An uncoupled pavement-urban canyon model for heat islands

Sushobhan Sen & Jeffery Roesler

University of Illinois at Urbana-Champaign

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Outline

- Introduction
- Pavement cases
- Meteorological cases & TMY
- Urban forms
- Results & Discussion
- Conclusion

Introduction

- Urban Heat Island (UHI) is a sustained temperature difference between urban and adjacent rural areas
  - UHI intensity: $\Delta T_{ur} = T_{urban} - T_{rural}$
  - Mesoscale definition (1 – 100 km length scales)
  - Microscale (< 1 km) variation within a city
- Can be measured at several heights, but most significant is **canopy height** (about 2.0 m above the ground)
- Challenges:
  - Finding the "right time" to model UHI
  - Incorporating pavement structure and properties

Pavement Cases

Layer	Dimensions	Materials			
		Case P (Control)	Case PL	Case PT	Case PC
Surface Course	100 mm	Concrete	Low-Density Concrete	TiO_2 Concrete	Concrete
Base Course	150 mm	Granular (A-2-4)	Granular (A-2-4)	Granular (A-2-4)	Cement-Treated Base
Subbase Course	300 mm	Granular (A-3)	Granular (A-3)	Granular (A-3)	Granular (A-3)
Subgrade	Semi-Infinite	Silty Soil (A-6)	Silty Soil (A-6)	Silty Soil (A-6)	Silty Soil (A-6)
		(Control)	**(Lower Density Surface)**	**(Higher Albedo Surface)**	**(Stabilized Base Layer)**

We know each of these cases has a different surface temperature at a given hour

(From Sen & Roesler, 2014 and Sen & Roesler, 2017)

Sen & Roesler (2017)

Typical Meteorological Year (TMY)

- Months that show **least deviation in dry bulb air temperature** from a 30-year average (1976 – 2005, TMY Series 3) – hourly data
- Obtained from the National Renewable Energy Lab (NREL), US DOE for 1020 locations
- Provides a climatological basis for selecting far field weather conditions
- Used extensively for building energy modeling, even required by law in some instances

Location and Weather Cases

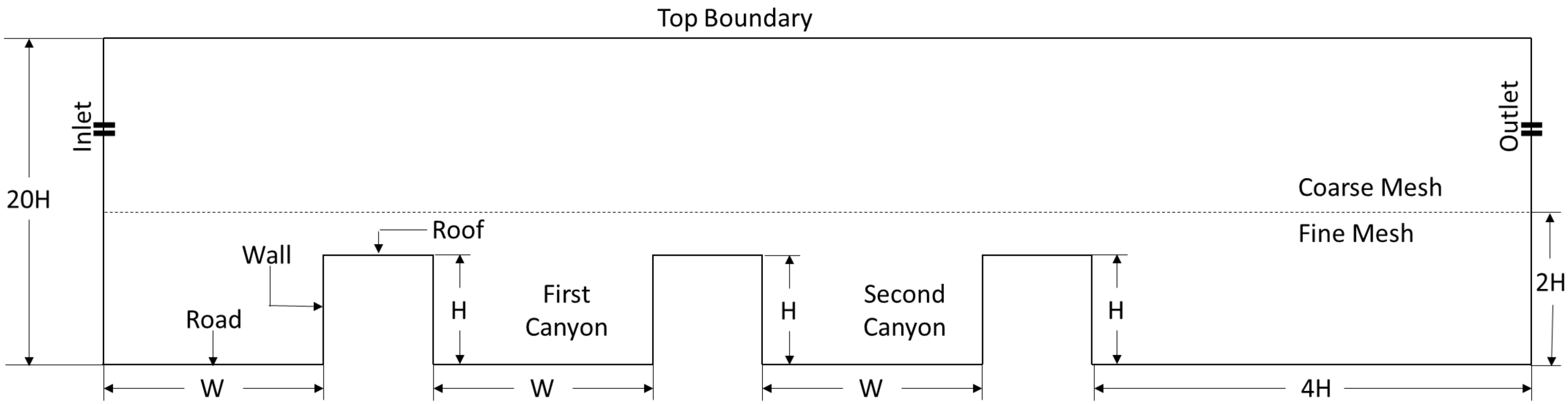
- Analysis for the warmest typical meteorological hour in Chicago, IL
  - July 19, 3:00 PM, base condition air temperature = 35°C
  - Assume low wind speed of 2 m/s (about 4.5 mph)
  - For comparison of UHI intensity: DuPage, IL (base condition air temperature = 31°C for a **‘mesoscale’ UHI intensity** of 4°C)

TMY+0 → **TMY+1** → **TMY+2**

- TMY+0
  - Base condition
- TMY+1
  - Moderate climate change
- TMY+2
  - High climate change

Sen & Roesler (2017)

Domain & Urban Forms



- Canyon width (W) fixed at 10 m
- Canyon height (H) increased with **aspect ratio** (AR) H:W = 0.5:1, 1:1, 2:1 (so H = 5, 10, and 20 m)

Sen & Roesler (2017)

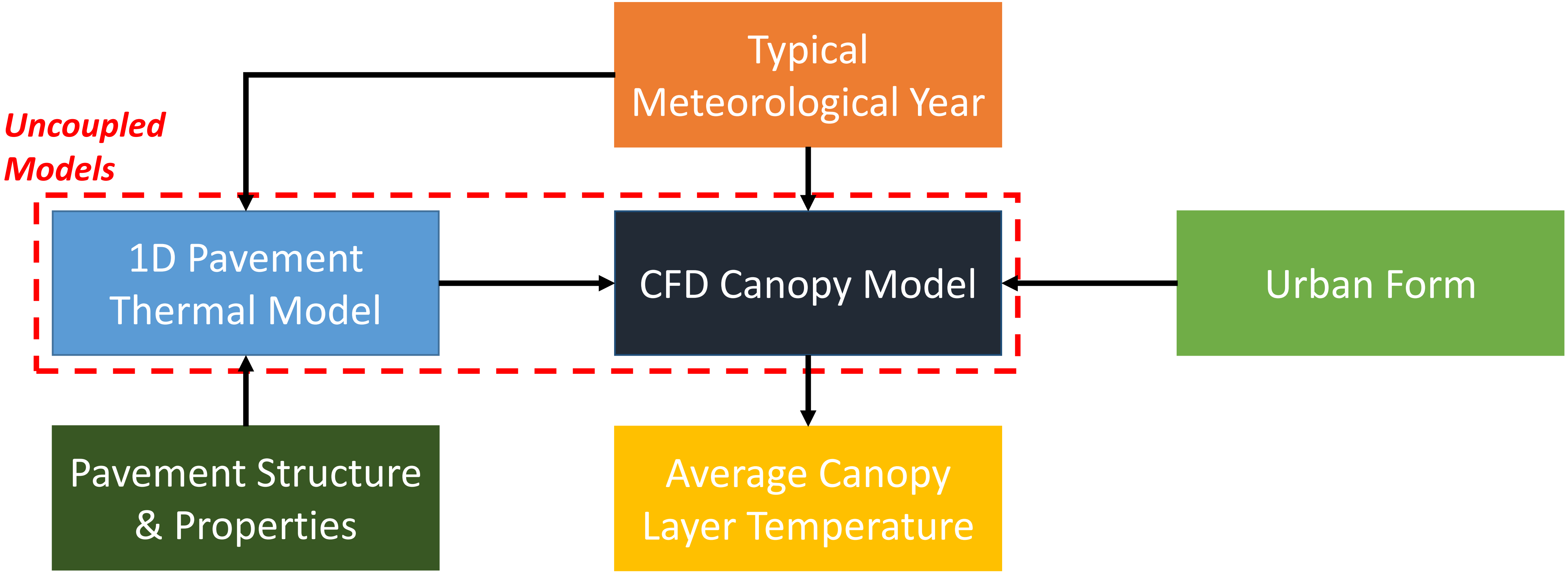
Pavement Modeling

- 1D Pavement Thermal Model – ILLITHERM (Sen & Roesler, 2016)
  - Finite difference solution to the Fourier Heat Equation (stabilized layers) and Philip-de Vries coupled heat and moisture model (granular layers)
  - Surface boundary condition: Incoming + outgoing radiation, convection (Robin condition)
  - Subgrade boundary condition: Constant deep-soil temperature (Dirichlet condition)
  - Evaluates surface temperature, used as BC for CFD Model

Canopy Modeling

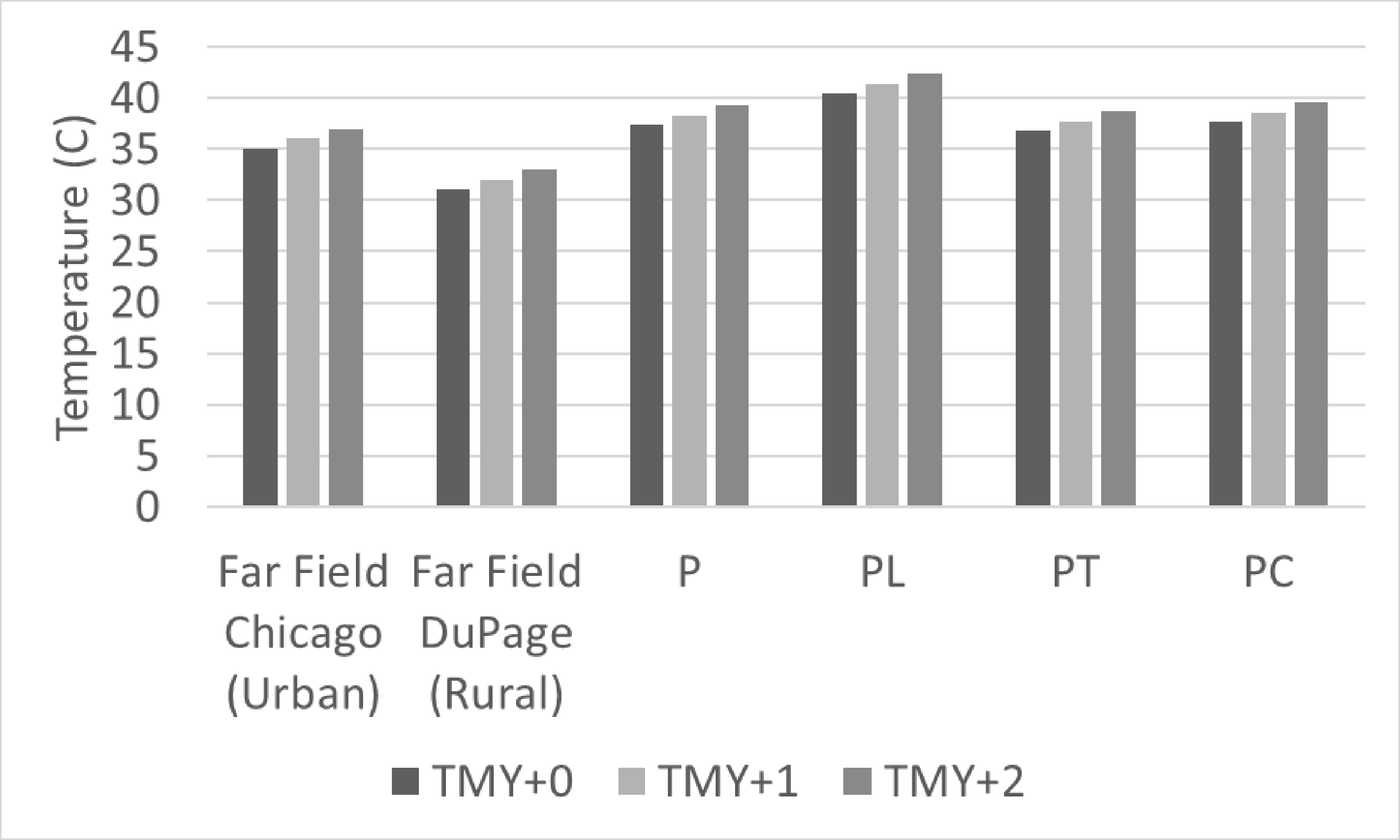
- 2D Finite Volume solution (0.25 m grid size in fine region, 5.0 m with inflation in coarse region) of the complete (Reynolds Average) Navier-Stokes (RANS) Equations + Energy Equation + $k - \epsilon$ turbulence closure model (buoyancy ignored)
  - Modeled using ANSYS FLUENT
- Inlet: Far field wind speed (2 m/s) and TMY temperature
- Outlet: Pressure outlet and TMY temperature
- Other walls: Symmetry condition (based on mesh convergence study), except canopy road (Dirichlet condition from pavement model) and buildings (*'turned off'*)

Research Approach

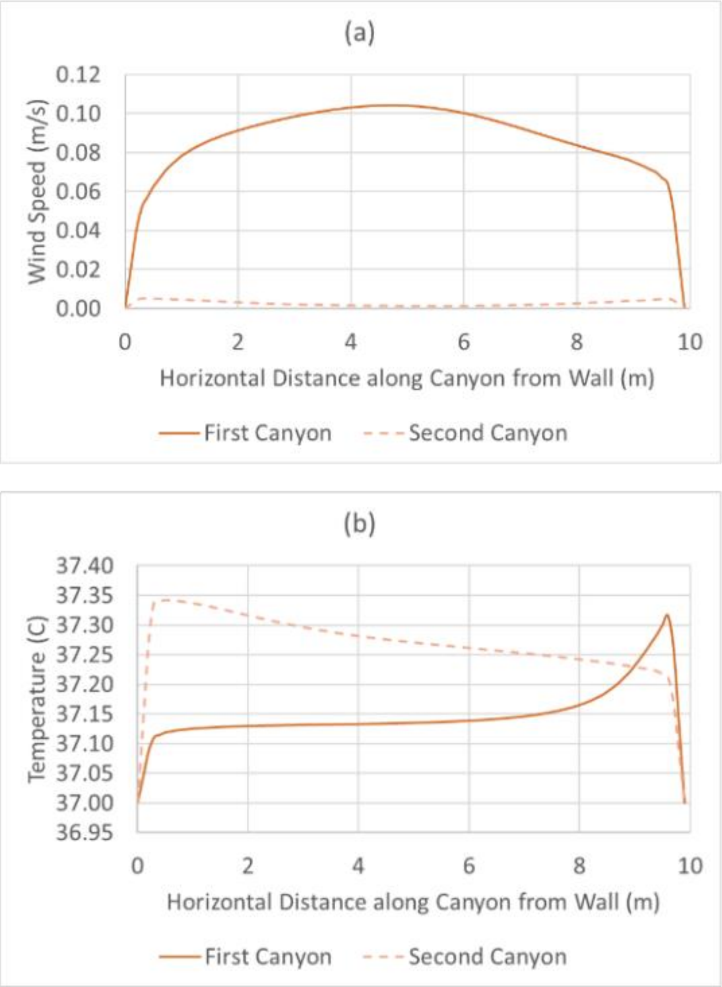


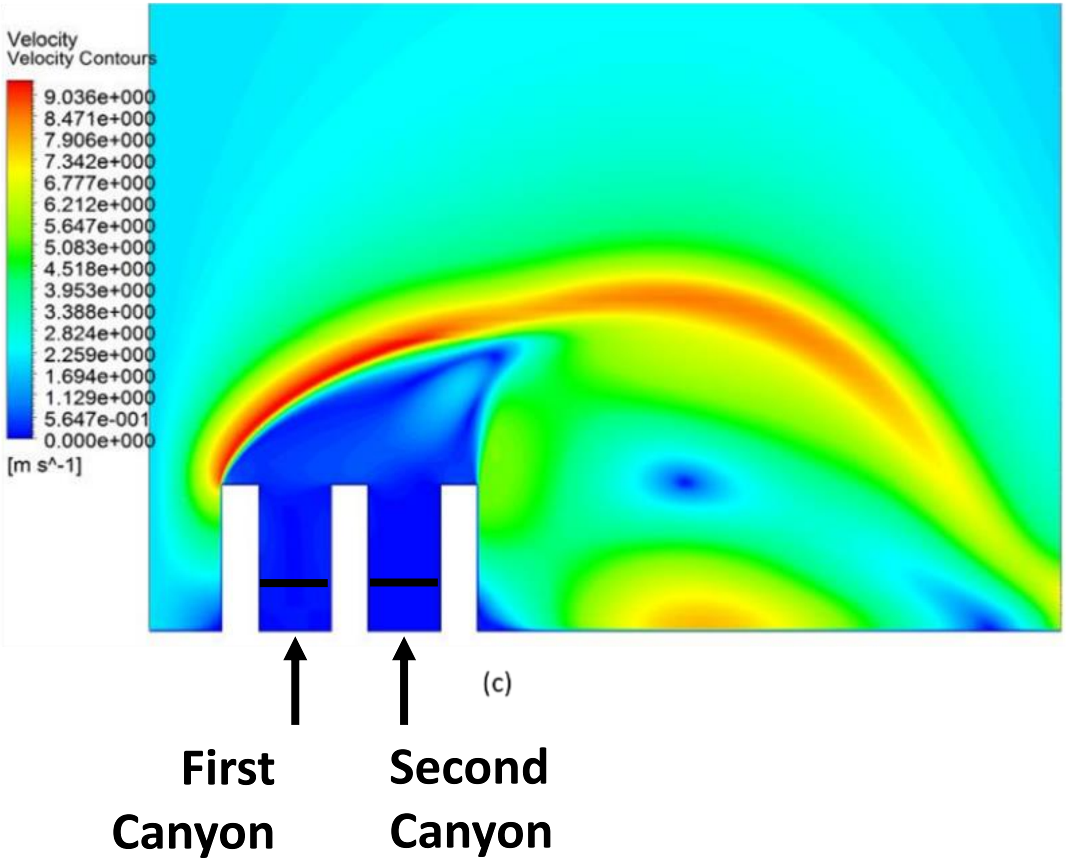
Results & Discussion

Surface Temperatures



Typical Results

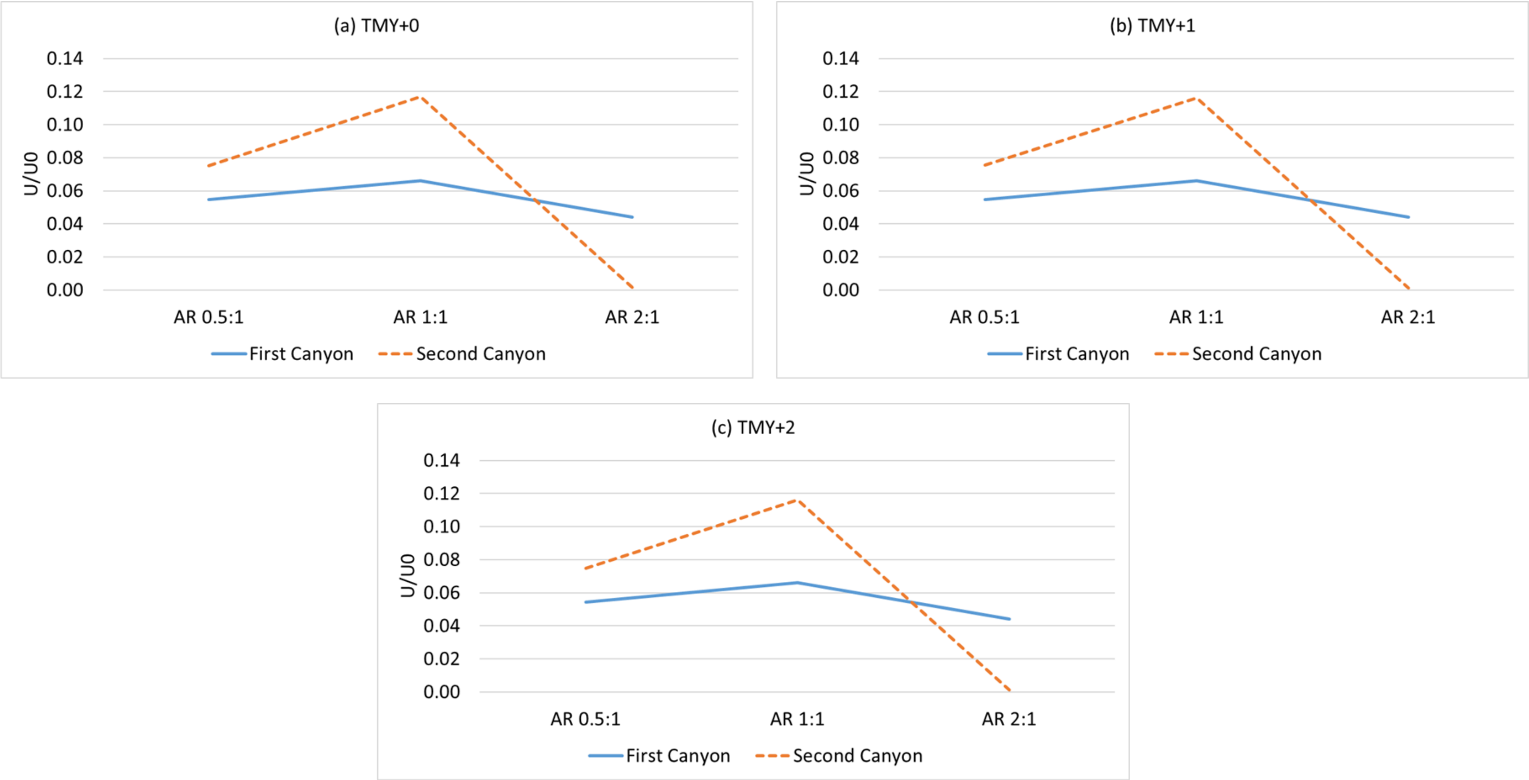




Sen & Roesler (2017)

Average Wind Speed at 2.0 m

Does not vary with far field temperature condition



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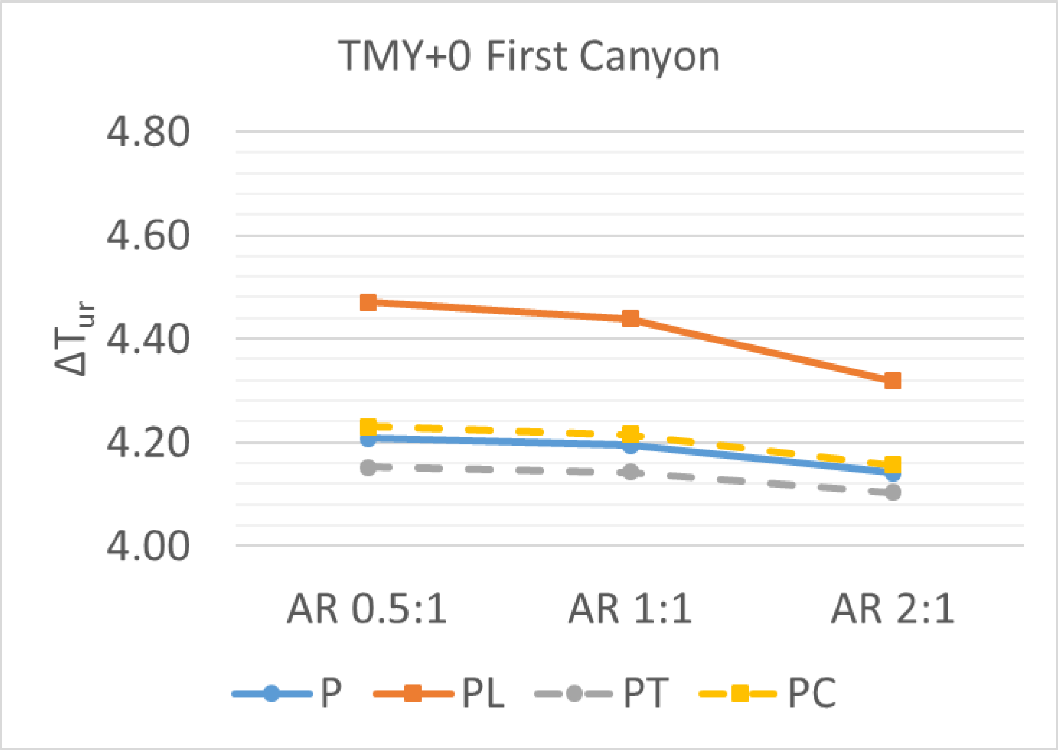
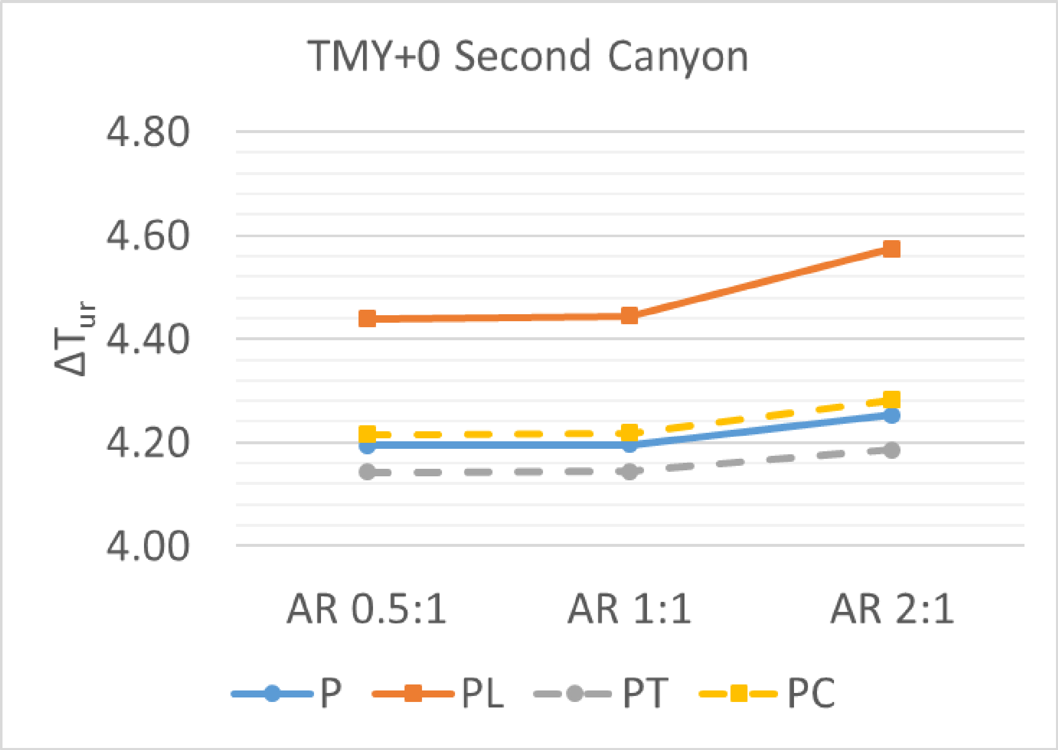
Temperatures (ºC): TMY+0





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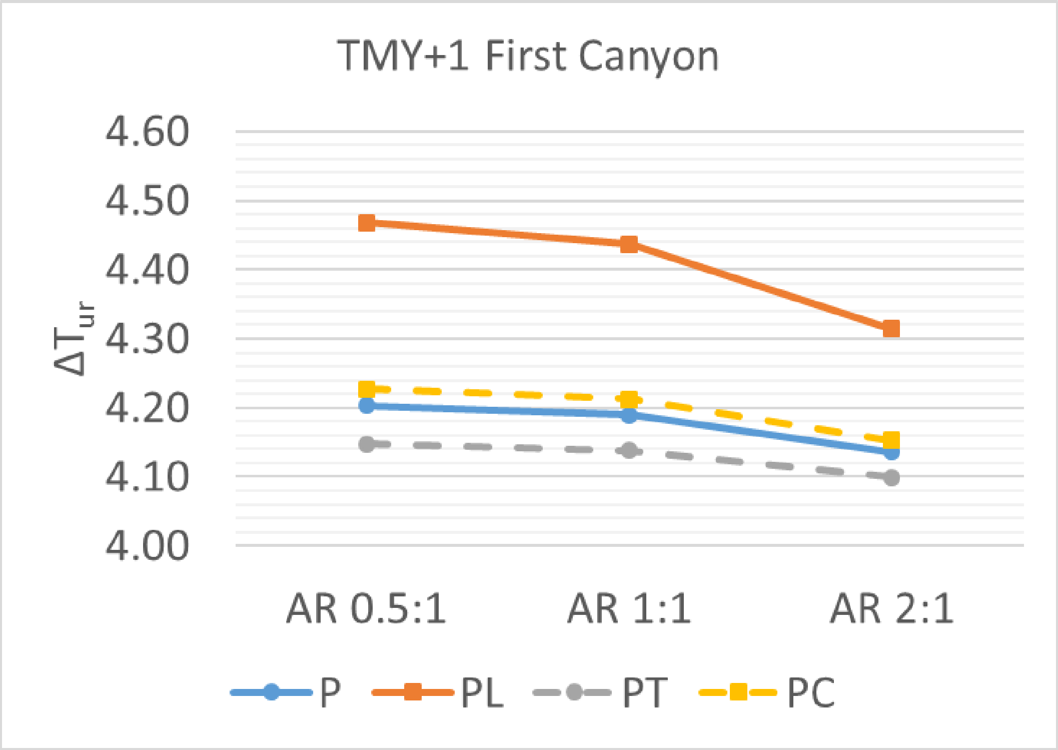
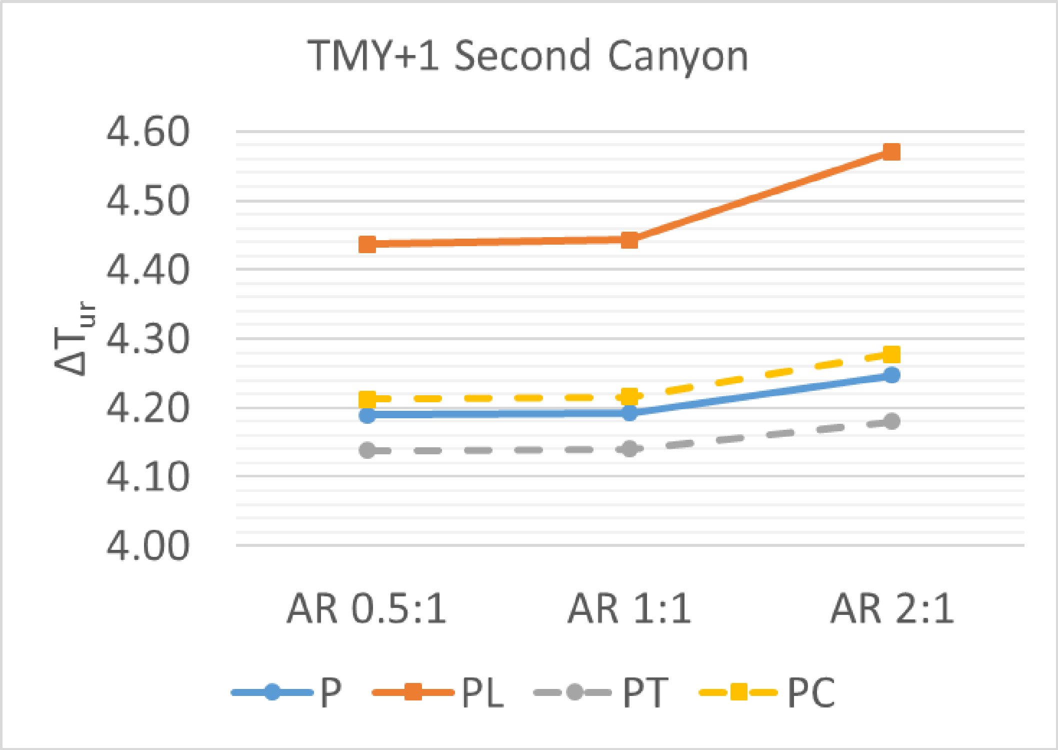
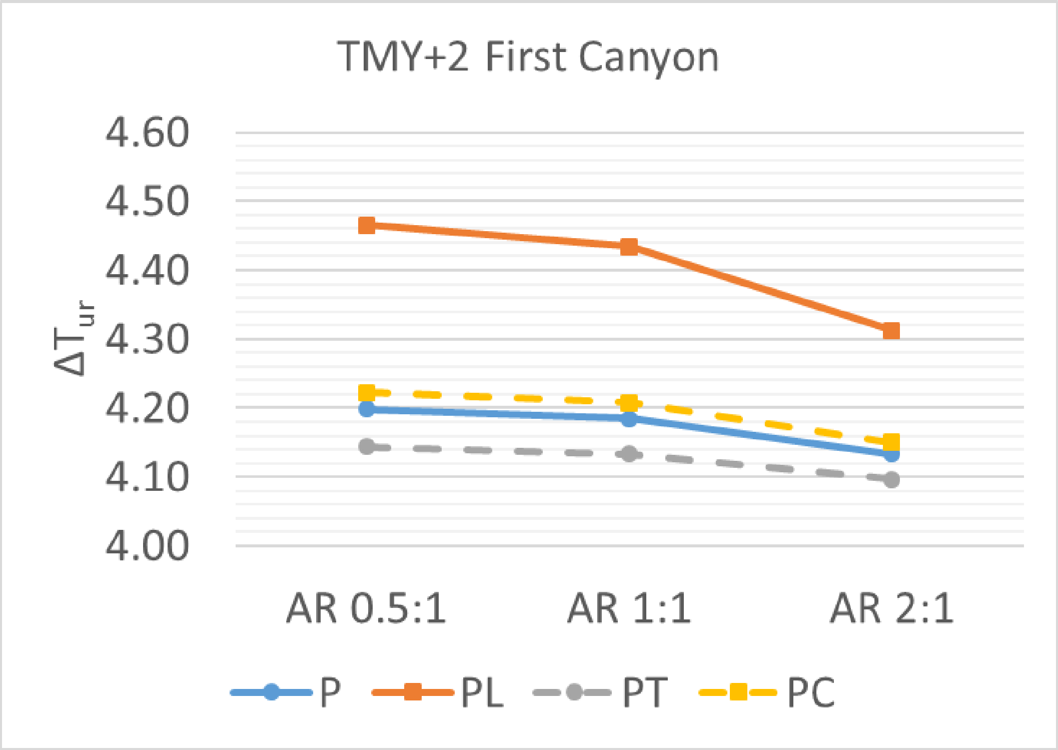
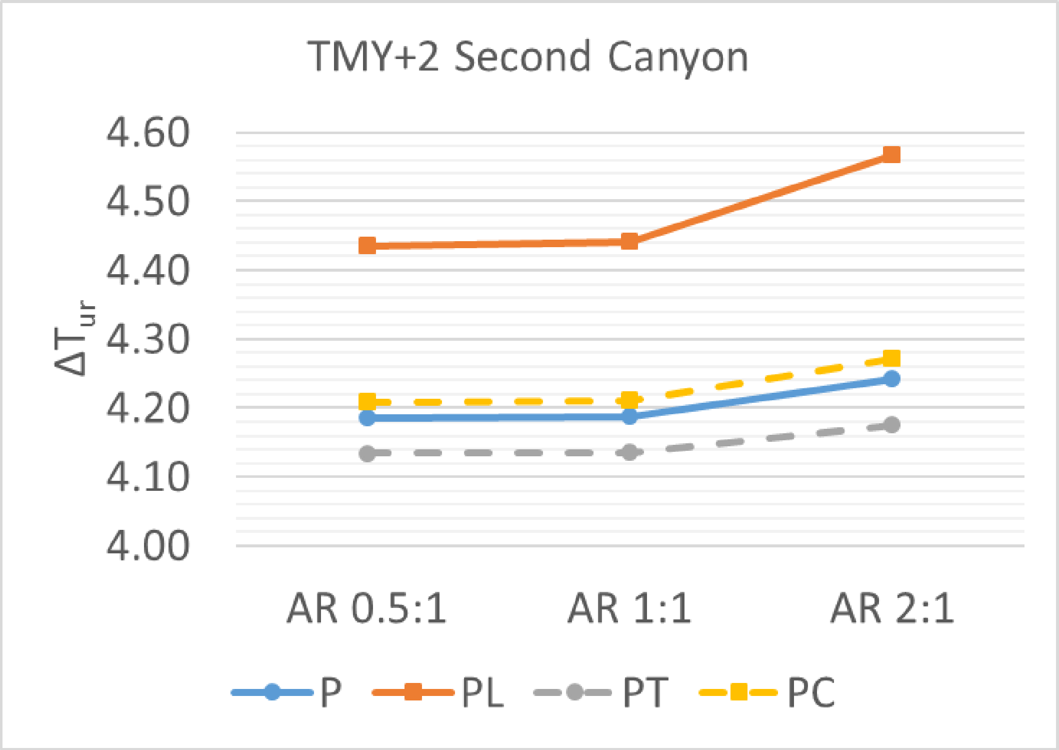
Temperatures (ºC): TMY+1





Temperatures (ºC): TMY+2





Sen & Roesler (2017)

Discussion

- For all cases, ΔT_{ur} of PL > PC > P (control) > PT
  - Correlates with surface temperature
- Canyon 1: ΔT_{ur} decreases with AR
- Canyon 2: ΔT_{ur} increases with AR
- Increase in far field air temperature does not increase ΔT_{ur} - but still bad news!

Conclusions

- Microscale UHI is influenced by heterogeneous urban form and materials
- Climate change can exacerbate UHI
- Questions for future research:
  - Will rural temperatures really increase as much as urban temperatures due to climate change?
  - How do different pavement types in the same city affect microscale UHI?

Acknowledgements

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UNIVERSITY TRANSPORTATION CENTER for HIGHWAY PAVEMENT PRESERVATION

Thank You

- Questions?