

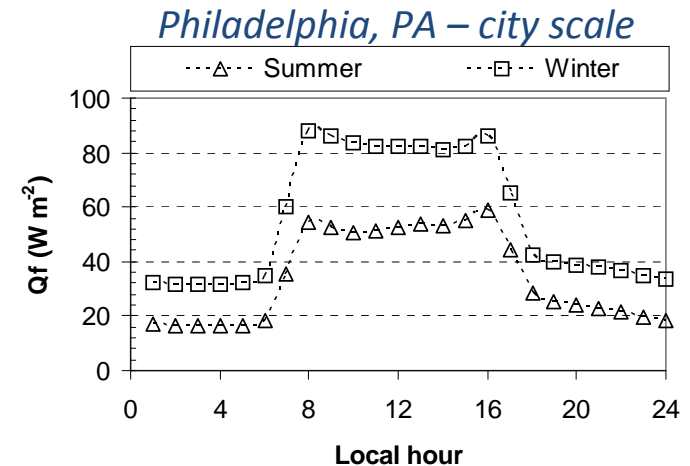
# Measurements and Modeling of the Urban Heat Island Effect: *The role of anthropogenic emissions*

Second Workshop on Earth Observation for Urban Planning and Management  
Hong Kong Polytechnic University

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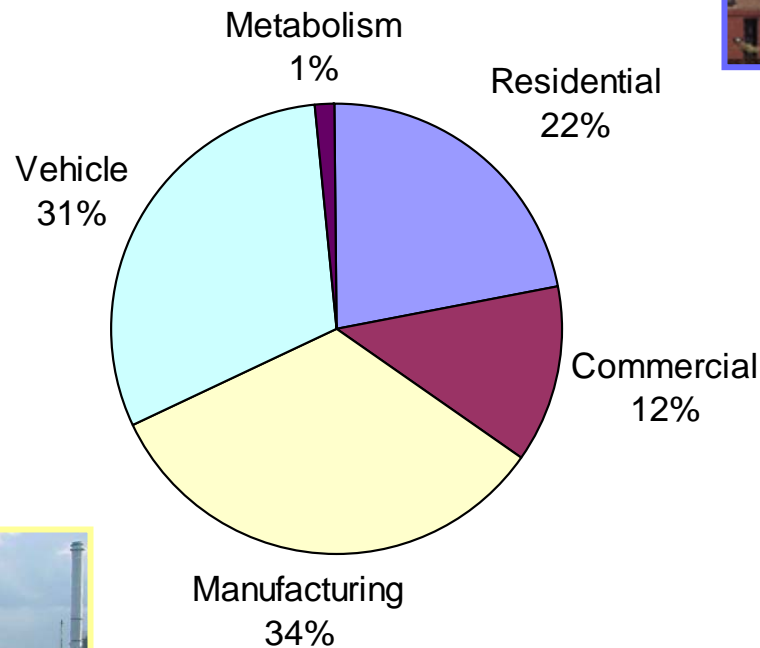
# What is anthropogenic heating ( $Q_f$ )?

- Heat generated from human activities.
- Typically largest in winter.
- Has diurnal, seasonal, and workday/non-workday profiles.
- Magnitude depends upon scale of interest\*
  - City scale  $\sim 10$ 's  $W/m^2$
  - Urban core  $\sim 100$ 's  $W/m^2$
  - Downtown building scale  $\sim 1000$ 's  $W/m^2$



# Energy Use Leading to Anthropogenic Emissions

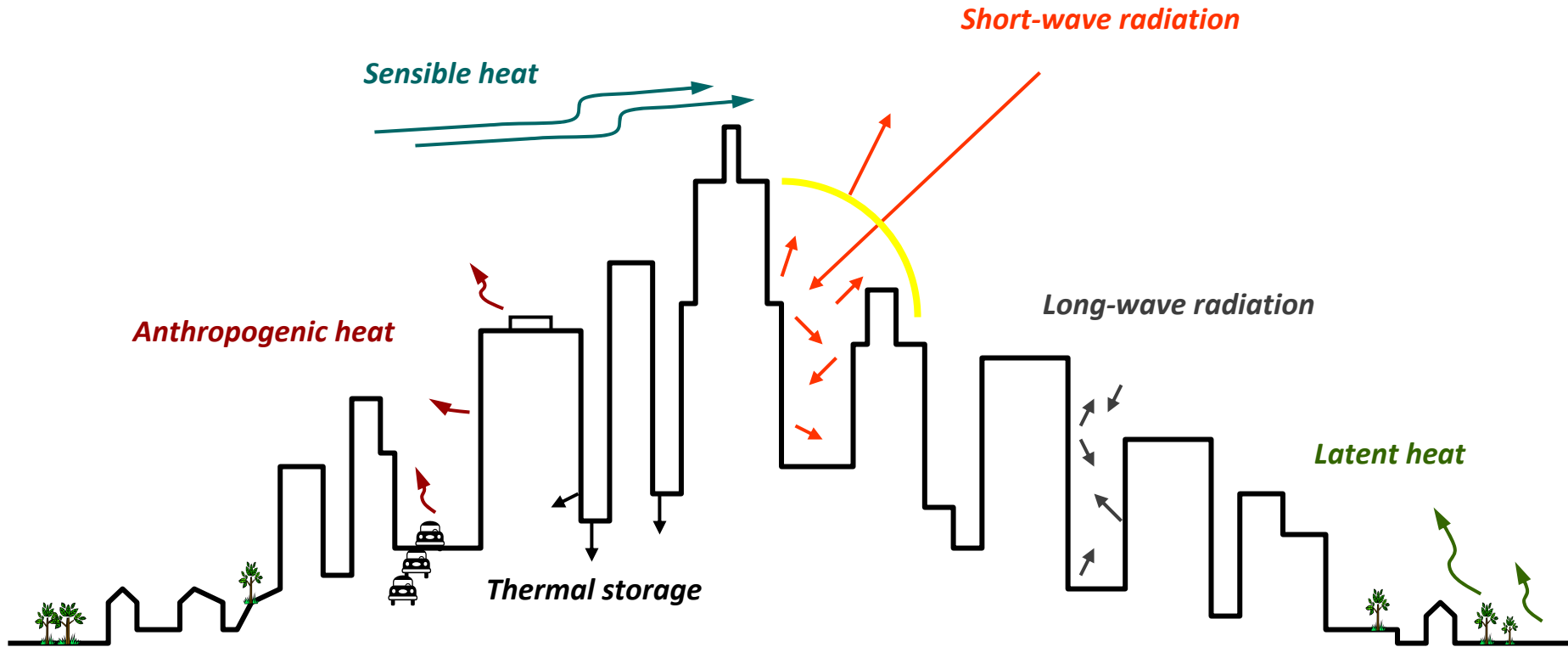
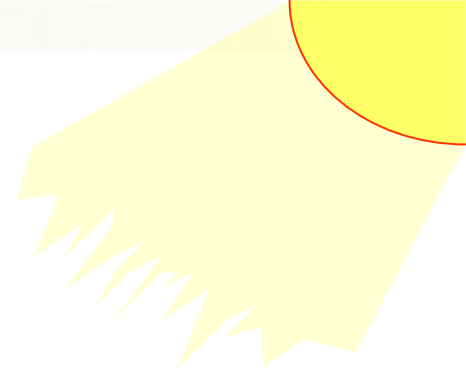
(U.S. Data)



Source: [www.eia.doe.gov](http://www.eia.doe.gov)

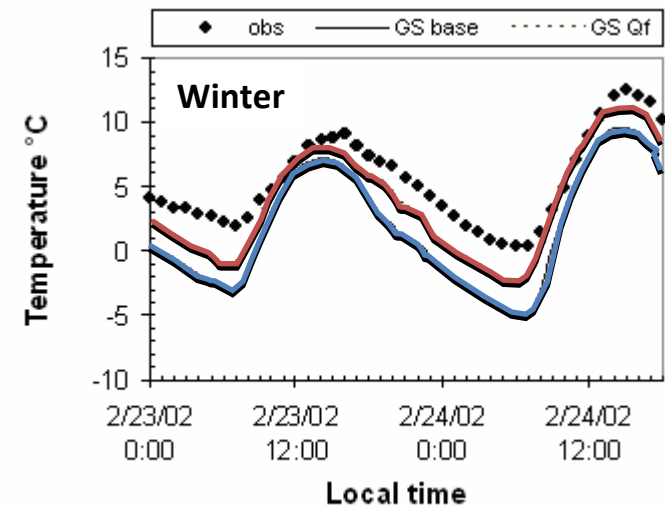
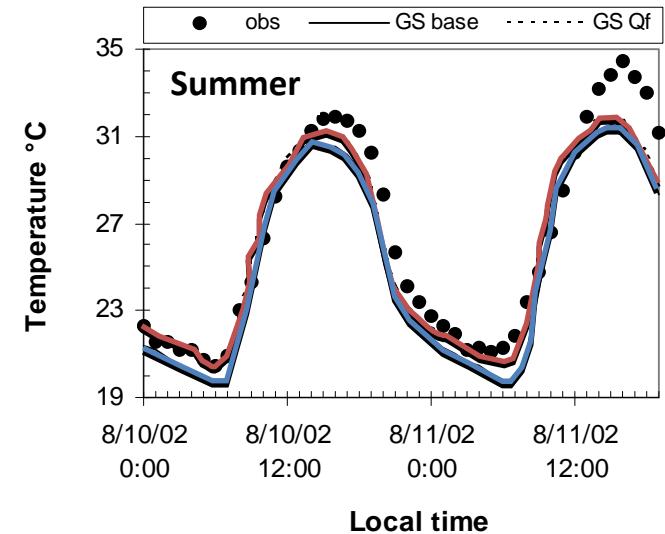
(site energy based on annual US consumption totals excluding waste heat at power plants & other losses)

# The Urban Energy Budget



# Modeled impact of anthropogenic heating on near surface air temperatures of Philadelphia

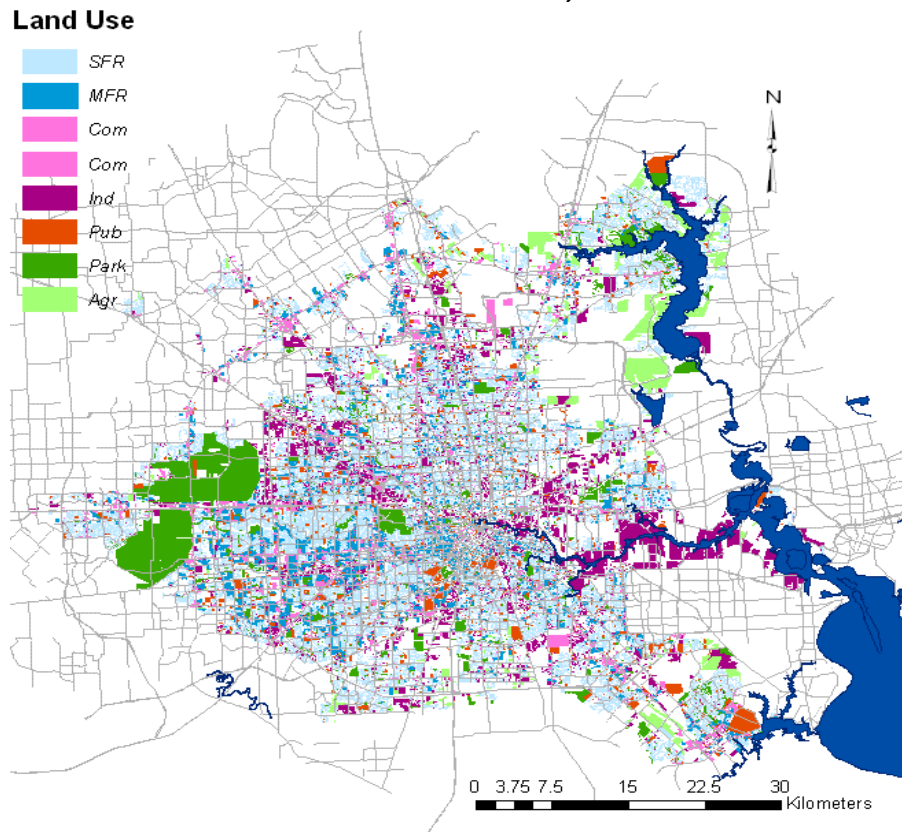
- Anthropogenic heat based on city-wide energy statistics.
- City-wide  $Q_f$  exceeded  $60 \text{ W/m}^2$  in summer and  $90 \text{ W/m}^2$  in winter
- **Case 1: With  $Q_f$**
- **Case 2: No  $Q_f$**
- Impacts on summer air temperature
  - <  $0.5 \text{ }^\circ\text{C}$  during day
  - $\sim 1 \text{ }^\circ\text{C}$  during night
- Impacts on winter air temperature
  - $\sim 1 \text{ }^\circ\text{C}$  during day
  - 2 to  $3 \text{ }^\circ\text{C}$  during night
- Similar to results of Ichinose for Tokyo



Fan and Sailor, *Atmos. Environment* (2004)

# Improving spatial resolution of anthropogenic heating

Land Use: Houston TX, USA



## Top-down Approach for $Q_f$

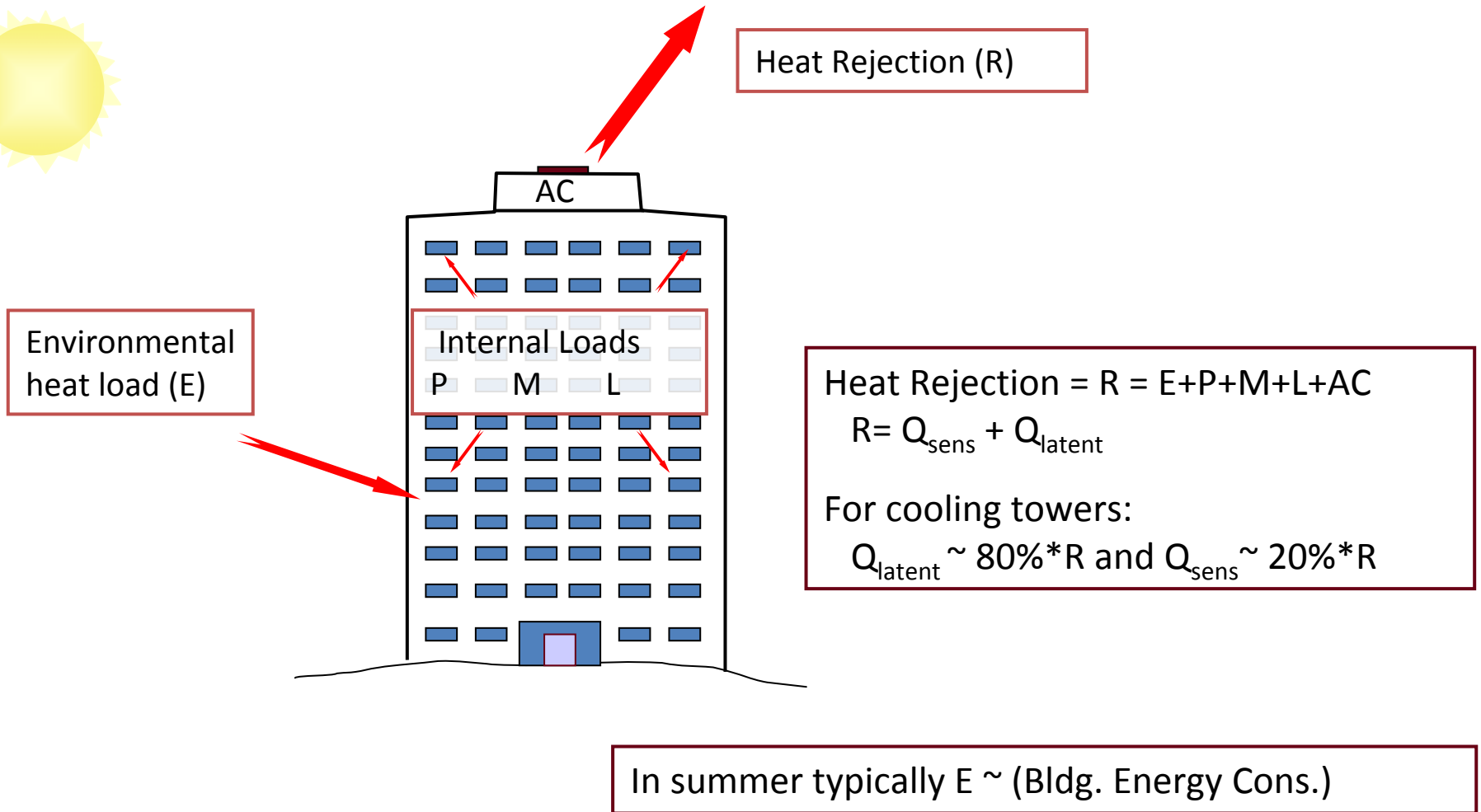
- Gather energy consumption data within each sector
- Allocate based on dominant land-use within model grid cell
- Apply simplified diurnal profile functions

Sailor and Lu, 2004

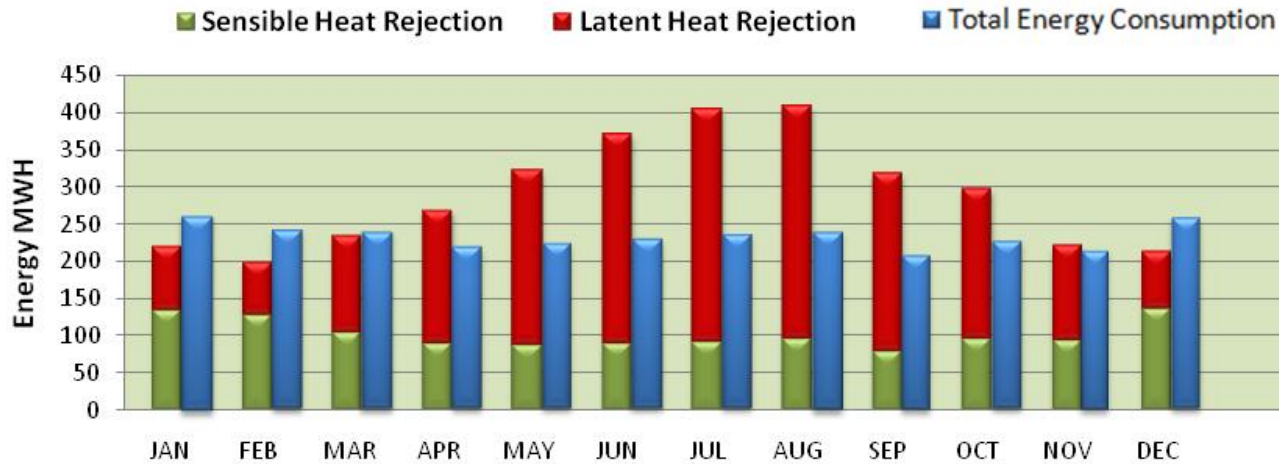
## Limitations:

- There is variability within land use categories
- Diurnal profiles not particularly accurate, especially for combustion fuels (NG)
- Moisture emissions not included
- $Q_f$  is not really the same as energy use

# Anthropogenic Heating $\neq$ Energy Consumption

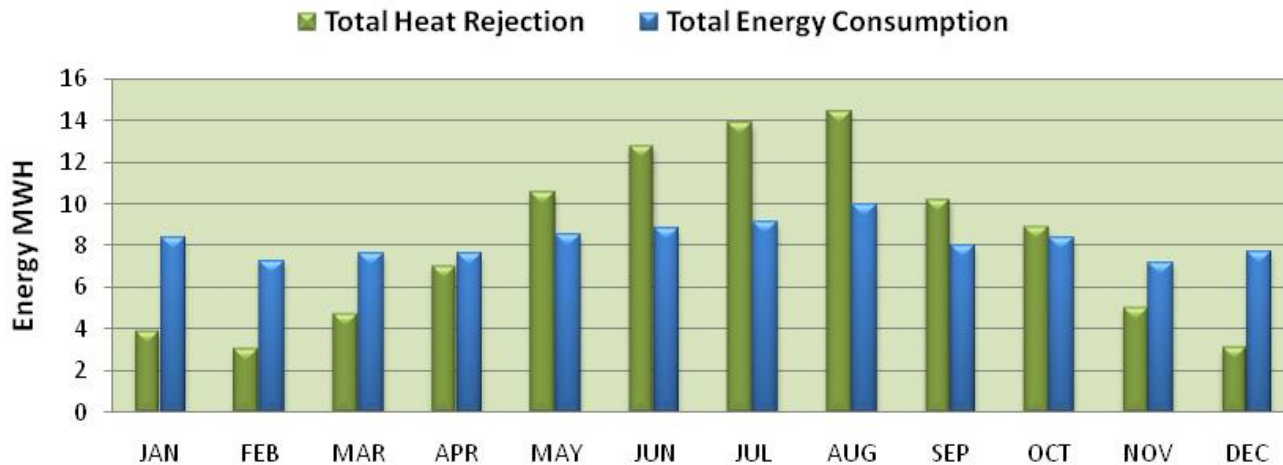


### Office (9569 sq.m)



From detailed building energy simulations...

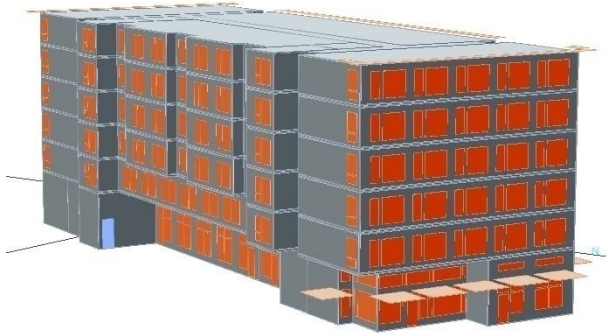
### Small Office (575 sq.m)



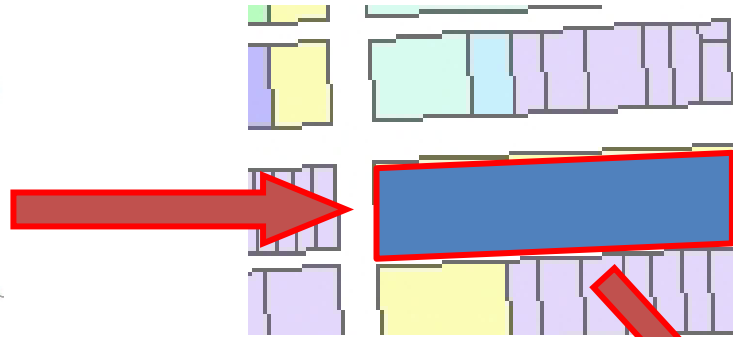
... it is crucial to understand both the characteristics and distribution of building stock...



# Bottom-up approach for the building sector



Building Scale

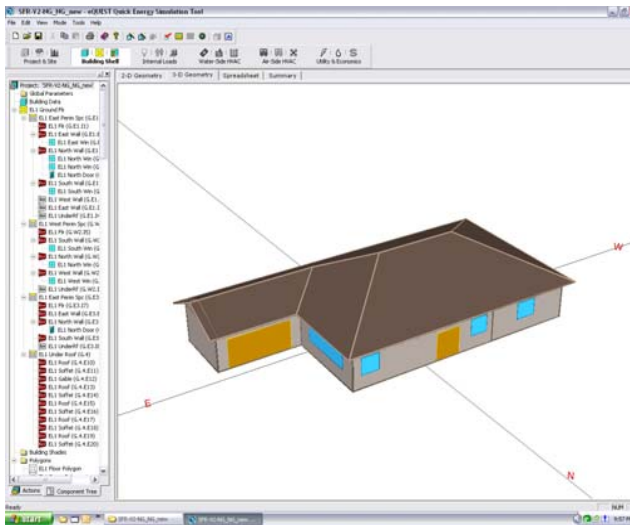
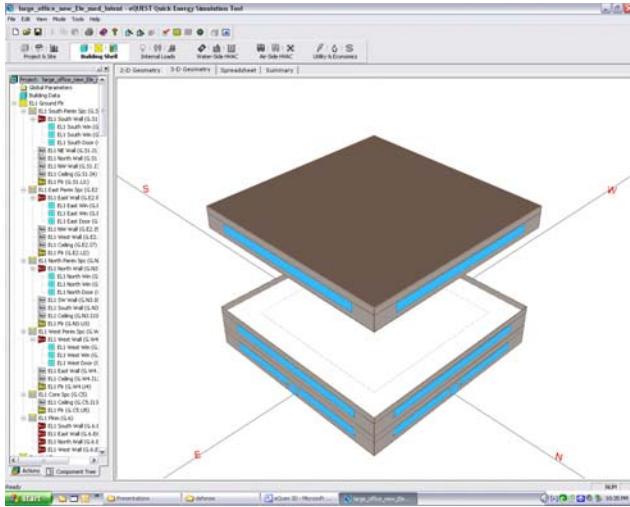


Tax lot Scale



Atmospheric Model  
Grid Cell Scale

# Building Prototype Definitions



National Commercial Building Stock  
(source: CBECS)

Filter Data by Climate Zone

- Building Type:**
1. Large office
  2. Small office
  3. Large retail
  4. Small retail
  5. Health care
  6. Restaurant
  7. Lodging
  8. Education
  9. Food sales
  10. Assembly
  11. Other

- Primary Heating:**
1. NG +
  2. Electric

22 building prototypes

National Residential Building Stock  
(source: RECS)

Filter Data by Climate Zone

- Building Type:**
1. Single Family
  2. Mult-Family

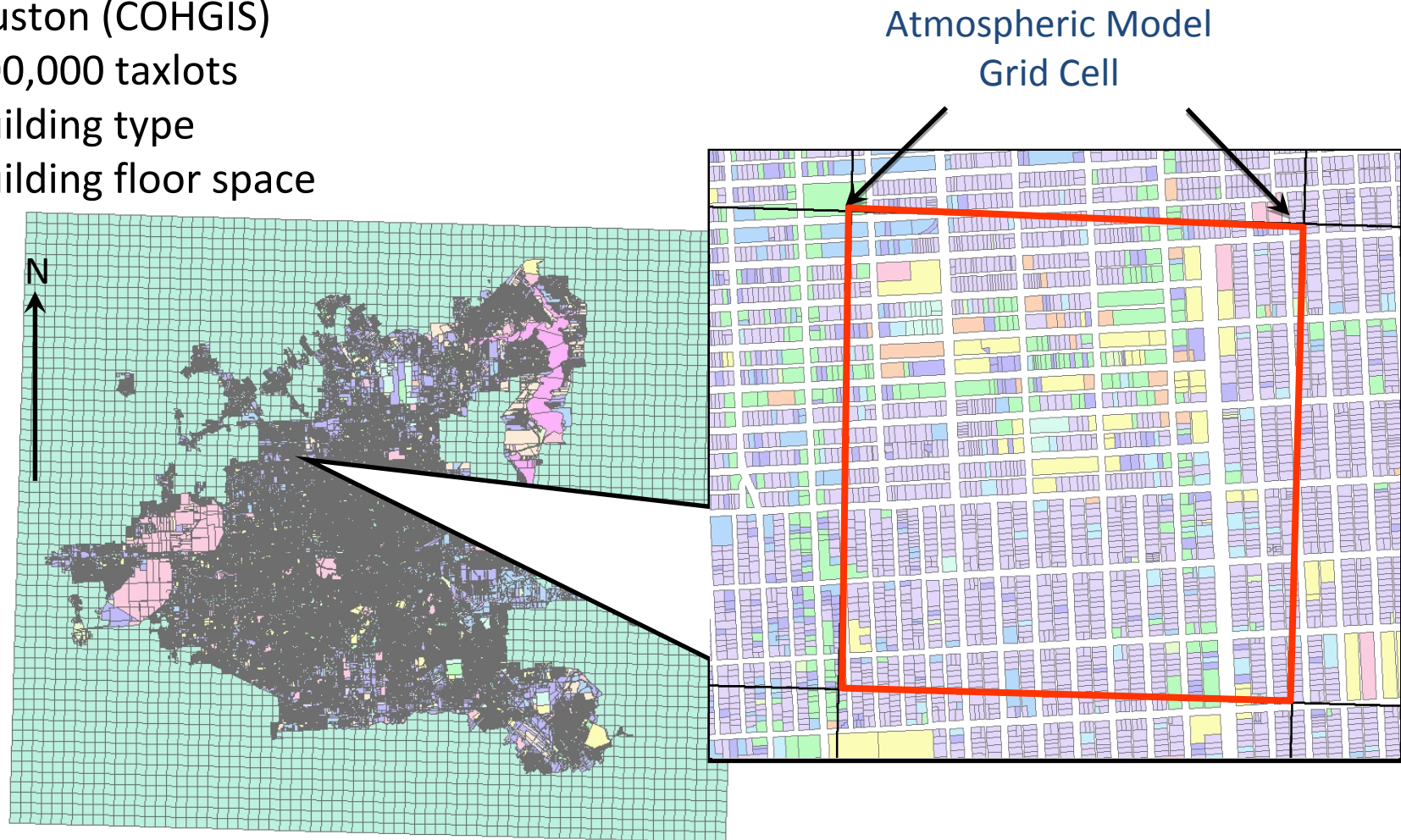
- Vintage:**
1. Pre 1980
  2. Post 1979

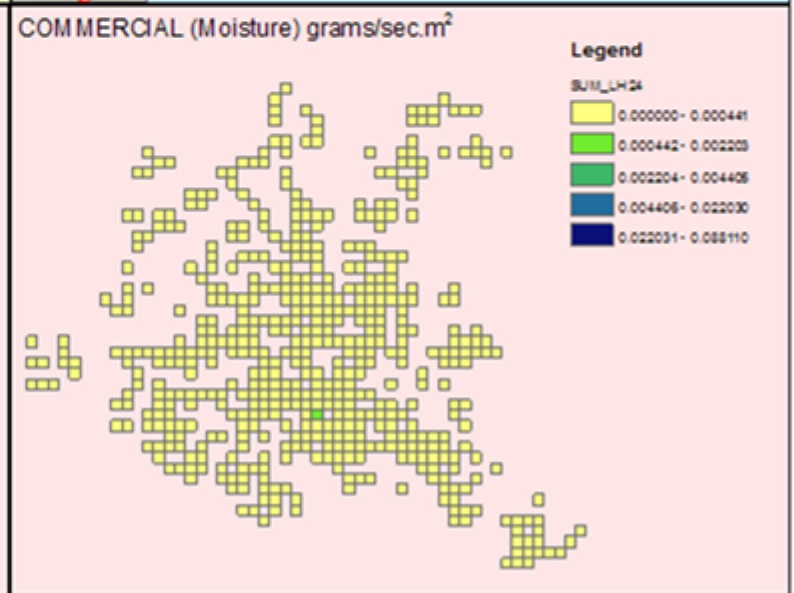
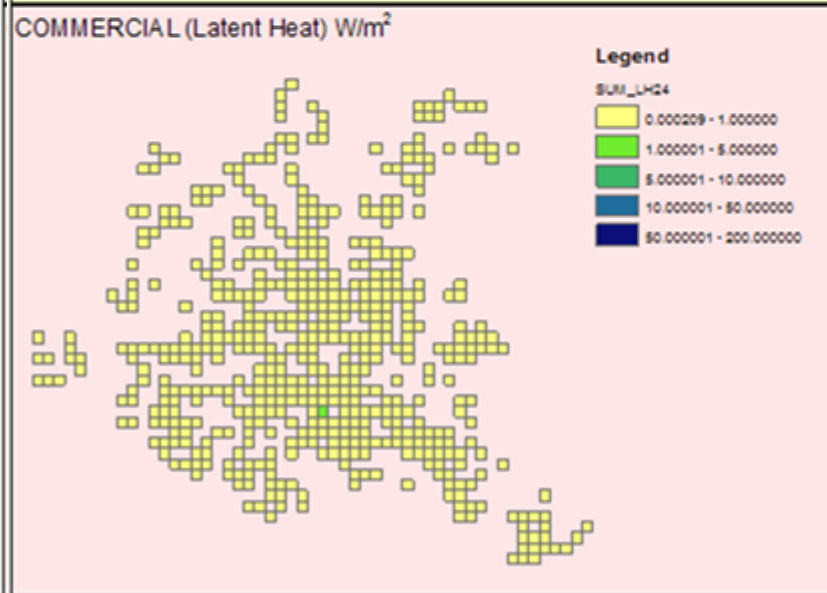
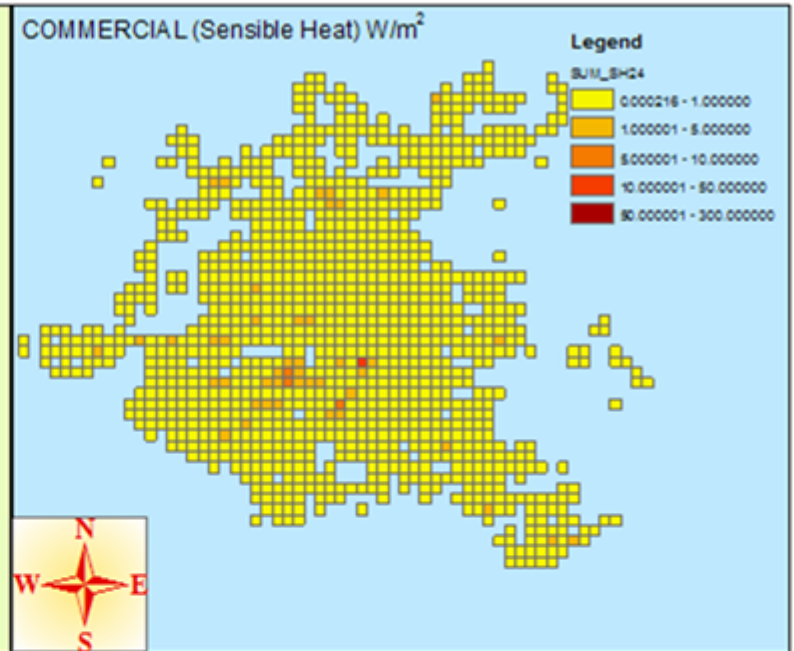
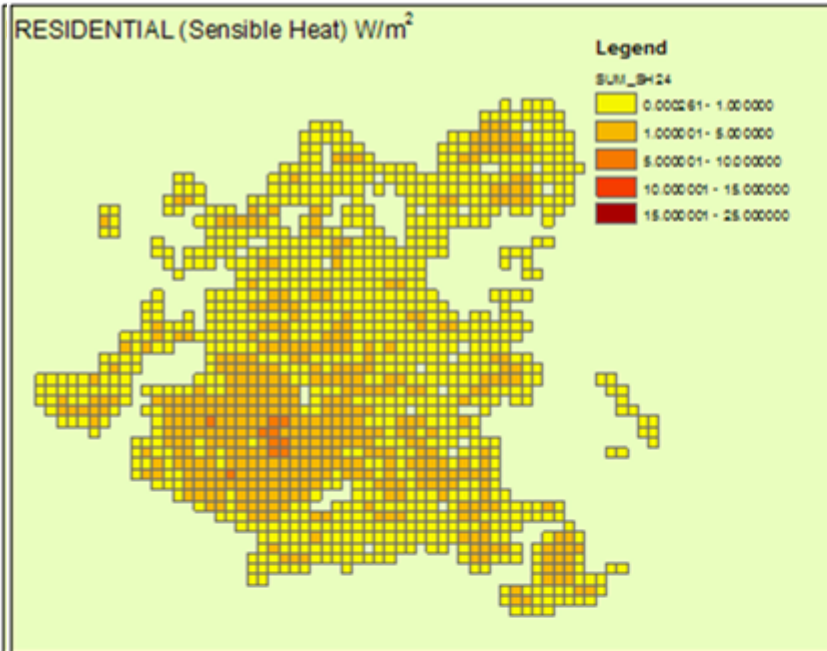
- Primary Heating:**
1. NG +
  2. Electric

8 building prototypes

# GIS parcel data

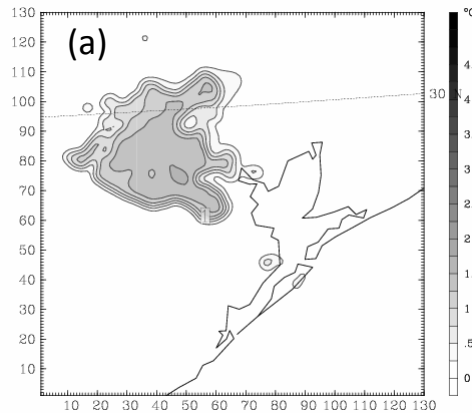
- Many cities have detailed GIS resources
- Houston (COHGIS)
  - 800,000 taxlots
  - building type
  - building floor space



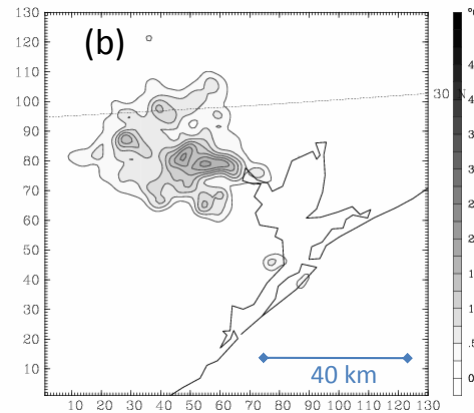


# Spatial variation in $Q_f$ is important!

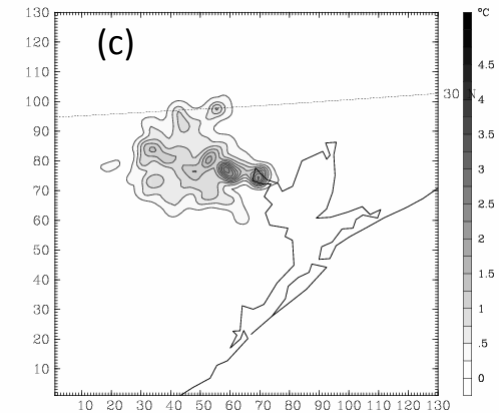
CityQf



LUQf



ParcelQf



- Anthropogenic sensible heating portion of UHI at 0600 local time for:
- (a) CityQf – a single city-wide value of hourly  $Q_f$
  - (b) LUQf – anthropogenic heat based on dominant land use
  - (c) ParcelQf – anthropogenic heat based on bottom-up approach

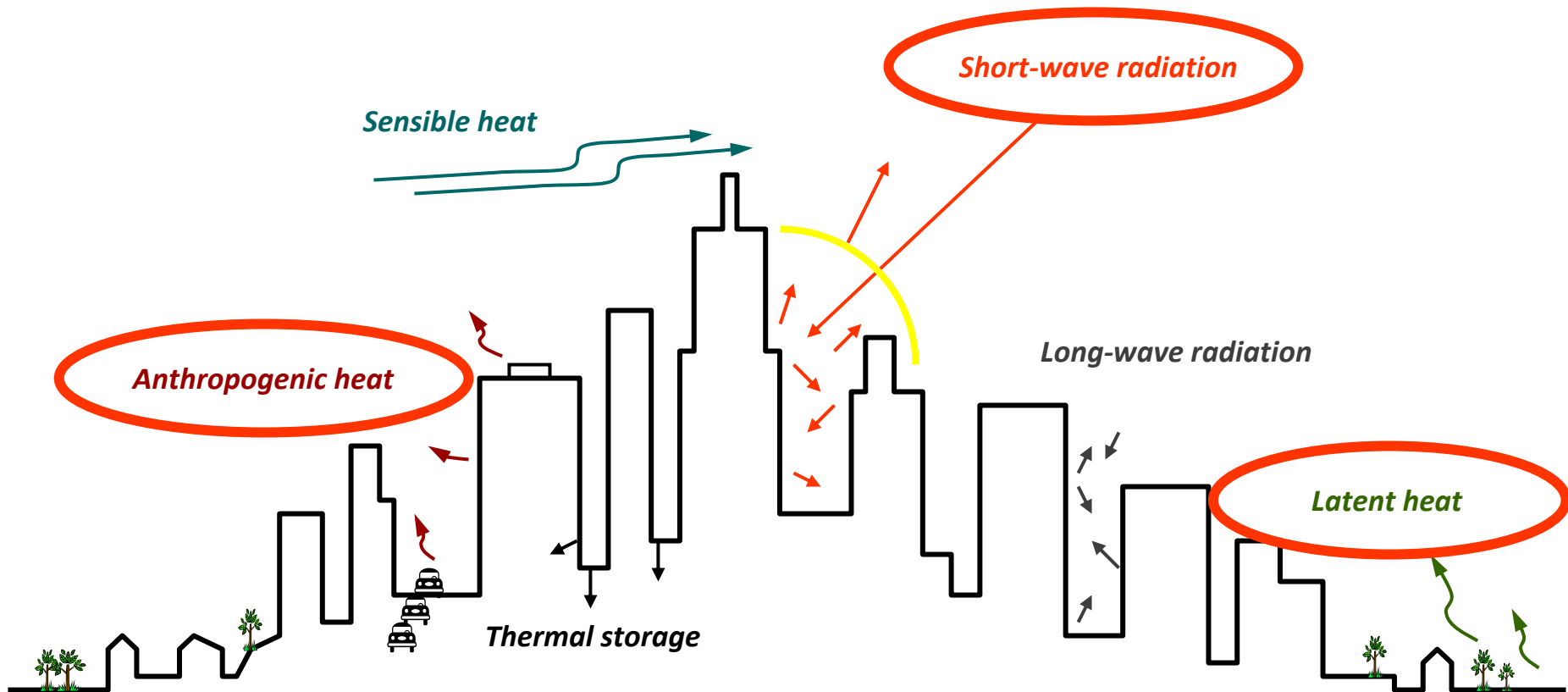
*Contour lines spaced every 0.25 °C.*

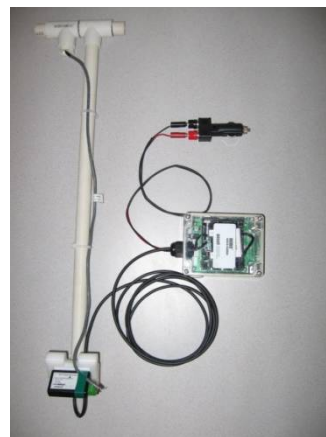
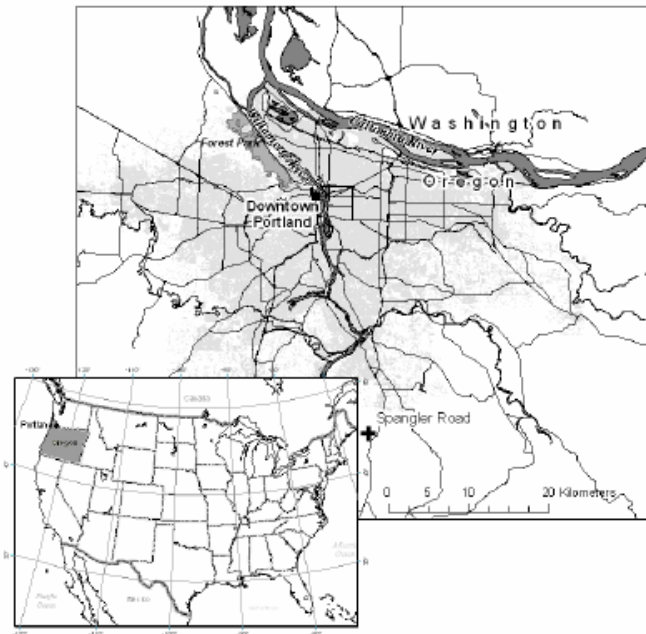
# Implications for Urban Planning and Management

- How shall we mitigate the urban heat island?
  - Urban vegetation & moisture
  - Urban albedo (solar reflectance)
  - Anthropogenic heating

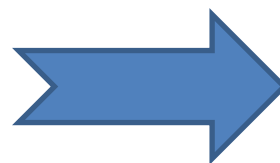
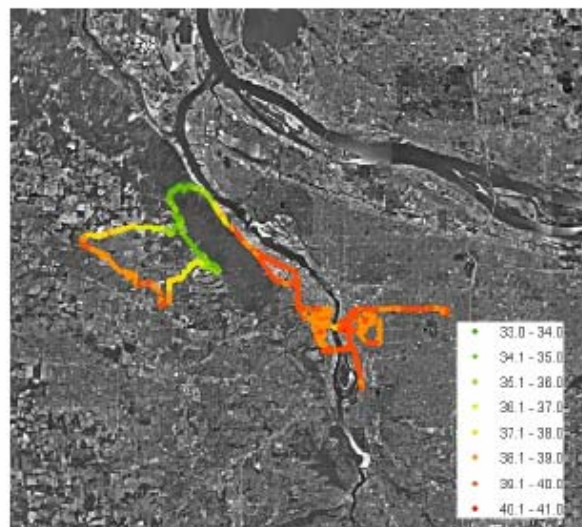


...what is the relative contribution of modifiable urban characteristics to the development of the urban heat island?



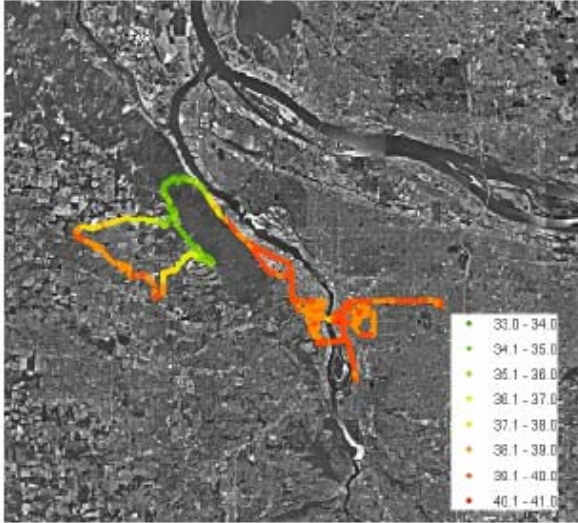


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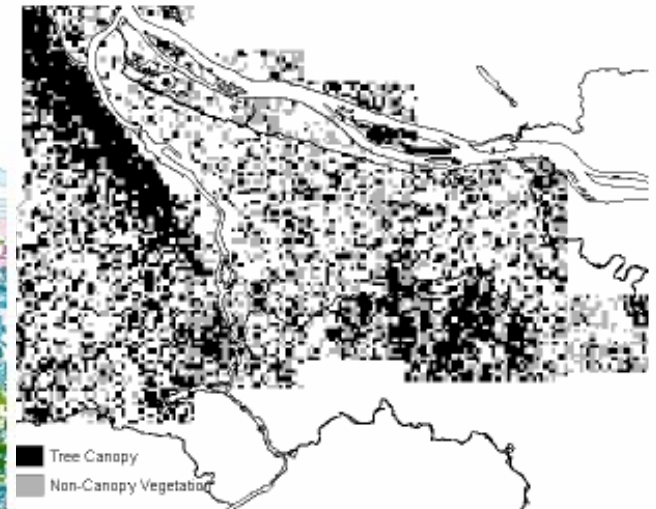
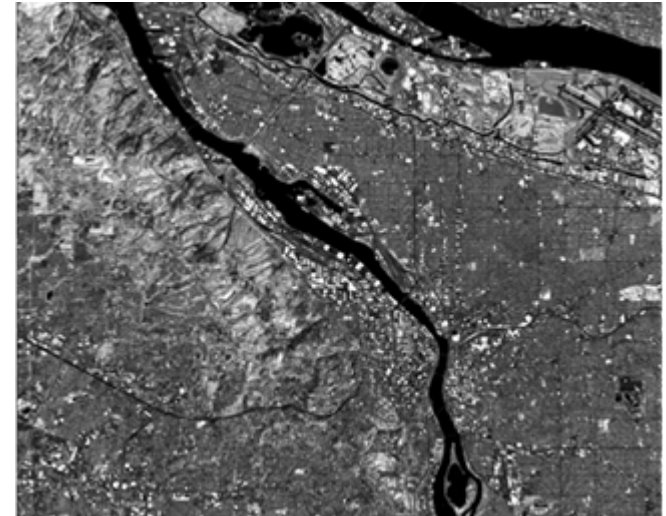


## Measurements of spatial variation in urban heat island



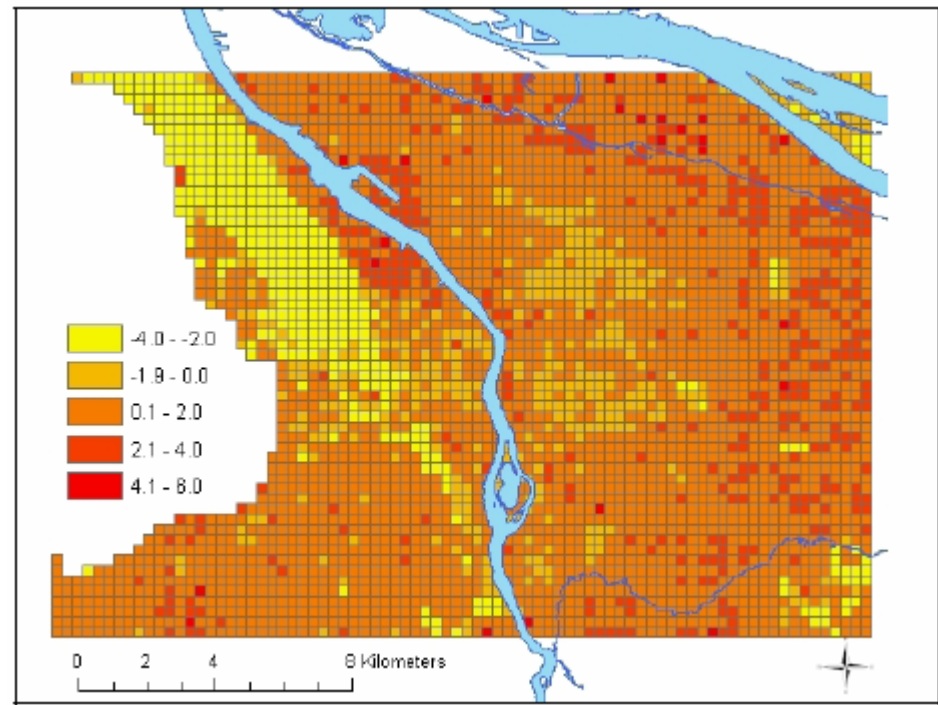
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## GIS & remote sensing resources for land use, albedo, vegetative cover, impervious surface, and anthropogenic heating



# Result: A predictive model of the near-surface air temperature heat island

- UHI = f (land use)
- UHI = f (albedo, vegetation, anthropogenic heating ...)



Land use based model of summer daytime UHI in Portland, OR.

# Conclusions

- Building energy consumption is not the same as waste heat emission
  - Building thermal load can be double the energy consumption
  - In urban core, much of the load is met through evaporative cooling
  - In areas with residential or smaller commercial buildings, however, the entire thermal load is sensible
- Vehicles and industry also contribute a significant amount of heat and moisture to the urban environment.
- Magnitude of total anthropogenic heating can rival the solar input. The resulting impacts on the urban heat island may be significant.
- To design effective urban heat island mitigation strategies, planners need to have quantitative information of the relative importance of modifiable urban characteristics.



# Acknowledgements

- National Science Foundation
- Dr. Melissa Hart, Alamelu Brooks, Hongli Fan, Shem Heiple, Lu Lu