# Urban heat islands

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https://www.architecturaldigest.com/story/architect-new-yorks-central-park-incredibly-unexpected-legacy

# Today's session

## Outline

- **Urban heat islands**
- Urban cooling strategies
- Urban dry islands

# Urban heat islands

**Urban heat islands (UHIs)**

Decades of research have shown that cities are almost always warmer than their surroundings. This phenomenon, known as the urban heat island (UHI), is one of the clearest examples of inadvertent climate modification due to humans. It has many impacts and can be seen for example in the flowering of plants, which occurs earlier in urban areas, in lower space heating costs but higher space cooling requirements in cities, on increased heat stress on human residents in summer and in less dense fogs and increased rate of chemical reactions leading to smog.

Wide paved surfaces, like this road in an Indian city, that are dark, dry and unshaded can become extremely hot (notice the mirage patches in the foreground).

Oke et al. (2017)

# Urban heat islands

## Urban heat islands (UHIs)

At first glance the UHI appears to be a simple phenomenon with obvious causes many of which were identified nearly two hundred years ago by Luke Howard (Howard, 1818). The root causes of the UHI are the changes urban development makes to the energy balance of the pre-urban site on which the city is built.

While the temperatures of an UHI are relatively straightforward to measure, there are several types of UHI each of which is temporally and spatially dynamic which makes it methodologically complex to study. Therefore, one should not refer loosely to the UHI as if it is a unitary phenomenon, but rather identify which type is being measured, described, interpreted or modelled.

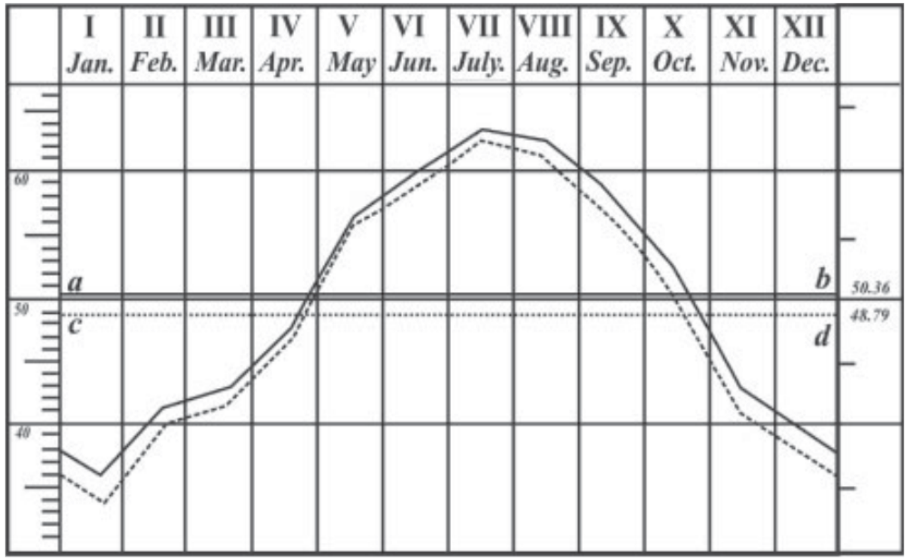


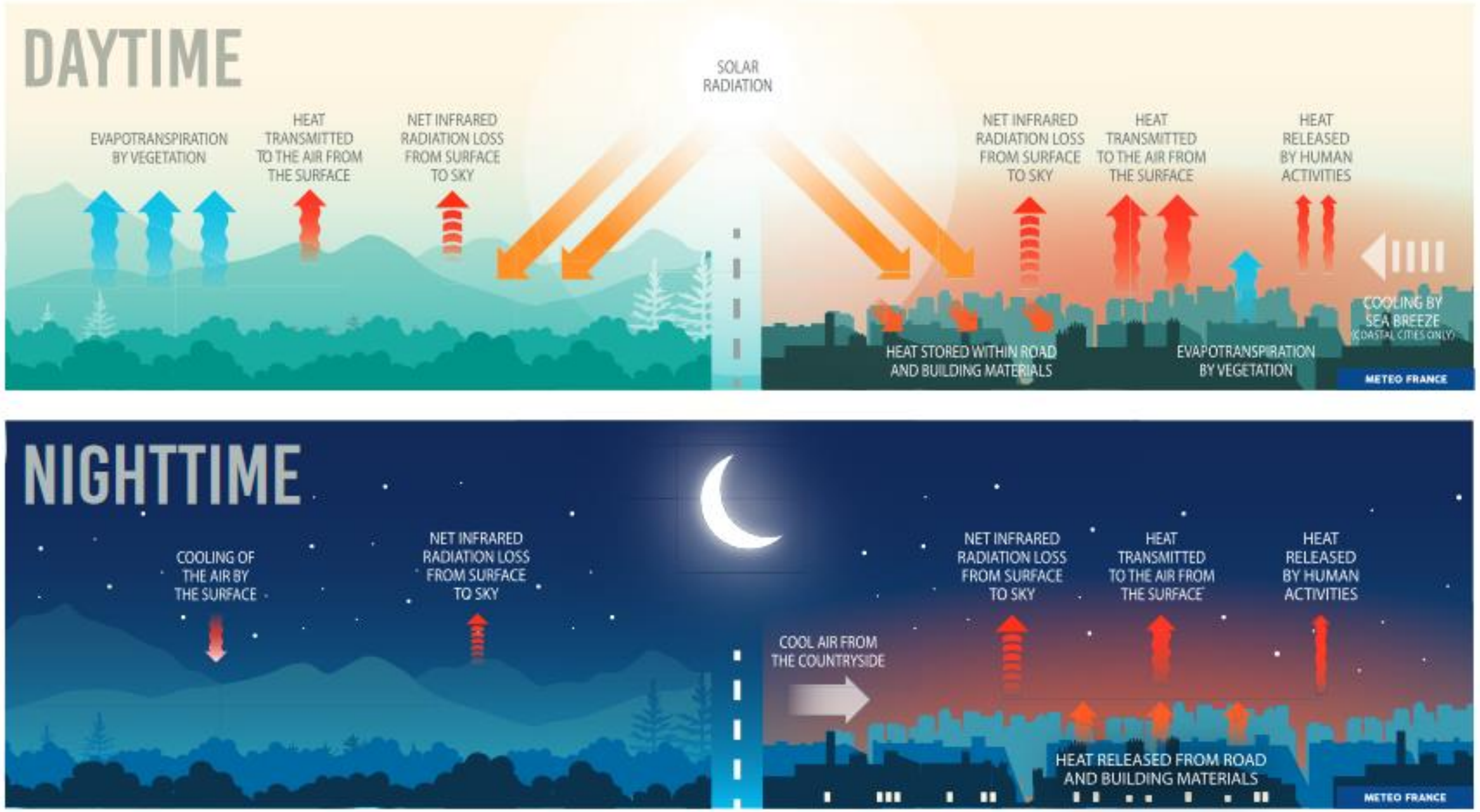

*Figure 3. The annual temperature curves for the city (solid) and the countryside (dashed). The labelled horizontal lines represent the means (based on the 30-year period 1797 to 1816) for the city (a–b) and countryside (c–d).* Redrawn from Figure 3 in the second edition of The Climate of London.

Mills (2008)

# Urban heat islands

**The main processes leading to the urban heat island.**

Urbanization of the surface and reduction of the vegetation cover strongly modify the energy exchanges.
During the day, a large part of the radiation coming from the sun heats the urban materials; this stored heat is released at night, limiting the nighttime cooling of the air in cities and creating the urban heat island. It is also influenced and modulated by the heat released by human activities and the air flow from the countryside and, for coastal cities, from the sea or large lakes.




[Urban Climates and Climate Change | Annual Review of Environment and Resources]

# Urban heat islands

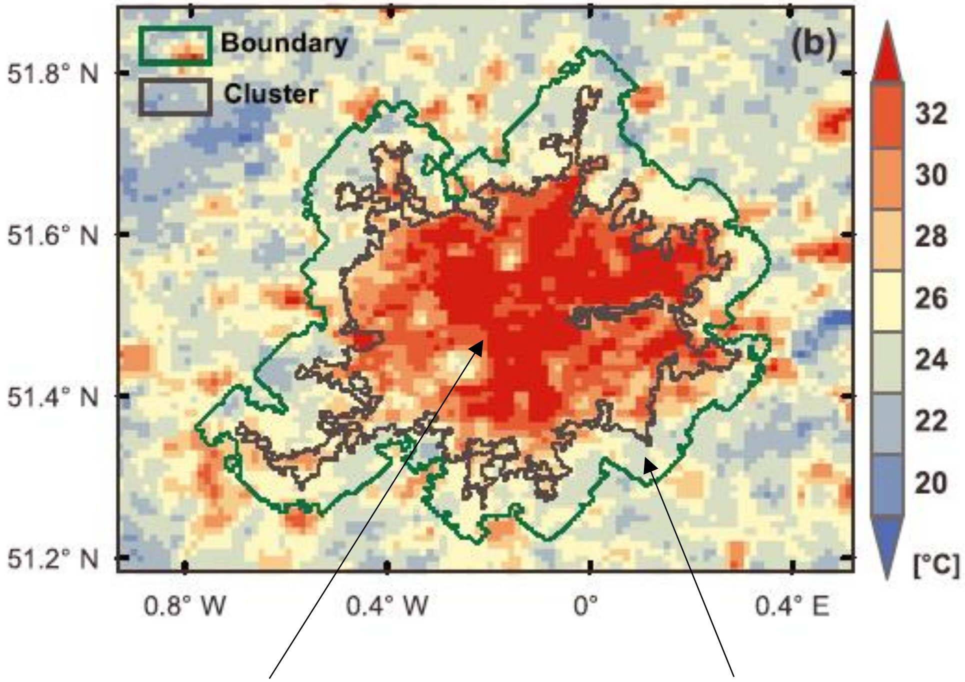
**Heat islands Magnitude**

The magnitude of urban heat islands is usually defined as the difference between the (maximum) **urban temperature, $T_U$**, and a representative temperature of the **surrounding rural area, $T_R$**, over a specified period.

Care is needed in both urban and rural environments to identify representative measurement locations; if spatial variability is large, it may be advisable to calculate a spatial mean temperature for each environment or calculate the difference spatially (using a reference rural value)

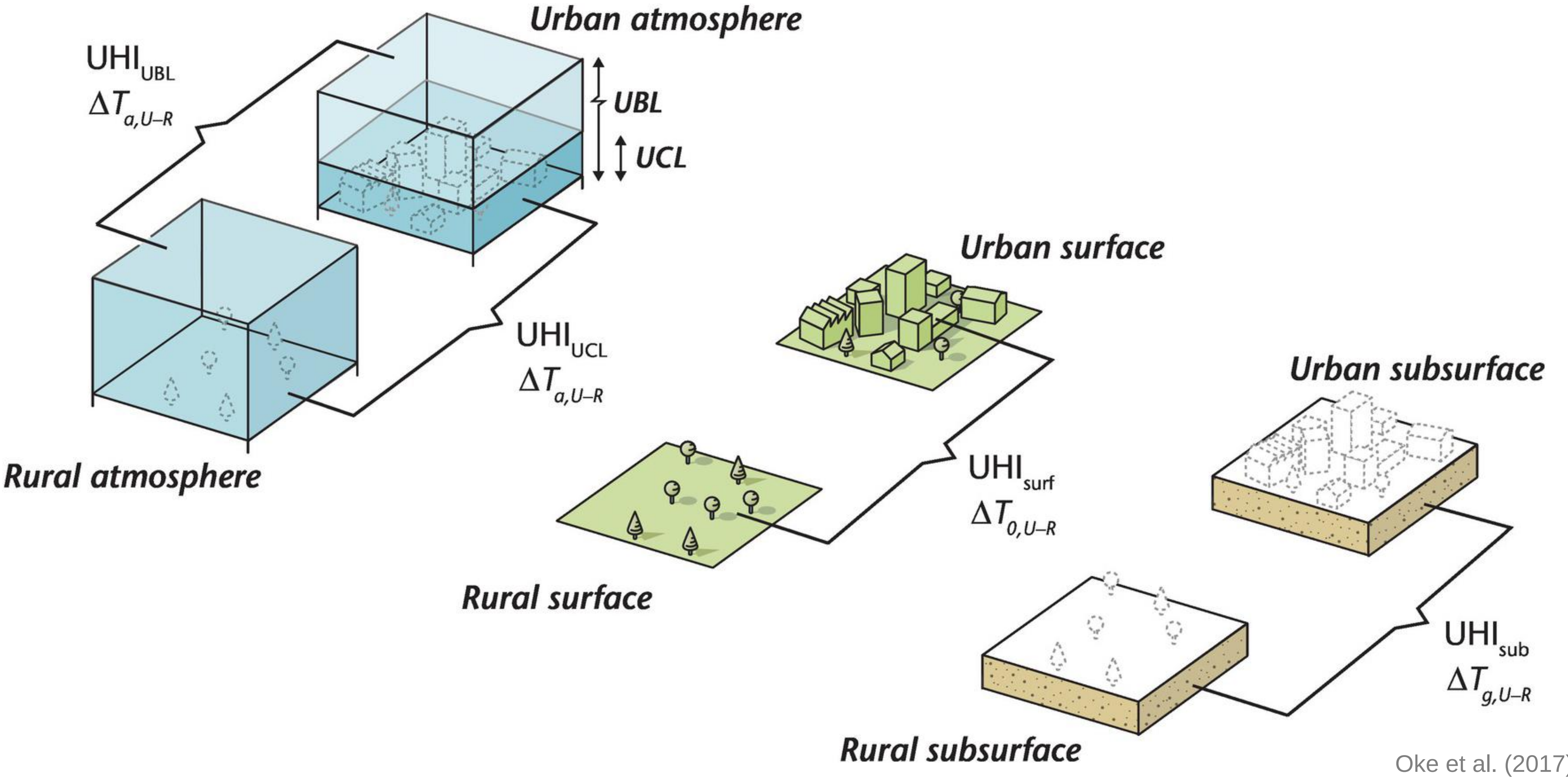
$$UHI_{type} = \Delta T_{U-R} = T_U - T_R$$

London surface temperature, Zhou et al. (2013), GRL




$$T_U > T_R$$

# Urban heat islands




Oke et al. (2017)

# Urban heat islands

## Types of urban heat islands

- **Subsurface urban heat island ($UHI_{Sub}$):** differences between temperature patterns in the ground under the city, including urban soils and the subterranean built fabric, and those in the surrounding rural ground.

- **Surface urban heat island ($UHI_{Surf}$):** temperature differences at the interface of the outdoor atmosphere with the solid materials of the city and equivalent rural air to ground interface. Ideally those interfaces comprise their respective complete surfaces (i.e. λc, see Section 2.1.1).

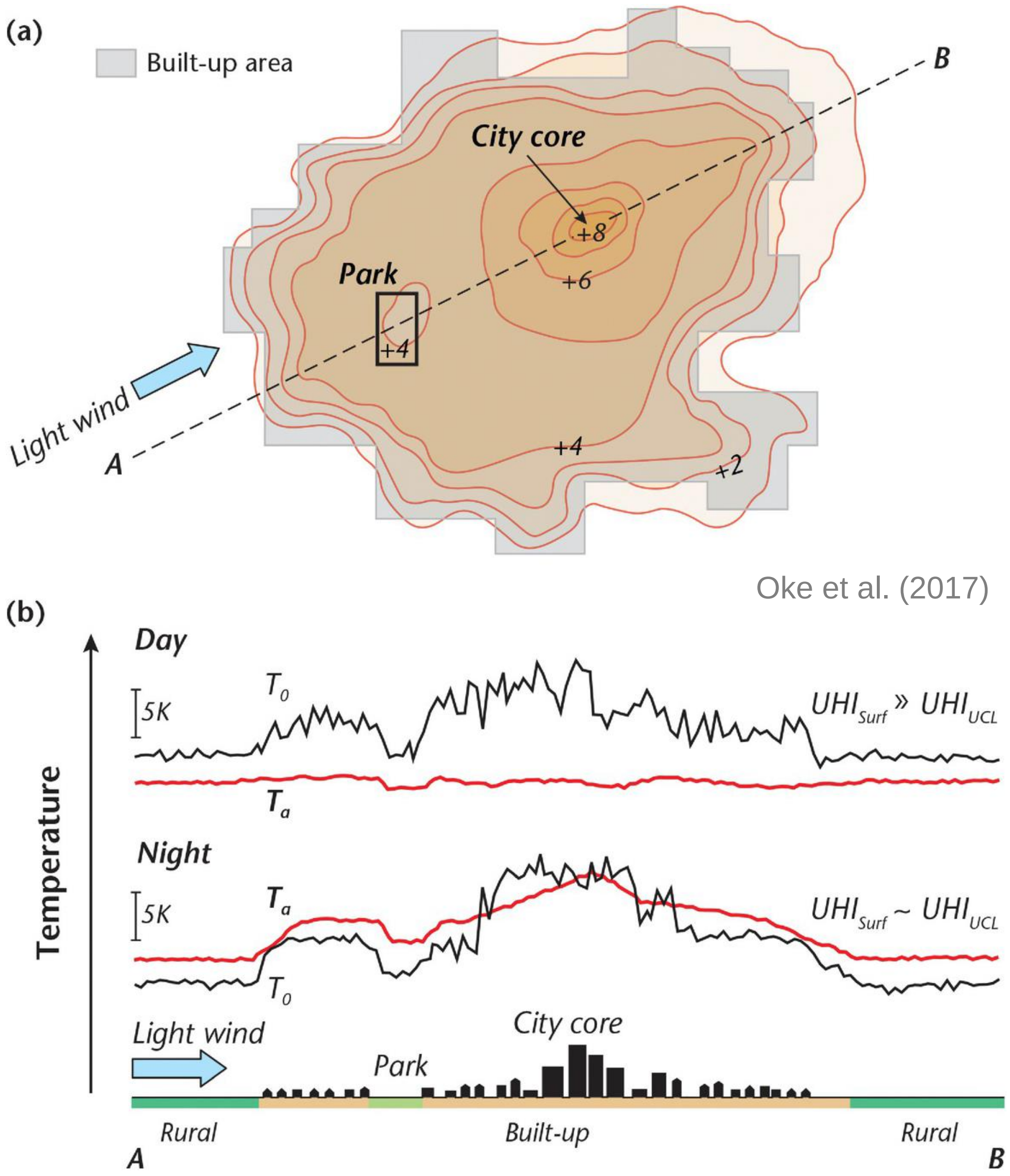
- **Canopy layer urban heat island ($UHI_{UCL}$):** difference between the temperature of the air contained in the urban canopy layer (UCL), the layer between the urban surface and roof level (the exterior UCL), and the corresponding height in the near-surface layer of the countryside.

- **Boundary layer urban heat island ($UHI_{UBL}$)**: the difference between the temperature of the air in the layer between the top of the UCL and the top of the urban boundary layer (UBL), and that at similar elevations in the atmospheric boundary layer (ABL) of the surrounding rural region.

# Urban heat islands

**Types of urban heat islands**

The term “heat island” was coined because of the similarity between the spatial pattern of the isotherms of air temperature in the UCL and height contours of an oceanic island. The analogy is apt for the surface, boundary layer and subsurface heat islands both by day and night, but for the $UHI_{UCL}$ it usually only describes the nocturnal case



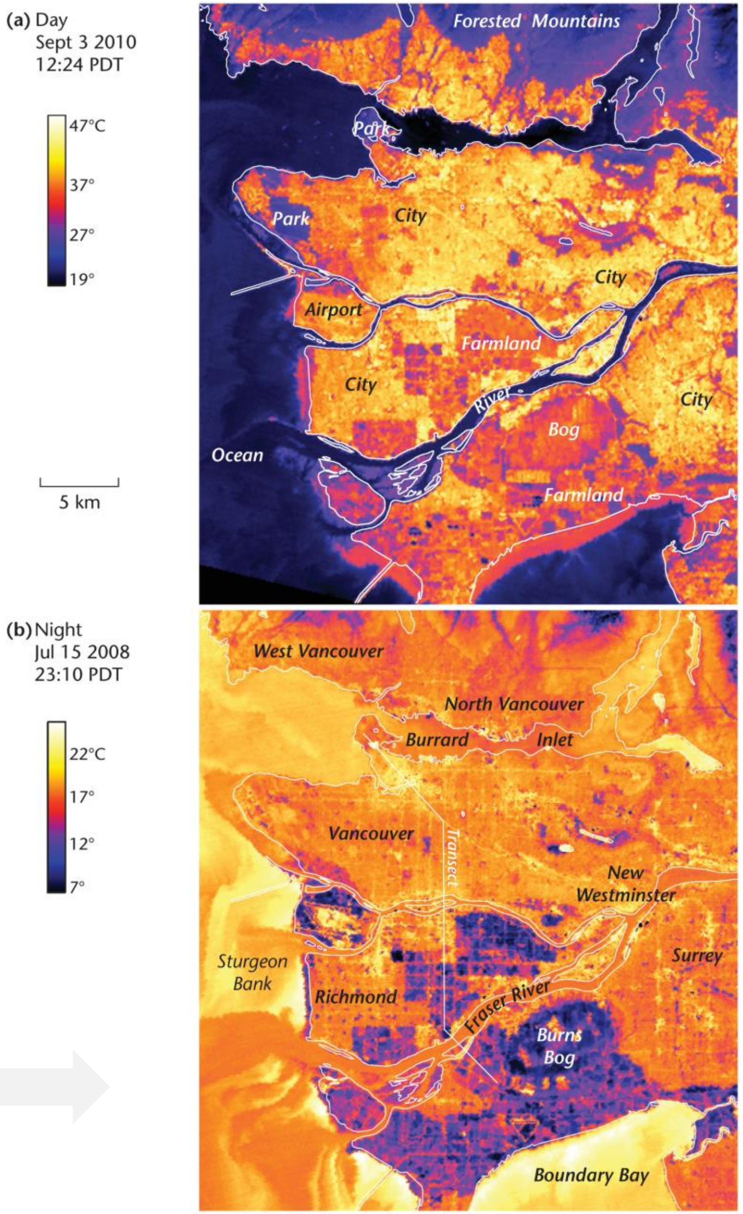

Oke et al. (2017)

# Urban heat islands

### Surface Heat Island (SUHI or $UHI_{Surf}$)

The $UHI_{Surf}$ for large areas of cities is usually estimated from remote observations of $T_0$. The instruments are mounted on an airplane, helicopter or satellite platform. Those observations can provide a spatially continuous image of urban $T_0$ across a city. This helps overcome difficulties associated with using *in situ* sensors to sample adequately the vast range of surface facets comprising an urban system.

Quantitative assessment of the spatial variation of $T_0$ requires corrections for atmospheric and surface **emissivity effects** and ideally for the **anisotropy** due to the corrugated nature of urban surface structure that creates 3D surface temperature patterns




Thermal images of surface brightness temperature for Vancouver, Canada. (a) Daytime and (b) Nighttime

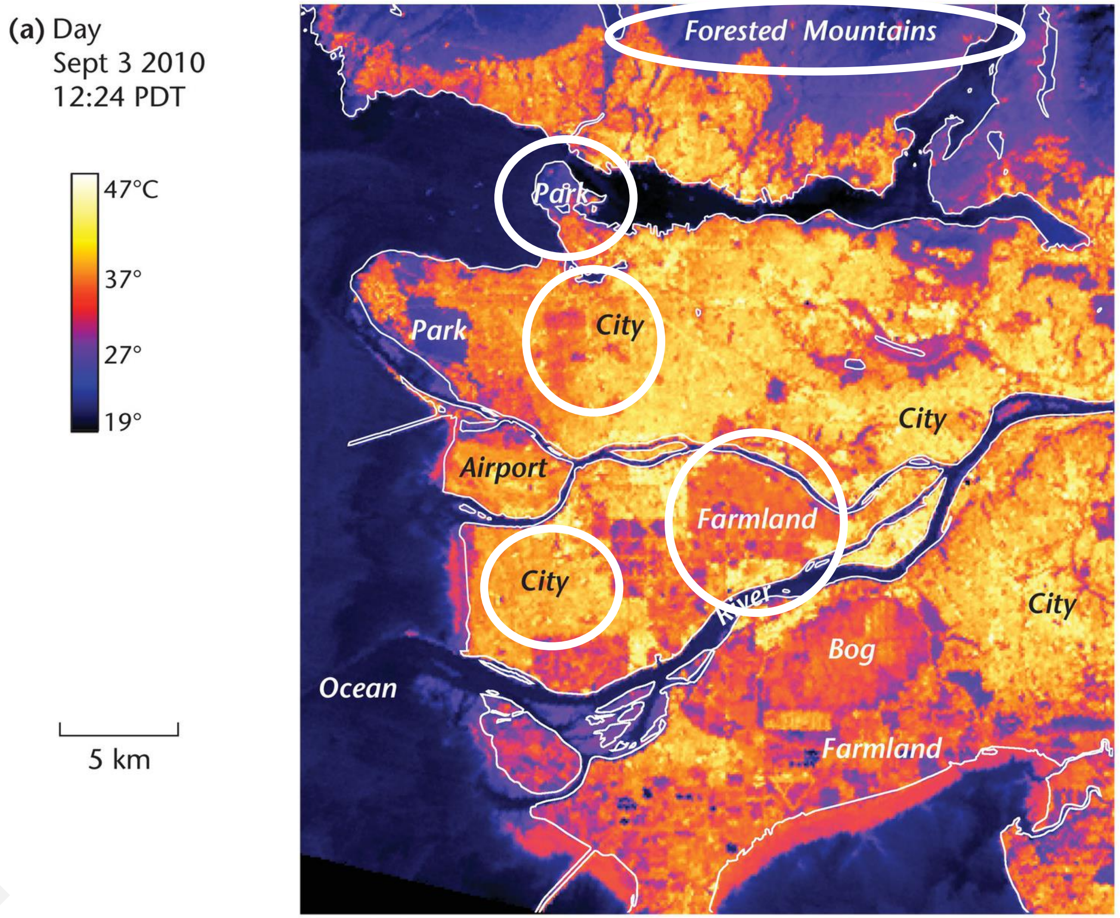
Oke et al. (2017)

# Urban heat islands

## Surface Heat Island (SUHI or $UHI_{Surf}$)

**Example: the case of Vancouver, Canada**

The urban area is bounded naturally: to the north by forested mountain slopes, to the west by ocean and to the south by a bog and farmland. The internal morphology of the built-up area is also evident. Light industrial, warehouses and transportation **infrastructure (airports, wide streets) are often relatively hot** during daytime. Areas of **tightly-packed tall buildings appear slightly cooler** because of mutual shade, whereas similarly highly developed, but less closely-spaced lower buildings, appear as warmer nodes. More heavily vegetated areas, especially with **tree canopies, have lower daytime $T_0$** (see western sections of the City of Vancouver compared to eastern districts). The **coolest surfaces in the daytime are water bodies** and areas of well-watered vegetation. To the south in the City of Richmond, strong contrasts in $T_0$ are associated with surfaces of intensive agricultural systems separated from highly developed urban areas by roads which give linear boundaries between the two land uses. These contrasting uses give consistently positive correlations between $T_0$ and the impervious surface fraction ($\lambda_i$), and strongly negative relations between $T_0$ and the vegetated surface fraction ($\lambda_v$)




Oke et al. (2017)

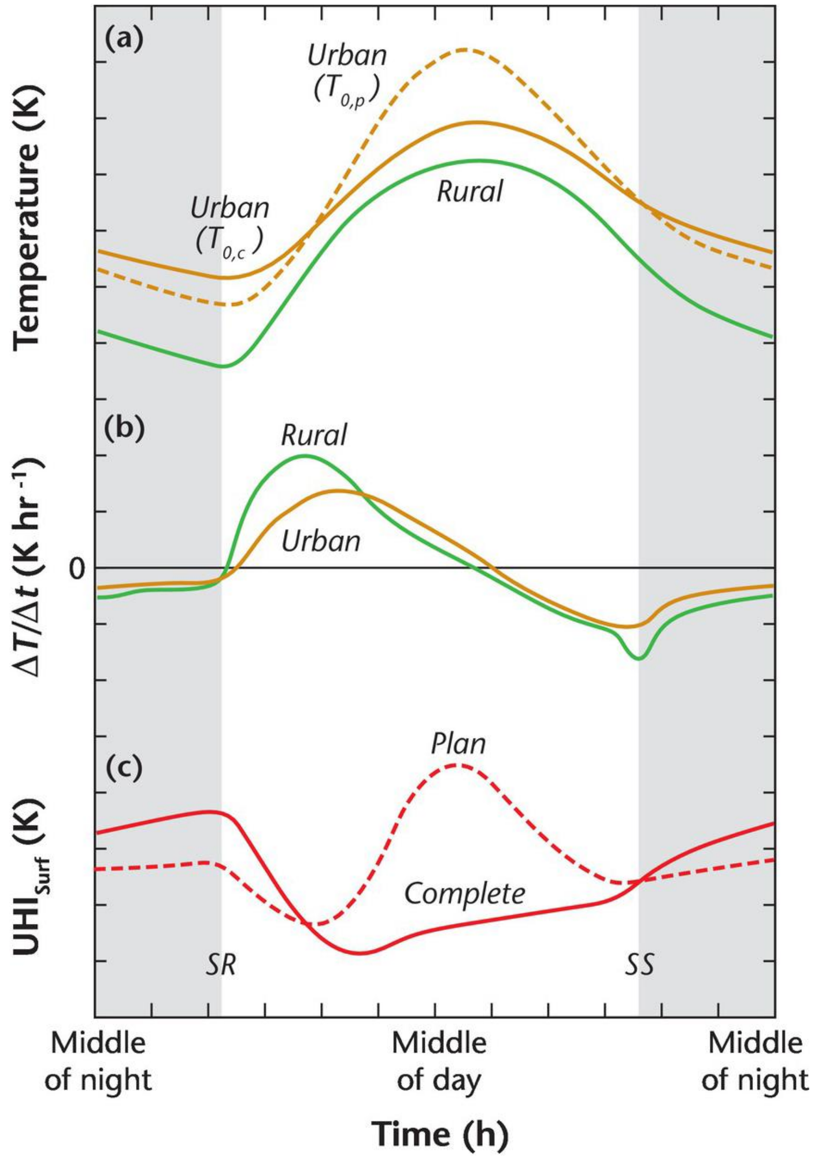
# Urban heat islands

## Surface Heat Island (SUHI or $UHI_{Surf}$)

Note that:

- assessment of $UHI_{Surf}$ from orbital (i.e. satellite) platforms depends on the timing of the overpass (this is often at a constant local time of day)
- Summing and averaging the $T_0$ of the myriad facets at the urban-air interface gives the **complete surface temperature ($T_{0,C}$)**
- The calculation of $T_{0,C}$ (by correcting for anisotropy) usually leads to a *decrease* in daytime estimates of urban system $T_0$ by over 3 K because the surfaces added are mainly vertical and are typically cooler than the unobstructed horizontal surfaces preferentially seen from above
- Nearly all estimates of $UHI_{Surf}$ from satellites or aircraft are made with **cloudless skies**

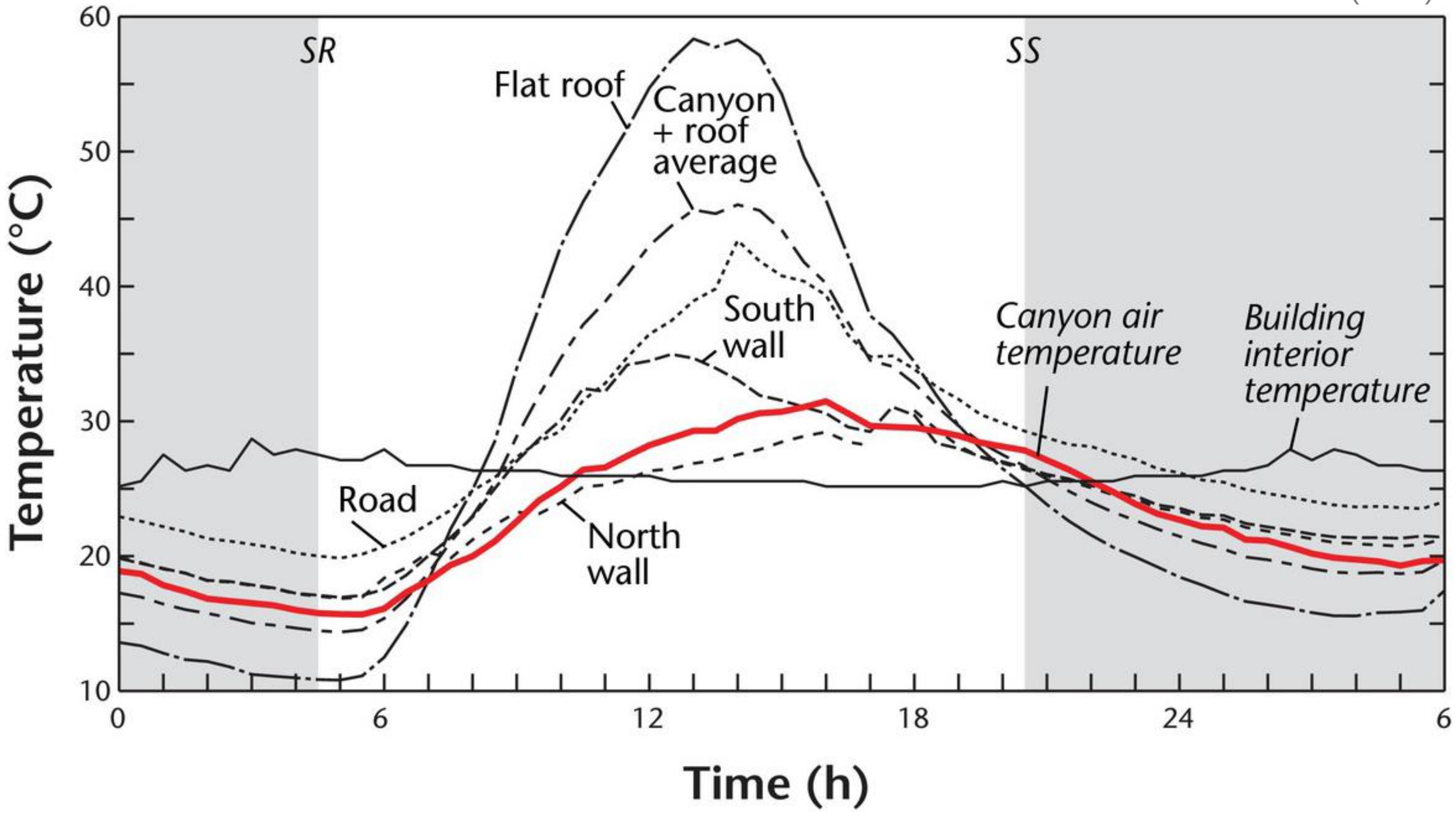
Oke et al. (2017)



# Urban heat islands

## Surface Heat Island (SUHI or $UHI_{Surf}$)

Oke et al. (2017)



# Urban heat islands

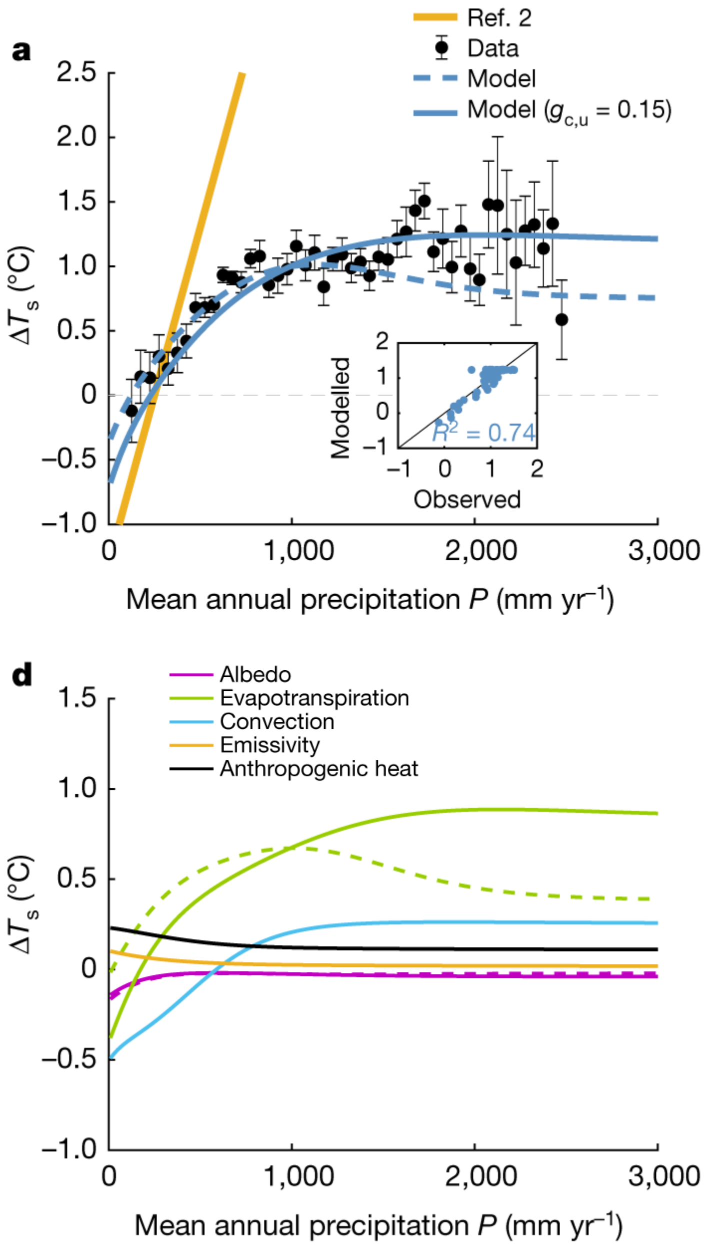
**Drivers of $UHI_{Surf}$**

During summertime (daily average), the SEB for a refence control volume can be written as:

$$C\frac{d\langle T_0\rangle}{dt} = Q^* - \rho C_p \frac{(\langle T_0\rangle - T_a)}{r_a} - L_v \cdot E + Q_F$$

$$\Delta T_{Surf} = f(\Delta Q^*, \Delta E, \Delta r_a, Q_F)$$

albedo emissivity

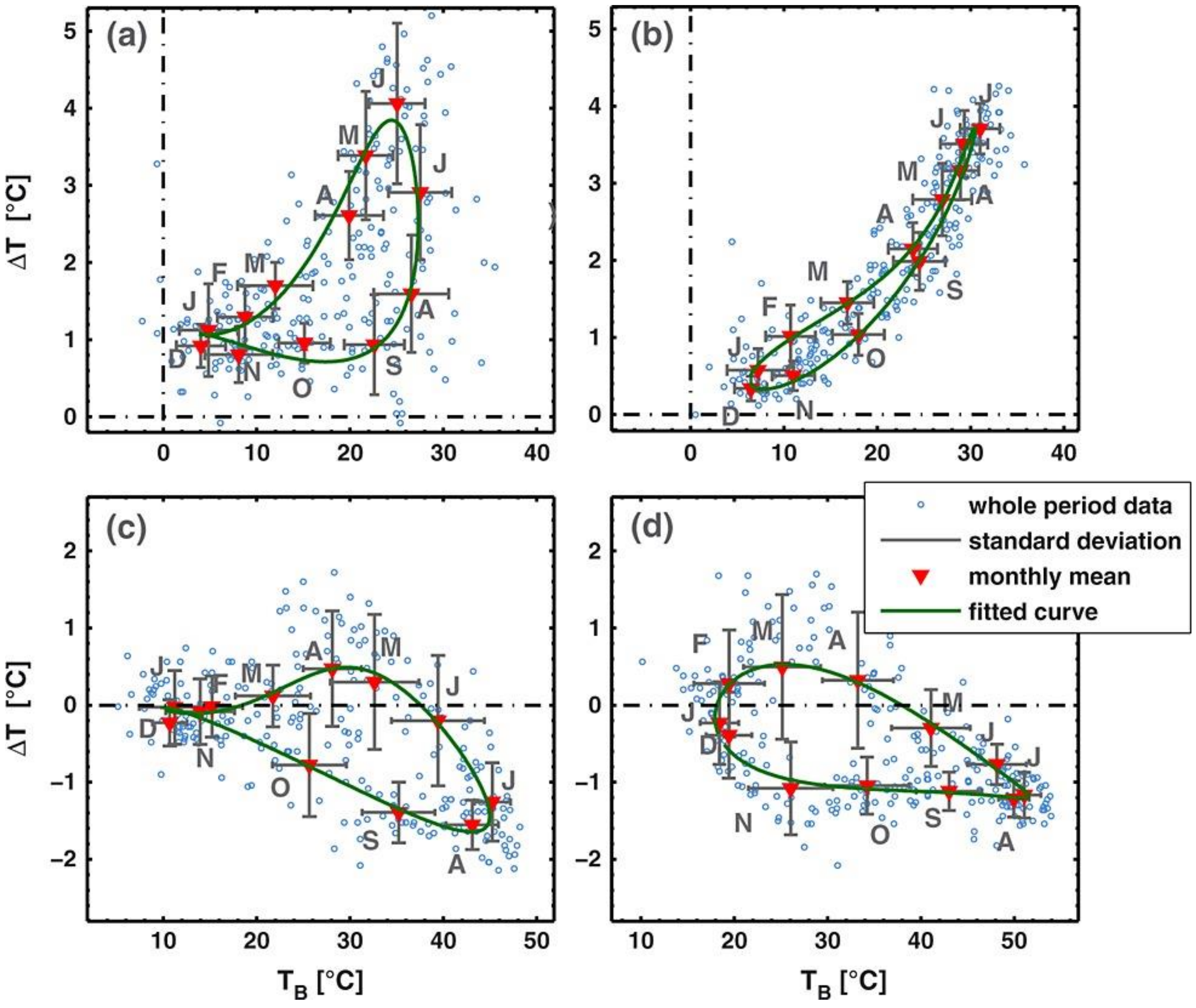



Manoli et al. (2019)

# Urban heat islands

**Seasonality of $UHI_{Surf}$**

Zhou et al. (2013)

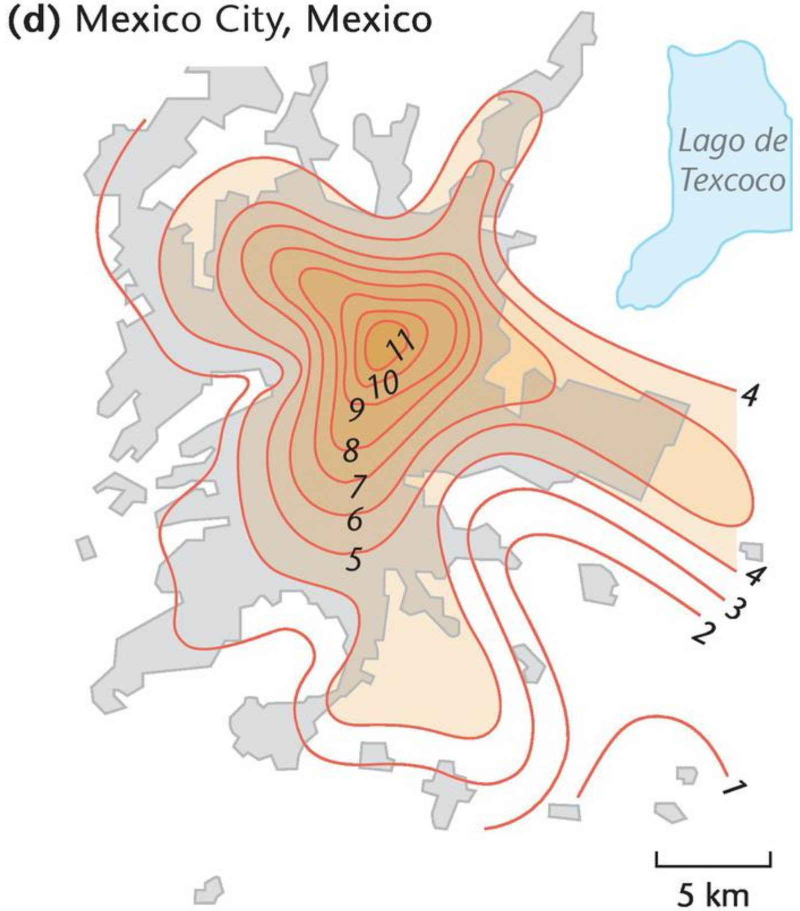


# Urban heat islands

**Canopy Layer Heat Island (CUHI or $UHI_{UCL}$)**

The canopy layer heat island ($UHI_{UCL}$) is observed using thermometers to measure air temperature ($T_a$) near the ground.

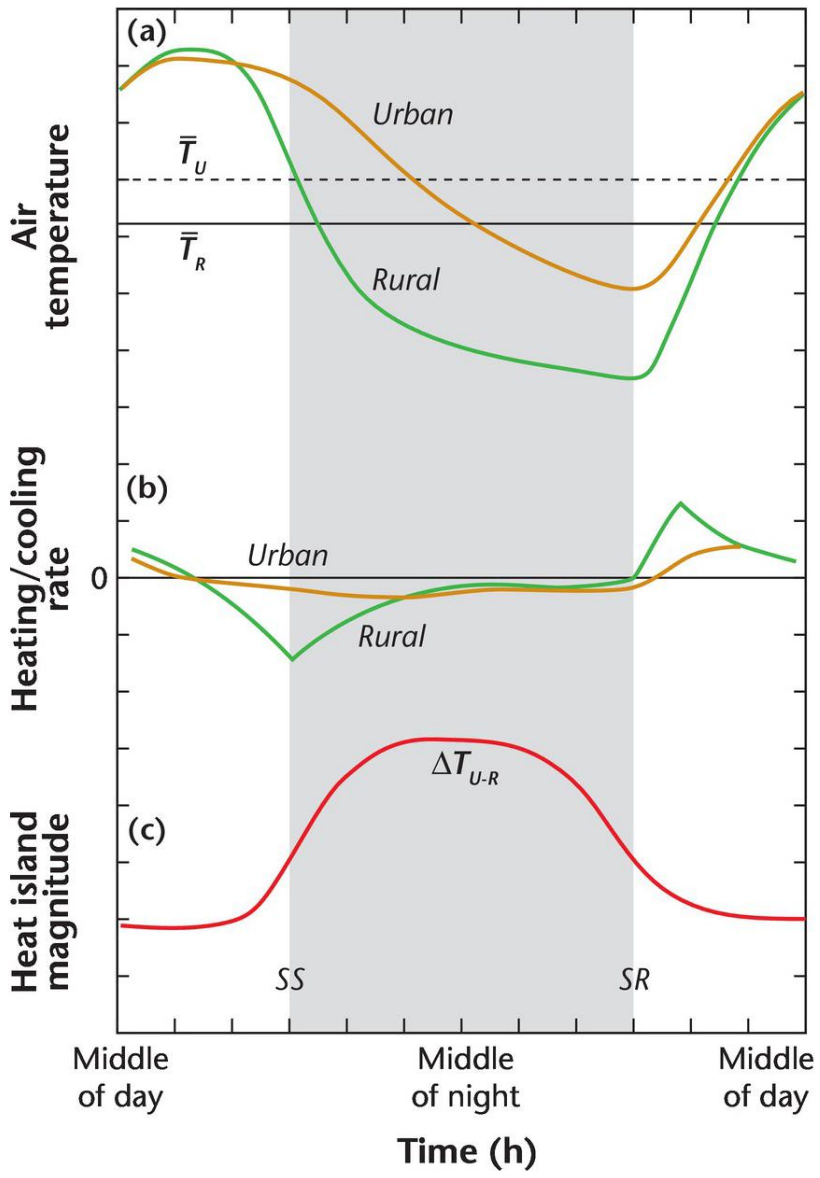
- Time (of day and year) and weather (wind, cloud) are strong controls on the $UHI_{UCL}$, the magnitude of which waxes and wanes in response to these modulating influences.
- To start, we focus on calm, clear nights when radiation cooling is strong and turbulent mixing is weak




Oke et al. (2017)

# Urban heat islands

Oke et al. (2017)



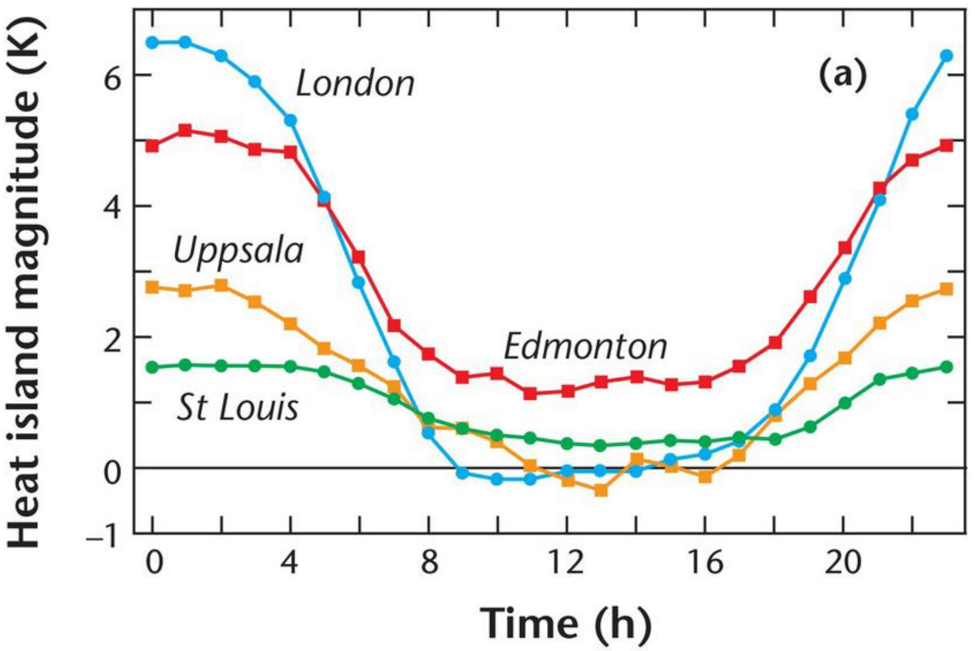

## Canopy Layer Heat Island (CUHI or $UHI_{UCL}$)

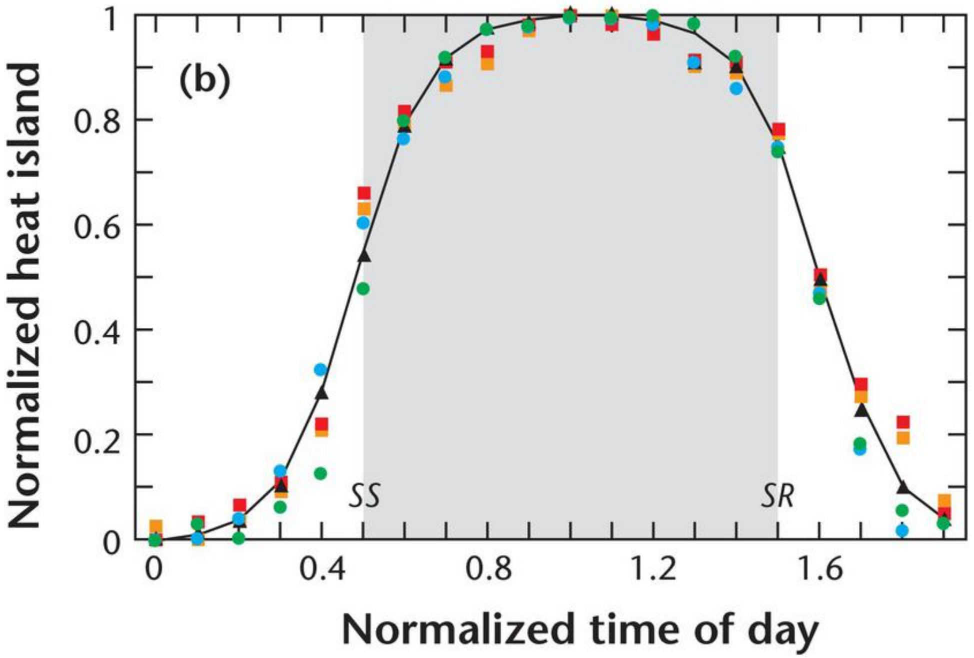
The $UHI_{UCL}$ effect is primarily a ***nocturnal*** phenomenon created because urban areas fail to cool as rapidly as the rural surroundings in the late afternoon and evening. Hence it is driven by differences in rates of urban warming and cooling which create the daily variation of the $UHI_{UCL}$

- Near **sunrise** rural areas are distinctly cooler, but soon air temperature increases rapidly because they are generally open to the Sun.
- By **midday** $T_U$ catches up to $T_R$, the overnight $UHI_{UCL}$ is rapidly eroded, so that by midday it is not uncommon for urban–rural differences to be slightly negative (cool island)
- After their **mid-afternoon** maxima both environments cool down. The rural cooling rate is much larger because $\psi_{sky}$ is large and thermal admittance (which depends on capacity and conductivity) is small. On the other hand, within the UCL it is sheltered, the horizon is restricted, heat is released more slowly from storage and plus there are anthropogenic heat emissions.

# Urban heat islands

## Canopy Layer Heat Island (CUHI or $UHI_{UCL}$)




(a) Diurnal evolution of the $UHI_{UCL}$ in four cities as observed in local time, and (b) the same data with UHI magnitude normalized by its amplitude and time by hours of daylight and darkness

Oke et al. (2017)

# Urban heat islands

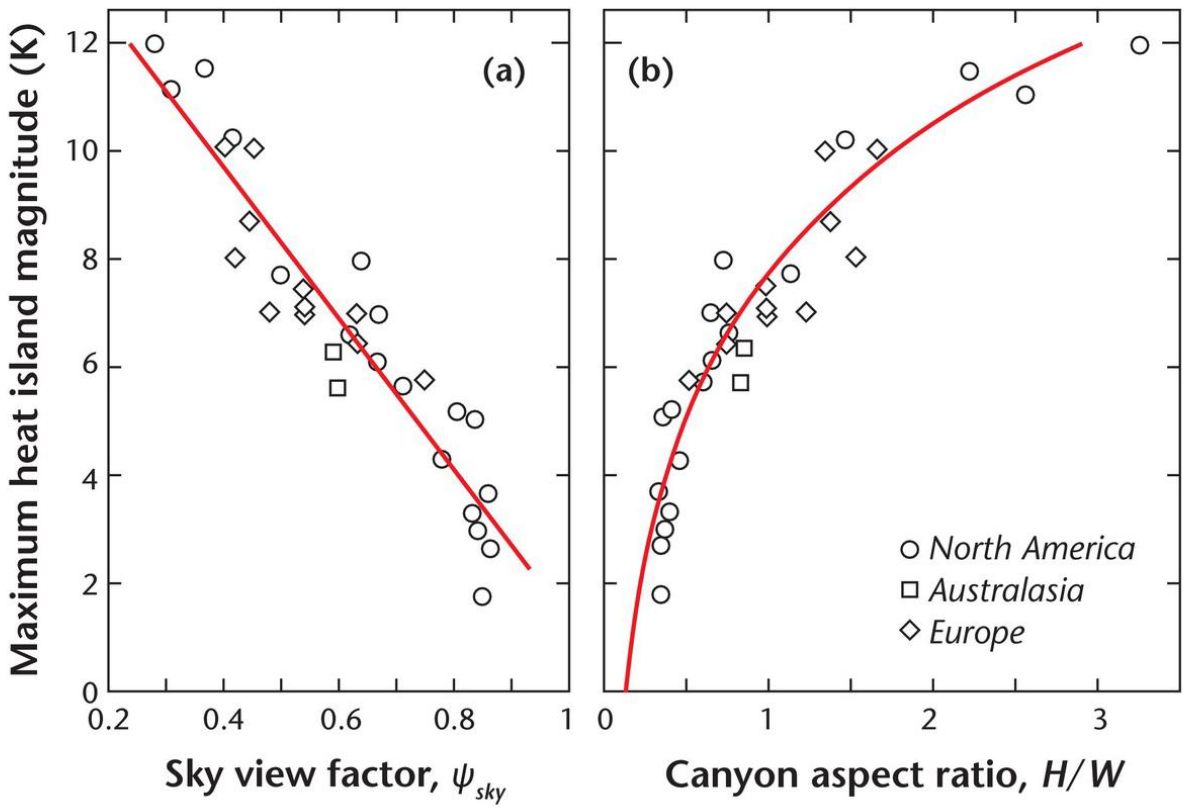
EPFL

## Canopy Layer Heat Island (CUHI or $UHI_{UCL}$)

City cores are generally characterized by greater density of buildings and other infrastructure, taller buildings, more anthropogenic heat, less vegetation and so on. The canyon aspect ratio (*H*/*W*) and the sky view factor ($\psi_{sky}$) of the street canyons in the city's core are reasonable surrogates of these characteritics.

The figure here shows the relation between these two measures and the maximum $UHI_{UCL}$. The results incorporate a wide range of settlements extending from small settlements (villages and towns) to large cities (with several million people).

Oke et al. (2017)



# Urban heat islands

## Effects of weather and surface conditions ($UHI_{UCL}$)

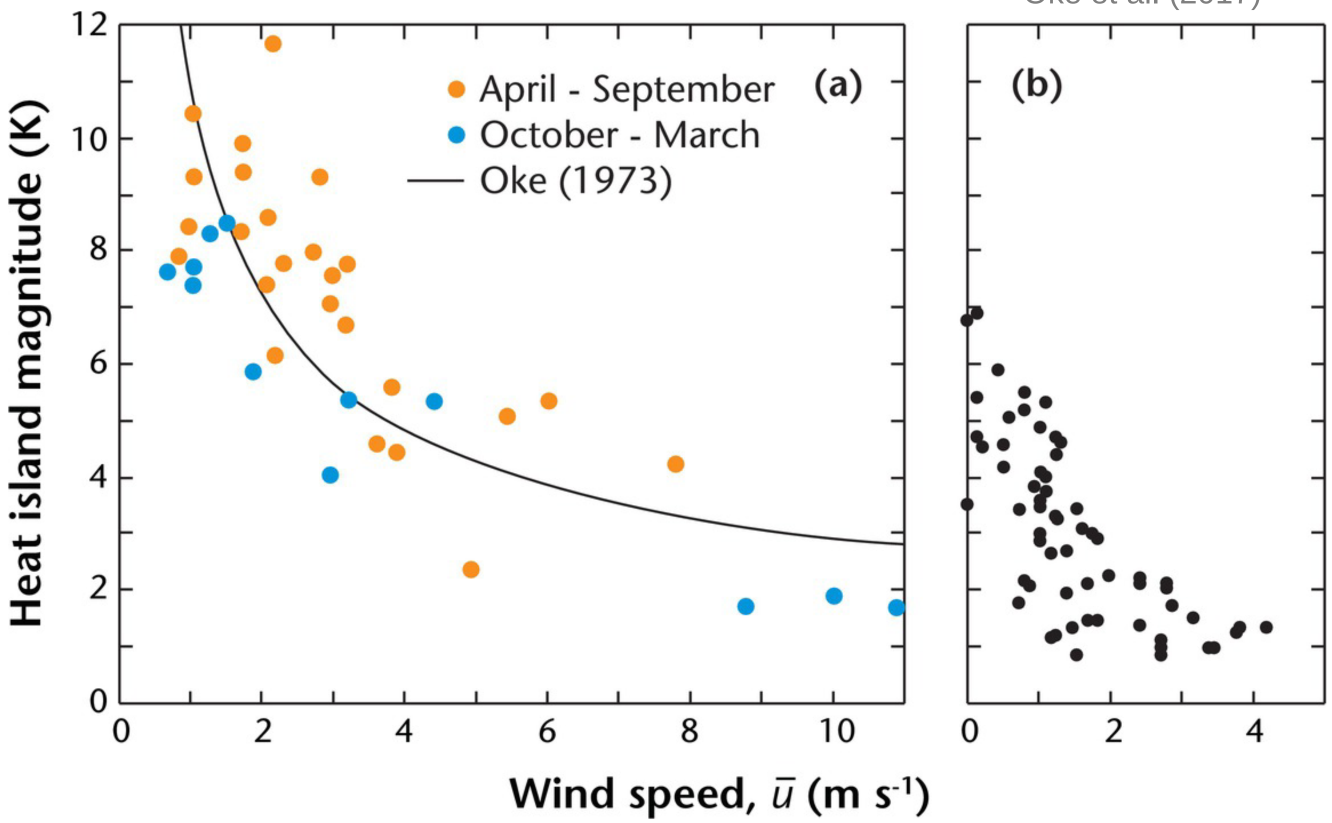
**Wind Speed**

Wind speed is the main driver of advection and turbulent exchanges that limit horizontal and vertical temperature differences. Its impact can be approximated by a power-law relation:

$$\Delta T_{U-R} \sim \overline{u}^{-k}$$

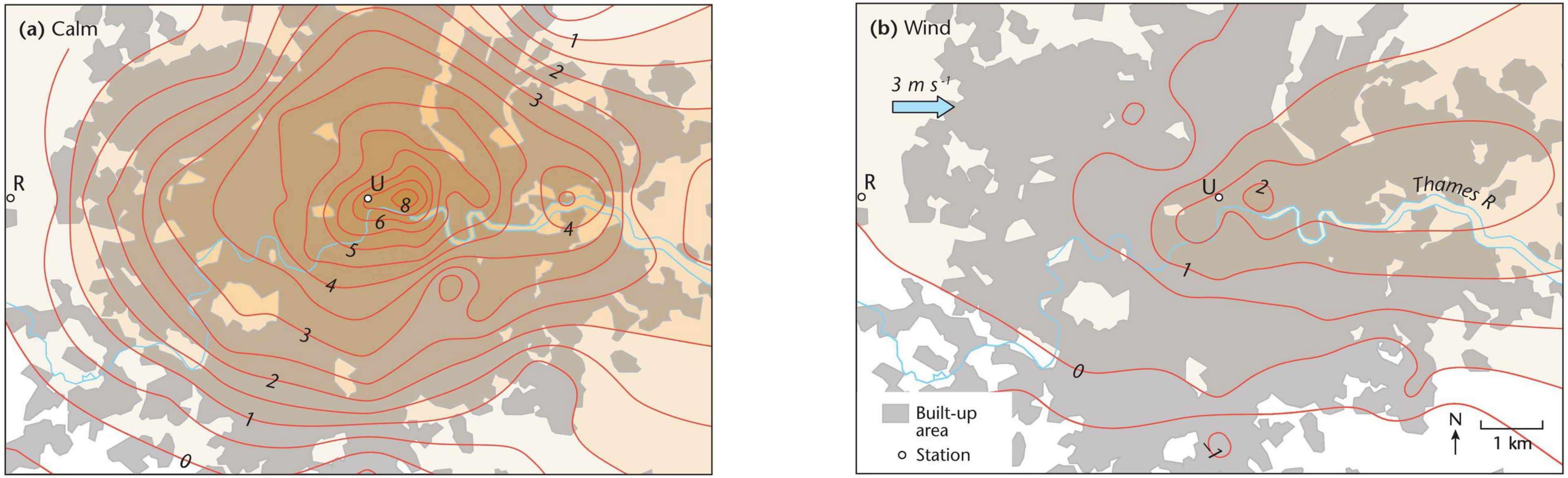
The relation between the regional wind speed and the nocturnal $UHI_{UCL}$. (a) In Vancouver, Canada, at the time of maximum heat island magnitude on cloudless nights (b) In London, United Kingdom the mean for the period 2200–0400h on all August and September days

Oke et al. (2017)



# Urban heat islands

## Effects of weather and surface conditions ($UHI_{UCL}$)




The effect of wind speed in reducing the magnitude and changing the shape of the nocturnal $UHI_{UCL}$ of London, United Kingdom: (a) calm day, (b) W wind at 3 m/s

Oke et al. (2017)

# Urban heat islands

**Effects of weather and surface conditions ($UHI_{UCL}$)**

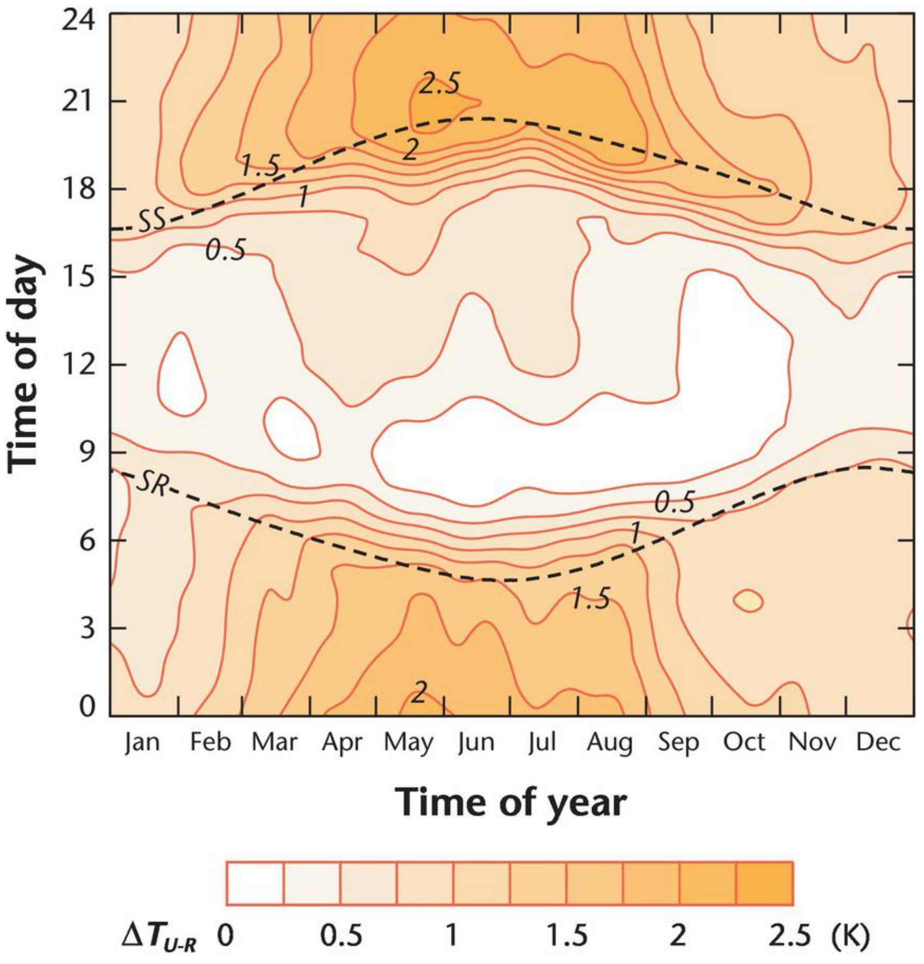
**Clouds:**

- Both cloud cover fraction (amount of sky obscured) and cloud type (indirectly related to height) are important modulating controls on the $UHI_{UCL}$
- the main impacts are the reduction of solar receipt and the trapping of longwave radiation by clouds

**Soil Moisture:**

- the variation in **<u>rural areas</u>** has a significant impact on the surface temperature, because of its dominant role in setting the thermal properties of the soil (admittance is larger for wet soils, hence weak cooling rates at night → small UHI) and evapotranspiration (if water stress, no evaporative cooling during day)

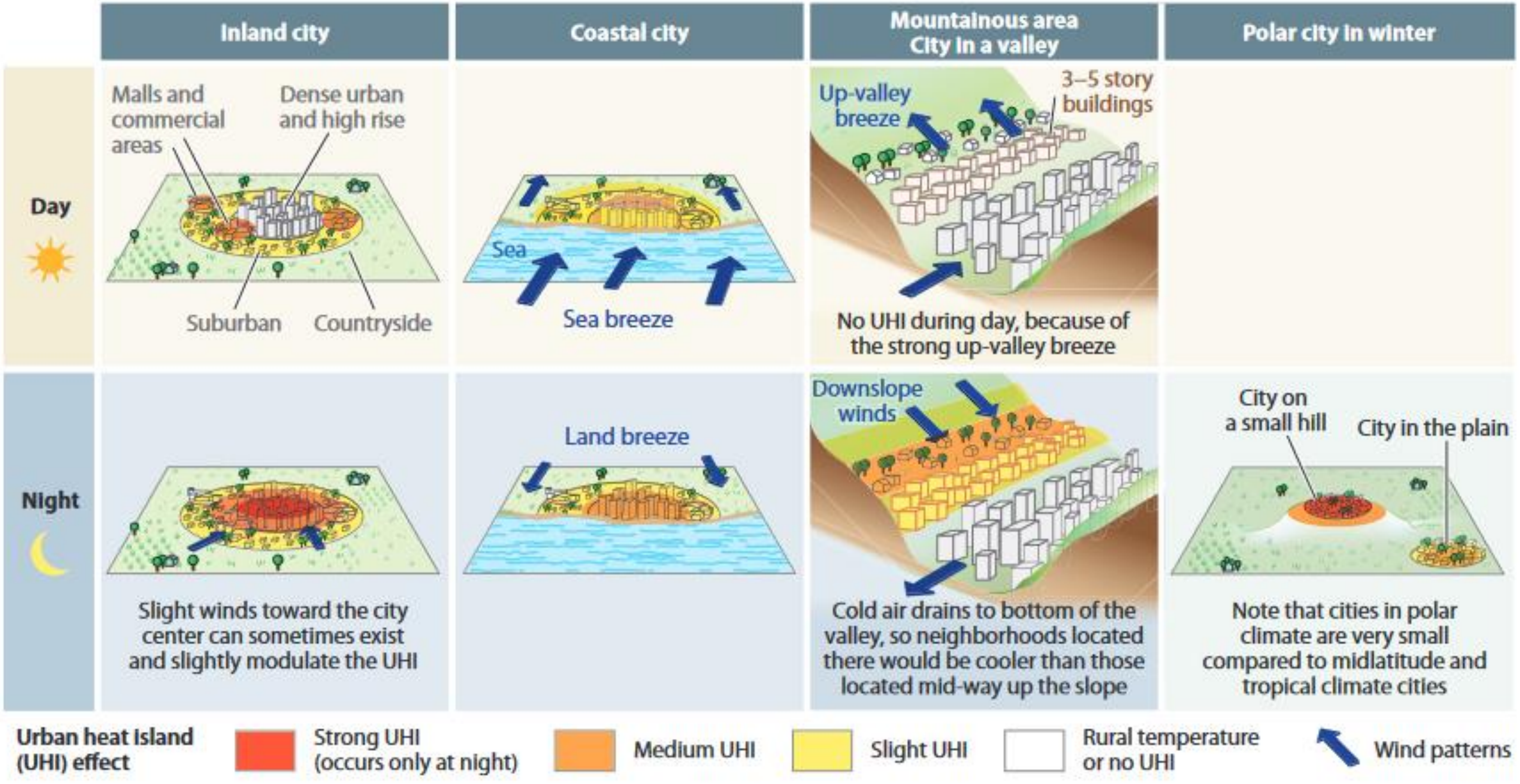
Oke et al. (2017)




Daily and seasonal variation of the $UHI_{UCL}$ (K) for Basel, Switzerland

# Urban heat islands

## Effects of weather and surface conditions ($UHI_{UCL}$)




Urban Climates and Climate Change | Annual Review of Environment and Resources

# Urban heat islands

EPFL

### Drivers of $UHI_{UCL}$

The causes of the $UHI_{UCL}$ are allied closely with those at the surface but the big difference is that they deal with a layer or volume of air, not just the air-surface interface

Naturally the surface temperature ($T_0$) remains critically important to that of the lowest layer of air ($T_a$), however, while the two are closely linked, the relationship is not linear.

| Cause | Description of cause |
|---|---|
| **Canopy layer heat island** ($UHI_{UCL}$) | |
| **Surface geometry** | **(a)** Increased surface area ($\lambda_c > 1$)<br>**(b)** Closely-spaced buildings<br>• – multiple reflection and greater shortwave absorption (lower system albedo);<br>• – small sky view factor ($\psi_{sky} < 1$) reduces net longwave loss, especially at night;<br>• – wind shelter in UCL reduces heat losses by convection and advection. |
| **Thermal properties** | Building materials often have greater capacity to store and later release sensible heat. |
| **Surface state** | **(a)** Surface moisture-waterproofing by buildings and paving reduces soil moisture and surface wetness.<br>**(b)** Convection favours sensible ($Q_H$) over latent heat flux density ($Q_E$).<br>**(c)** *If snow* – lower albedo in city gives relative increase of shortwave absorption compared to rural areas. |
| **Anthropogenic heat** | Anthropogenic heat release due to fuel combustion and electricity use is much greater in city. |
| **Urban 'greenhouse effect'** | Warmer, polluted and often more moist urban atmosphere emits more downward longwave radiation to UCL. |

Oke et al. (2017)

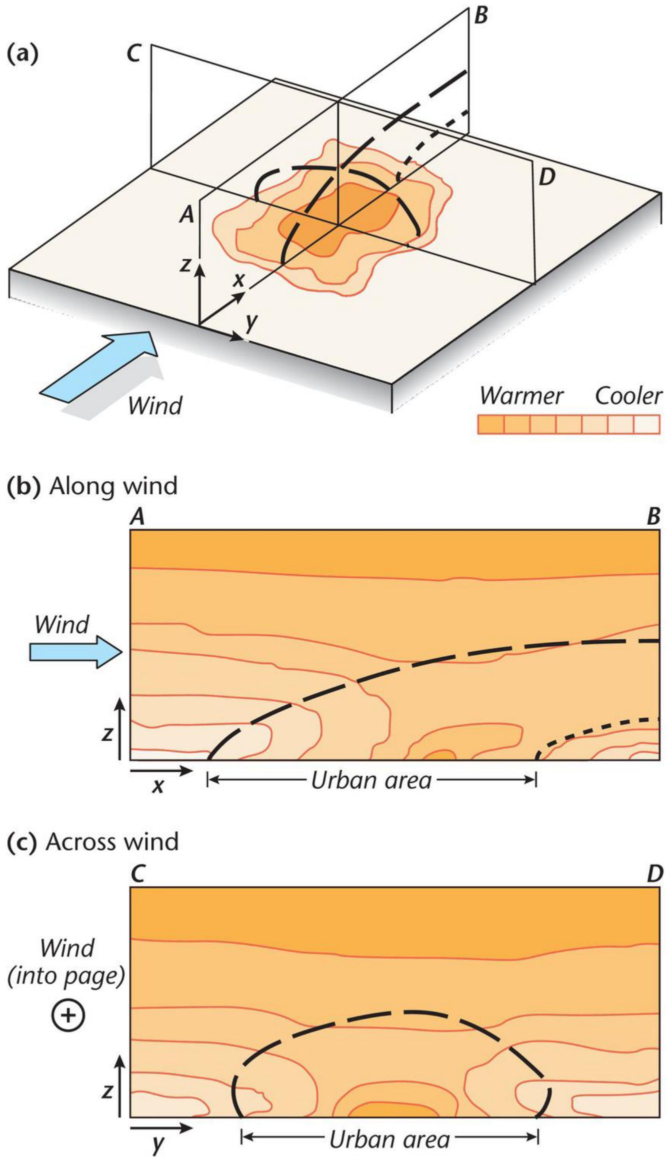
# Urban heat islands

**Boundary Layer Heat Island ($UHI_{UBL}$)**

Naturally there is continuity between isotherm patterns in the UCL, and those just above, at the base of the UBL

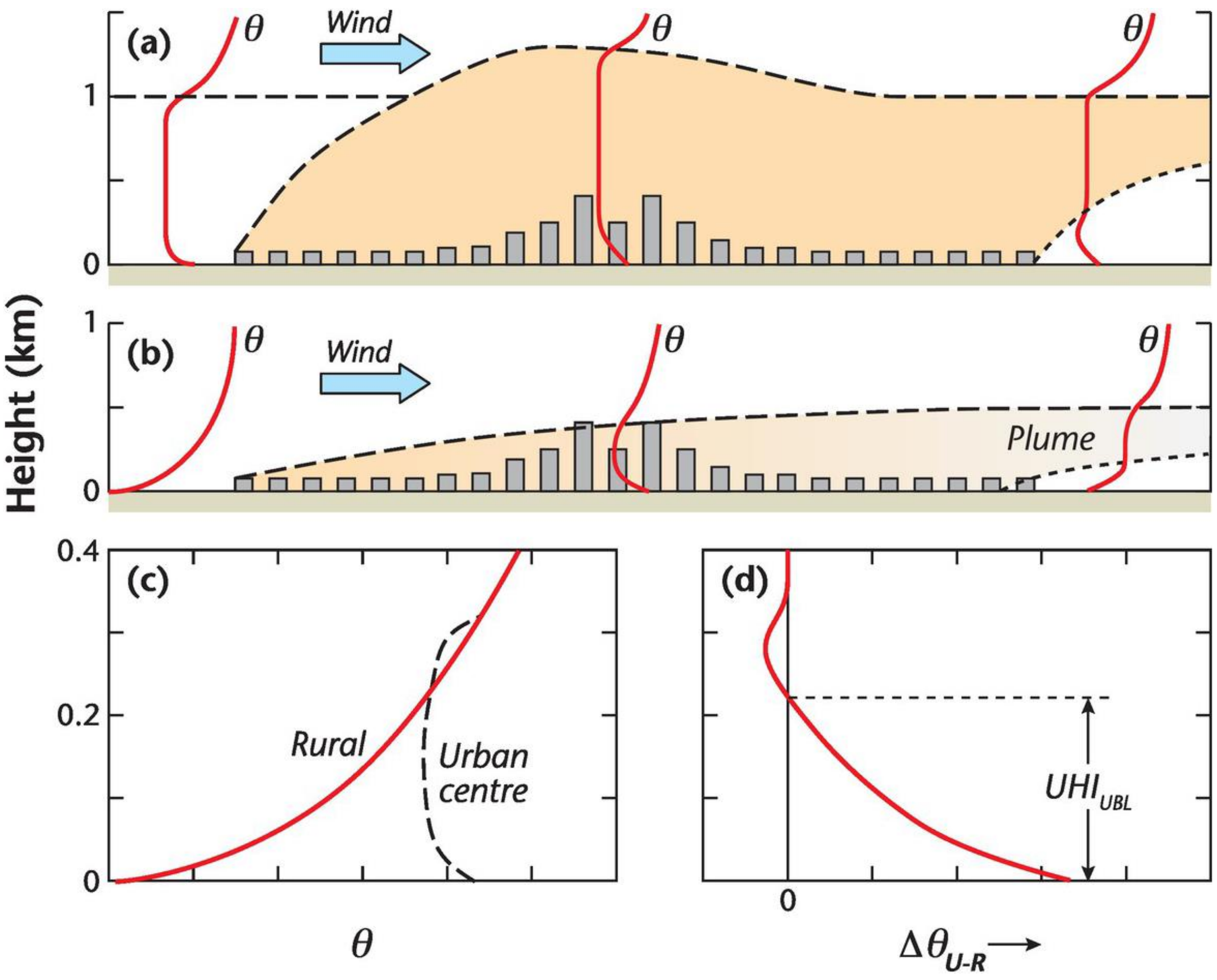
Two forms of the UBL are observed:

- the **urban dome** is found with calm, or very weak, airflow. This generates the self-contained UHI circulation discussed
- the **urban plume** form is found in both stable and unstable conditions: t
  - he first plume case typically occurs at night, when weak or moderate winds advect stable air across a city.
  - The second plume case occurs by day when an unstable ABL is advected by moderate airflow across a city with strong sensible heat fluxes.




Oke et al. (2017)

# Urban heat islands




Idealized summary of the thermal structure of the UBL during fine weather, in **(a)** daytime, **(b)** at night. **(c)** Rural and city centre profiles at night define the variation of the magnitude of the UHI with height, and its depth. Temperature profiles use potential temperature (*θ*)

Oke et al. (2017)

# Today's session

## Outline

- Urban heat islands
- **Urban cooling strategies**
- Urban dry islands

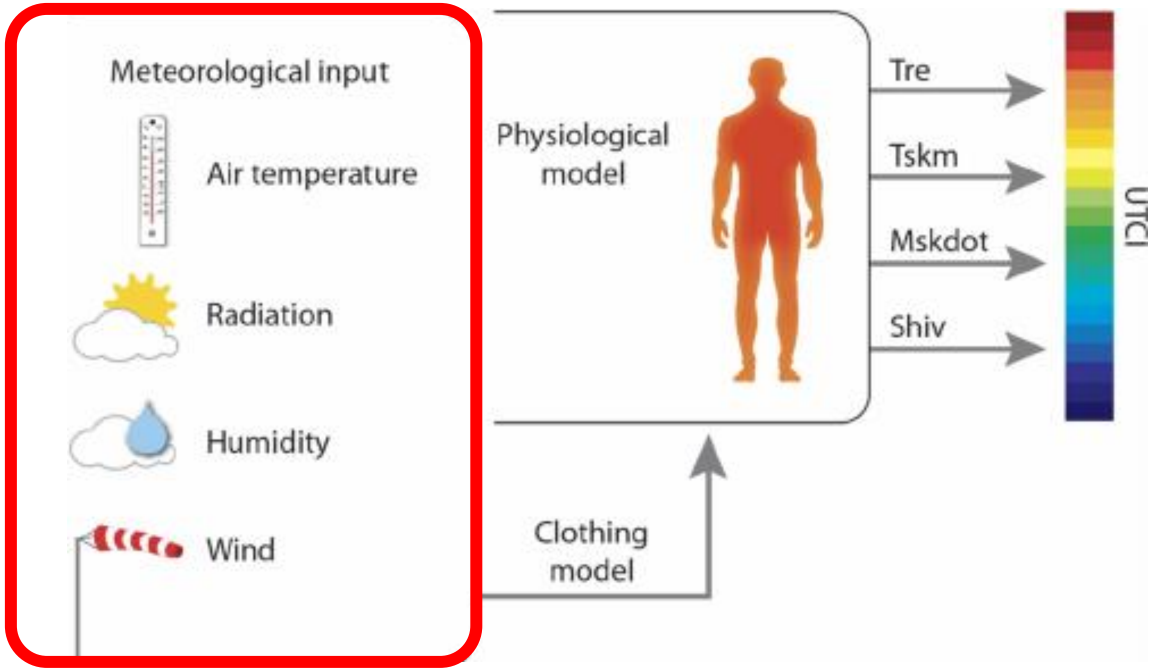
# Urban dry islands

**Thermal comfort & wellbeing**

A great number of indices have developed that link thermal responses to measures of ambient stresses and body strains.

Examples include the Humidex and Wind Chill Index (WCI), Physiological Equivalent Temperature (PET), Universal Thermal Climate Index (UTCI).

These indexes are generally calculated starting from meteorological inputs (wind velocity, air temperature, radiation, and humidity).




Conceptual description of the UTCI (source: Google Images)

# Urban cooling

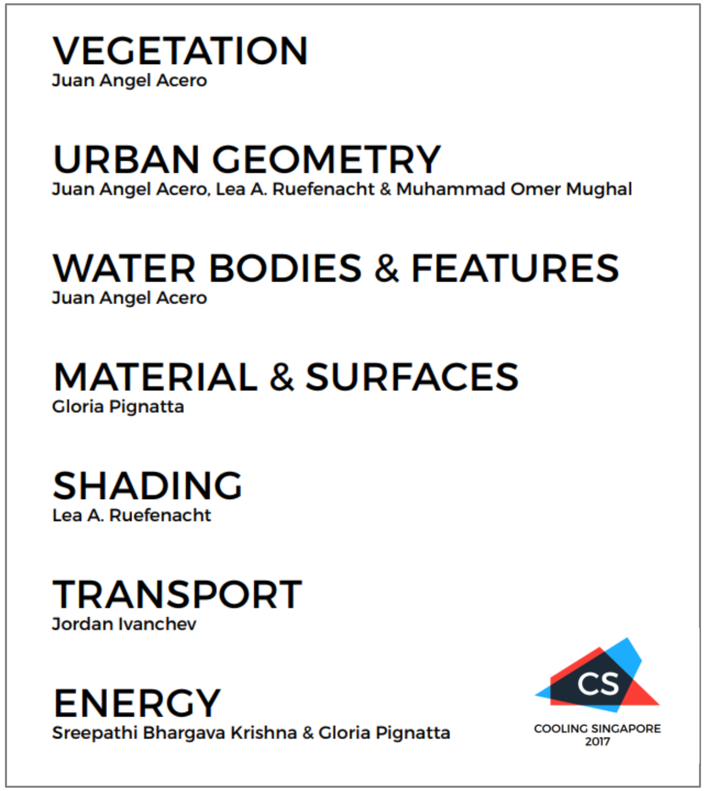
EPFL

[Strategies for cooling Singapore](#)

| Table 1 The need for heat sensitive design |
| --- |
| **Health:** 20% of homes in England overheat[3] and overheating-risk will increase in the future, particularly for vulnerable and elderly populations[4]. Overheating risk can occur alongside poor indoor air quality[9]. |
| **Climate Mitigation:** the government has pledged Net Zero emissions by 2050, and many organisations have declared climate emergencies. Heat sensitive design reduces summer cooling demand and winter fuel bills[7]. |
| **Climate Adaptation:** hotter temperatures and heatwaves are becoming more frequent. Heat sensitive design is needed at all scales (urban to building) to increase infrastructure and built environment resilience and improve thermal comfort[10]. |
| **Air pollution:** features that promote cooling like open space and good ventilation also benefit air quality[11]. |
| **Environmental Justice:** vulnerable communities are more likely to live in dwellings prone to overheating, and have less access to indoor cooling or cooling urban green space, exacerbating existing health inequalities and inequities[12]. |

TDAG (2021)

# Urban cooling



VEGETATION
Juan Angel Acero

URBAN GEOMETRY
Juan Angel Acero, Lea A. Ruefenacht & Muhammad Omer Mughal

WATER BODIES & FEATURES
Juan Angel Acero

MATERIAL & SURFACES
Gloria Pignatta

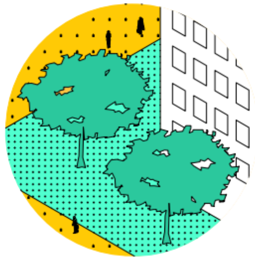
SHADING
Lea A. Ruefenacht

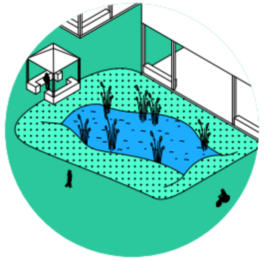
TRANSPORT
Jordan Ivanchev

ENERGY
Sreepathi Bhargava Krishna & Gloria Pignatta



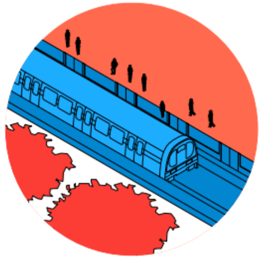
PLANTING GREENERIES
**VEGETATION AROUND BUILDINGS**





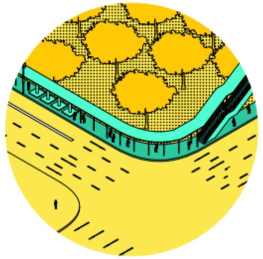
FEATURES
**PONDS ON ROOFS/ GROUND FLOOR**

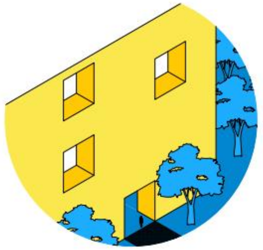
TRAFFIC REDUCTION
**PUBLIC TRANSPORT**



GEOMETRY OF URBAN CANYON
**SKY VIEW FACTOR**

SHELTER DESIGN
**SHADED PEDESTRIAN SPACES**





BUILDINGS
**COOL FAÇADES**

[Strategies for cooling Singapore]

# Urban cooling

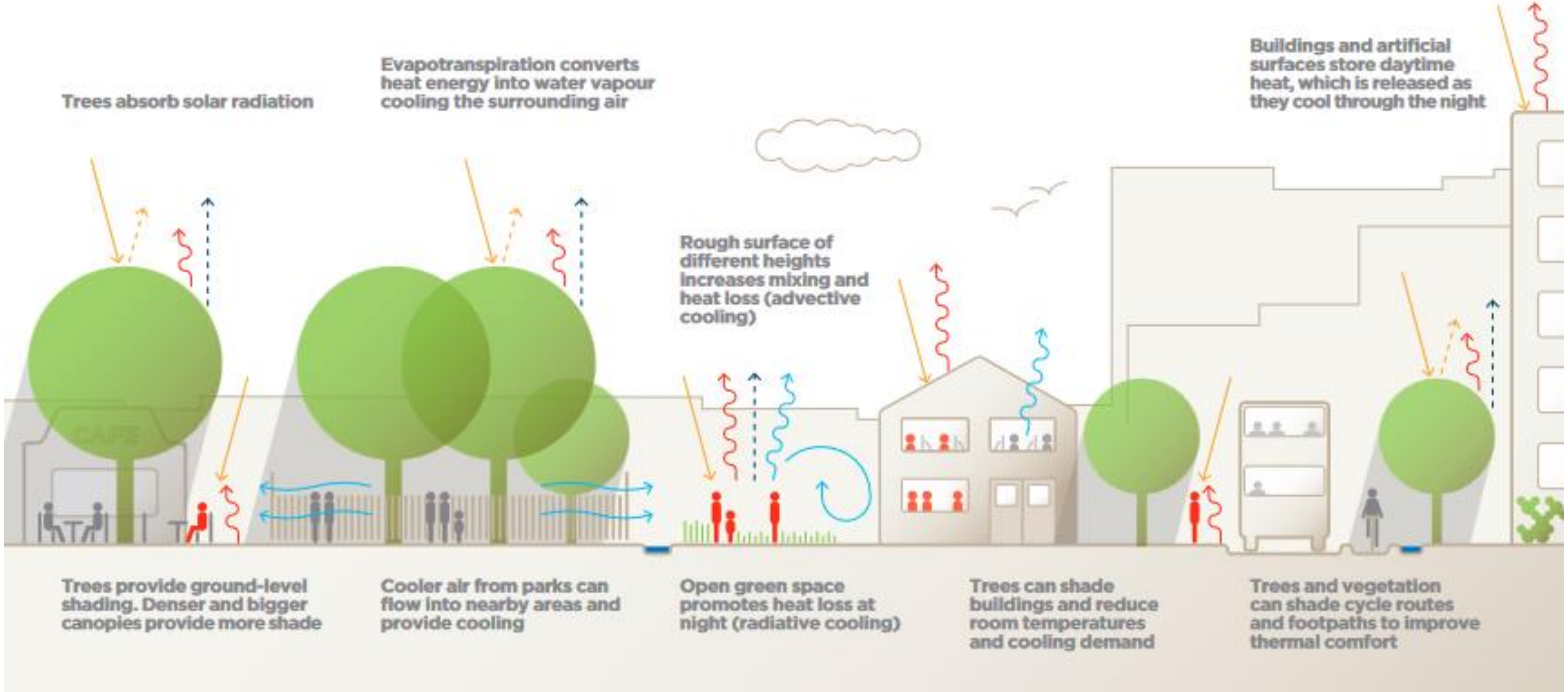
EPFL

Table 2 **Factors affecting urban heat**

| Factor | Effect | Mitigation |
|---|---|---|
| **Meteorology** | UHI is greatest in dry, still (anticyclonic) conditions with limited wind to mix and disperse heat. | Use urban-scale design to promote air flow and mixing (and prevent heat build-up). |
| **Time** | Typically the UHI is greater at night as densely urbanised areas retain heat and cool more slowly. | Consider timing of landuse; night time overheating is less problematic in empty offices. |
| **Climate change** [16] | Hot days increasing in frequency and temperature. Trend towards drier summers (especially SE England) and increasing drought risk. Drier weather reduces cooling by evapotranspiration. | Use climate projections to understand future trends and climate risks. Plan and design-in cooling (eg blue-green infrastructure) as urban areas have long lifespans and will exist in hotter temperature extremes. |
| **Landscape** [13,15,17] | Topography influences wind strength, direction, and turbulence, influencing dispersion of heat. Urban areas in valleys or at the base of slopes may have reduced air circulation and heat dispersion. Coastal areas have onshore/offshore winds. | Use landscape level-design to promote air flow and mixing. Support water storage and blue-green infrastructure to maximise landscape cooling potential. Dry natural land surfaces behave similarly to artificial land surfaces without water and/or vegetation. |
| **Urban form** [13,15,17] | The 3D form of streets and neighbourhood, such as street width, building height and orientation, determines air flow, sky view factor and how easily an area can lose heat by advective mixing or radiative cooling. | Opening up urban areas to increase sky view factor (radiative cooling) and promote air flow, ventilation and mixing (advective cooling) can increase heat loss. |
| **Building function** [14,17,18] | Building function and occupancy pattern (eg residential versus commercial) determine overheating risk (Fig, 1). Care homes, schools and hospitals have vulnerable populations at risk of overheating. | Undertake heat-risk mapping across urban areas and consider placing vulnerable populations/ occupancy patterns in areas of lower overheating risk (eg less dense or with more GI). |
| **Materials and ventilation** [17,18,19,20] | Materials and colour determines albedo and heat storage. Glazing can reflect heat away, sometimes onto other surfaces. When transparent it increases internal temperatures and heat storage. Inadequate ventilation can prevent heat dispersion and cooling. | Consider material use in UHI, particularly specific materials designed for cooling eg cool pavements, cool roofs, green roofs and facades. Ensure sufficient natural ventilation to prevent reliance on air-conditioning for cooling. |
| **Emissions** [21] | Waste heat from transport, industrial/residential heating/cooling and people adds warmth to areas. | Use passive cooling techniques wherever possible to reduce heat emissions from air conditioning. |
| **Blue and Green Infrastructure** [19,20,22,23] | Blue green infrastructure provides cooling via: high albedo, shade, evapotranspiration, sky view, at a range of scales from local (green roof) to neighbourhood (park) and city wide (strategic GI design). Water is essential for cooling via evapotranspiration, and can lower urban temperatures. | |

TDAG (2021)

# Urban cooling

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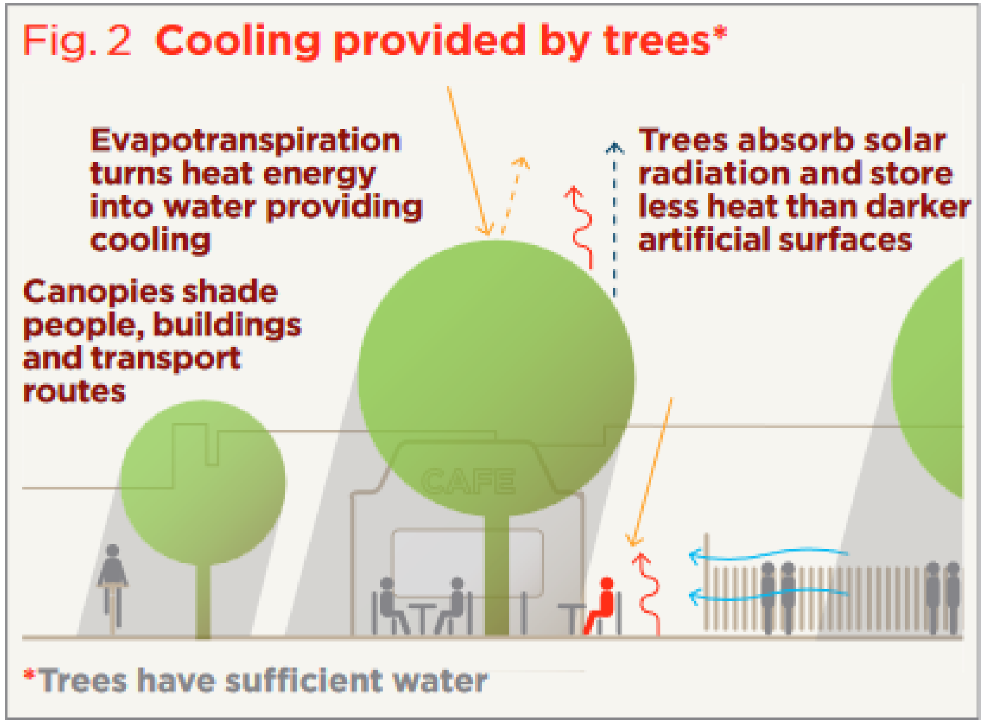
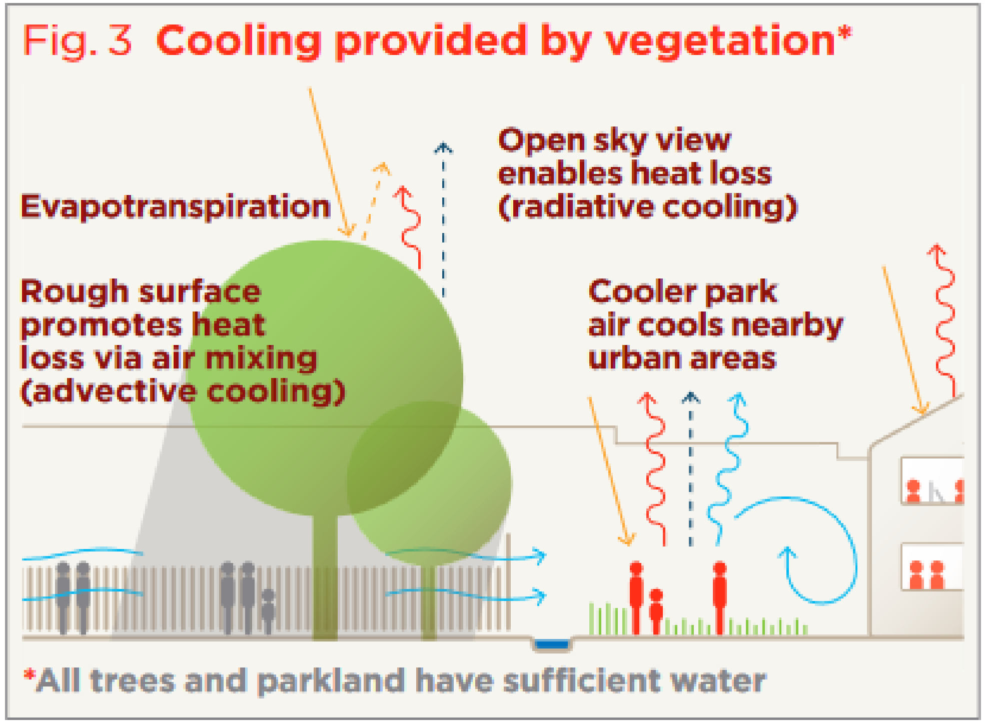
# Urban cooling

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# Urban cooling

## What can practitioners do?

- **Understand the UHI intensity.** Where measurements are unavailable, the most intense UHI is likely co-located with high density urbanisation and least open and/or green space. Some large cities (eg London) are considered entirely within an UHI, but its intensity varies considerably. Mapping Local Climate Zones helps categorise urban density and green space. If making measurements, take these under clear, calm conditions at night to assess maximum UHI magnitude.
- **Heat sensitive strategic planning.** Consider the development's function in relation to the UHI and Local Climate Zones to prevent lock-in, eg a residential development in a dense urban form that will require air-conditioning without suitable natural ventilation or mitigation via building design and materials.
- **Consider site design and materials.** This includes the urban form and its sky view factor, GI and cooling materials such as green roofs and cool pavements. These determine heat loss and thermal comfort, both on and beyond the development. Consider mobility; how will people travel to/from the site and what heat will they produce?
- **Assess building overheating risk.** Building interior and exterior thermal comfort are determined by surroundingurban form, building design and ventilation, and function.
- **It is never too late to mitigate.** Many of the mitigation techniques can (and should) be applied retrospectively.

# Urban cooling

The Guardian (2022)

**Table 3 Factors for planting for cooling (adapted from Forestry Commission[22])**

| Plant Selection[25] | Planting Conditions |
|---|---|
| – Suitability to site.<br>– High reflectance eg light colour leaf.<br>– High transpiration rates eg species with broad leaves.<br>– Large stature trees with wide, dense canopies and/or high density of leaves to provide shade.<br>– Drought tolerant. | – Adequate water supply.<br>– Ample rooting space.<br>– Un-compacted and fertile soil.<br>– Use vegetated surfaces or permeable/porous pavements.<br>– Appropriate site design eg space to grow, sufficient light, aspect. |

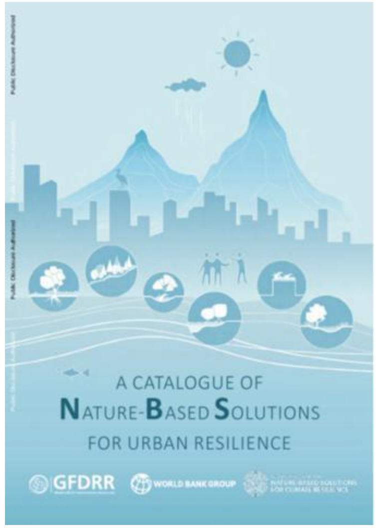
TDAG (2021)

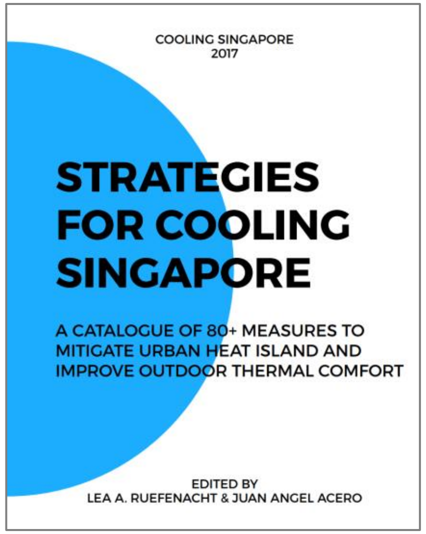
# Urban cooling

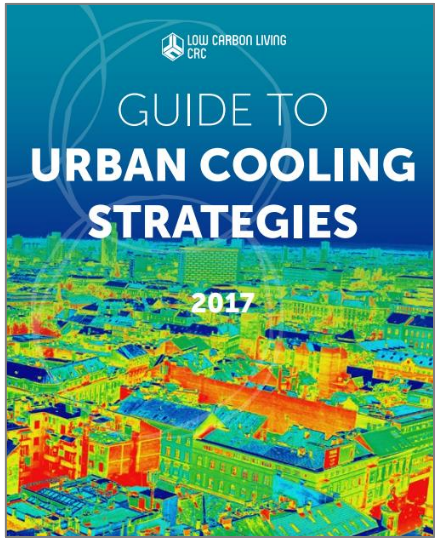
EPFL

## Useful readings

- A catalogue of NBS for urban resilience (World Bank)
- Strategies for cooling Singapore (ETH Zurich, see pdf in Moodle)
- Greenery as a mitigation and adaptation strategy to urban heat (Wong et al. – see pdf in Moodle)
- First steps in urban heat for built environment practitioners (TDAG – see pdf in Moodle)
- Guide to urban cooling strategies (see pdf in Moodle)



# Today's session

## Outline

- Urban heat islands
- Urban cooling strategies
- **Urban dry islands**

# Urban dry islands

### Atmospheric moisture

As a general rule, densely built urban landscapes are **“arid”** by design. Whilst there may be a plentiful water supply, the predominant impervious surface cover and the relative lack of vegetation means there is relatively little water available for ‘natural’ evaporation.

The direct injection of water into the atmosphere by human activities (air conditioning systems, fuel combustion, cooling towers, etc.) partly compensates but, overall, the water content of the urban atmosphere is low especially in daytime, compared with the surrounding environment.

Visible atmospheric moisture from natural and anthropogenic sources in the early morning in Vancouver, Canada

Oke et al. (2017)

# Urban dry islands

## Atmospheric moisture

Atmospheric water vapour (humidity) is more complicated both to describe and to monitor than temperature, because of the compressible nature of the atmosphere. We can define the following direct measures of atmospheric humidity:

- **Absolute humidity ($\rho_v$)** is the ratio of the mass of water vapour ($m_w$) to the total volume of air ($V$) in g $m^{-3}$ (also called: vapour density). The volume of air varies with pressure ($p$). That restricts the use of $\rho_v$ to applications over small height intervals
- **Specific humidity ($q$)** is the mass ratio (in g $kg^{-1}$) between the mass of water vapour ($m_w$) and the mass of moist air ($m_a$). Specific humidity is a conservative humidity measure. This means for an air parcel, it does not change even if pressure or temperature changes.
- **Vapour pressure ($e$)** is the partial pressure (in Pa) exerted by water vapour molecules in an air sample

**Relative humidity (RH)** is the ratio (in %) of the actual vapour pressure to the saturation vapour pressure at the given $T_a$ and $p$ (i.e., the maximum water vapour pressure in the air before it causes saturation and condensation):

$$RH = 100 \frac{e}{e_{sat}(p, T_a)} \ [\%]$$

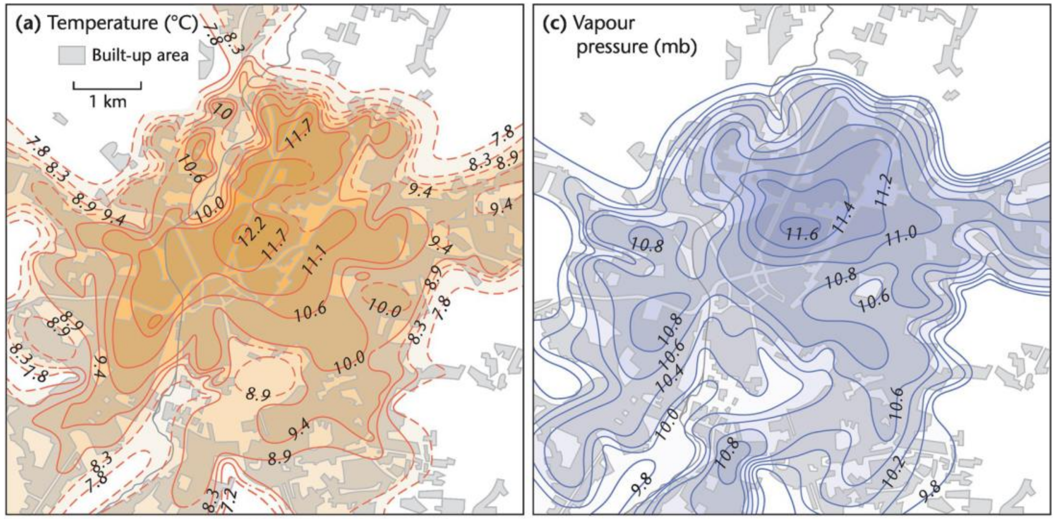
# Urban dry islands

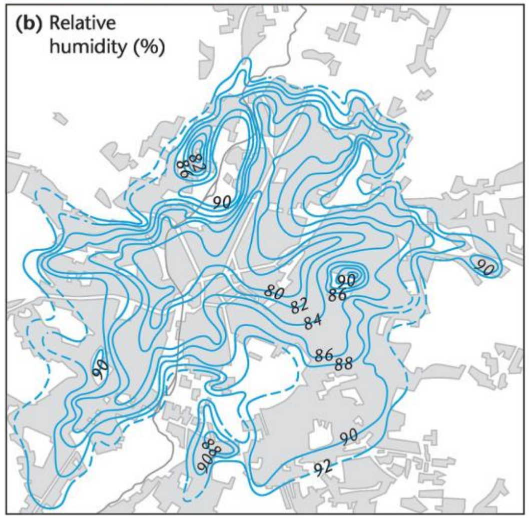
**Urban effects on humidity**

This nocturnal pattern is fairly typical, especially in larger cities: the spatial distribution of *e* in the UCL follows the density of built structures and land cover resulting in an **urban moisture excess** (UME). On the other hand, **RH is lower** in the city center and there is strong correspondence between the fields of $T_a$ and *RH.*

At first glance this might appear counterintuitive but the explanation is that at **night** urban air often does have greater moisture content, but its vapour is further from saturation owing to higher air temperature (i.e.. the UHI).

$e_U > e_R$




$RH_U < RH_R$

Detailed maps from automobile surveys of (a) the air temperature $T_a$ (°C) and atmospheric humidity using both (b) *RH* (%) and (c) vapour pressure, $e_a$ (hPa), in Leicester, United Kingdom on a calm, clear summer night

Oke et al. (2017)

# Urban dry islands

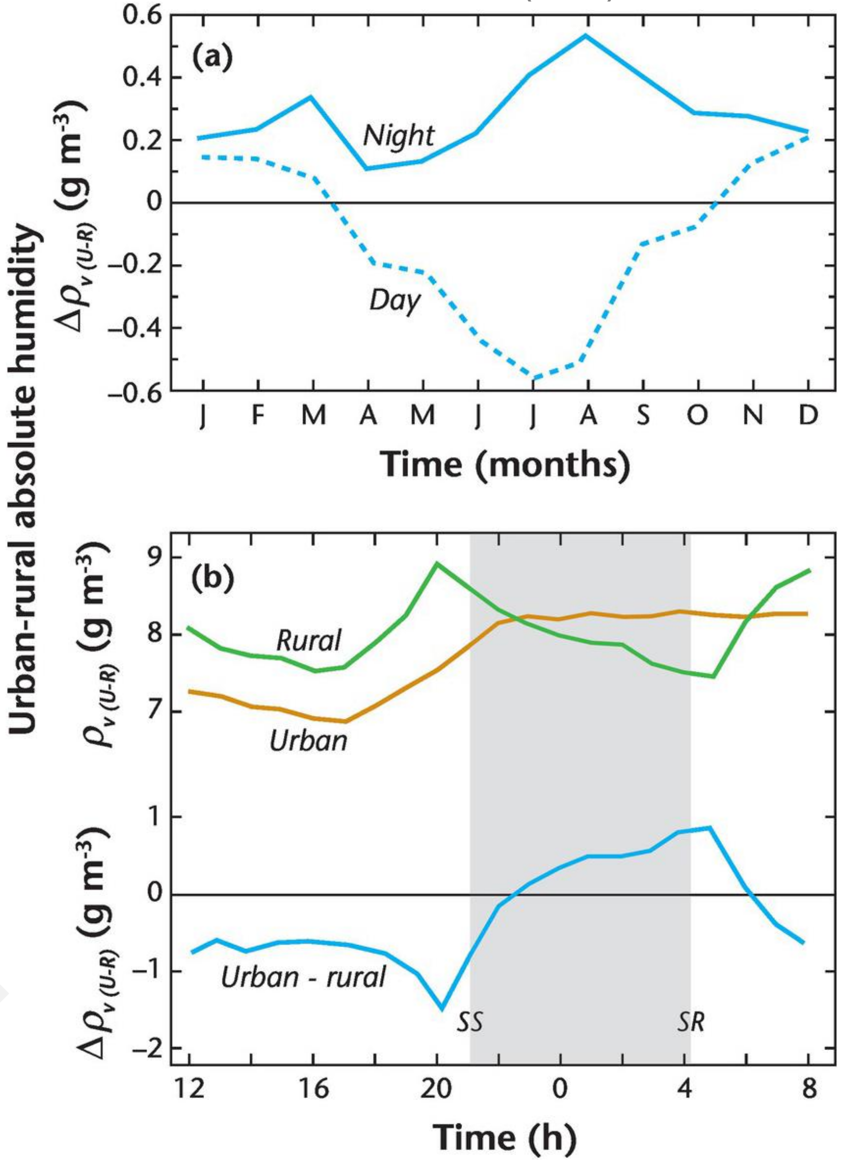
## Drivers of humidity changes

In **summer** there is an urban daytime moisture deficit and nighttime surplus:

- The former is mainly a result of **lower E** in the city due to the greater impermeable surface cover (pavement, buildings) and compacted soils. These are compounded by the greater vertical transport and mixing in cities that enhance exchanges between near-surface air and the drier air above roof level.
- At night the UME is probably a result of two factors:
  - **dewfall** may be reduced in the city because of the warmth of the SUHI
  - **emissions** of anthropogenic water vapour.

Urban effects on humidity in Edmonton, Canada. (a) The seasonal variation of the urban–rural difference of absolute humidity ($\Delta\rho_{v\ U\_R}$) by day and at night. (b) Hourly variation of $\rho_v$ and their difference on cloudless summer nights

Oke et al. (2017)

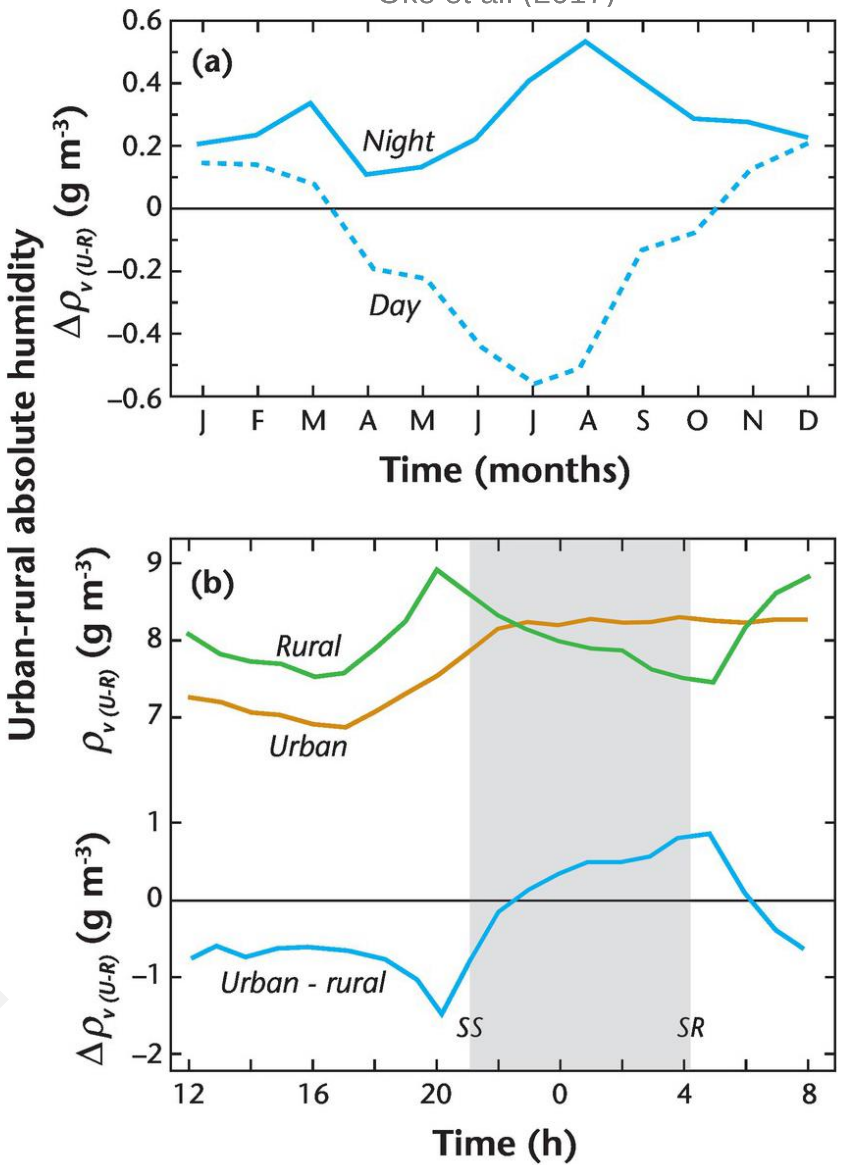


# Urban dry islands

## Drivers of humidity changes

In **winter** a moisture surplus is found both day and night in cities. It is largely due to anthropogenic emissions from space heating appliances and vehicles.

Oke et al. (2017)



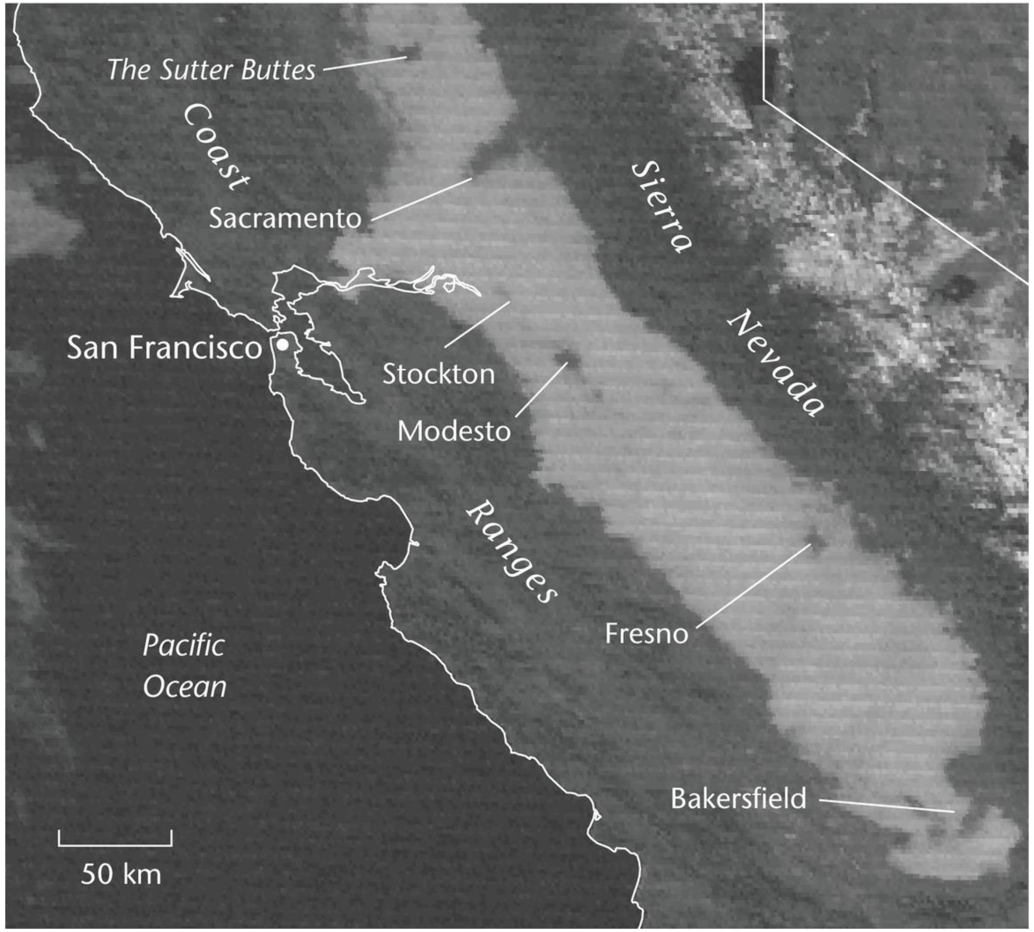

Urban effects on humidity in Edmonton, Canada. (a) The seasonal variation of the urban–rural difference of absolute humidity ($\Delta\rho_{v\ \ U\_R}$) by day and at night. (b) Hourly variation of $\rho_v$ and their difference on cloudless summer nights

# Urban dry islands

Oke et al. (2017)

## Drivers of humidity changes

- In some cities, **extensive irrigation** in urban neighbourhoods introduces surface and atmospheric water that raises humidity above values found in the countryside. This effect may occur during a dry spell or where the city is located in an arid climate.
- In the absence of air pollutants (chiefly smoke particles) that can initiate the condensation process at lower relative humidity, the UHI phenomenon **decreases the frequency of fog occurrence** in cities. However, poor air quality can overcome the UHI effect and cause a dramatic increase in fog, particularly where the city is located in geographic circumstances otherwise normally conducive to fog formation.




GOES satellite image of the Central Valley of California covered with fog. Patches clear of fog are located over the major urban centres in the valley

# Urban dry islands

## Clouds and precipitation

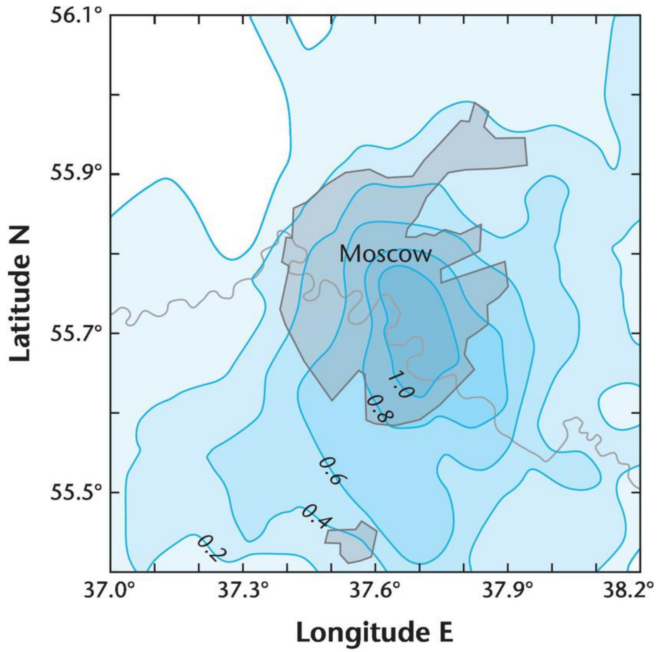
- During the summer season when instability and convective uplift dominate, **increased cloudiness and enhanced precipitation** is found in and downwind of cities.
- This urban effect on clouds and precipitation is due to the **combined influence of the urban heat island** (UHI)**, surface roughness** and **aerosols**.
  - UHI and roughness enhance cloud formation and precipitation via low-level convergence and uplift. Under calm or light wind conditions, **convergence due to the urban heat island circulation** appears to be most important cause. With stronger winds, **moving regional storms may bifurcate and/or split** over cities.
  - Aerosol number, size, type and chemical characteristics can **enhance, suppress or delay precipitation processes** (e.g., radiation cooling vs condensation nuclei)
- Limited research indicates that cities **reduce the frequency of freezing rain and snow**

Oke et al. (2017)

# Urban dry islands

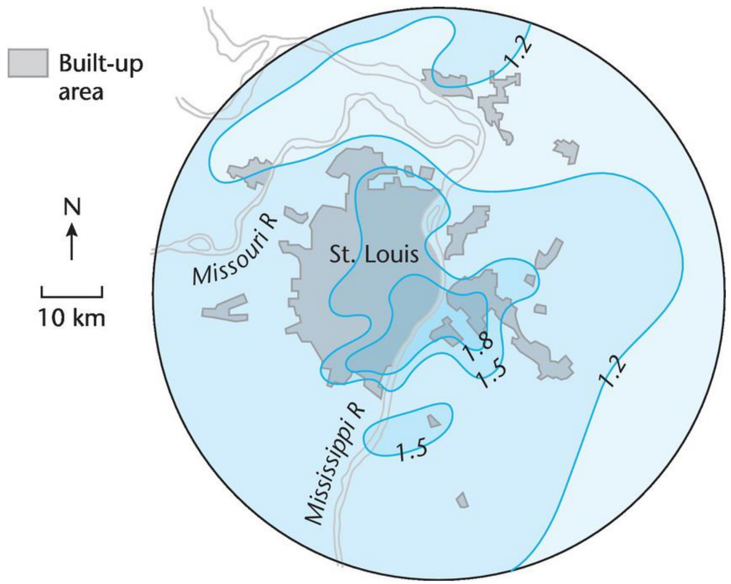
## Clouds and precipitation

### Cloud cover




Spatial distribution of the differences in average fractional cloud cover (labelled in tenths) over Moscow, Russia

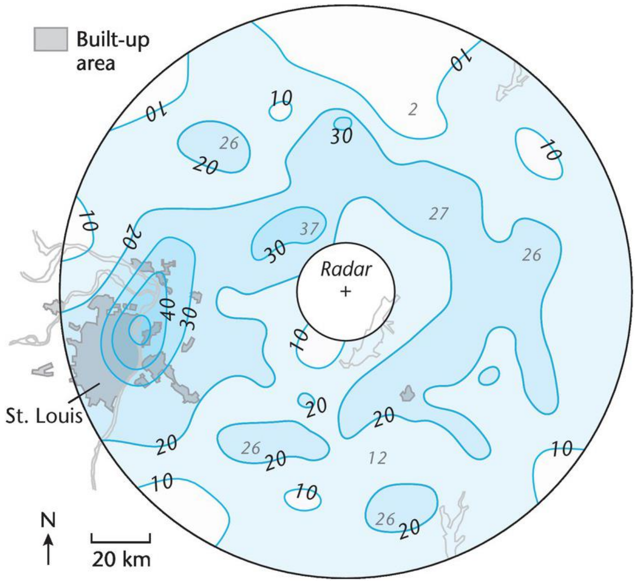
### Cloud base height




Summer afternoon cloud base heights (km) in the St. Louis area

Oke et al. (2017)

### Precipitation




Map of radar first echo densities that represent the initiation of convective cloud precipitation. The radar is located east of St. Louis