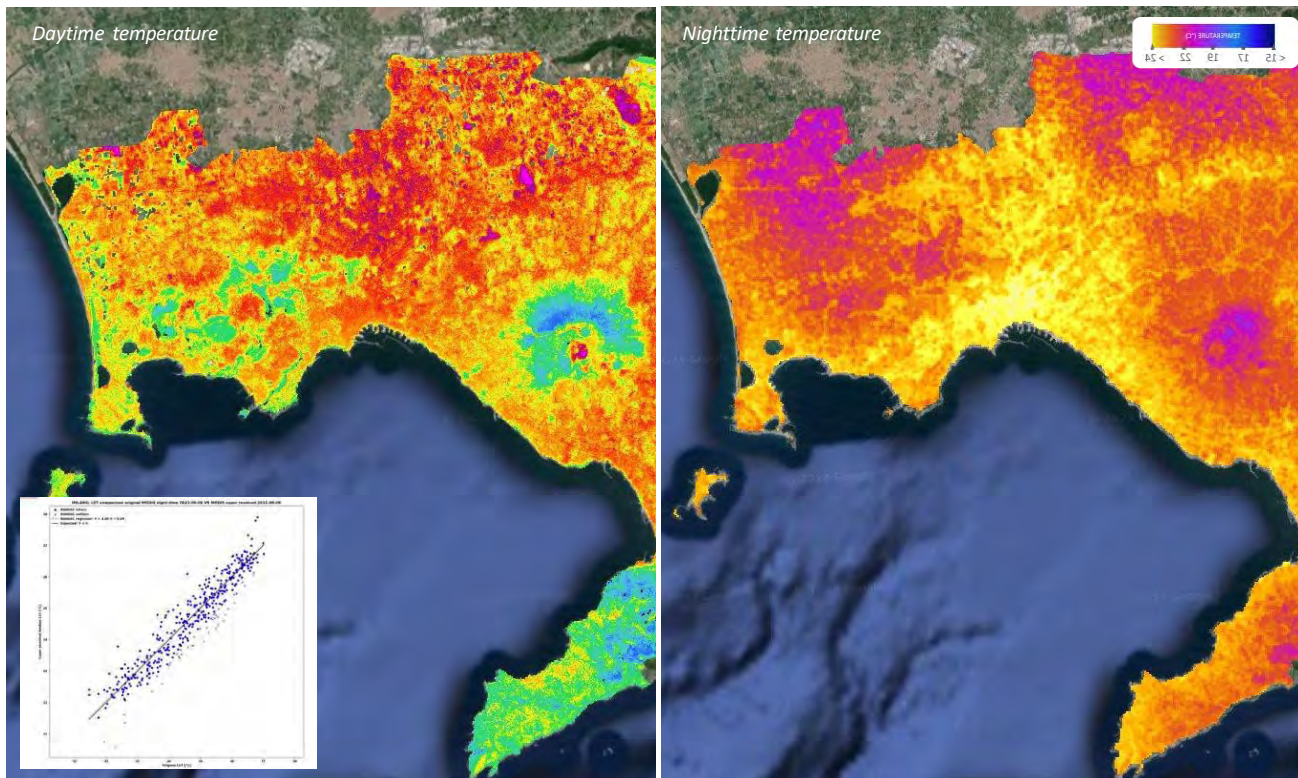
EVIDENCE



Park cooling depends on size, canopy, moisture and surrounding urban form. A dry, exposed lawn does not provide the thermal protection of tree shade.

TEMPERATURE ASSESSMENT (B.2)

The Temperature Assessment service delivers a detailed mapping of the **land surface temperature and heath island severity** in the urban area. The products support the administrations in understanding the heath island phenomenon and planning interventions to mitigate the negative effects of warming. The temperature and heat islands are assessed **frequently at day and night at high spatial resolution** and provided as monthly and/or medium to long-term averages (annual averages of temperatures from June to September, quadrennial, 10-years, custom, etc.). Statistical analysis can be extracted and periodically reported. Data are available during the year, from January to December, to evaluate the phenomenon in summertime and wintertime. The results have been validated using ground stations.

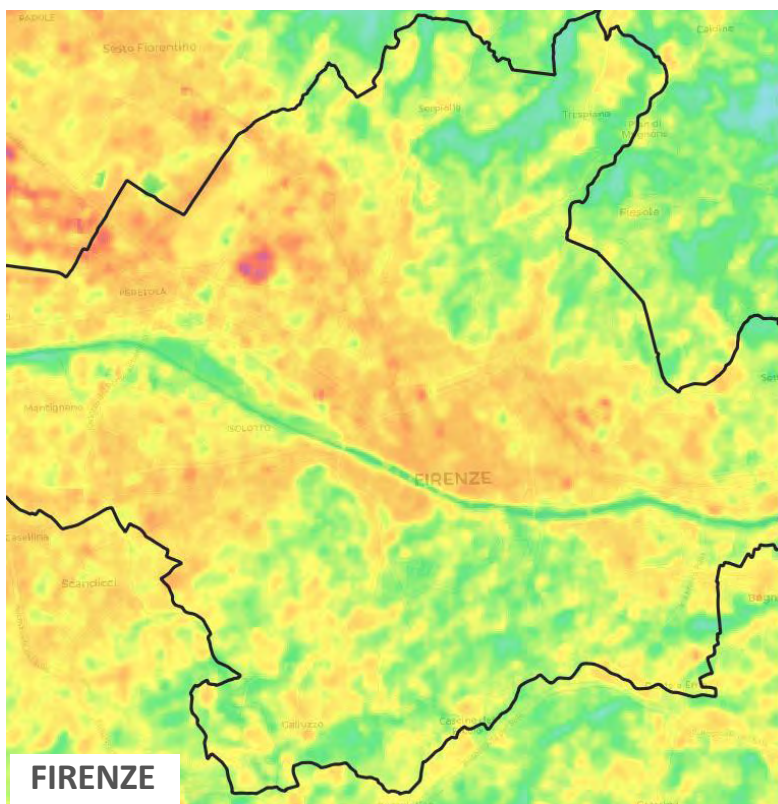


SPATIAL RESOLUTION	10m/100m
TEMPORAL RESOLUTION	Monthly (from January to December), medium to long-term averages (annual, quadrennial, 10 years, etc.). Daytime and nighttime
GEOGRAPHICAL COVERAGE	Global
DATA INPUTS	Thermal satellite data and multispectral data (e.g., Landsat, Sentinel-2, Sentinel-3)
OUTPUT FORMAT	GeoTiff, Cloud Optimized GeoTIFF (COG)
OUTPUT LAYERS	Land Surface Temperature (Celsius degrees), and Heath Island severity from 0 (no SUHI) to 5 (severe SUHI)
PROCESSING TIME	3 hours
INTEROPERABILITY	Compatible with GIS software (e.g., QGIS, ArcGIS), WebGIS
USER ACCESSIBILITY	Desktop Application (GIS software), WMS/WCS, Report
CUSTOMIZATION	Customization properties of the specific GIS platform used (e.g., users can choose color scheme for representing the layer). Customizable SUHI severity classes.
SCALABILITY	Supports processing of large datasets and can be extended to new geographical areas, depending on the availability of input data.
COMPLIANCE	Adherence to relevant regulations or standards (e.g., GDPR, ISO standards).

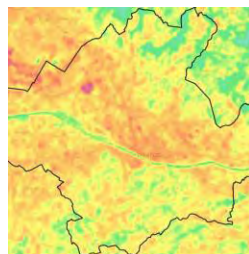


THERMAL MAPPING (LST) ES: 4 years series

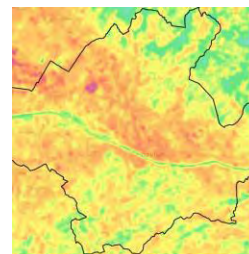
2013-2016



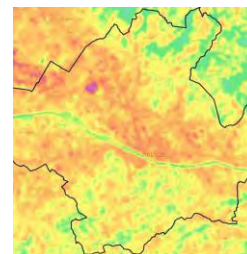
2014-2017



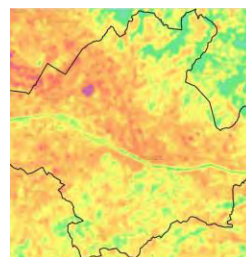
2015-2018



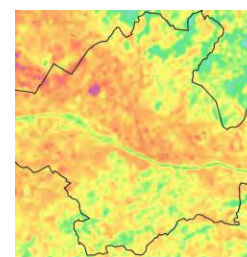
2016-2019



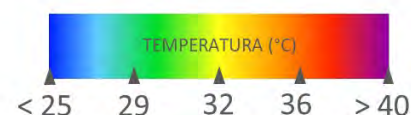
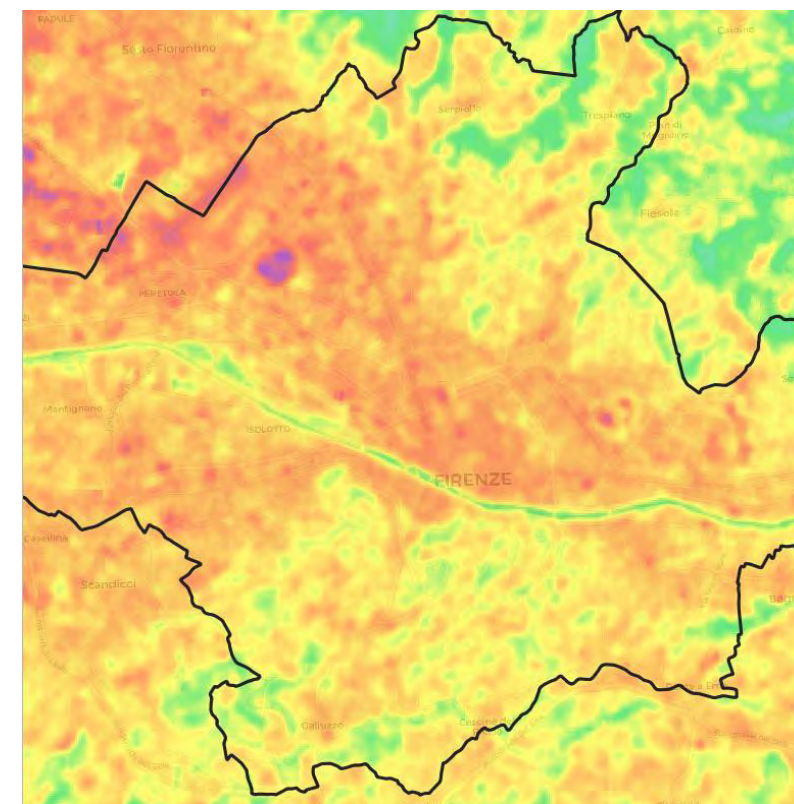
2017-2020

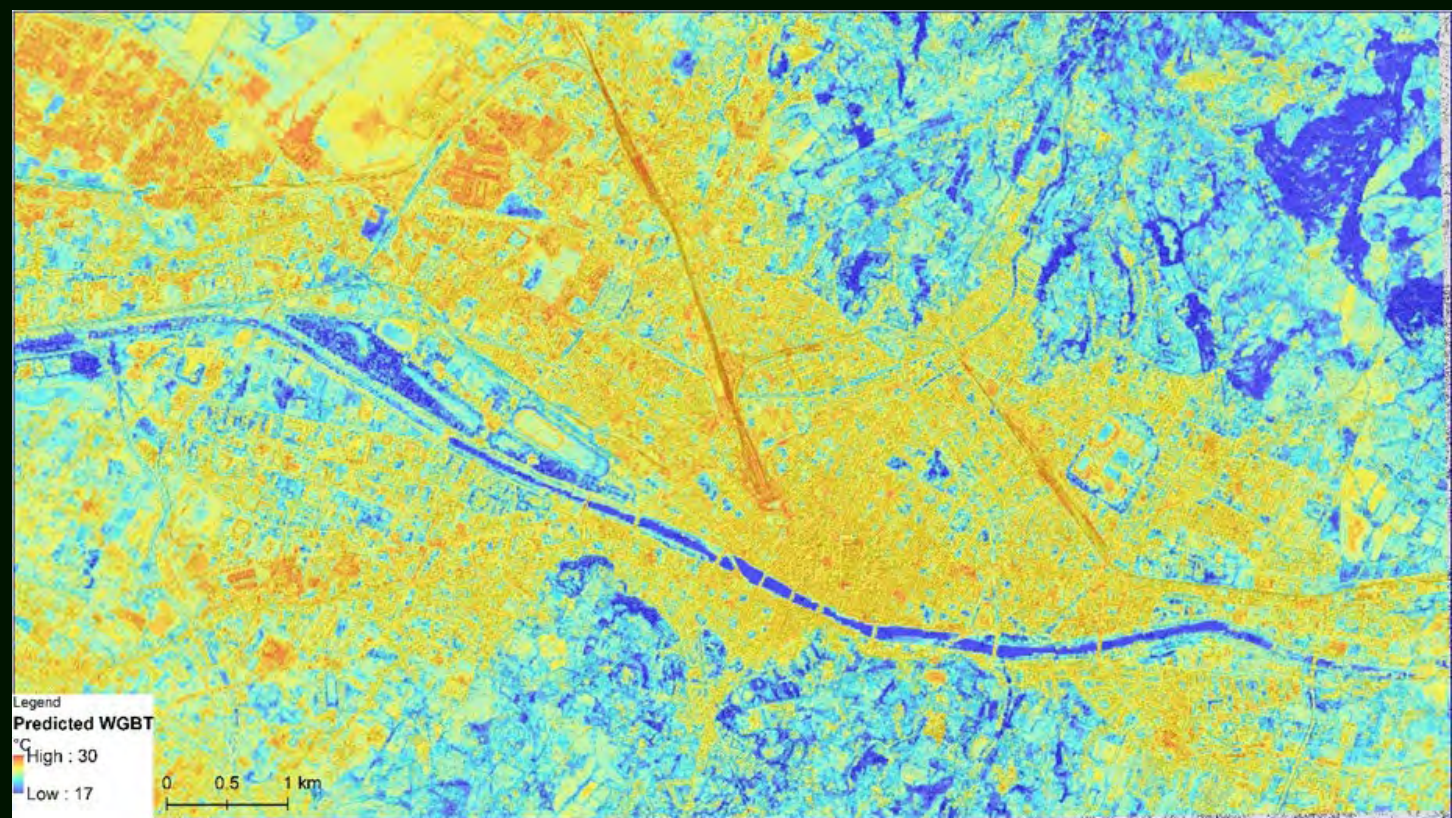
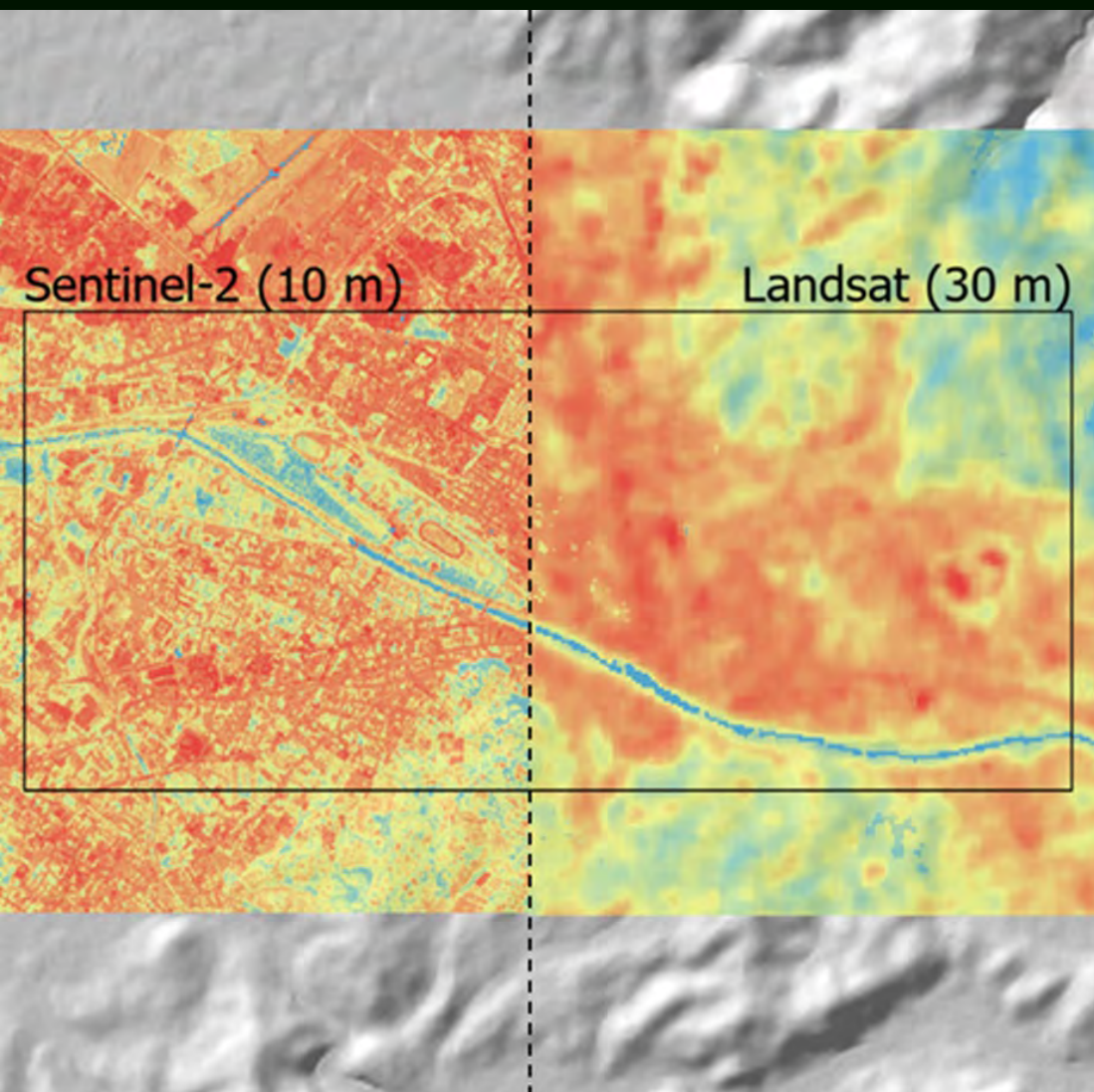


2018-2021



2019-2022

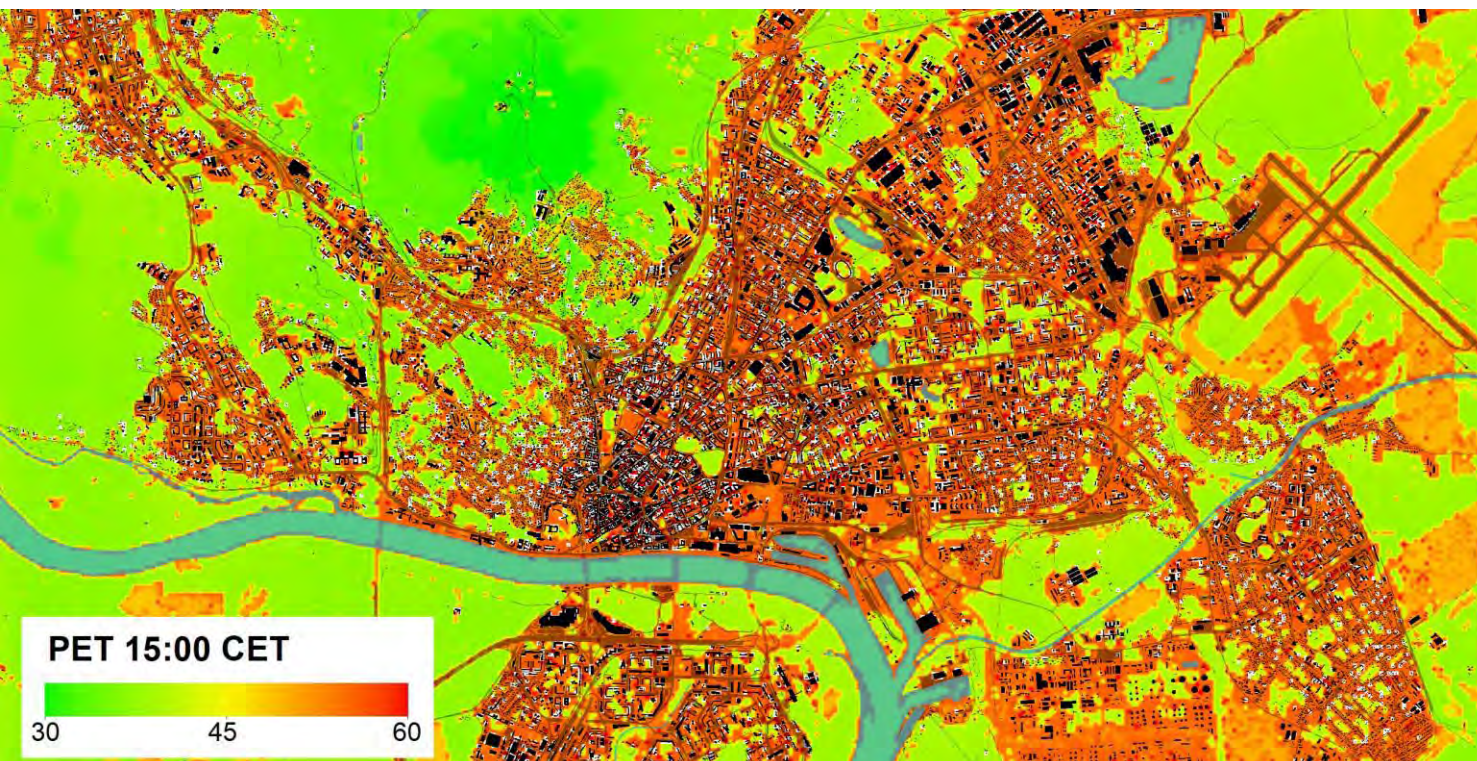




**Mondanelli, Francini, Chirici, Coccozza, Salbitano
2025. Coupling remote sensing data and local
meteorological measurements to predict thermal
stress and its potential mitigation by urban forests.
UFUG**

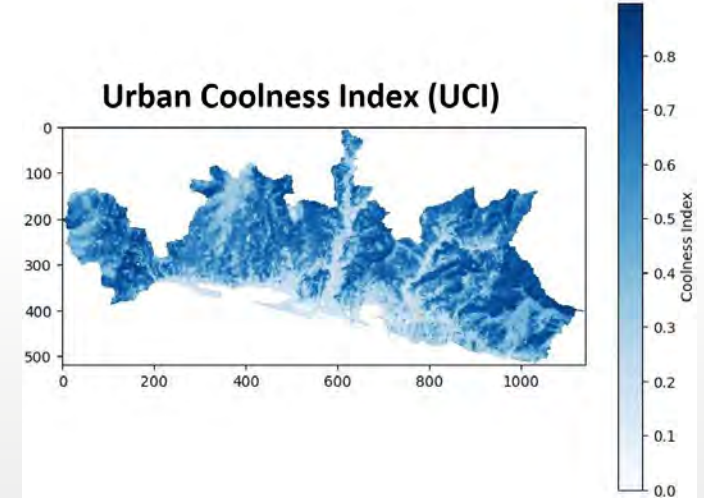
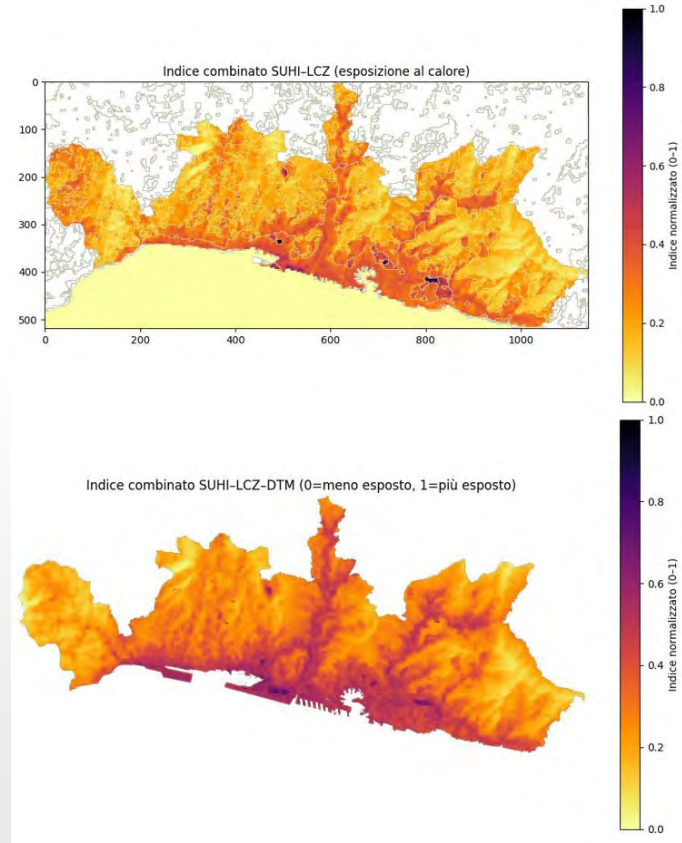
THERMAL STRESS ASSESSMENT (B.3)

The service derives **high-resolution maps of heat stress indices (PET, SET, UTCI)** based on the use of various high-resolution input data, the use of advanced preprocessing software, and ENVI-met software. For the creation of the model domain land cover, building model and tall vegetation data are necessary. The atmospheric outputs from simulations are used for the calculation of the heat stress indices in the BIOMET module. The heat stress indices are compared to the population grids containing the structure of the population. The population structure data consists of two categories permanent and temporary population, both classified into several age categories within the grid. A weighted arithmetic mean is used for each age category to quantify the impact of heat stress on different population groups.

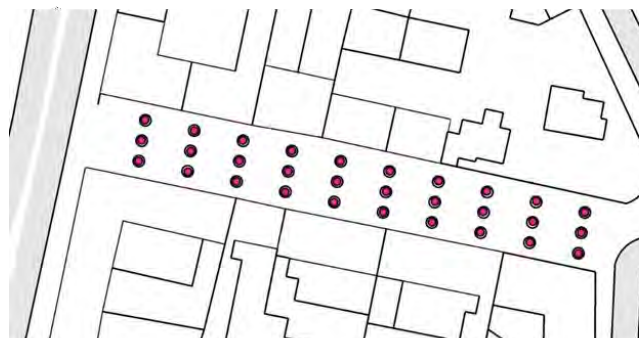


SPATIAL RESOLUTION	20 m (Kosice), 40 m (Bratislava), 100 m (population grids)
TEMPORAL RESOLUTION	24 hours single day case study, 15:00 CET for heat stress Kosice – 30.6.2022, Bratislava 8.7.2021
GEOGRAPHICAL COVERAGE	Regional coverage of the main Slovakian cities
DATA INPUTS	Satellite imagery, vector layers, LiDAR point clouds, population grids, SYNOP forcing data
OUTPUT FORMAT	GeoTIFF, png, shapefile
OUTPUT LAYERS	Land use, heat stress indices
PROCESSING TIME	5 months (atmospheric simulations)
INTEROPERABILITY	standard GIS format (geospatial data)
USER ACCESSIBILITY	Web portal (download), desktop application
CUSTOMIZATION	Raw data can be used for further processing and analysis
SCALABILITY	The methodology can be applied to any city with available data
COMPLIANCE	n/a

LCZ typology figure



Identifying thermal discomfort safe areas (Genova, Italy). Mindicity - EFI



P1



P2

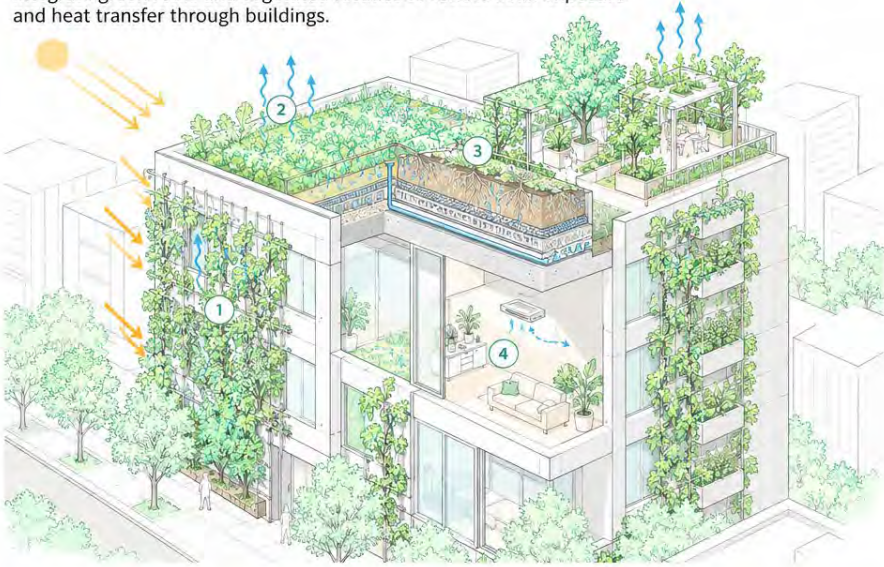


P3

Year 2 to 5 from planting date		Current	P1	P2	P3
Carbon dioxide uptake	kg	168	348	498	606
Assimilated Carbon dioxide	kg*year ⁻¹	140	290	415	505
Air pollution removal					
	O ₃ kg*year ⁻¹	0,023333	0,048333	0,069167	0,084167
	NO ₂ kg*year ⁻¹	0,163333	0,338333	0,484167	0,589167
	SO ₂ kg*year ⁻¹	0,023333	0,048333	0,069167	0,084167
	PM ₁₀ kg*year ⁻¹	0,023333	0,048333	0,069167	0,084167
Temperature reduction outdoor (street level)^					
	°C	0,1	0,4	0,8	1,1
% of total					
Annual Water retention	run off	1,0	3,0	4,8	6,0
^Calculated on the peak heat hour during summer days					

BUILDING SOLUTIONS

Integrate green roofs and vegetated facades to reduce solar exposure and heat transfer through buildings.



COOLING PROCESSES



Foliage shades surfaces.
Vegetation shades roof and wall surfaces, reducing direct solar radiation and limiting heat absorption.



Evapotranspiration dissipates energy.
Plants release water to the atmosphere when water is available, dissipating energy and cooling surfaces.



Substrates modify heat transfer.
Roof substrates and vegetation reduce heat transfer through the roof and increase thermal storage, keeping interiors cooler.



Lower cooling demand.
Reduced heat gains can lower the need for air-conditioning, which in turn reduces waste heat released to the outside.

DESIGN & SUITABILITY



Extensive green roofs
Lightweight, shallow substrates with drought-tolerant plants.



Intensive roof gardens
Deeper substrates with shrubs and trees; provide usable green space where accessible.



Ground-based green facades
Plants rooted in the ground, climbing on building facades.



Facade-bound greening
Modular systems with substrates attached to facades.

Check structural capacity, waterproofing, drainage, fire requirements and maintenance needs. Match plant species to exposure conditions and water supply.



Evidence note: Building and surface cooling do not imply equivalent street-level air cooling. Performance depends on building fabric, roof height, coverage and moisture.

World Bank (2021), A Catalogue of Nature-based Solutions for Urban Resilience, pp. 84–97. Cooling interpretation: author synthesis.

BENEFITS



Lower building heat gains
Shaded and vegetated surfaces reduce heat transfer into the building.



Stormwater retention
Substrates retain rainwater, reducing runoff.



Habitat
Provides habitat for birds, insects and other urban biodiversity.



Usable green space
Intensive roofs can provide accessible recreational space.

VERIFY PERFORMANCE



Measure roof or wall surface temperature
Compare vegetated and non-vegetated surfaces.



Measure indoor operative temperature
Assess indoor conditions against a comparable baseline building.



Monitor substrate moisture
Check that vegetation has sufficient water availability.

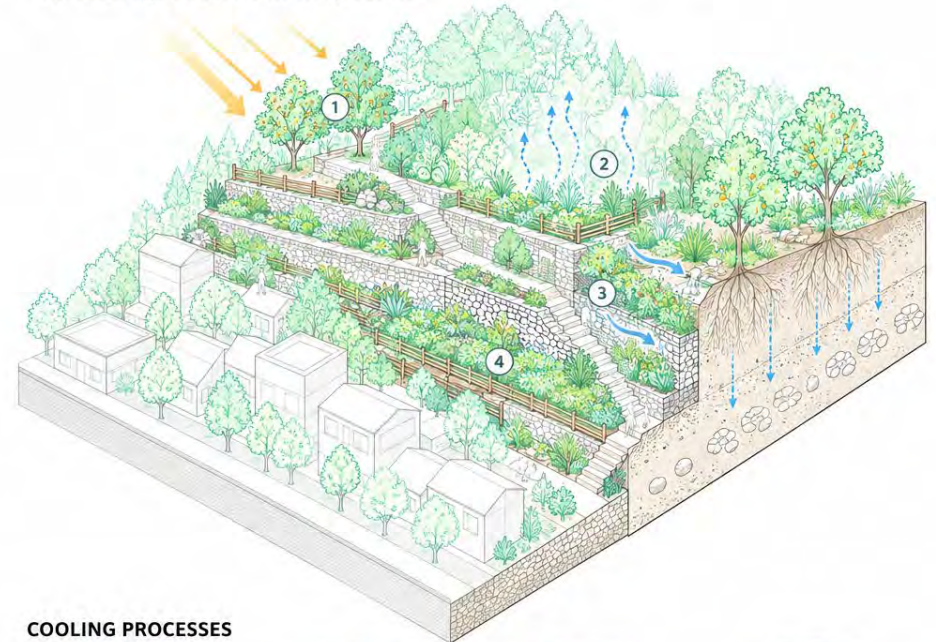


Compare cooling energy use
Monitor air-conditioning energy demand against a similar non-vegetated baseline.

Independent cooling-focused adaptation.

TERRACES AND SLOPES

Restore vegetated slopes and terrace systems to retain soil and water, with cooling as a complementary benefit.



COOLING PROCESSES



Trees shade paths and terrace surfaces.



Vegetation and moist soil release water vapour.



Slower runoff can improve root-zone water availability.



Vegetated ground reduces exposed surface heating.

DESIGN & SUITABILITY



- Establish continuous cover.
- Fit planting to slope stability and soil depth.
- Maintain drainage and terrace walls.
- Avoid waterlogging or infiltration that destabilizes slopes.

BENEFITS



- Erosion control.
- Slope protection.
- Cultural landscapes.
- Local thermal relief.

VERIFY PERFORMANCE



- Monitor vegetation cover.
- Monitor soil moisture.
- Assess shaded surfaces and air temperature.
- Inspect drainage and slope movement.



EVIDENCE: Cooling depends on vegetation and water availability. Bare stone terraces provide no inherent evaporative cooling; neighbourhood cooling must be verified.

World Bank (2021), A Catalogue of Nature-based Solutions for Urban Resilience, pp. 56–69. Cooling interpretation: author synthesis.

Independent cooling-focused adaptation.



European
Environment
Agency



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Cooling buildings sustainably in Europe: exploring the links between climate change mitigation and adaptation, and their social impacts

Briefing | Published 10 Nov 2022

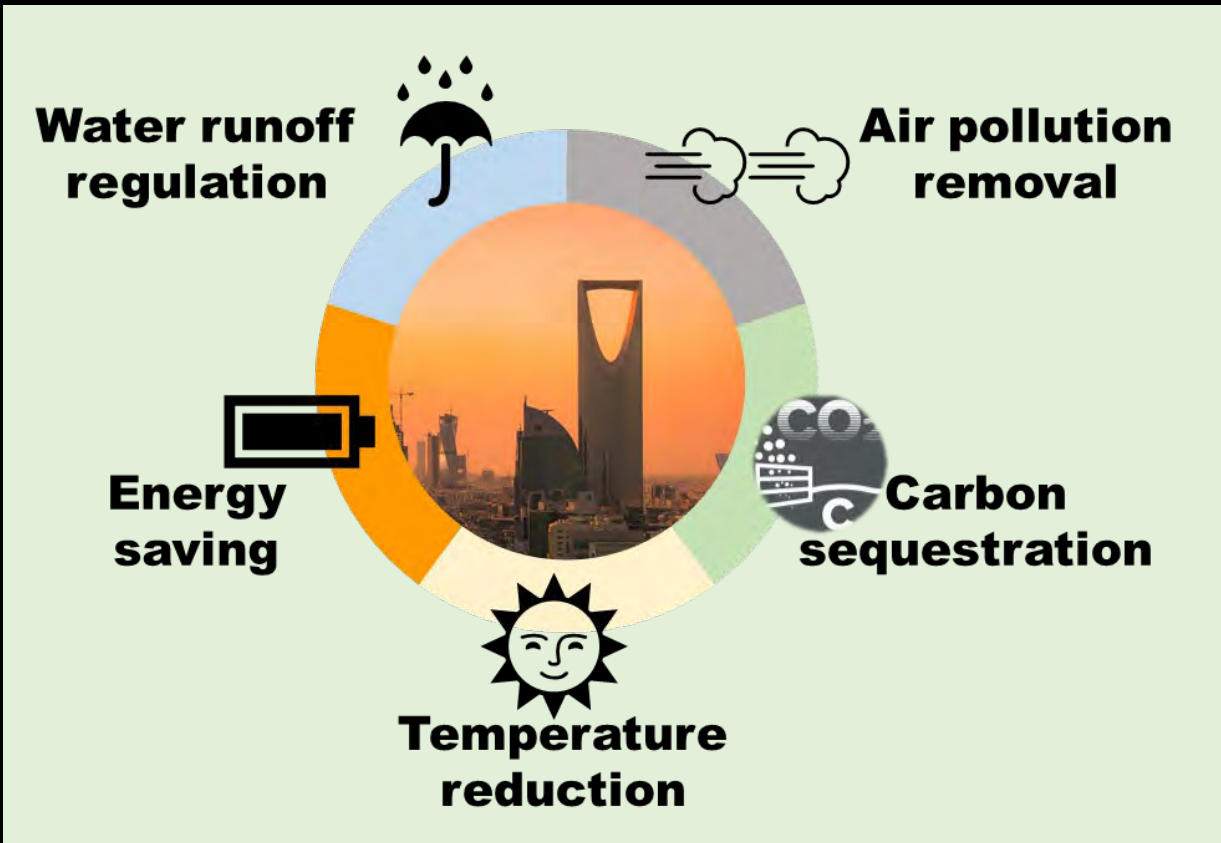
Image © Geralt on pixabay

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<https://www.eea.europa.eu/en/analysis/publications/cooling-buildings-sustainably-in-europe-exploring-the-links-between-climate-change-mitigation-and-adaptation-and-their-social-impacts>



The Benefits of PR&W for Riyadh



Tab 1

Component	Metrics Unit	Min	Max
PM ₁₀ removal (dry dep)	$\text{g} \cdot \text{m}^{-2} \cdot \text{year}^{-1}$	0,42	9,21
NO _x absortion/removal	$\text{g} \cdot \text{m}^{-2} \cdot \text{year}^{-1}$	0,37	3,57
O ₃ removal/absorption	$\text{g} \cdot \text{m}^{-2} \cdot \text{year}^{-1}$	1,2	7
SO ₂	$\text{g} \cdot \text{m}^{-2} \cdot \text{year}^{-1}$	0,2	1
C sequestration	$\text{kg} \cdot \text{m}^{-2} \cdot \text{year}^{-1}$	0,1	2
Temperature reduction indoor	°C	0,5	11
Temperature reduction outdoor (street level)	°C	0,1	4
Annual energy saving	% of tot year dissipat	6,5	35
Annual Water runoff retention	% of tot run off	40	90

102 papers were analysed so to better estimate of the potential benefits.

How?

The values were then counterchecked and adapted to the climate of Riyadh according to the baseline research outputs

Viability and significance in term of benefits

All the components checked are positively influenced by implementing PR&W solutions

The most effective and significant results can be achieved in:

1. Indoor Temperature reduction
2. Annual water runoff retention
3. PM₁₀ removal
4. Energy savings
5. Outdoor (atmospheric) Temperature reduction
6. O₃ control

The effectiveness in providing benefits is related to the characteristics of the solutions adopted. The

feasibility of the solutions as regards the possibility of having robust and constant benefits over time therefore depends on the design choices and the continuity of management and care programs

Comfort in the living environment

Control and safety contrasting flash storms and floods

Outdoor health

Lower energy costs and indirect emissions

GREEN ROOFS, COOLER WALLS, COOLER CITIES

How living buildings reduce heat — directly and indirectly

1 THE HEAT CHALLENGE



Our roof and walls soak up the sun.

Hot building surfaces store energy and transfer heat indoors.

2 DIRECT: SHADE



Leaves shade the roof and facade.

Less solar energy reaches the building envelope.

3 DIRECT: EVAPOTRANSPIRATION



Evaporating water uses heat.

Plants and moist substrates cool surfaces and nearby air; water availability matters.

4 INDIRECT: LOWER HEAT GAIN



Less heat reaches our rooms.

Roof layers and facade shade can reduce and delay heat transfer indoors.

5 INDIRECT: LESS WASTE HEAT



Less cooling demand can mean less waste heat outside.

Lower air-conditioning use can also reduce electricity demand and related emissions.

6 SCALE UP WITH CARE



A living network, cared for over time.

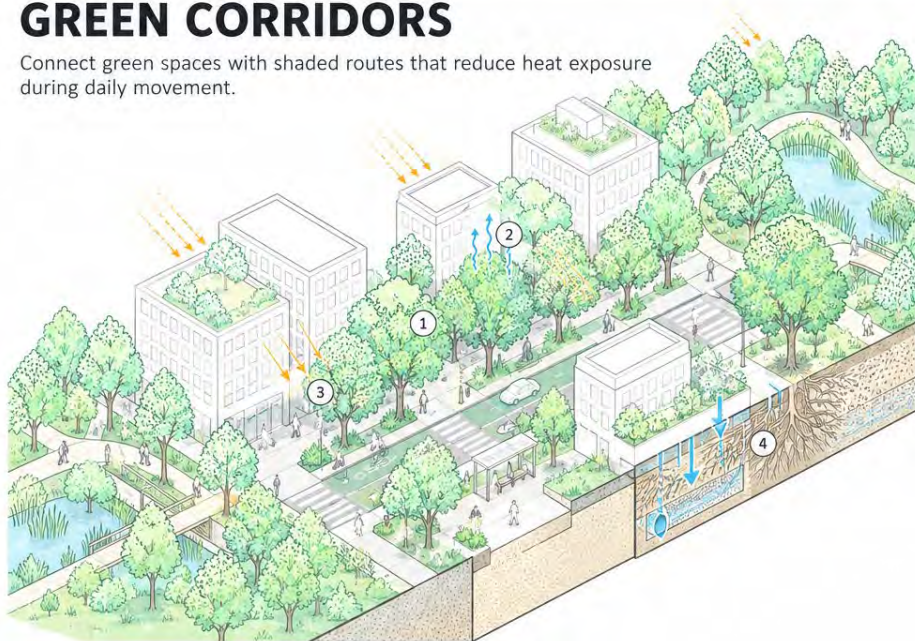
Combine building greenery with street shade. Local cooling depends on climate, design, water and maintenance.

Cooler surfaces do not automatically mean equally cooler streets.

Design for plant survival, safe roof loads, waterproofing and sustainable water use.

GREEN CORRIDORS

Connect green spaces with shaded routes that reduce heat exposure during daily movement.



COOLING PROCESSES



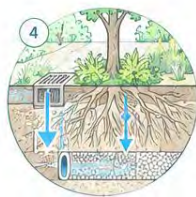
Linked tree crowns shade walking and cycling routes.



Transpiration uses energy and supports local air cooling.



Shaded pavements and facades absorb less solar energy.



Connected rooting areas and captured runoff sustain canopy function.

DESIGN & SUITABILITY



Close shade gaps at crossings and transit stops; allow soil volume for mature trees. Match crown form to street geometry and preserve ventilation, visibility and utility access.

BENEFITS



Thermal comfort and active mobility



Habitat connectivity



Stormwater regulation



More liveable and resilient cities

VERIFY PERFORMANCE



Measure shaded route continuity, canopy cover, radiant exposure, wind and air temperature at pedestrian height.

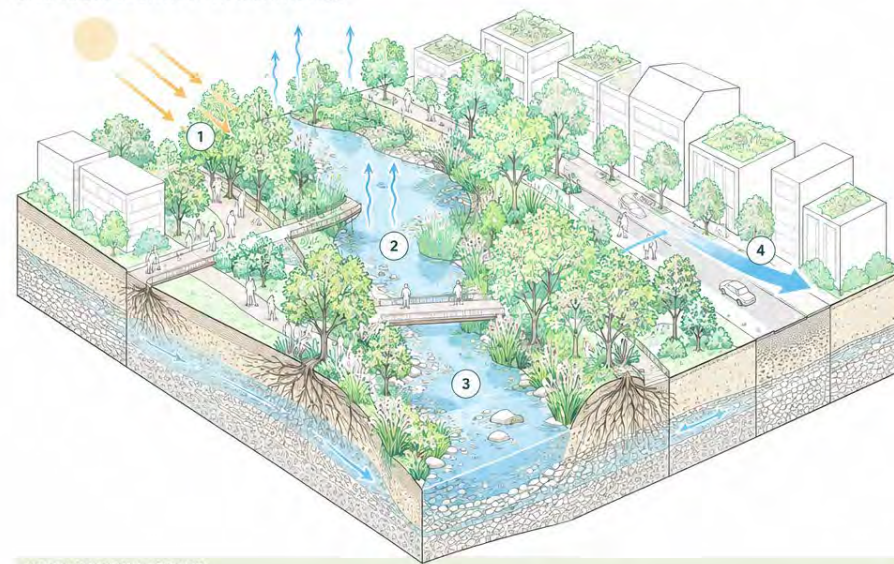


EVIDENCE & LIMITATIONS

Cooling follows canopy and site conditions. Dense planting in narrow street canyons can restrict airflow; continuity alone does not guarantee lower air temperature.

RIVER AND STREAM RENATURATION

Recover river processes and riparian vegetation to improve ecological condition and local thermal environments.



COOLING PROCESSES



Riparian trees shade water and walking routes.



Vegetation and open water support evaporative cooling.



Shading moderates stream temperature for aquatic life.



Air movement may carry cooler air into adjacent streets.

DESIGN & SUITABILITY



- Restore hydrology and native riparian cover.
- Connect shaded public routes while retaining flood conveyance and ventilation.
- Provide safe flood access arrangements.

BENEFITS



- Aquatic habitat.
- Improved water quality.
- Recreation and amenity.
- Local heat regulation.

VERIFY PERFORMANCE



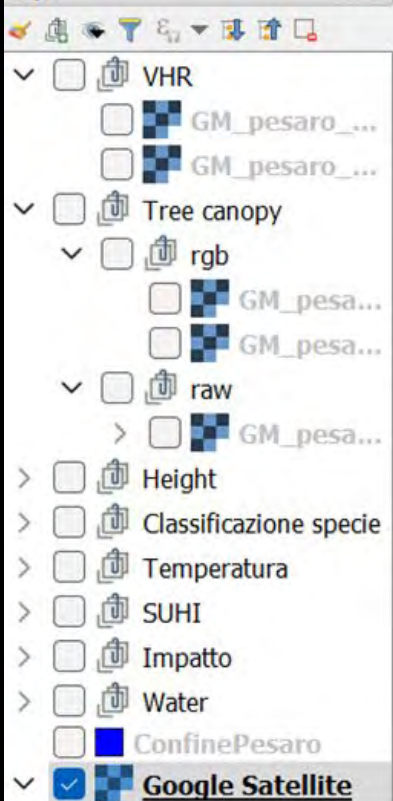
- Measure water temperature, air temperature, humidity, wind and pedestrian radiant exposure along bank-to-street transects.

EVIDENCE NOTE

Cooling varies with water temperature, flow, canopy and built form. Open water can retain heat at night; higher humidity can offset comfort gains.



Layer

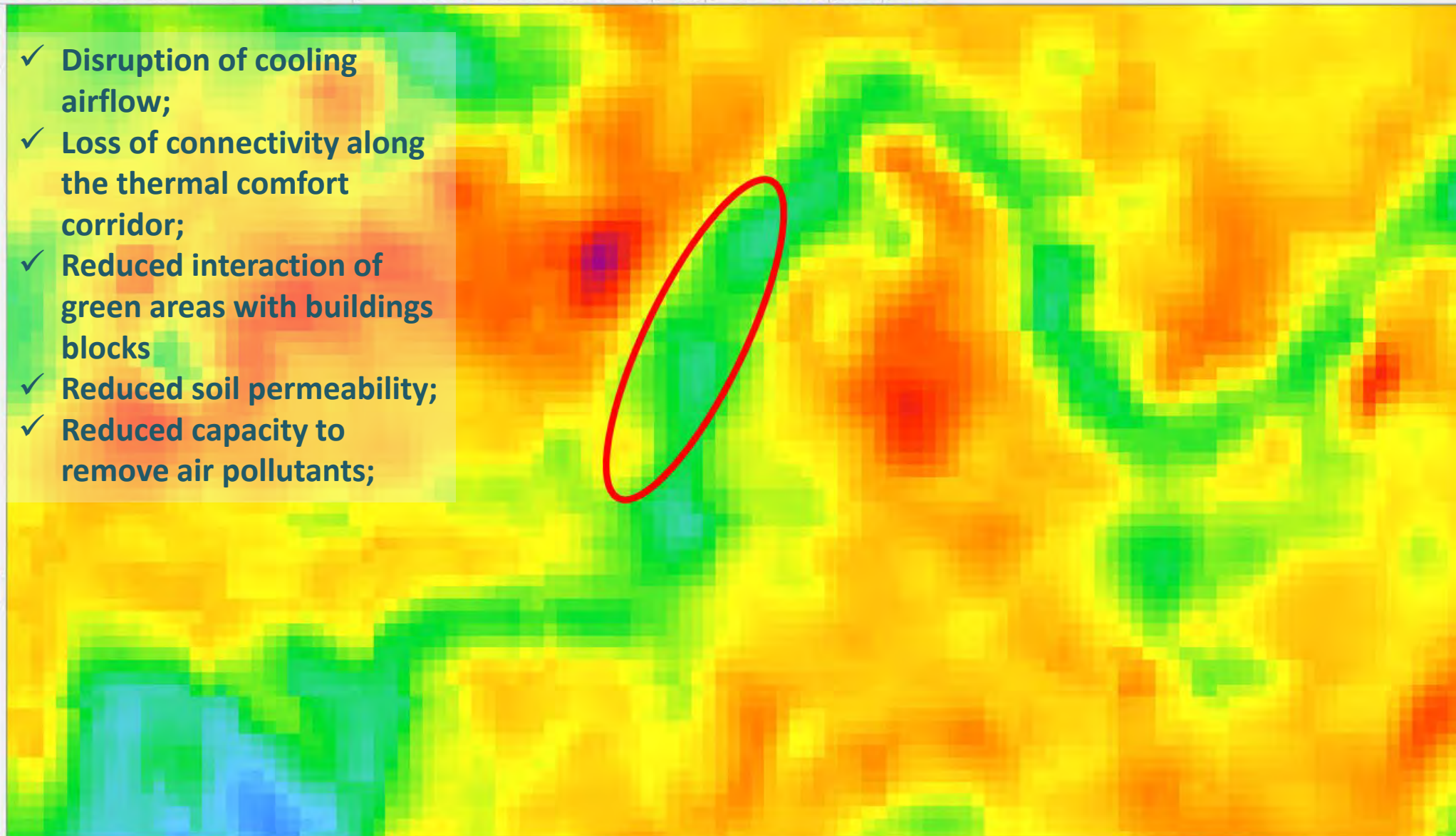




Layer

- ✓ ☐ VHR
 - ☐ GM_pesaro_...
 - ☐ GM_pesaro_...
- ✓ ☐ Tree canopy
 - ✓ ☐ rgb
 - ☐ GM_pesaro_...
 - ☐ GM_pesaro_...
 - ✓ ☐ raw
 - > ☐ GM_pesaro_...
- > ☐ Height
- > ☐ Classificazione specie
- > ☒ Temperatura
- > ☐ SUHI
- > ☐ Impatto
- > ☐ Water
- ☐ ConfinePesaro
- ✓ ☒ Google Satellite

- ✓ **Disruption of cooling airflow;**
- ✓ **Loss of connectivity along the thermal comfort corridor;**
- ✓ **Reduced interaction of green areas with buildings blocks**
- ✓ **Reduced soil permeability;**
- ✓ **Reduced capacity to remove air pollutants;**





Layer

- ☒ VHR
 - ☐ GM_pesaro_...
 - ☐ GM_pesaro_...
- ☒ Tree canopy
 - ☒ rgb
 - ☐ GM_pesar...
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- ☐ SUHI
- ☐ Impatto
- ☐ Water
- ☐ ConfinePesaro
- ☒ Google Satellite





A

Or



B

?

NbS family	Small-scale air cooling	Large-scale cooling potential	Interpretation and conditions
Urban Forests	High	High	Extensive canopy and evapotranspiration provide a strong combination. Larger effects require sufficient cover, healthy trees and available soil water.
Open Green Spaces	High when tree-rich	High when extensive or distributed	Wooded parks and gardens rank above predominantly dry, open lawns. Composition matters as much as the label “green space”.
Green Corridors	Moderate–high	High when widely distributed	Tree-lined networks distribute cooling through the built environment. Canopy, rooting conditions and ventilation determine performance.
River and Stream Renaturation	Moderate–high	Moderate–high	Strongest where restoration combines riparian canopy, water and permeable banks. Cooling transfer into streets depends on airflow and urban geometry.
River Floodplains	Moderate–high	Moderate–high	Large vegetated floodplains can support substantial cooling, particularly where summer moisture persists. Seasonal flooding alone does not ensure summer performance.
Natural Inland Wetlands	Moderate–high; potentially high	Moderate–high where extensive	Evapotranspiration and water–atmosphere exchanges can generate strong local effects. Humidity and nighttime heat storage complicate the benefits.
Constructed Inland Wetlands	Moderate–high	Moderate; potentially higher where extensive	Performance varies with area, vegetation and hydraulic design. Surface-flow and subsurface-flow systems should not receive identical ratings.
Urban Farming	Moderate; higher in wooded systems	Limited–moderate	Orchards and agroforestry generally offer more sustained thermal benefits than seasonal vegetable beds. Irrigation, crop cover and harvest cycles are decisive.
Bioretention Areas	Limited–moderate; higher with trees	Limited individually; moderate as a network	Cooling depends on vegetation and retained moisture. Their usual small footprint limits the effect of individual installations.
Building Solutions	Limited–moderate at pedestrian level	Moderate under extensive deployment	Green roofs and facades can strongly affect building surfaces and heat gains, while producing smaller or less consistent street-level air cooling.
Terraces and Slopes	Limited–moderate	Conditional; insufficient comparative evidence	Cooling comes mainly from vegetation and soil moisture, rather than terracing itself. Wooded slopes may perform much better than sparsely planted terraces.
Mangrove Forests	Potentially substantial locally; insufficient basis for a comparative rank	Uncertain	Canopy and evapotranspiration offer plausible benefits, but salinity and coastal meteorology matter. Evidence does not support a general city-cooling rank.
Salt Marshes	Conditional; unranked	Uncertain	Evaporative exchanges occur, but comparative evidence of cooling experienced by adjacent urban populations is insufficient.
Sandy Shores	No dependable intrinsic cooling rank	Uncertain	Exposed sand can become hot. Sea-breeze cooling cannot be attributed to beach or dune restoration without separating meteorological effects.

The role of trees in urban cooling

Greener cities
for a better
tomorrow



More trees = cooler, more livable and more resilient cities

NATURE IN CITIES. VALUE FOR TODAY, SAFETY FOR TOMORROW.



PEOPLE
ENVIRONMENT
COMMUNITY
FUTURE



Thanks

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