URBAN CLIMATOLOGY

2. Factors controlling urban climate, energy balance, urban boundary layer

Paper to read

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ORIGINAL PAPER

Quantifying the influence of land-use and surface characteristics on spatial variability in the urban heat island

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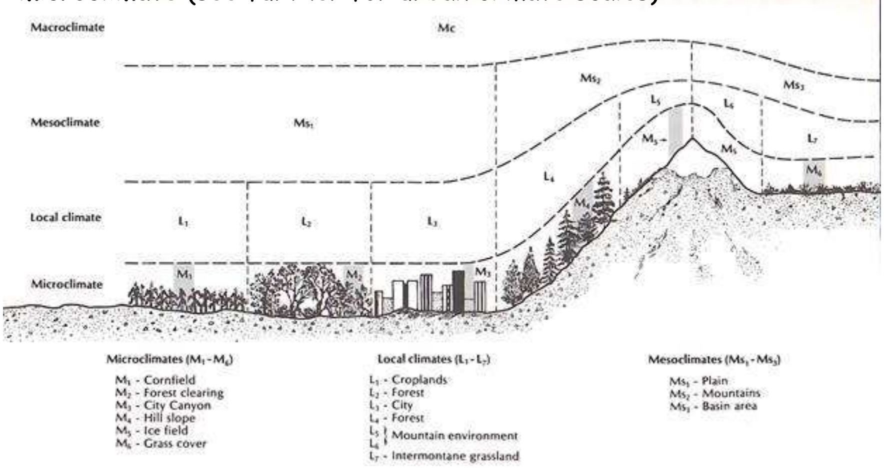
https://is.muni.cz/auth/el/sci/podzim2022/ZX601/um/67875456/02_Hart_Sailor_TAC_2009.pdf

2.1 Factors controlling urban climate

Climate categories (scales)

- Urban climate is a typical example of the **local climate**. However, it can be studied on different scales from **mesoclimate** to **microclimate** (see further for urban climate scales)



Source: *Climatology*, Oliver and Hidore, P.163.

2.1 Factors controlling urban climate

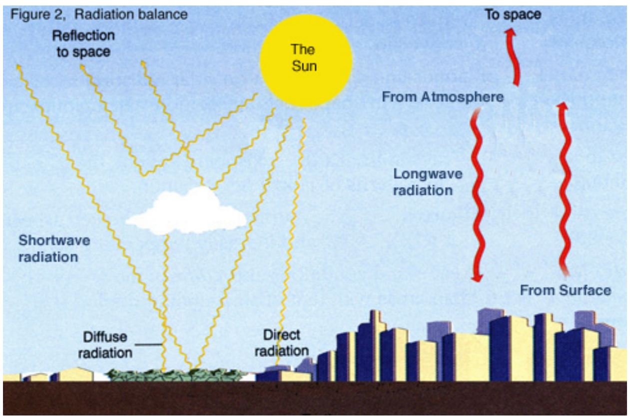
- For **local climate** category it is typical that processes in lower layers of the atmosphere are primarily formed by radiative, thermal, aerodynamic, and moisture **properties of active surfaces**
- Active surface (layer) is the surface or layer at which **energy** is **re-distributed** (e.g. reflected) or **transformed** to another type of energy

- In broader sense active surface **controls the exchange of energy, mass and momentum**

2.1 Factors controlling urban climate

1) **Thermal and radiation properties** of active surfaces, which are decisive for the intensity of absorption and reflection of short-wave electromagnetic radiation and emission of long-wave radiation
2) **Surface geometry** of active surfaces, which increases their total area, contributes to a significant proportion of surfaces with vertical orientation, to the creation of so-called street canyons and to high roughness
3) **Waterproofing** of active surfaces forming increased runoff of precipitation, reducing evapotranspiration and air humidity
4) **Atmospheric pollution** related to the occurrence of pollutants in the air and increased occurrence of condensation nuclei
5) **Anthropogenic heat**

Thermal properties of the surface materials (radiation balance)



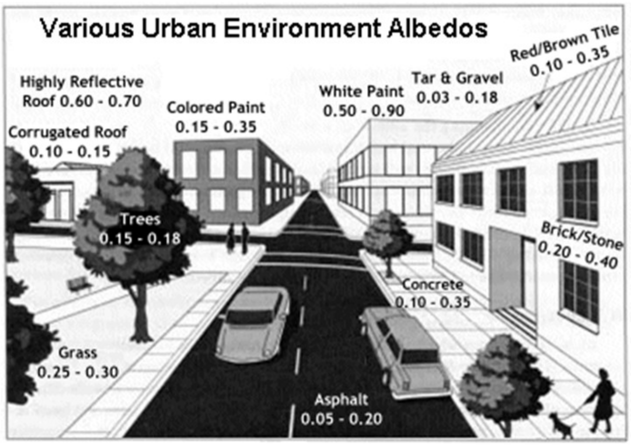
Thermal properties of typical urban surfaces cause **accumulation** of thermal energy during the day and its **release** during the night

Thermal properties of the surface materials

Comparison of selected thermal characteristics for typical urban and rural surfaces (modified after Oke, 1987 and Zmarsly et al. 2002)

Material	Density ρ/kg m^{-3}	Specific heat c/J kg^{-1} K^{-1}	Heat capacity cρ/J m^{-3} K^{-1}	Thermal conductivity λ/W m^{-1} K^{-1}	Thermal diffusivity a/m^2 s^{-1}	Thermal admittance b/J s$^{-0.5}$ m^{-2} K^{-1}
Asphalt	2,100	920	$2.0 \cdot 10^6$	0.75	$0.4 \cdot 10^6$	1,200
Loamy soil (40 % pore space; dry)	1,600	900	$1.4 \cdot 10^6$	0.25	$0.2 \cdot 10^6$	600
Ratio Asphalt/ Loamy soil	1.3	1.02	1.4	3.0	2.0	2.0

Thermal properties of the surface materials (albedo)

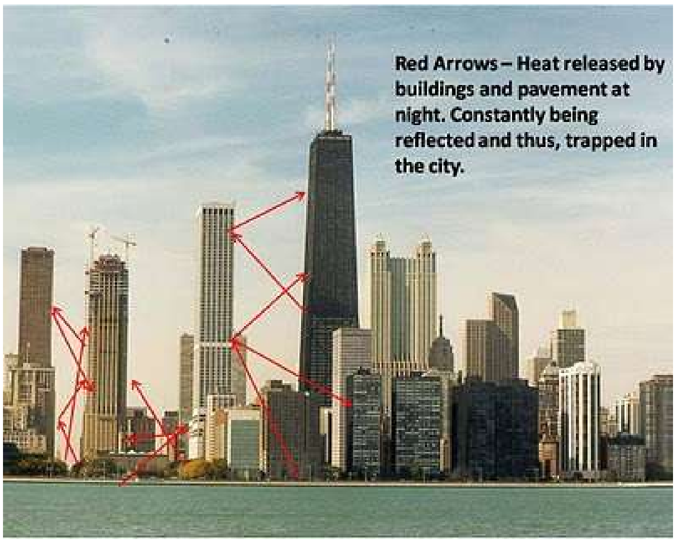


Albedo values of urban surface materials

Material	Albedo (%)
Concrete	27.1
Blacktop/asphalt	10.3
Brick, red	32.0
Brick, yellow/buff	40.0
Brick, white/cream	60.0
Glass	9.0
Paint, dark	27.5
Paint, white	68.7
Roofing shingles	25.0
Snow, weathered	55.0
Stone	31.7
Tar-gravel roof	13.5
Yard (90% lawn, 10% soil)	24.0

Albedo of urban areas is lower (10–15 %) that that of rural areas

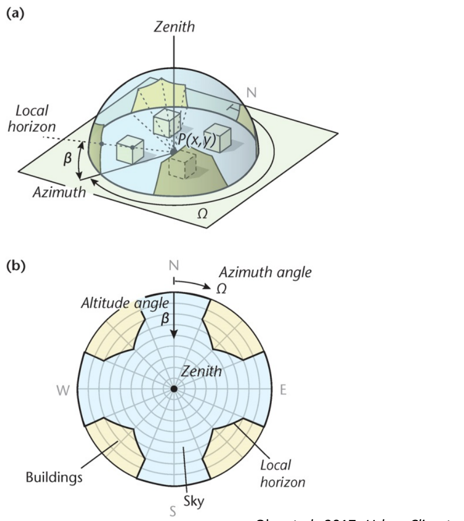
Surface geometry



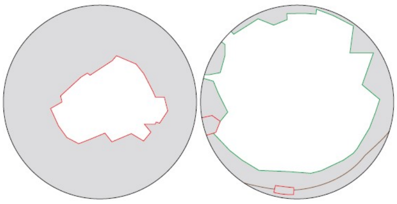
- Height to Width Ratio (H/W)
- Sky View Factor (SVF)

Surface geometry

Sky View Factor (SVF)

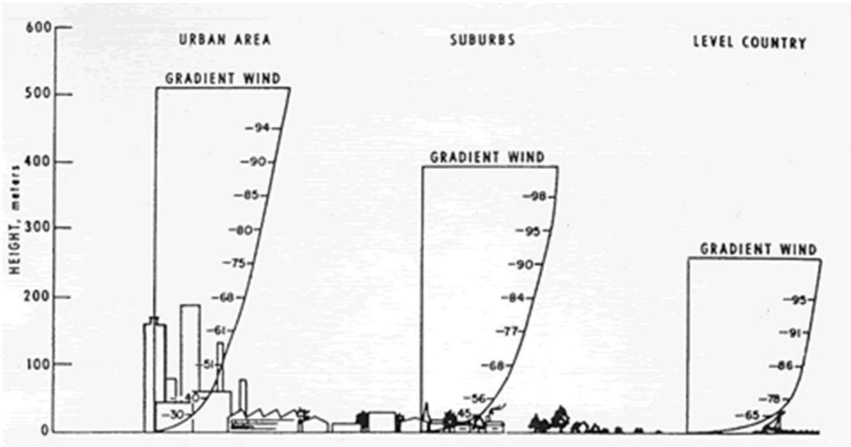


Oke *et al.*, 2017, *Urban Climates*



Urban SVF   Rural SVF

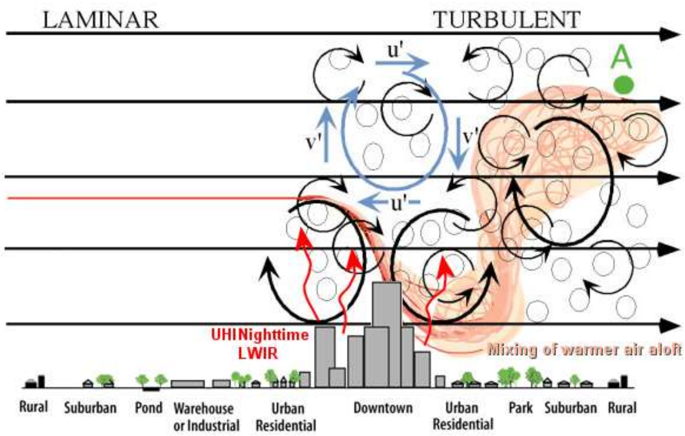
Surface roughness



source: http://www.mfe.govt.nz/

General decrease of wind speed in „strong flow“ situations

Surface roughness

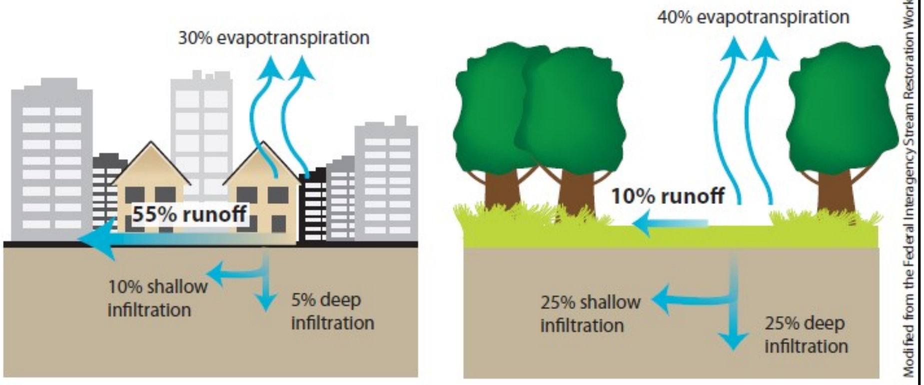


source:https://www.quora.com/

Higher turbulence due to higher air instability (strong local winds in „UHI situations")

Surface waterproofing

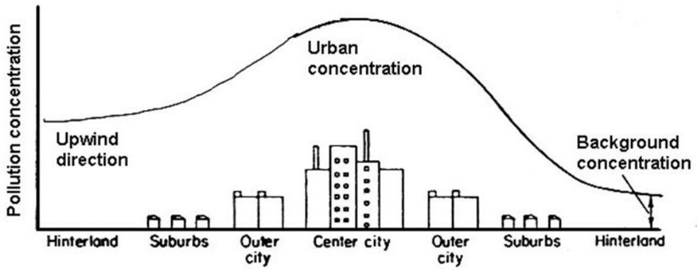
Higher proportion of impervious surfaces is responsible for direct changes in **moisture conditions** and changes in **water balance** and indirect changes in **temperature conditions**



- Lower soil moisture and higher drought danger
- Lower evapotranspiration causes higher air temperatures
- High and fast surface runoff
- Polluted surface runoff

Air pollution

Average air pollution concentration over an urban area

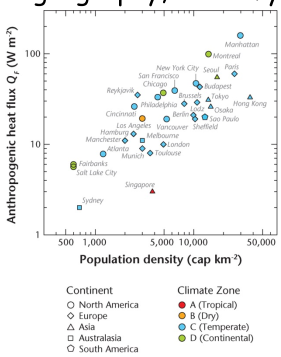


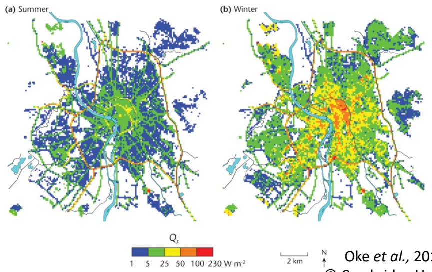
Factors increasing urban air pollution:

- Higher concentration of sources (vehicles, industry, heating)
- Lower wind speed due to surface roughness
- Role of relief (basins, concave shapes of urban relief)
- Higher stability of urban atmosphere (temperature inversions)

Anthropogenic heat

- Results mainly from electrical and chemical energy that are **converted to heat** and released in UBL.
- Includes three main sources: **buildings, transport, and metabolism:** fuel combustion in and industry, heating and cooling of, many processes of everyday life lightning, heating of water, etc.
- Depends on **population density**, but very regionally specific (climate and geography, economy, transport modes, cultural habits etc.)





Oke *et al.*, 2017, *Urban Climates*

Modeled heat anthropogenic heat flux density in Toulouse, France

- Typical daily and seasonal variations, direct measurements are replaced with estimates (modelling)

2.2 Energy balance of urban/rural areas

The city energy balance can be simplified to:

$$Q^* + Qf = Qe + Qh + \Delta Qs + \Delta Qa$$

where: Q^* = net all-wave radiation
$= K^* + L^*$ (net shortwave and longwave radiation)
Qf = anthropogenic heat emission ($Qfv + Qfh + Qfm$)
Qe = latent heat flux
Qh = sensible heat flux
ΔQs = net heat storage in the city
ΔQa = net advection into or out of the city.

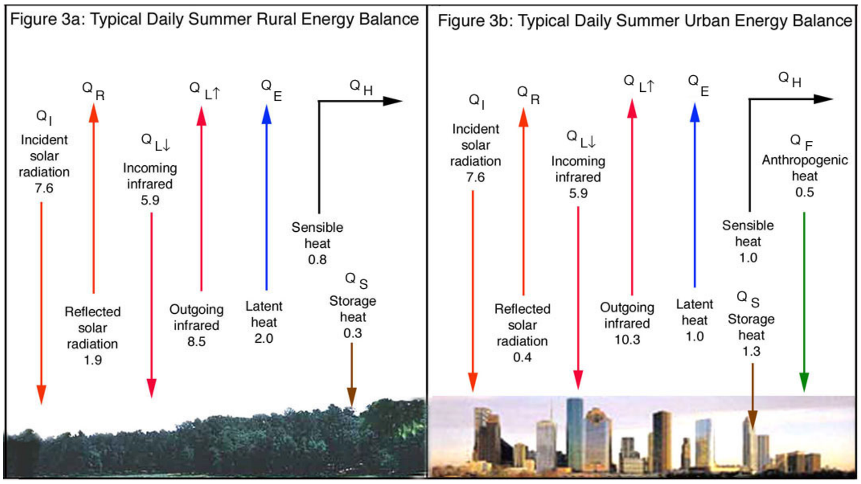
Latent heat – energy released or absorbed by a body during phase transition.

Evapotranspiration (from liquid water to water vapour) – consumption of latent heat

Condensation (from water vapour to liquid water) – release of latent heat

Sensible heat – energy transported to atmosphere via turbulent exchange

Energy balance of urban/rural areas



Day-night differences in energy balance

Day

	Incoming Radiation (from sun)	Shortwave Radiation (from clouds & ground)	Heat Loss (from evapora-tion)	Long-wave Radiation (from clouds)	Long-wave Radiation (from ground)	Heat Loss (from air move-ment)	Heating of the Ground (from conduc-tion)
Rural Surface	100	24	24	35	54	8	30
Urban Surface	100	5	1	35	69	10	53

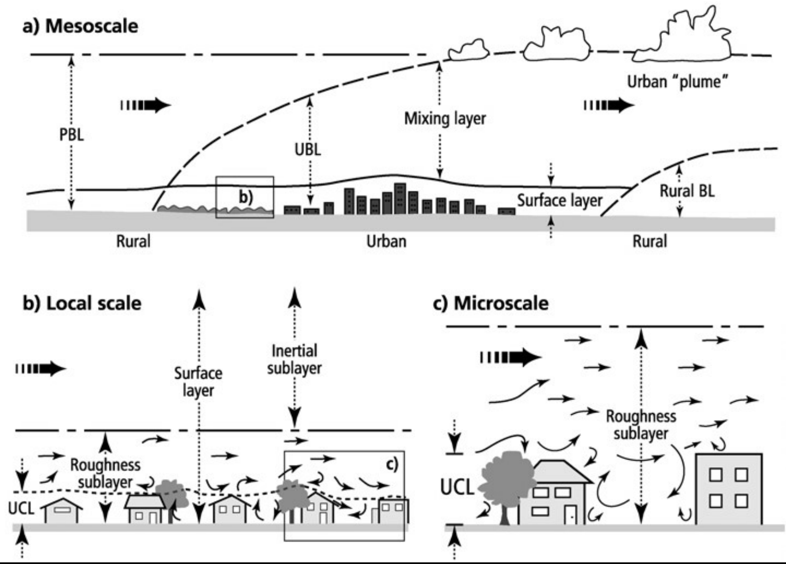
Night

	Heat Loss (from evapora-tion)	Long-wave Radiation (from clouds)	Long-wave Radiation (from ground)	Heat Loss (from air move-ment)	Heat Loss of the Ground
Rural Surface	1	33	44	1	11
Urban Surface	1	33	50	2	22

Relative differences in surface energy balance (SEB) of urban and rural surfaces during day (**positive** SEB) and night (**negative** SEB) (Oke et al. 1998; Alberti 2008)

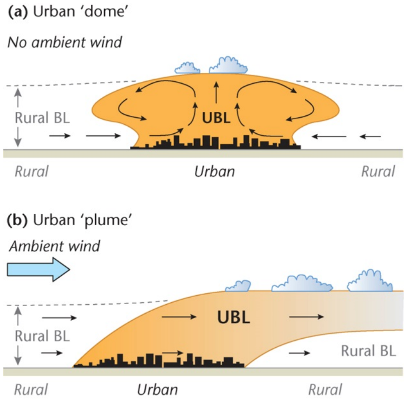
2.3 Stratification of lower urban atmosphere

- **Urban boundary layer** (Rural boundary layer, Planetary boundary layer)
- **Urban canopy layer** (UCL)



2.4 Another factors controlling urban climate

- role of weather types (radiation dominated vs. advection dominated)



- important role of local geography (relief)

Typical features of urban climate

Table U2 Urban climate effects for a mid-latitude city with about 1 million inhabitants (values for summer unless otherwise noted)

Variable	Change	Magnitude/comments
Turbulence intensity	Greater	10–50%
Wind speed	Decreased	5–30% at 10 m in strong flow
	Increased	In weak flow with heat island
Wind direction	Altered	1–10 degrees
UV radiation	Much less	25–90%
Solar radiation	Less	1–25%
Infrared input	Greater	5–40%
Visibility	Reduced	
Evaporation	Less	About 50%
Convective heat flux	Greater	About 50%
Heat storage	Greater	About 200%
Air temperature	Warmer	1–3°C per 100 years; 1–3°C annual mean up to 12°C hourly mean
Humidity	Drier	Summer daytime
	More moist	Summer night, all day winter
Cloud	More haze	In and downwind of city
	More cloud	Especially in lee of city
Fog	More or less	Depends on aerosol and surroundings
Precipitation		
Snow	Less	Some turns to rain
Total	More?	To the lee of rather than in city
Thunderstorms	More	

(Landsberg 1981)

2.4 Final remarks and questions

1. What are the main factors controlling urban climate?
2. What are the main terms of urban climate energy balance?
3. How we can define urban climate scales?
4. What are the main features of vertical stratification of the atmosphere in urban environment?
5. What other factors form typical urban climates?