

The Urban Heat Island (UHI) – Causes, Impacts, and Mitigation Strategies

David Sailor, Ph.D.
Mechanical and Materials Engineering
Portland State University

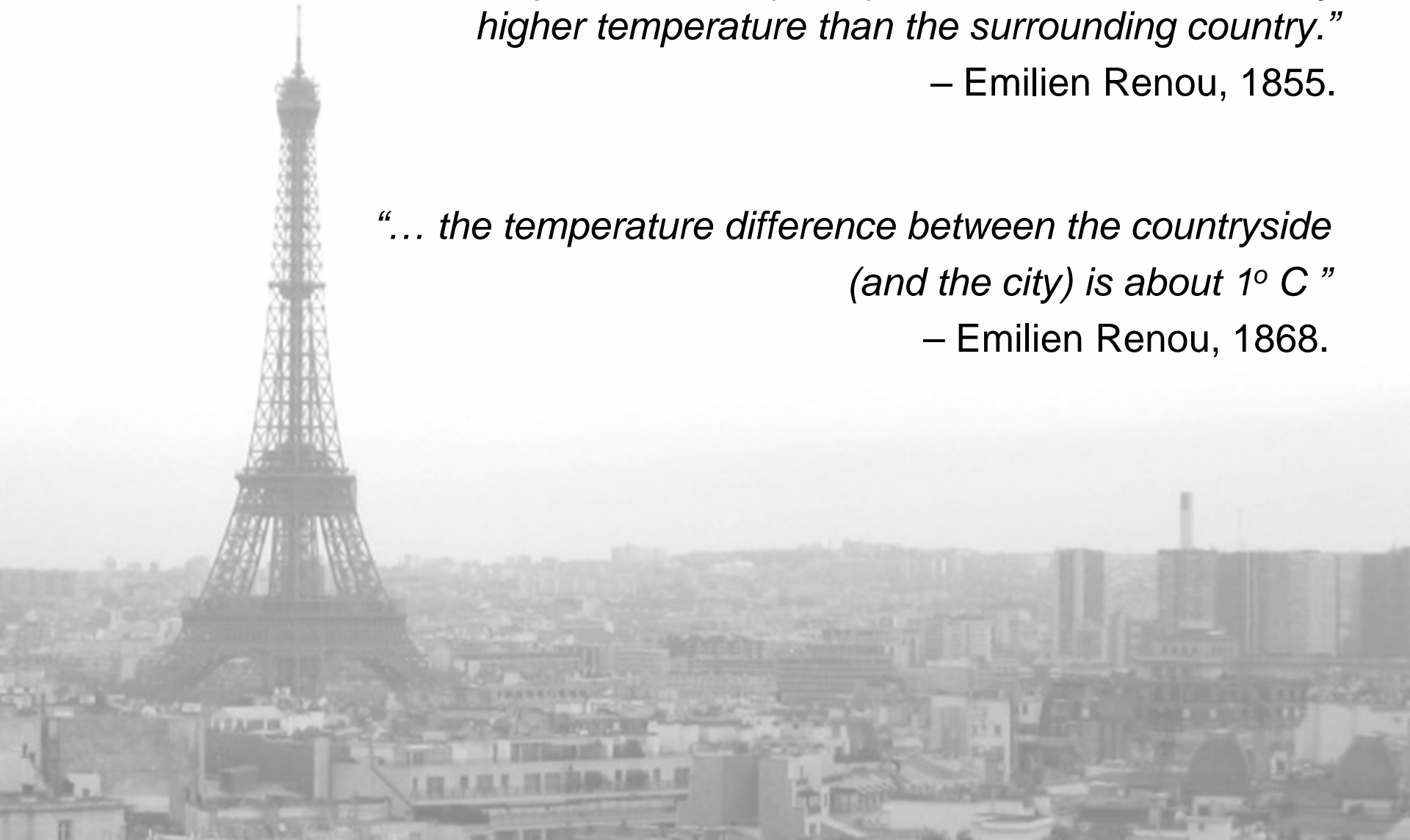
Presented to:
State Clean Energy-Environment Technical Forum
U.S. EPA
May 10, 2007

“The respiration of humans and animals, above all the fumes of innumerable chimneys, maintain above Paris a rust-colored haze ... it is impossible that (Paris) should not have a notably higher temperature than the surrounding country.”

– Emilien Renou, 1855.

“... the temperature difference between the countryside (and the city) is about 1° C ”

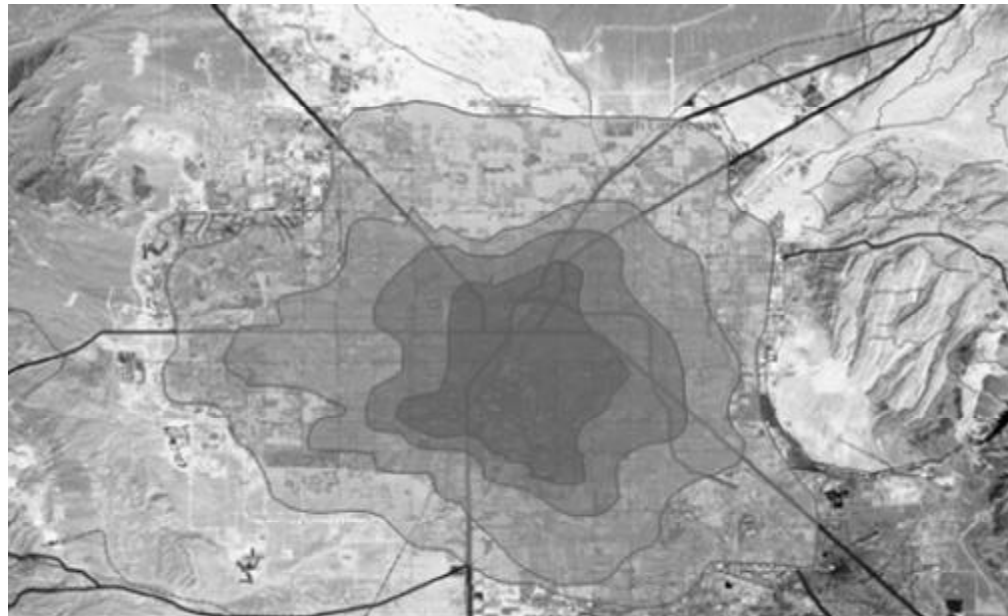
– Emilien Renou, 1868.



Urban Heat Island (UHI)

“An area of higher temperatures in an urban setting compared to the temperatures of the suburban and rural surroundings. It appears as an ‘island’ in the pattern of isotherms on a surface map.”

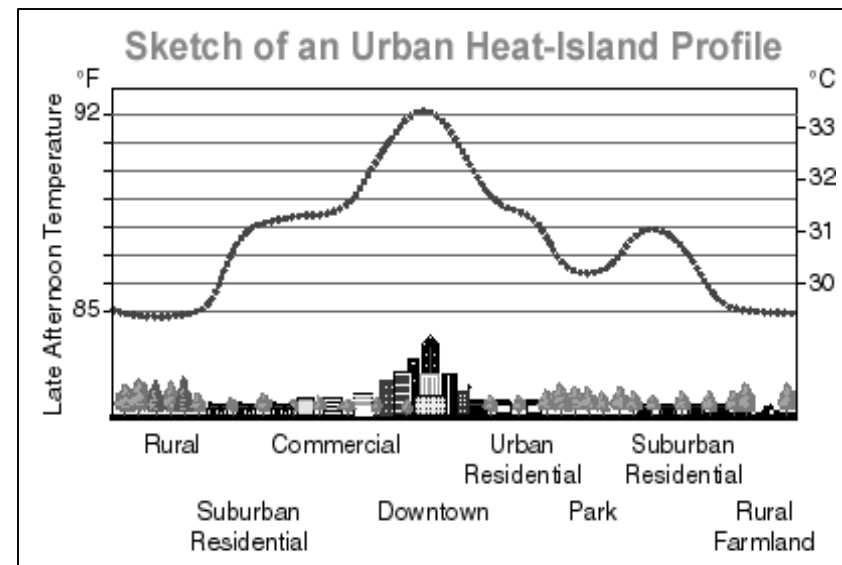
- Glossary of Weather and Climate, Ira Geer, Ed.



Urban Heat Island Complexities

- hourly and seasonal variability
- dependence on large scale weather conditions
- surface UHI vs. air temperature UHI
- geographic/topographic causation
- importance of other weather variables

$$UHI = T_{\text{urban}} - T_{\text{rural}}$$



Why do we care about the UHI?

(...3 of the many reasons...)

1. AIR QUALITY:

Ozone concentrations are affected by...

emissions

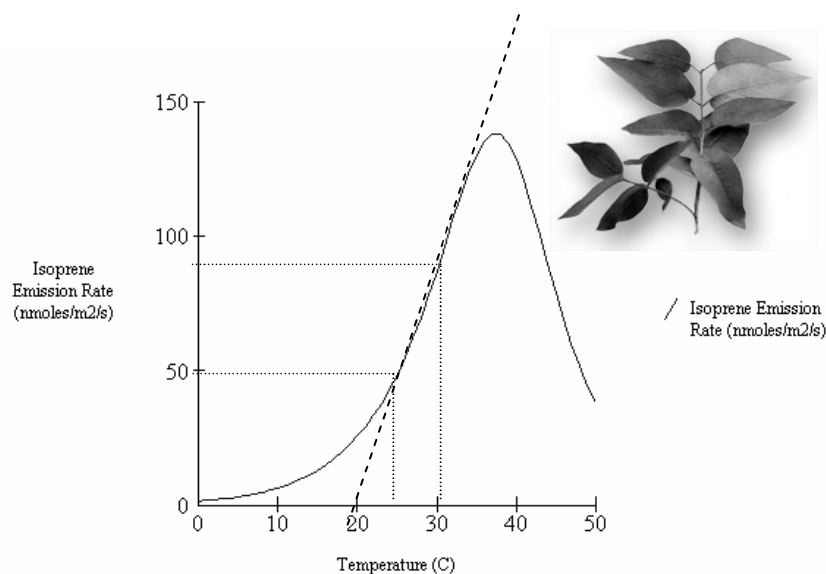
mixing & dispersion

chemical reactions in the atmosphere

... which are, in turn, affected by the UHI

Emissions Increase with Air Temperature

- Hydrocarbon emissions from plants
 - Hydrocarbon (monoterpene and isoprene) emissions increase by 10% per °C
- Emissions from human-related sources
 - power plant emissions increase 5% per °C (in summer)
 - motor vehicle running losses increase by 7-14% per °C
 - fugitive emissions at fueling stations increase with temperature



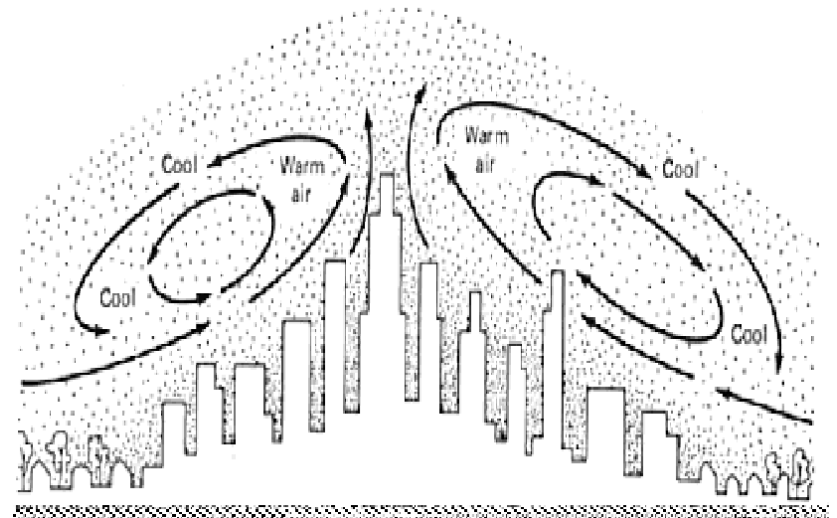
UIUC –WILMOVAC project



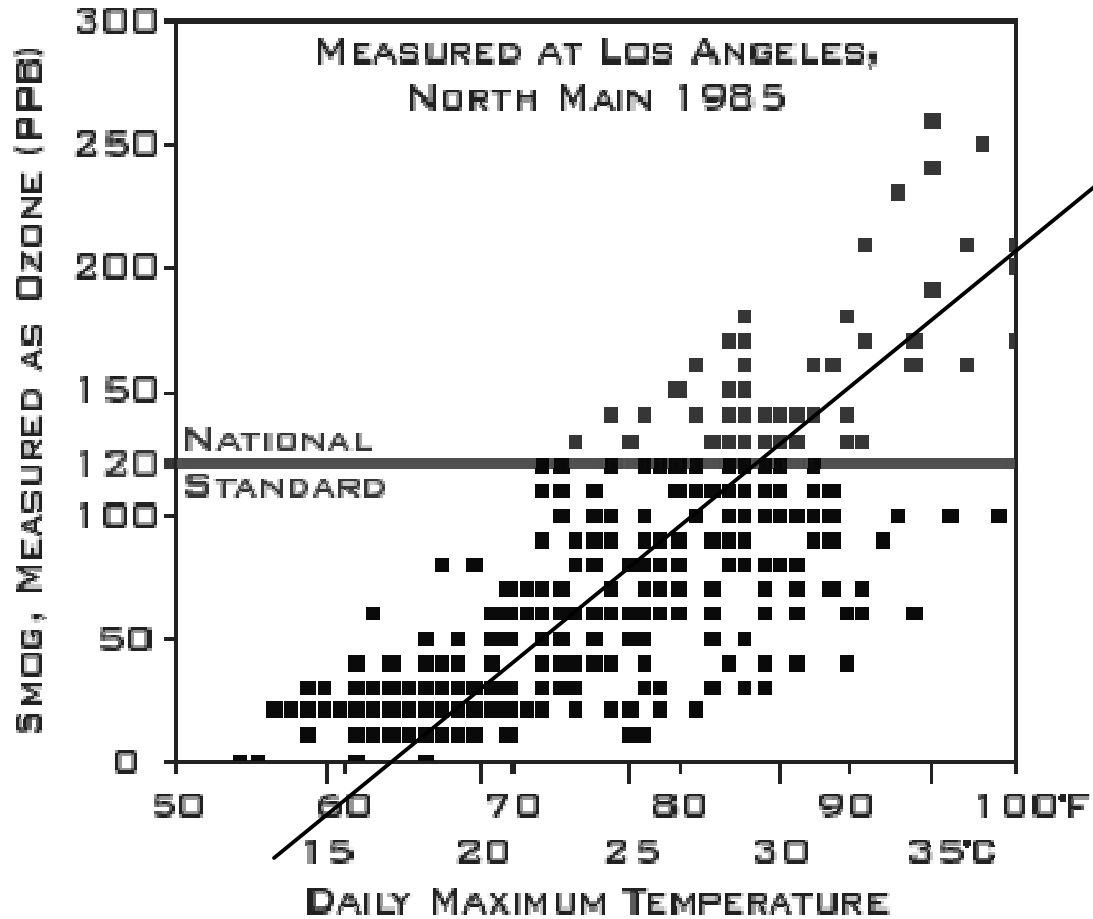
The UHI Affects Mixing and Atmospheric Chemistry

- Pollutant mixing and dispersion
 - UHI raises mixing height
 - UHI creates an “urban plume”

- Atmospheric chemistry
 - rate constants for many key reactions in the formation and destruction of ozone are temperature-dependent

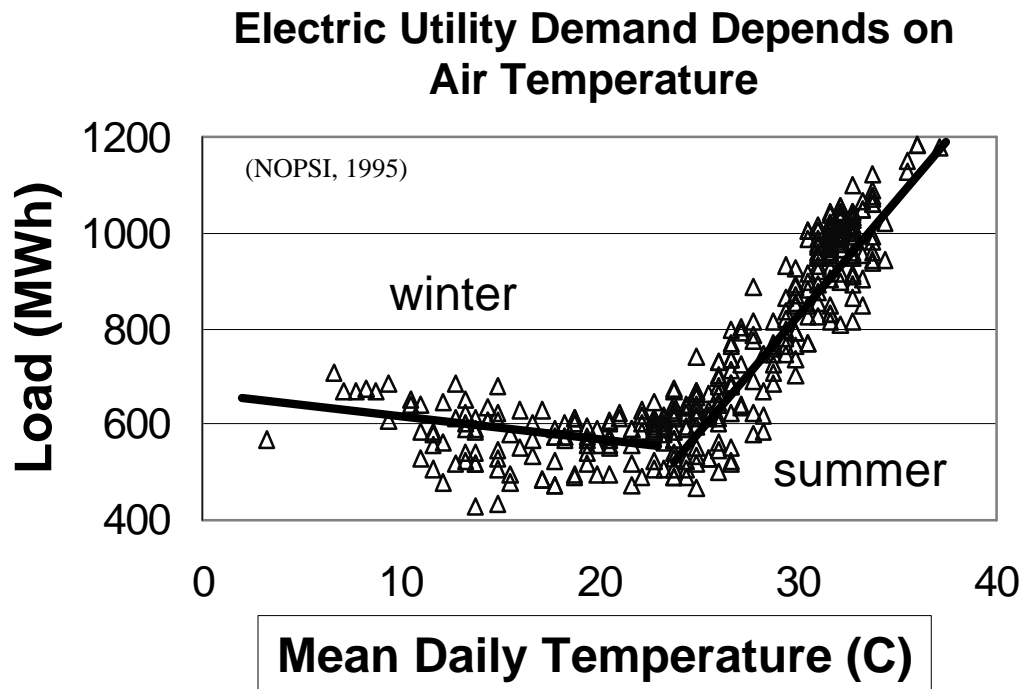


LBNL Heat Island Group



On hot summer days peak ozone concentration increases by 2 to 4% for each degree C increase in air temperature.

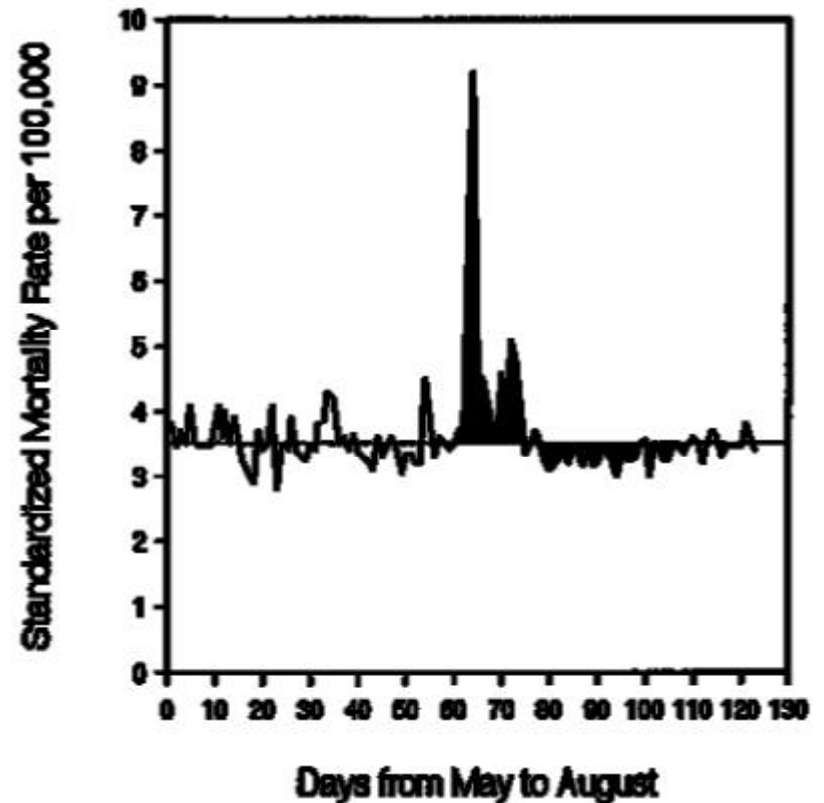
2. ENERGY CONSUMPTION:



Summer electricity loads increase by 3 to 5% for each degree C increase in air temperatures.

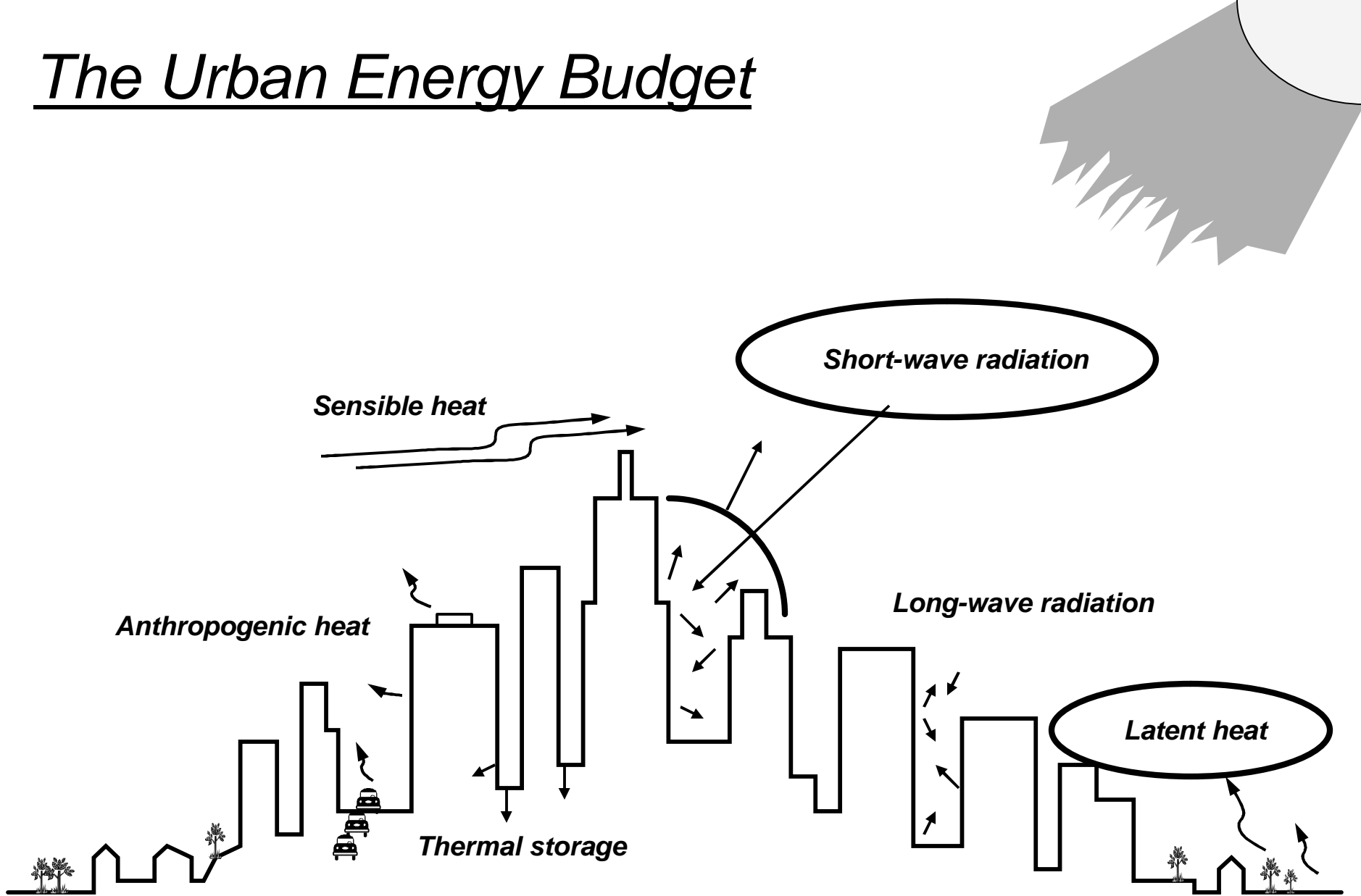
3. HUMAN HEALTH:

- Heat-related mortality
 - 1000 to 1500 annual heat-related deaths in the U.S. (Changnon et al., 1996, Kalkstein 2006)
 - mortality rates depend upon max/min temperatures & humidity
- Heat-related morbidity
 - heat stroke
 - respiratory diseases



What are the underlying causes of the UHI?

The Urban Energy Budget



Urban surfaces do not reflect much solar radiation (they have low albedo) and so they heat up...

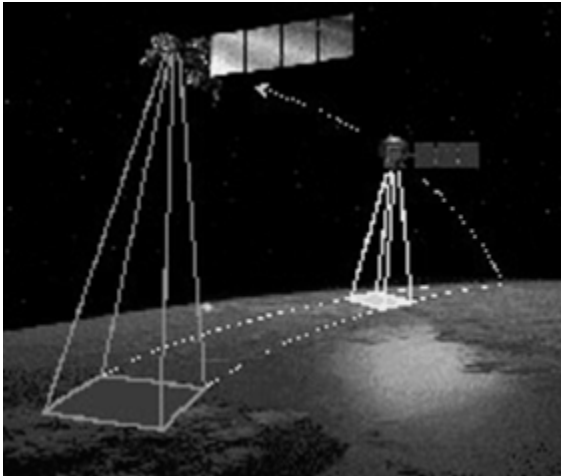
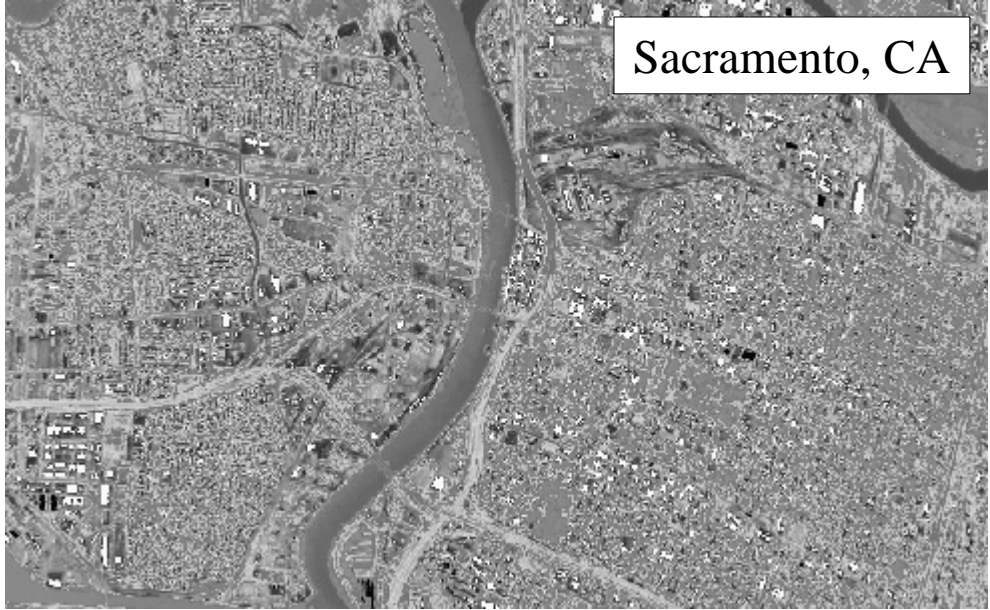


Urban areas lack vegetation and moisture, so they cannot cool themselves through evaporative cooling...

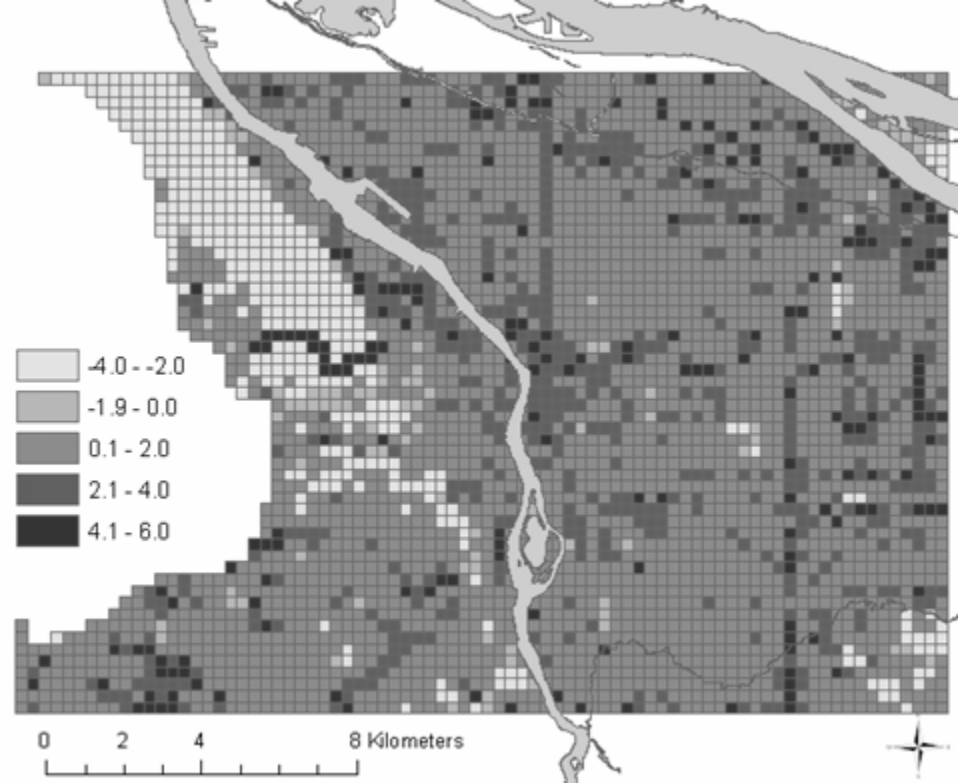


Image from: NASA, 1997 ATLAS multispectral false-color image of Atlanta GA (vegetation is red)

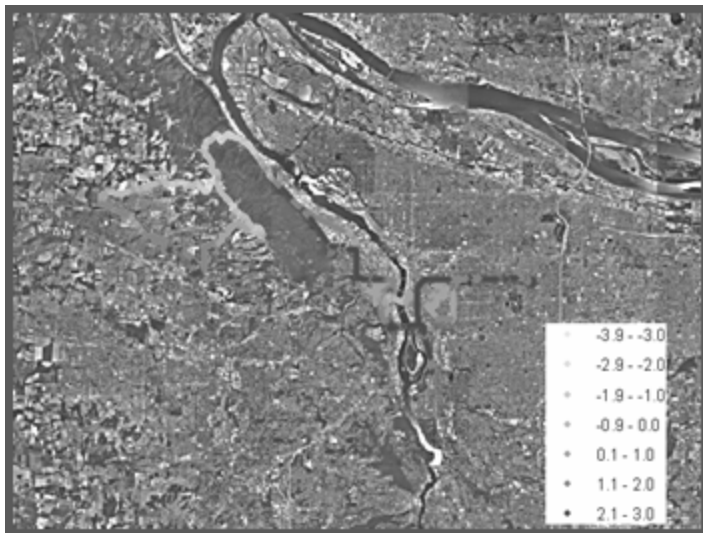
Surface UHI (skin temperature)



Air Temperature UHI



Predicted summer weekday UHI intensities in Portland OR, (°C) at 200m grid resolution (D.J. Sailor, 2007).



How can we mitigate the UHI?

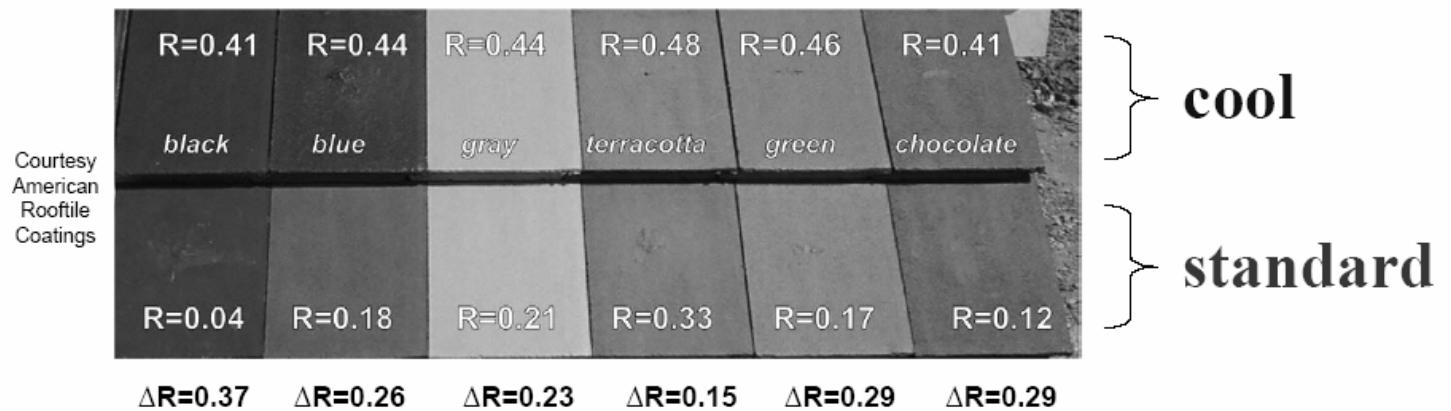
the causes of the UHI suggest the solutions...

Evaporative cooling

- Green roof systems
 - improve building energy performance
 - cool rooftop surfaces
 - have other environmental benefits
- Shade Trees
 - shade building surfaces, AC condenser units, and people
 - provide evapotranspiration benefits
- Porous pavement systems
 - reduce runoff
 - provide evaporative cooling benefits



Urban albedo

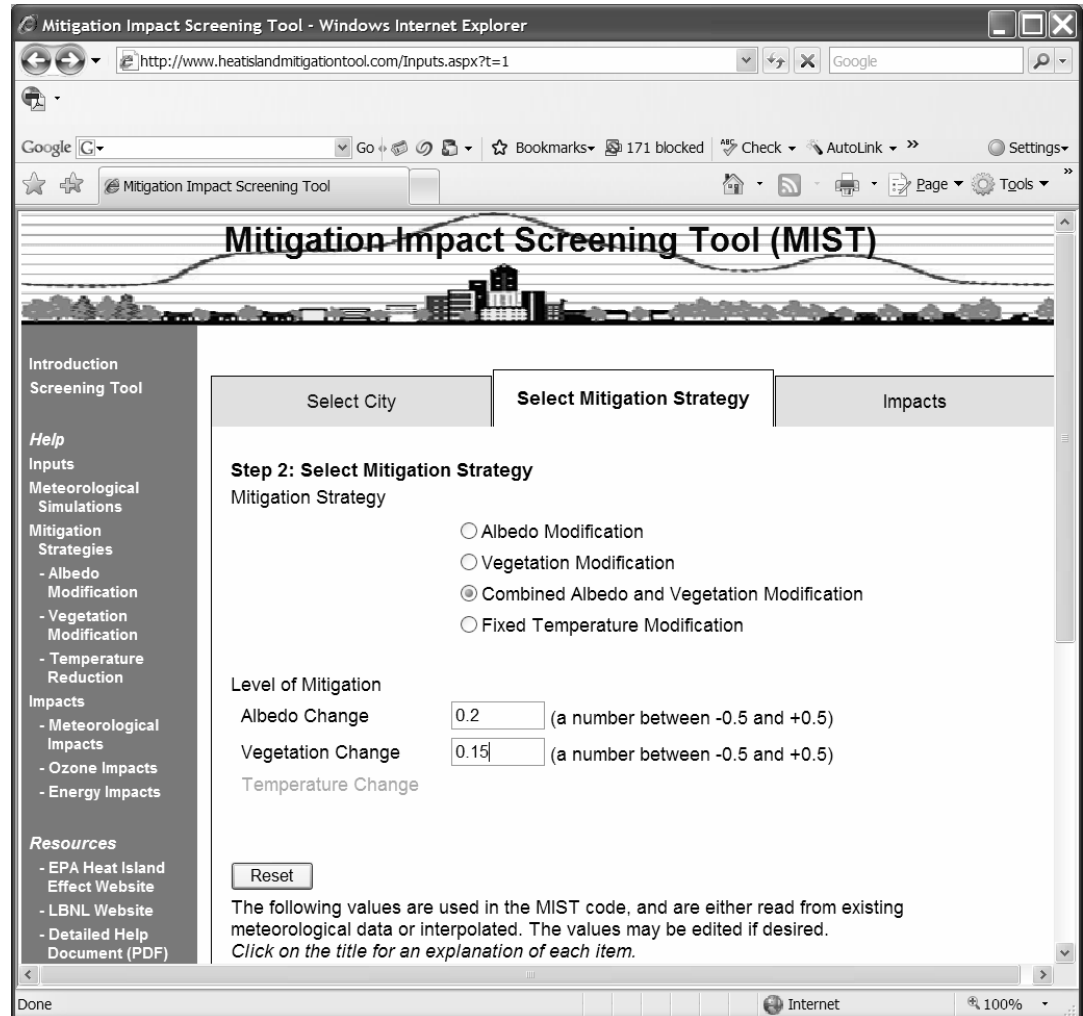


From: Urban Heat Island Group – Lawrence Berkeley National Laboratory

What impact could we expect from UHI mitigation?

<http://www.heatislandmitigationtool.com>

- An atmospheric model was used to estimate air temperature impacts of UHI mitigation
- Atmospheric model output was fed into models of energy consumption and air quality
- Results are integrated into a user-friendly screening tool → MIST




... but what about implementation issues for UHI mitigation ?

Ronnen Levinson → Cool roofs

Dave Nowak → Urban forestry

David Hitchcock → state/local govt. (big picture issues)