Seminar 52

How Big Are the Climate Variations Within a City and How Much Do They Impact Building Energy Use?

The impact of trees on passive survivability during extreme heat events in warm and humid regions

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ORLANDO
2020 WINTER CONFERENCE
AND AHR EXPO

Learning Objectives

- Understand current modeling challenges for urban vegetation
- **Q&A:**

These are the Overall Session Objectives that were submitted for CEU approval for the session and not just your portion. Your Session Chair should provide you with this information or it can be found at the bottom of your Speakers Corner or on the Speaker's Resources page.

***This is a required slide if you are a Seminar, Conference Paper, Technical Paper, or Workshop. The text below must be included on this slide.

Overview

Goal:

- Build, calibrate, and validate urban energy models for three “East Bank” neighborhoods in the City of Des Moines, Iowa, which can then be generalized to other communities and locations for the purpose of aiding in decision making

Approach:

- integration of diverse data sets through data driven models describing human behaviors, building energy dynamics, and near-building climates to create a complex urban systems framework for modeling and simulation.
- ABM modeling conducted to determine the effects of different policy levers on increasing residential weatherization adoption, including: Availability/characteristics of government-funded assistance programs;
- Combining empirical data for local climate and microclimate (as influenced by vegetation and compiled based on an onsite inventory), with modeling data for climate change projections (based on the North American Regional Climate Change Assessment Program (NARCCAP) data) and human behaviors (through surveys and ABM outputs) to predict energy use dynamics.

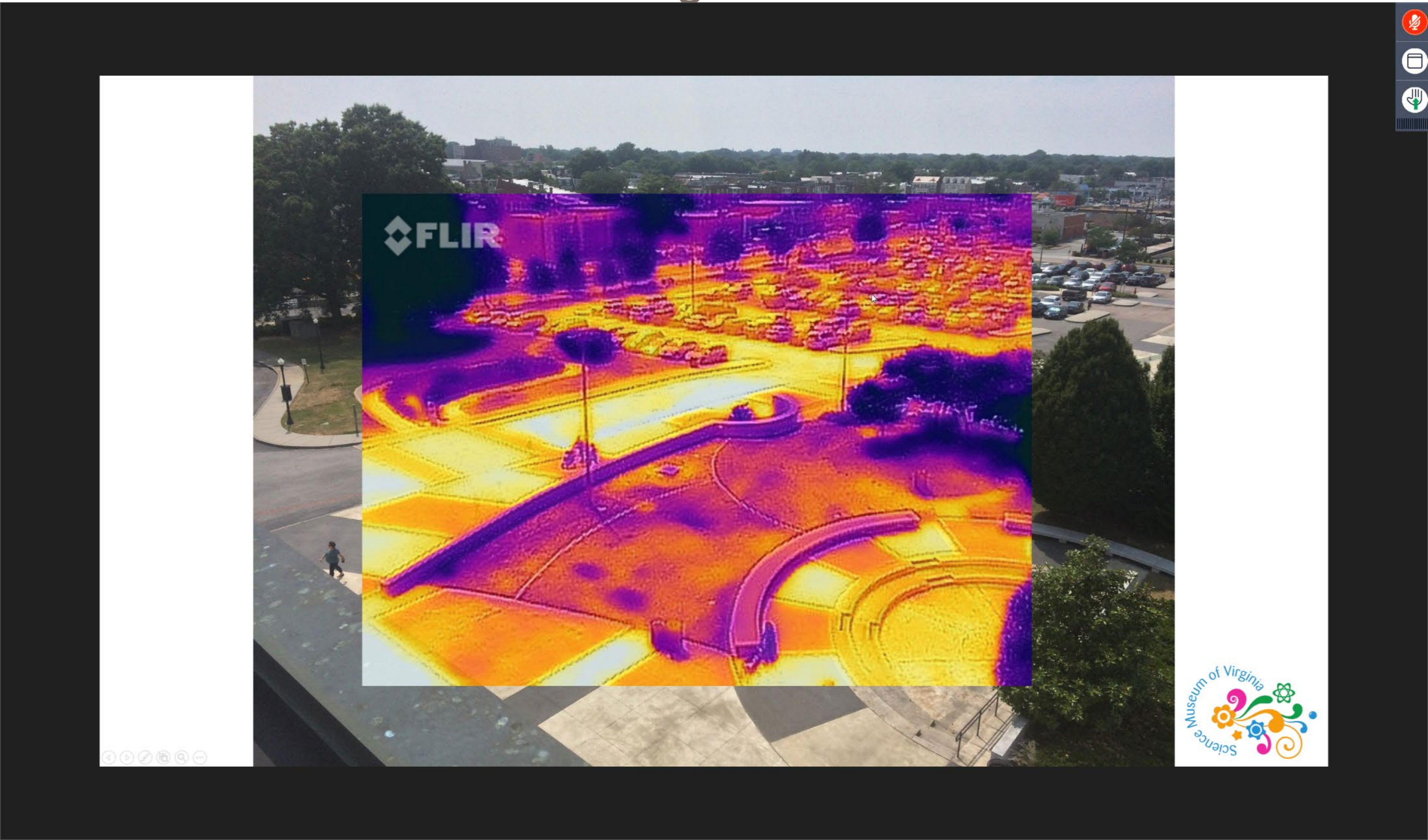
Current Results:

- Differentiated energy use schedules developed based on local data collection through surveys and action projects at various community events
- A hybrid physics data modeling framework in development to combine building and near-building (vegetation) thermal conditions using computational fluid dynamics (CFD) models.

Urban Vegetation

The urban issue

Science Museum of Virginia webinar on extreme heat



Union of Concerned Scientists

Killer Heat in the United States: Climate Choices and the Future of Dangerously Hot Days (2019)

Extreme Heat & Climate Change

HOW OFTEN WILL YOU ENDURE EXTREME HEAT WHERE YOU LIVE?

This tool shows the rapid increases in extreme heat projected to occur in locations across the US due to climate change. Results show the average number of days per year above a selected heat index, or "feels like" temperature, for three different time periods: historical, midcentury, and late century.

The results highlight a stark choice: We can continue along our current path, where we fail to reduce heat-trapping emissions and extreme heat soars, or we can act decisively now and stop the worst from becoming reality.

TYPE IN YOUR LOCATION (CITY OR COUNTY): Des Moines, IA

CHOOSE HOW HOT: Above 100°

GO

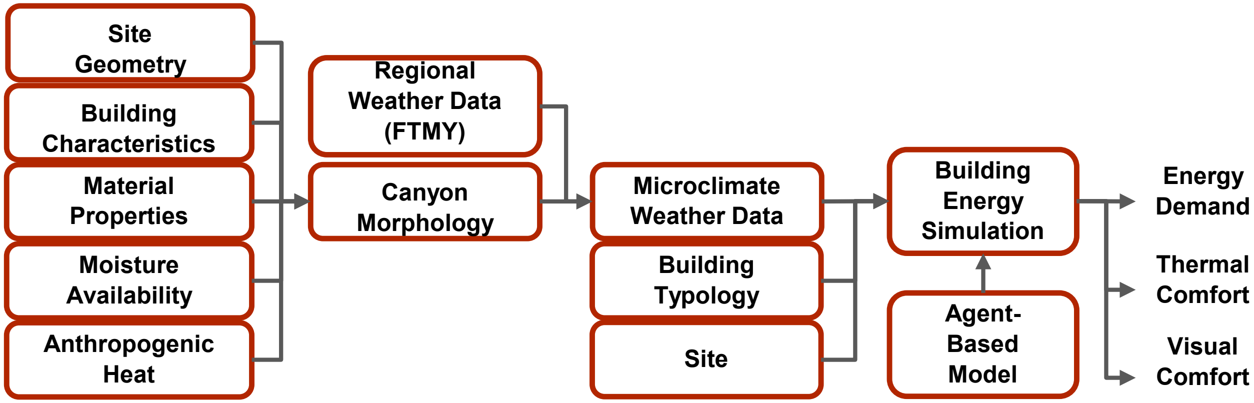
WHERE WE ARE NOW	WHERE WE ARE CURRENTLY HEADED		WITH BOLD ACTION
Historically	**Midcentury**	**Late Century**	**Extreme Heat Limited to**
1971-2000 average	2036-2065 average	2070-2099 average	
5	33	59	24
DAYS PER YEAR	DAYS PER YEAR	DAYS PER YEAR	DAYS PER YEAR

The choice is clear: We can limit future extreme heat events but we must take bold action **now** to address the climate crisis.

The Midwestern Climate Challenge

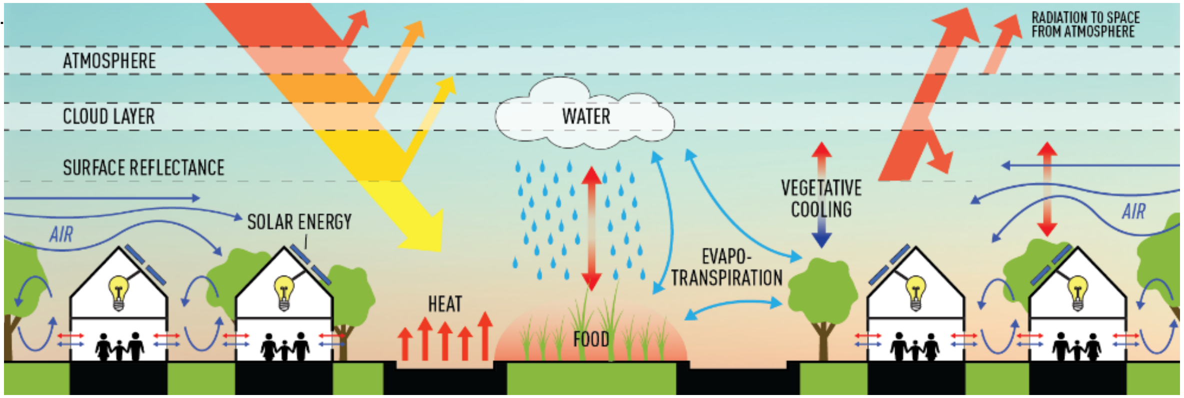
- The likelihood of extreme heat events is predicted to increase markedly in the Midwest region of the United States. By mid-century (2036–2065), one year out of 10 is projected to have a 5-day period that is 13°F warmer than a comparable earlier period
    - (1976–2005; Melillo et al. 2014).
- Nearly 50% of homes in low-income neighborshoods in this region do not have functioning central air-conditioning.
    - (Polk County Health Department Assessor Data)

Microclimate Characterization



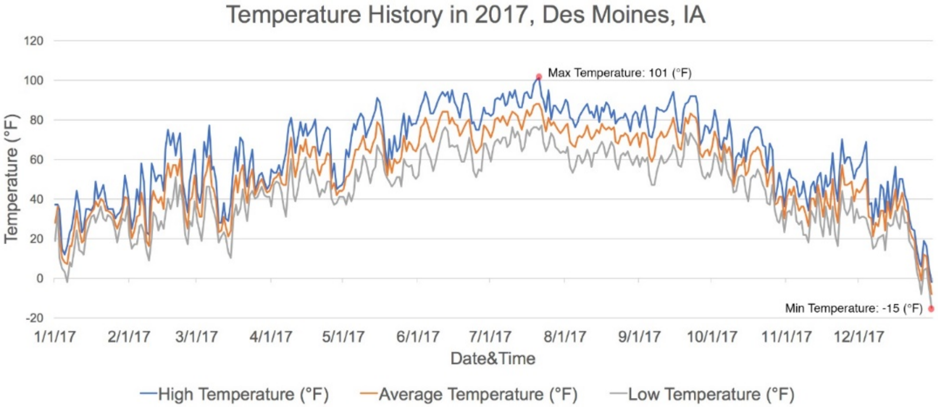
Patton, S. L. (2013). *Development of a future typical meteorlogical year with application to building energy use.* (Master of Science Thesis), Iowa State University, Ames, Iowa. (Paper 13635).

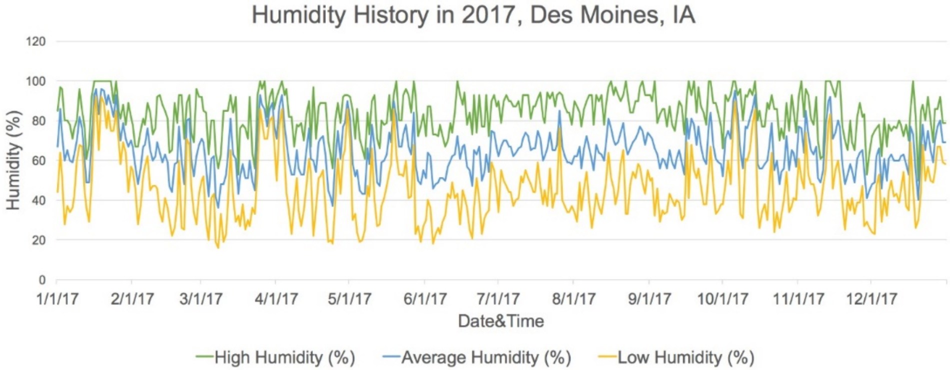
Kalvelage, K., Dorneich, M., & Passe, U. (2015, 7-9 Dec). Simulating the future microclimate to identify vulnerable building interior conditions. *Proceedings of the 14th International Conference of the International Building Performance Simulation Association*, Hyderabad, India.



Urban Context and Weather History Iowa

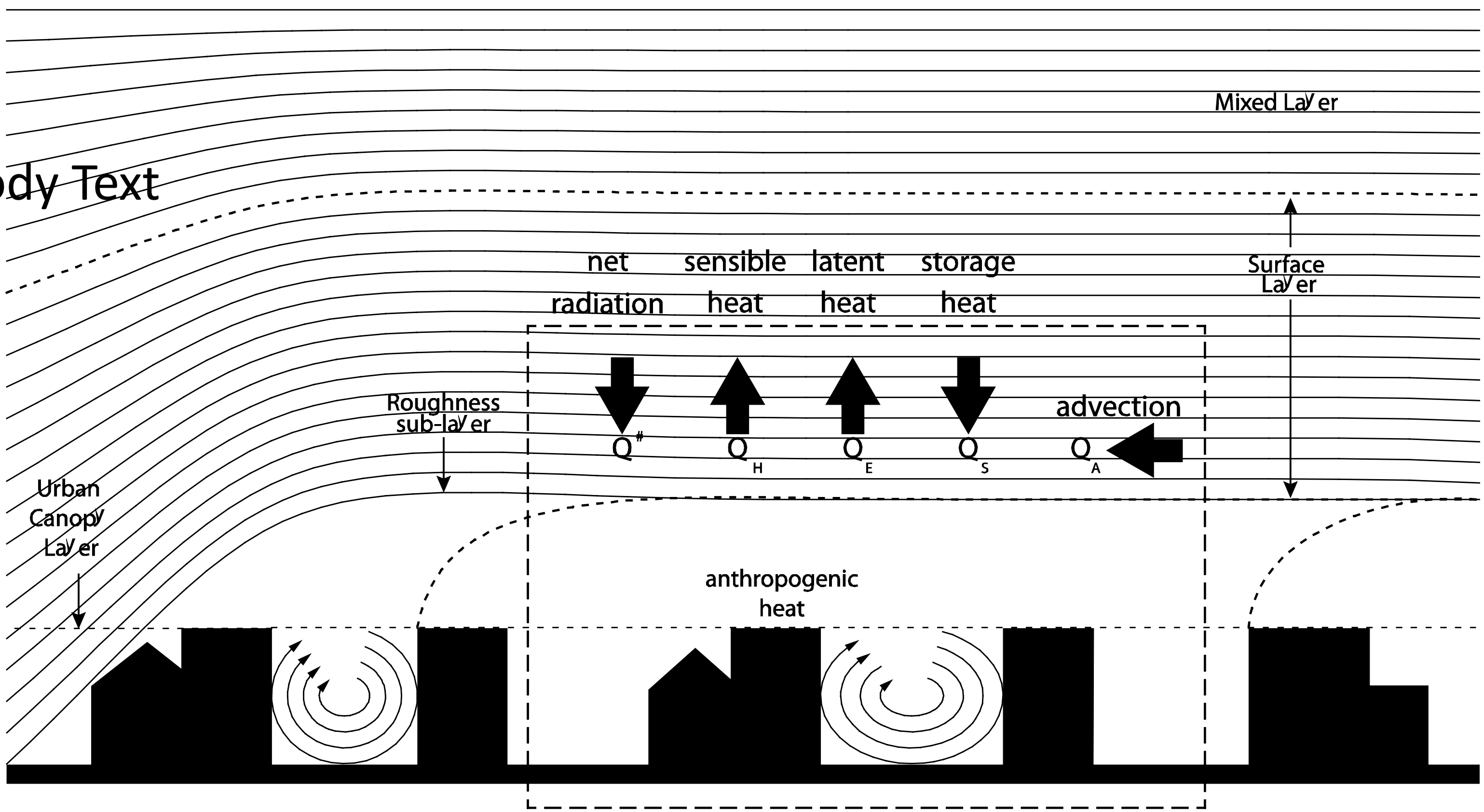
Capitol East Neighborhood, Des Moines, IA: 1142 trees and 340 buildings



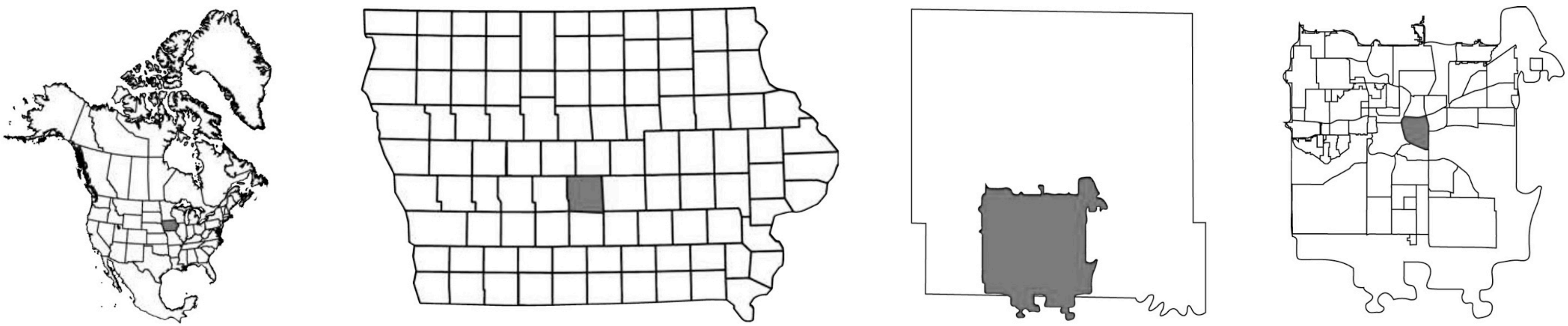


Urban surface energy balance

Body Text



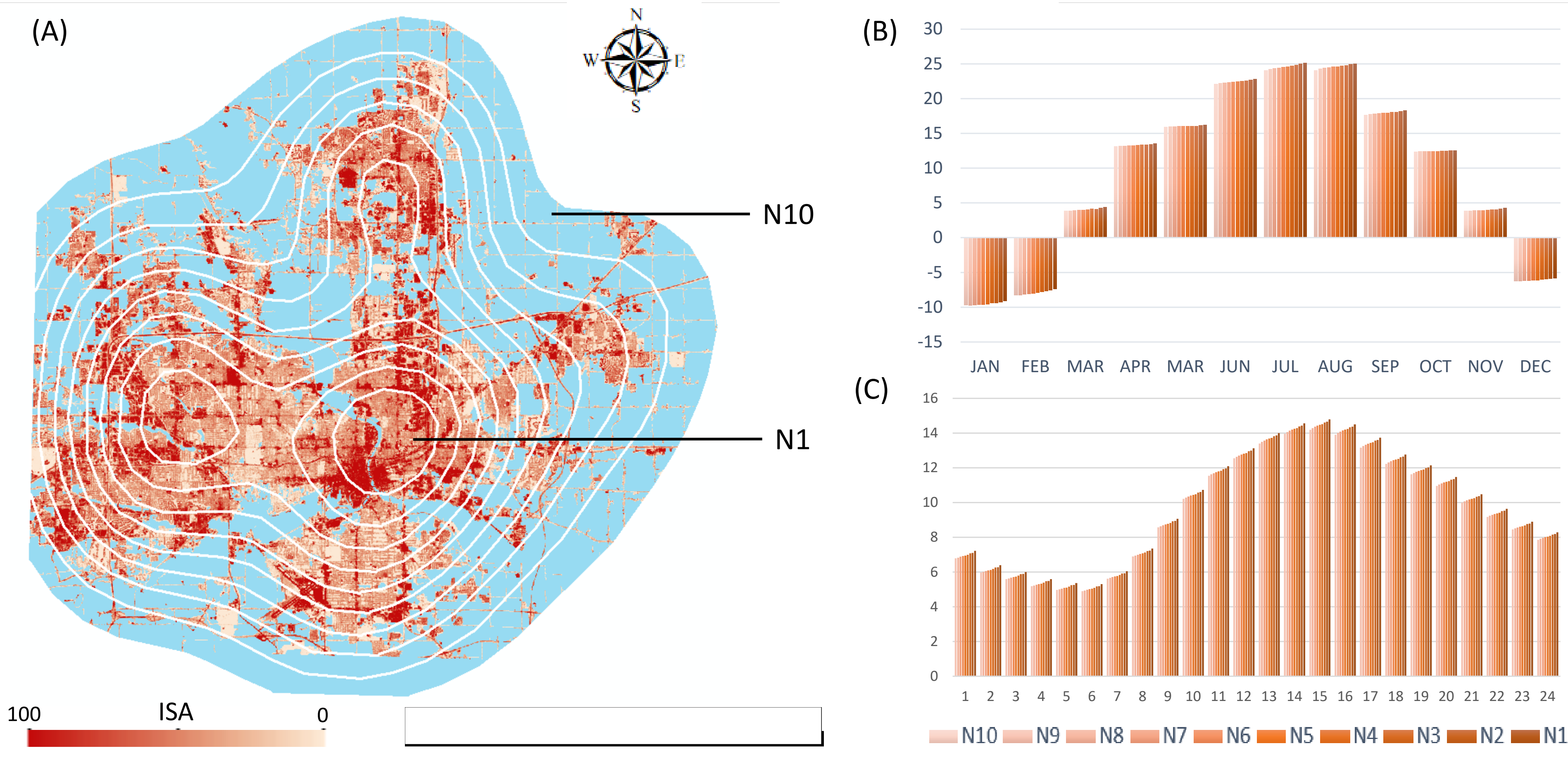
East Bank Neighborhoods / Des Moines, Iowa



North America Iowa Polk County Des Moines

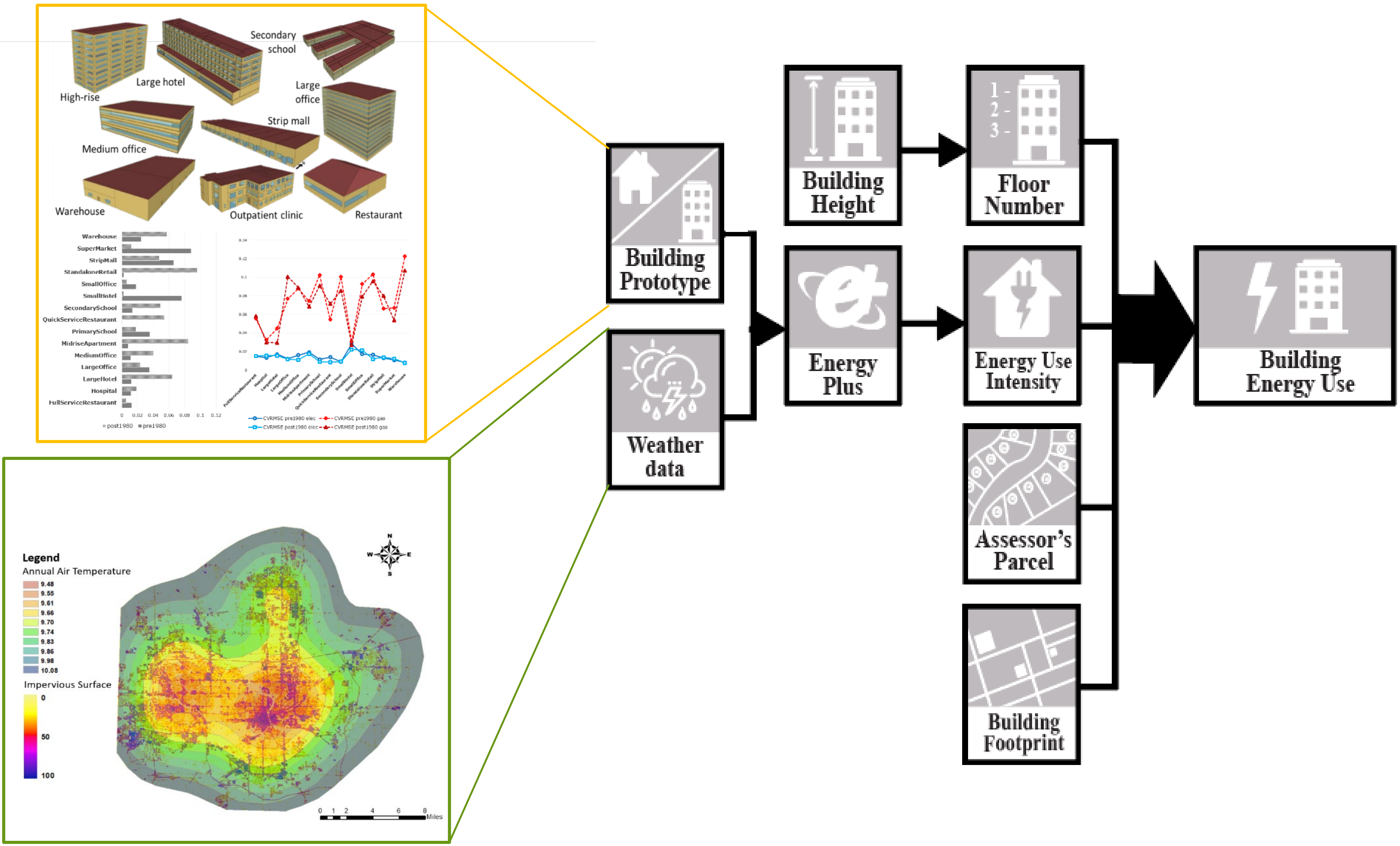
- Median income is less than half that of Des Moines
- Strong neighborhood associations
- Have participated in a revitalization program
- Large youth population
- Multilingual communities

Urban heat island

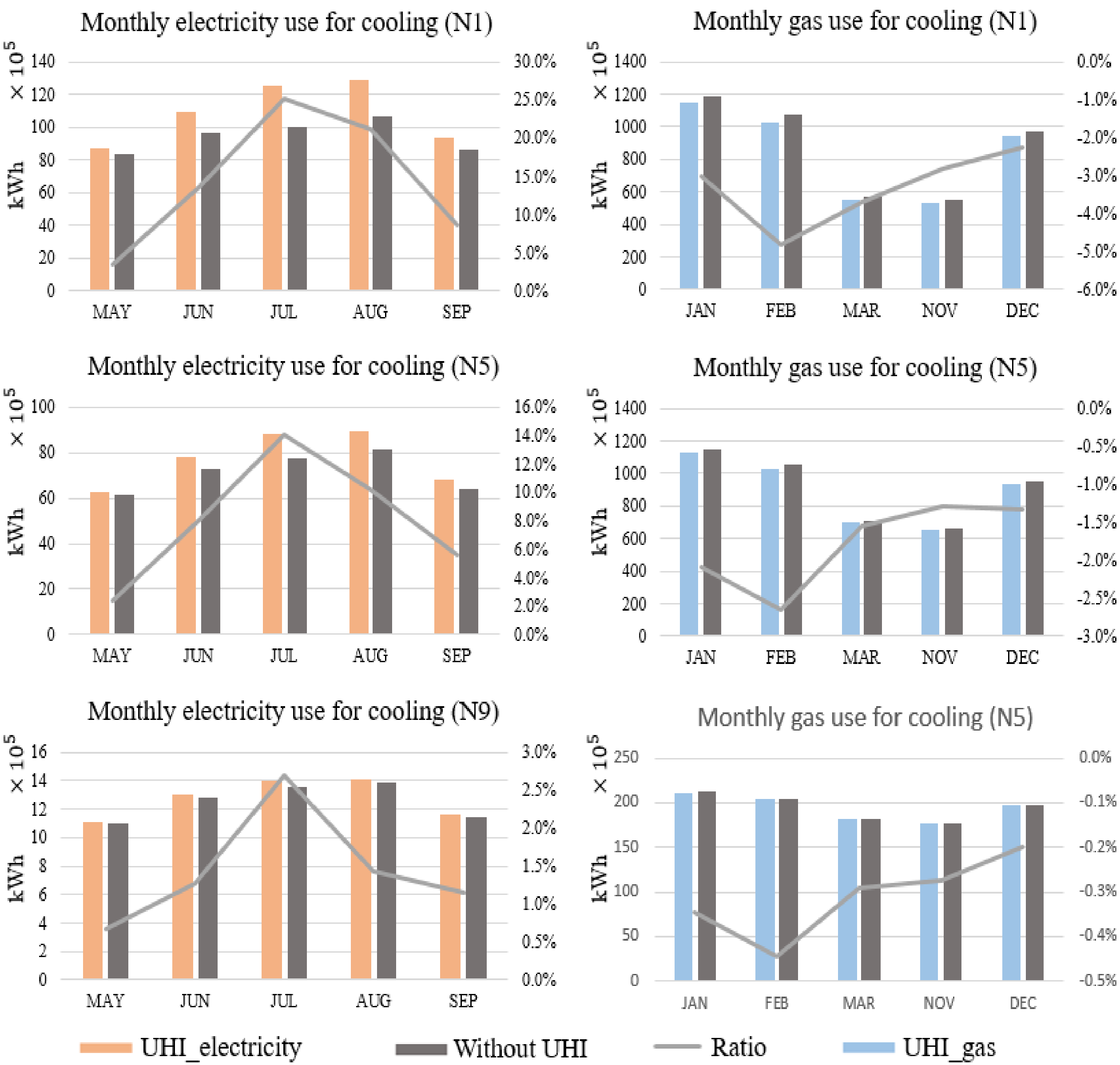


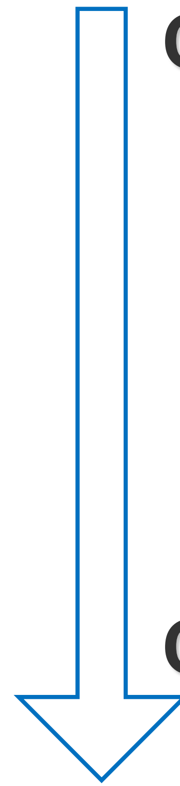
- (A): Climate zones in the study area
- (B): Monthly temperature patterns and UHI pattern
- (C): Hourly temperature patterns and UHI pattern

The framework



UHI impacts (monthly pattern)



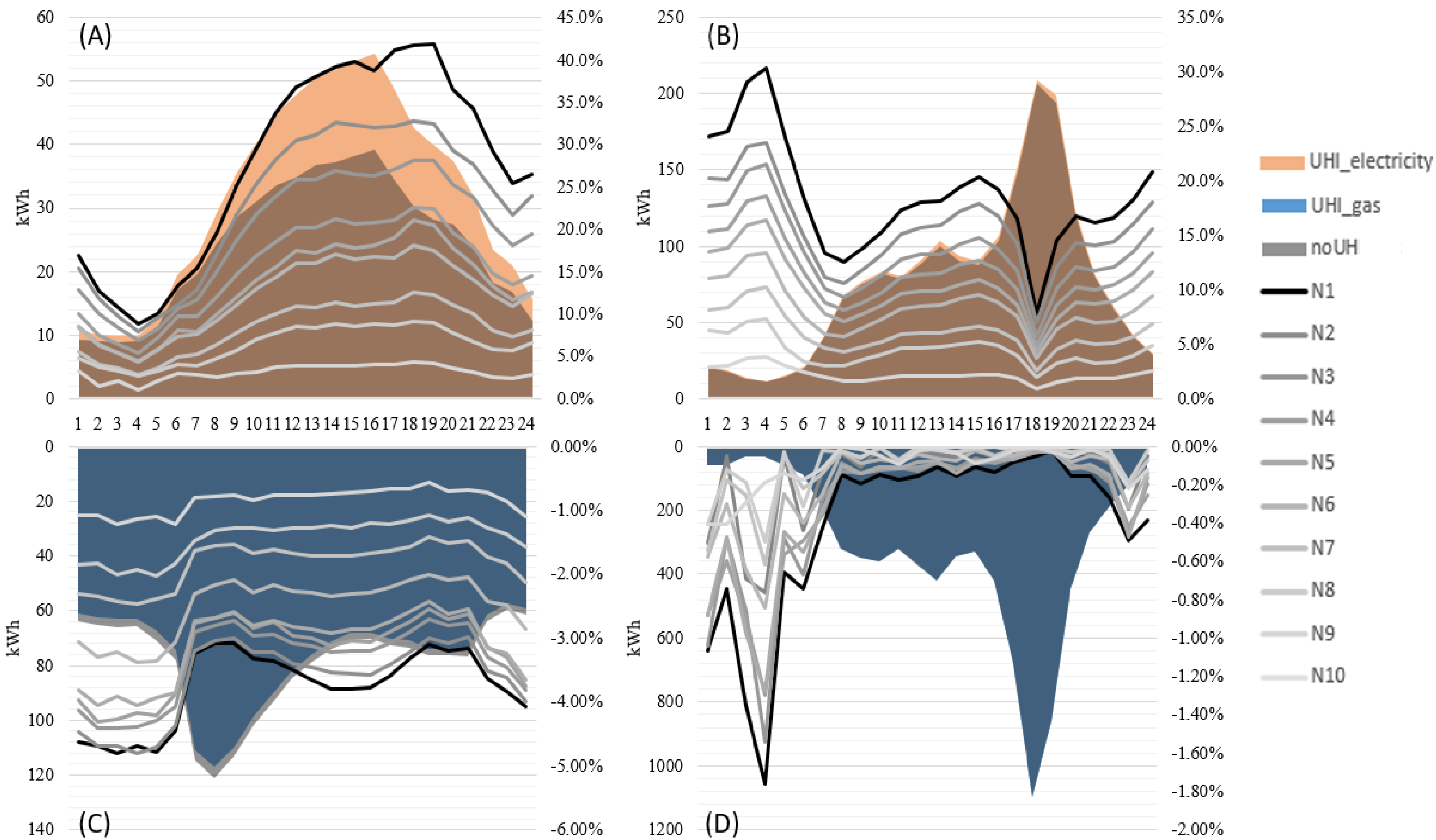


City center

City outskirt

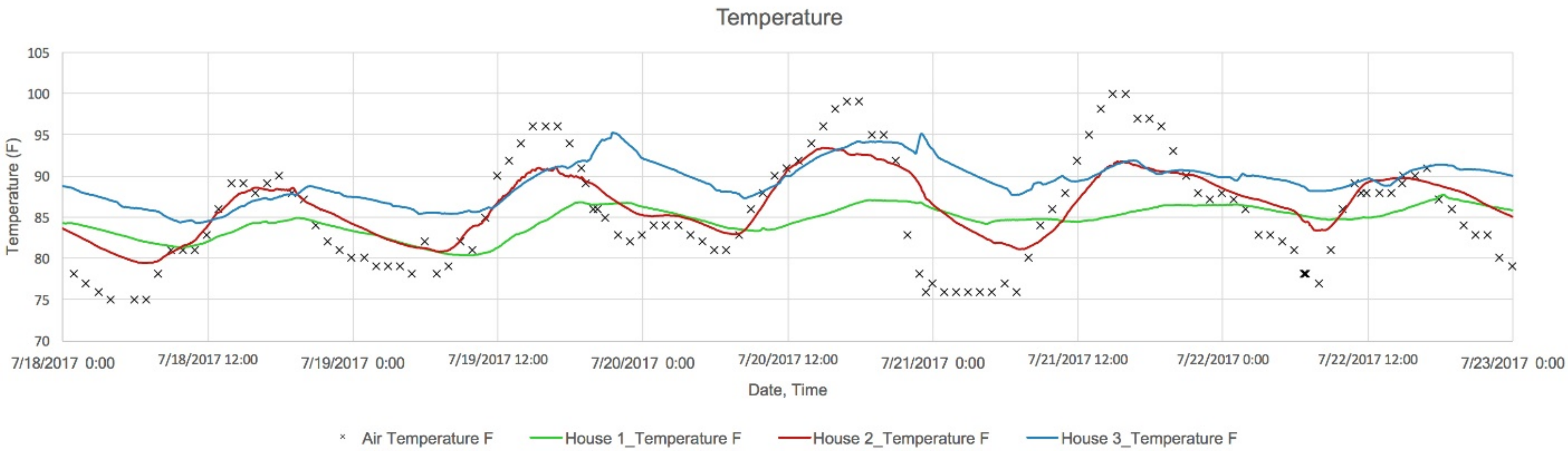
Electricity-summer | Gas-winter

UHI impacts (diurnal pattern)



Commercial-summer	Residential-summer
Commercial-winter	Residential-winter

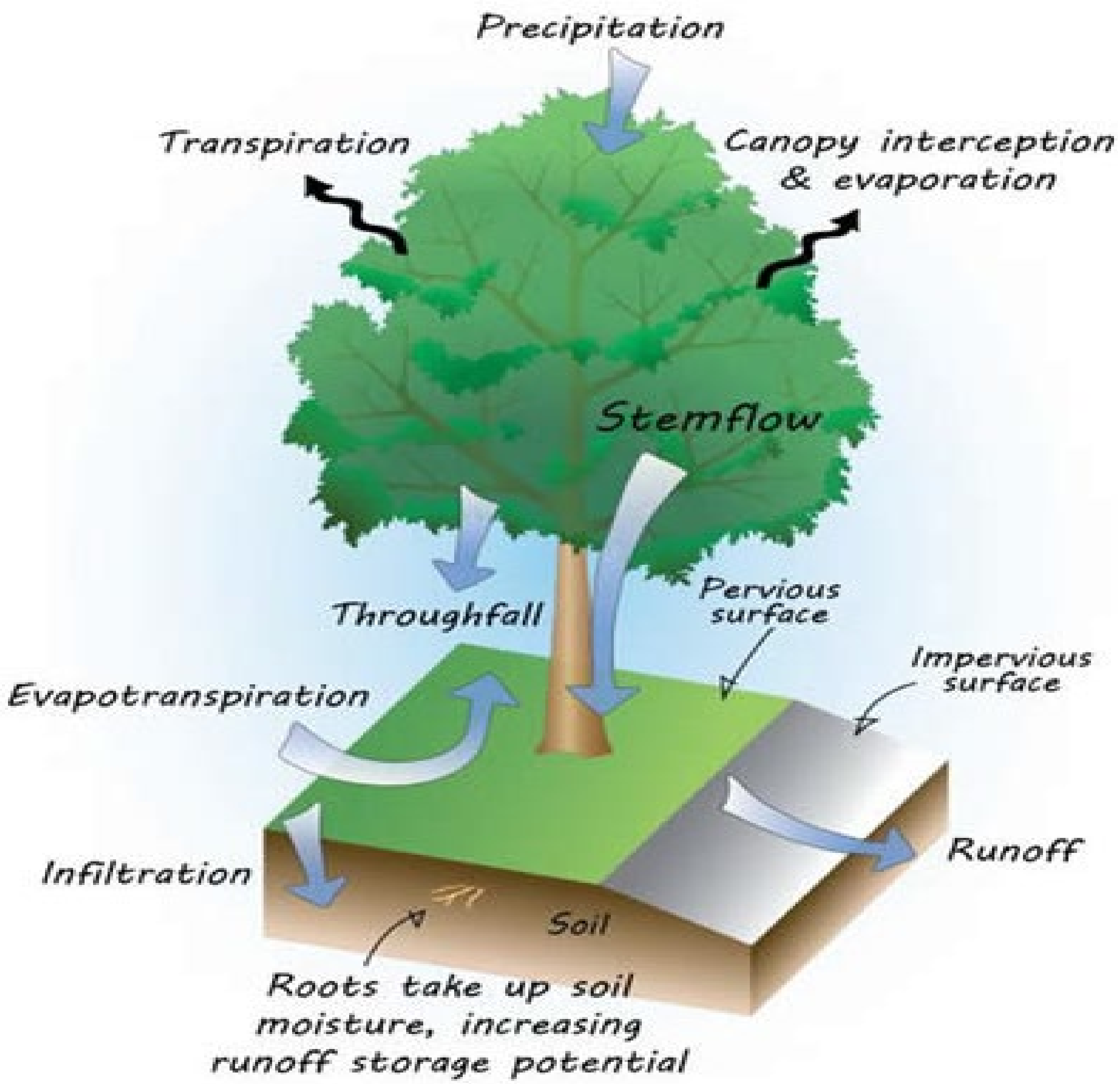
Urban Context and Weather History Iowa

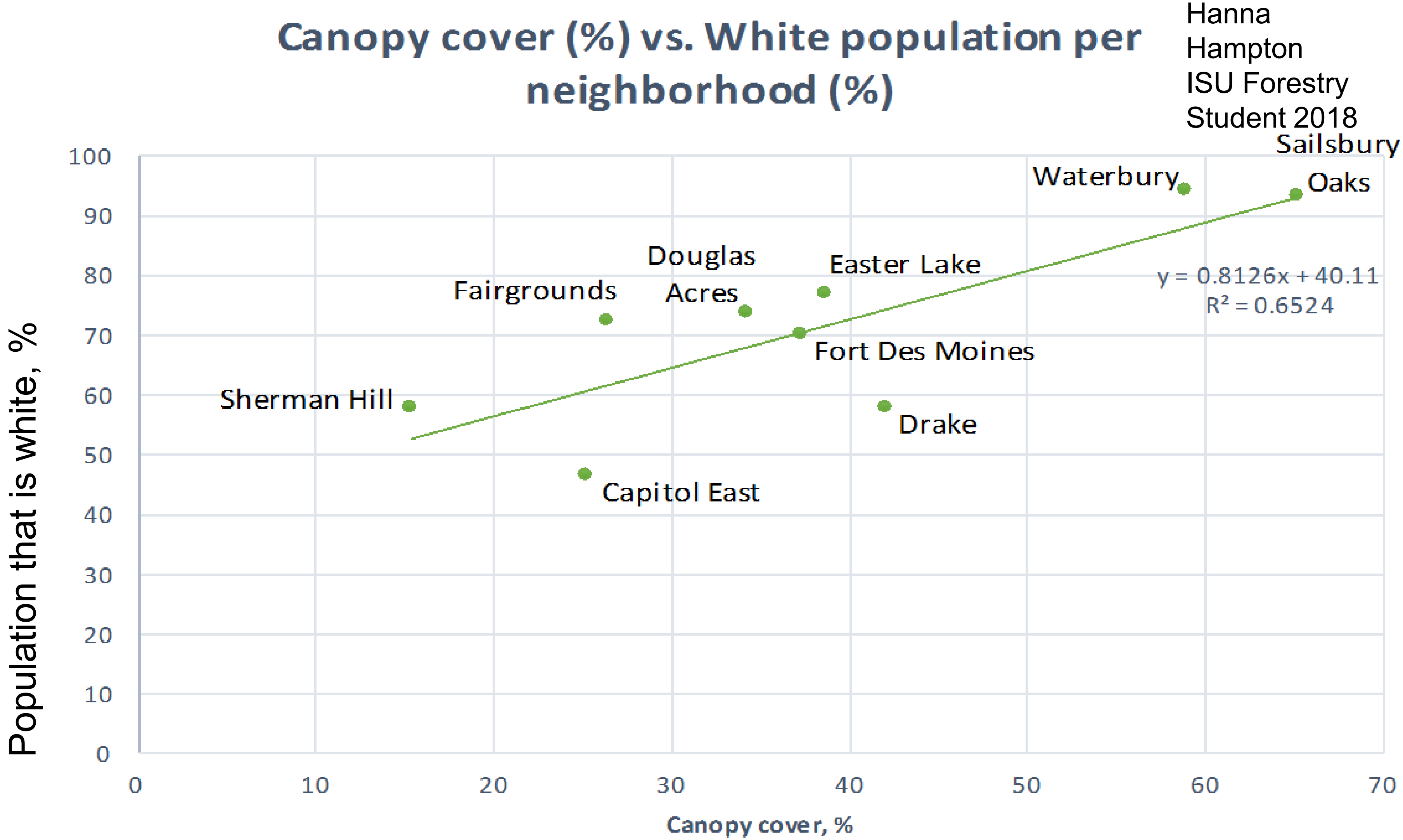


Temperature profiles of three homes during a July 2017 extreme heat event

Stormwater Benefit of Trees

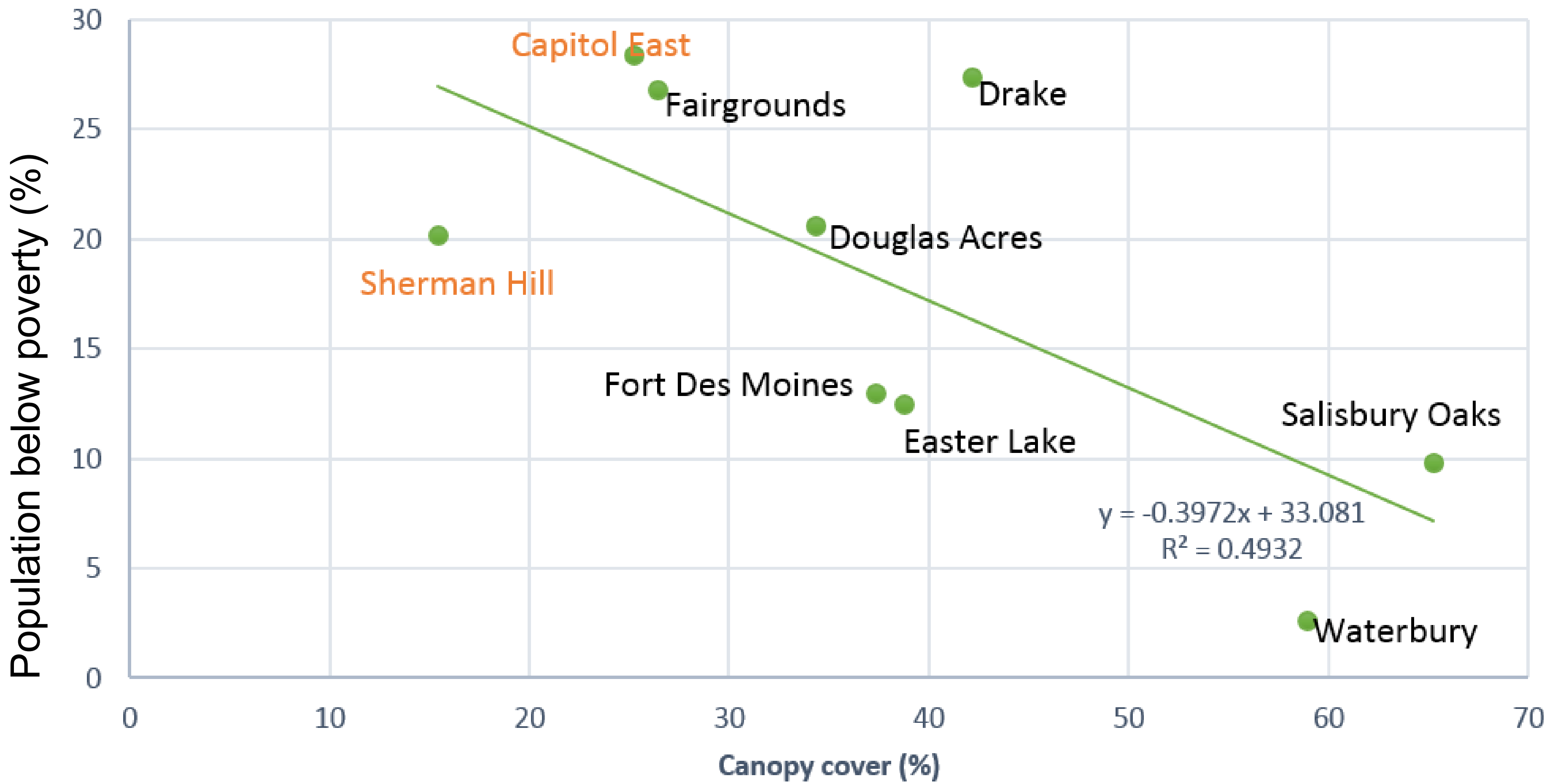
- Intercept rainwater on leaves and branches
- Divert rainwater into soil
- Use rainwater, increasing the runoff storage potential
- Release rainwater back into the atmosphere through transpiration = cool the air





Credit:
Hanna Hampton
ISU Forestry Student 2018

Population below poverty (%) vs. Canopy cover (%)



A comprehensive tree inventory

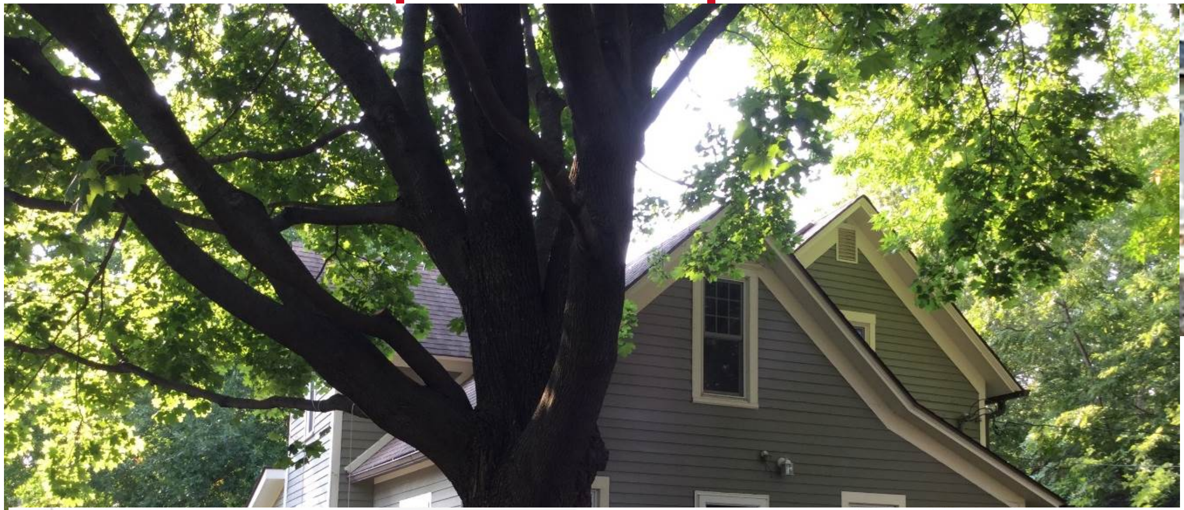
1) More detailed and comprehensive inventory in Capitol East include tree canopy shapes, dimensions and condition ratings for:

- 509 (100%) street trees
- 1141 (~45%) of yard trees (central and northeastern C.E.)

2) Interactions with community

- During inventory activities
- Capitol East Neighborhood National Night Out event - local residents, Park and Recreation personnel and local police

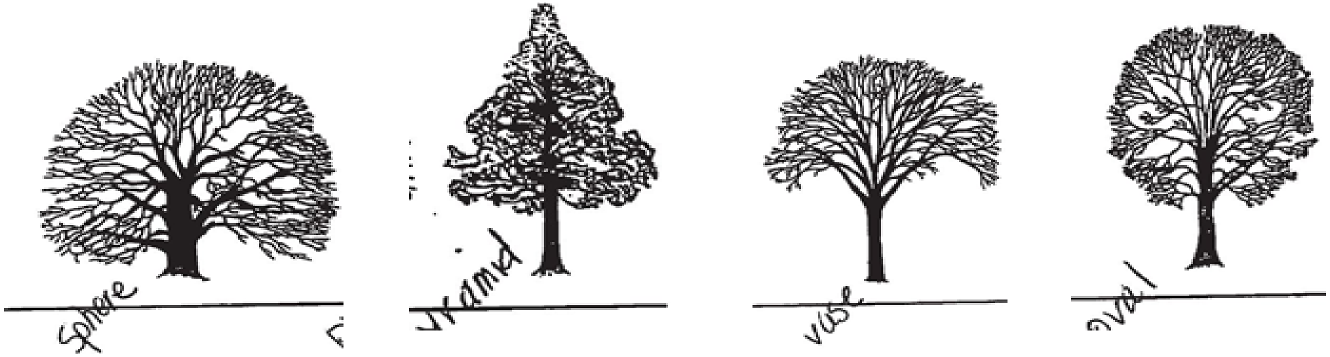
Temperature reduction depends on
....Distance
....Evapotranspiration rate

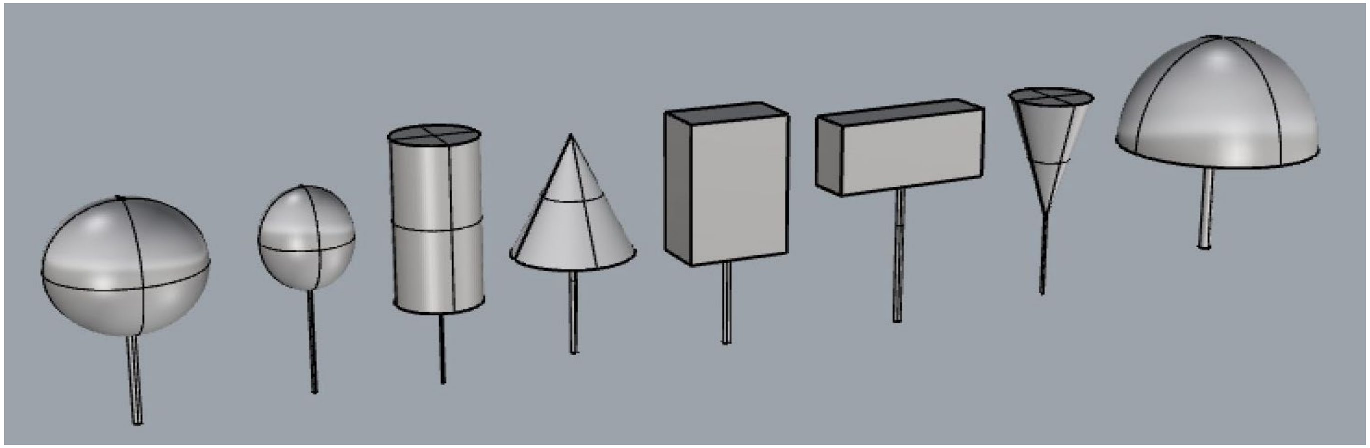


Urban Forestry students conducting inventory supervised by Dr. Janette Thompson and Breanna Marmur

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	New_Tree_ID	Land_Use	Street_Yard	Species	%_Canopy_Filled	Shape_1	DBH (in)	Height_to_top (ft)	Height_to_live_crown (ft)	Canopy_North_South (ft)	Canopy_East_West (ft)	Comments	Latitude	Longitude
2	1001	Residential	Yard	Mulberry spp	60	Umbrella	16	26	8	18	16		41.593210108	-93.590604187
3	1002	Residential	Yard	N. Hackberry	90	Ellipsoid	5	16	1	8	9		41.593210727	-93.590693415
4	1003	Residential	Yard	Silver Maple	65	Paraboloid	25	36.9	12.1	40.2	36.2		41.592823056	-93.590591690
5	1004	Residential	Yard	Mulberry spp	85	Umbrella	13	24.5	7	19	27	12	41.592912068	-93.590616213
6	1005	Residential	Yard	Silver Maple	80	Paraboloid	29.5	63.1	13	41	43		41.592919988	-93.590642176
7	1006	Residential	Yard	Jap. Lilac	90	Umbrella	3	14	1	13	12	2	41.592958102	-93.590709942
8	1007	Residential	Yard	Swamp W. Oak	75	Ellipsoid	14	47.2	16	27	28		41.593006890	-93.590722754
9	1008	Residential	Yard	Siberian Elm	75	Paraboloid	32.5	54.2	20.3	41.3	44		41.593015729	-93.590754270
10	1009	Residential	Yard	Tree of Heaven	80	Umbrella	37	65	13	39	41		41.593134643	-93.590789050

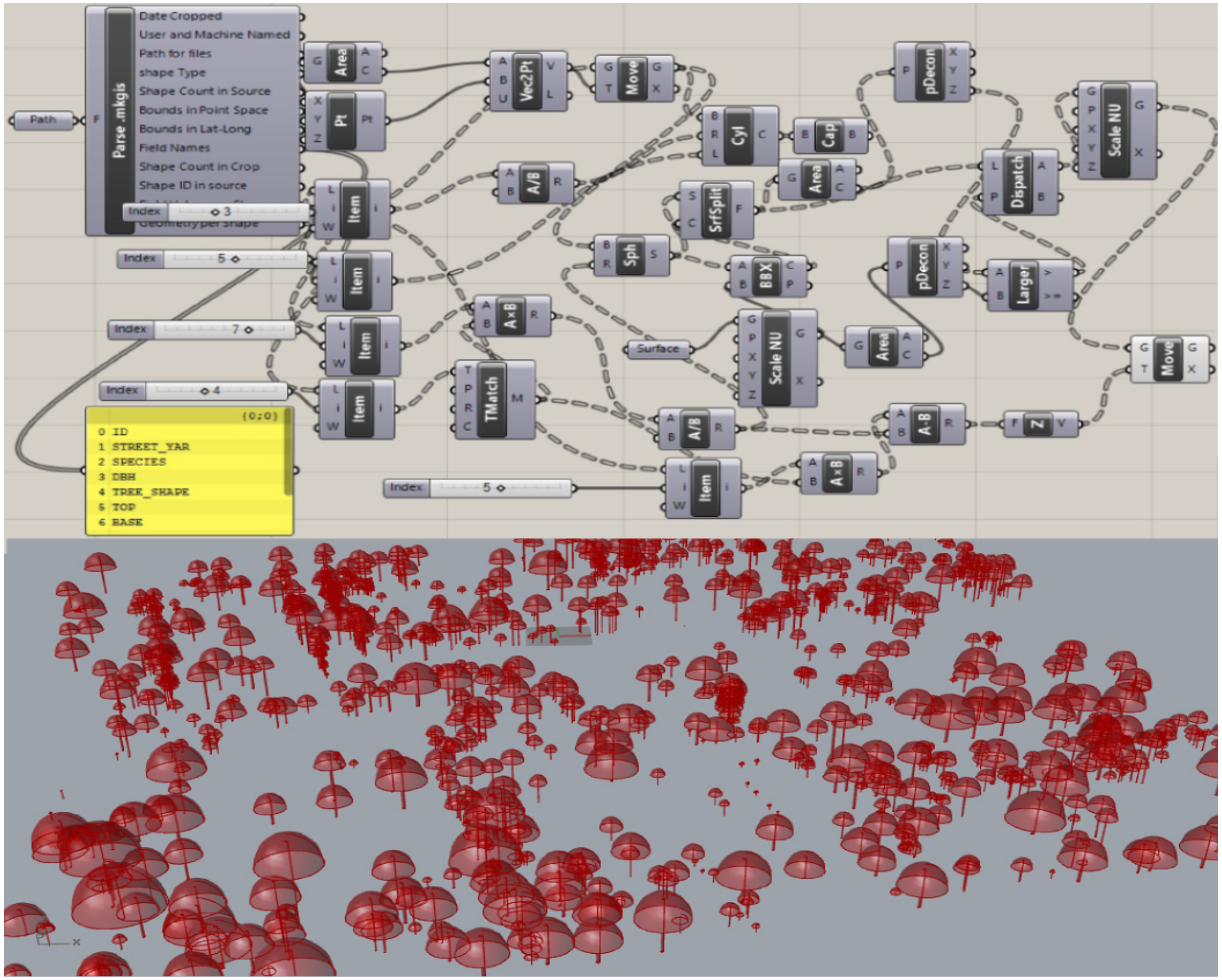
8 Tree shapes



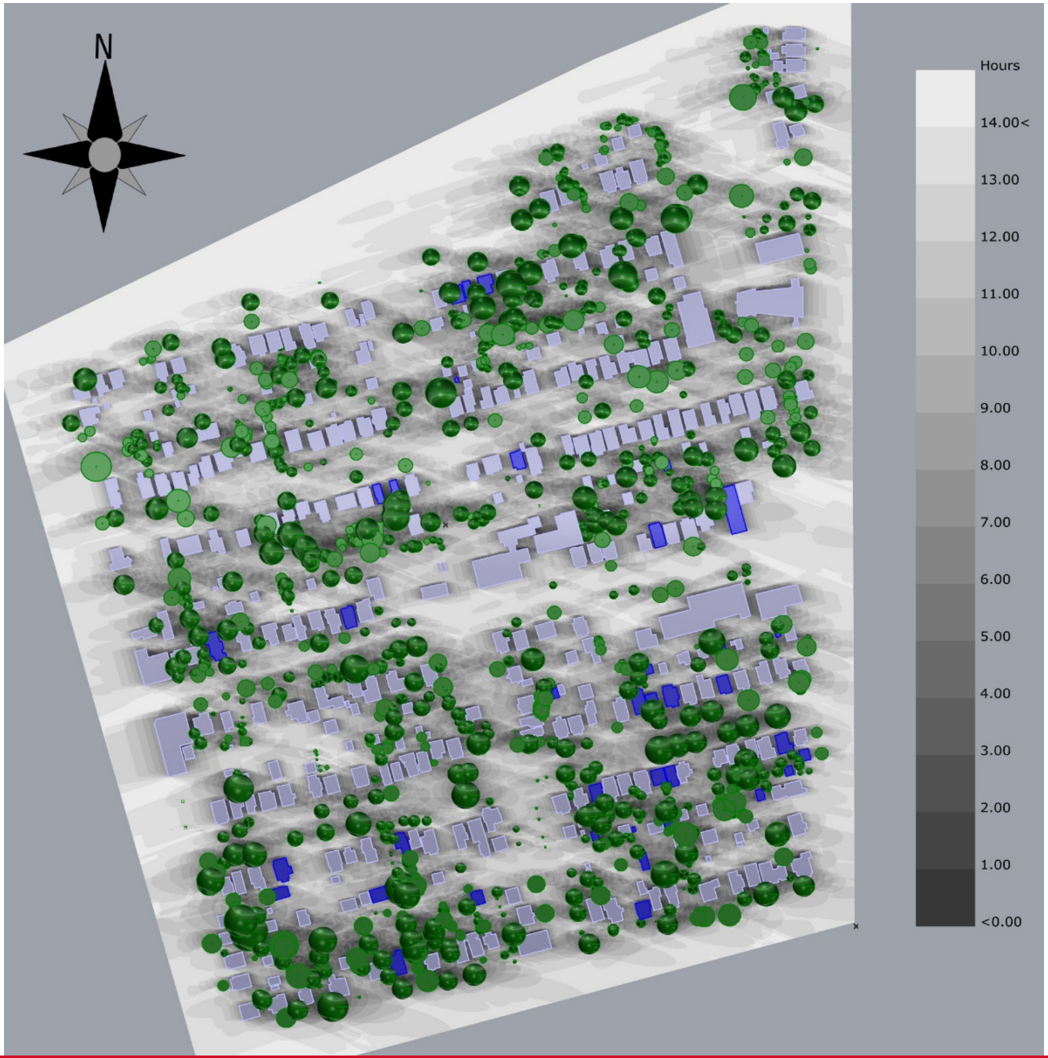


spheres, ellipsoids, cylinders, cones, horizontal rectangular cuboids, vertical rectangular cuboids, umbrella shapes, and paraboloids

Integrating Urban Trees into Energy Models



"Baked" visualization model in Rhinoceros



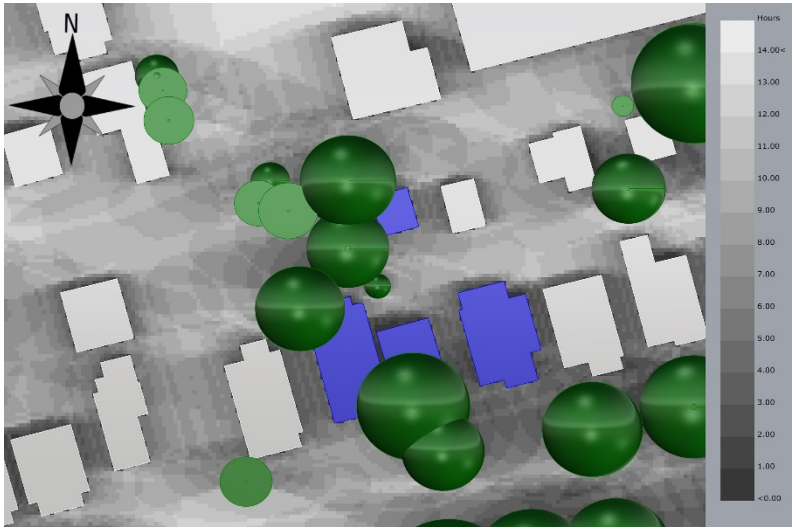
Buildings indicated in blue are those with more than 5% reduction in cooling demand for the scenario with trees.

Umi, Rhino based design environment [*http://www.urbanmodeling.net/*](http://www.urbanmodeling.net/).

Results

- Trees resulted in 1% to 20% potential active cooling energy savings for spring and summer months (May to September).

- There were approximately 40 buildings with potential cooling energy savings more than 5%.



- Nearly all buildings showing substantial differences in cooling demand in the model with trees are well shaded by trees, especially those located south of buildings.

CFD Adaptive Meshing Refinement

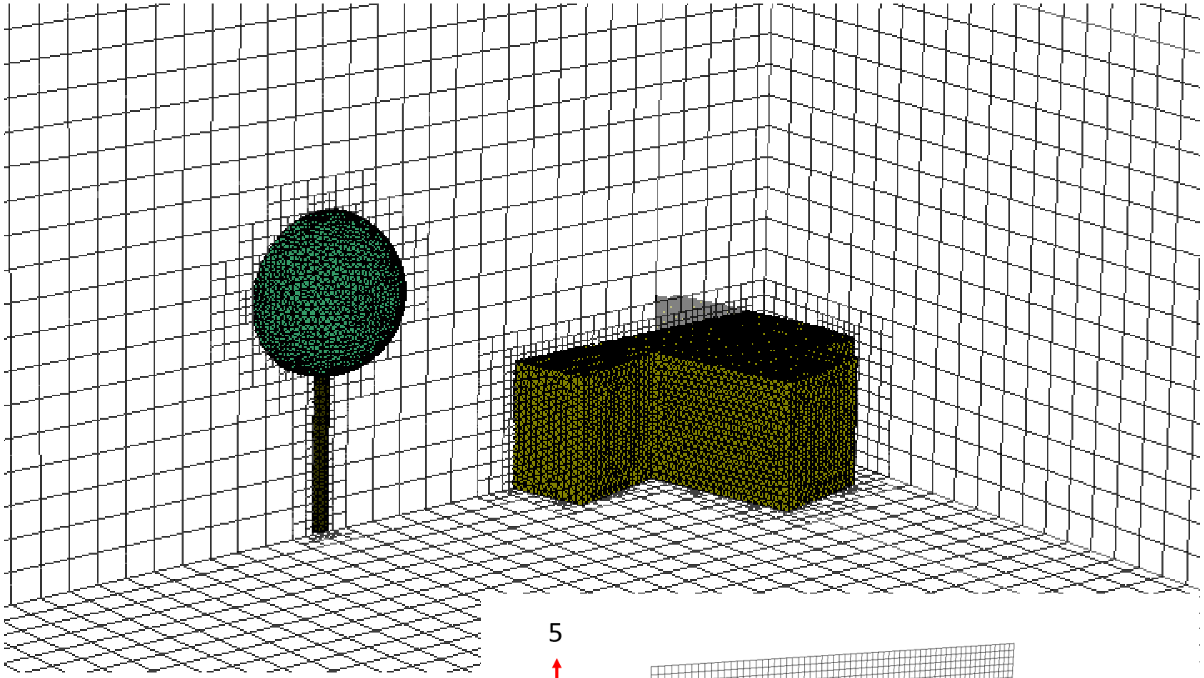
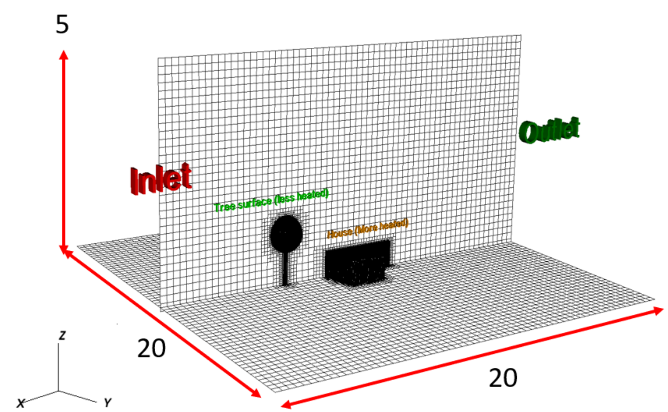


Figure 3. Mesh with adaptive refinement around the interfaces of immersed geometries with enforced 2:1 balancing



Size of tree (trunk height/canopy diameter)		
Small	Medium	Large
1.25/1	1.5/1.25	1.75/1.5
Placement of tree (distance from front of house)		
1.5	2.5	5

Table 4: Size and placement of tree (H is height of house).

Tree size and velocity patterns

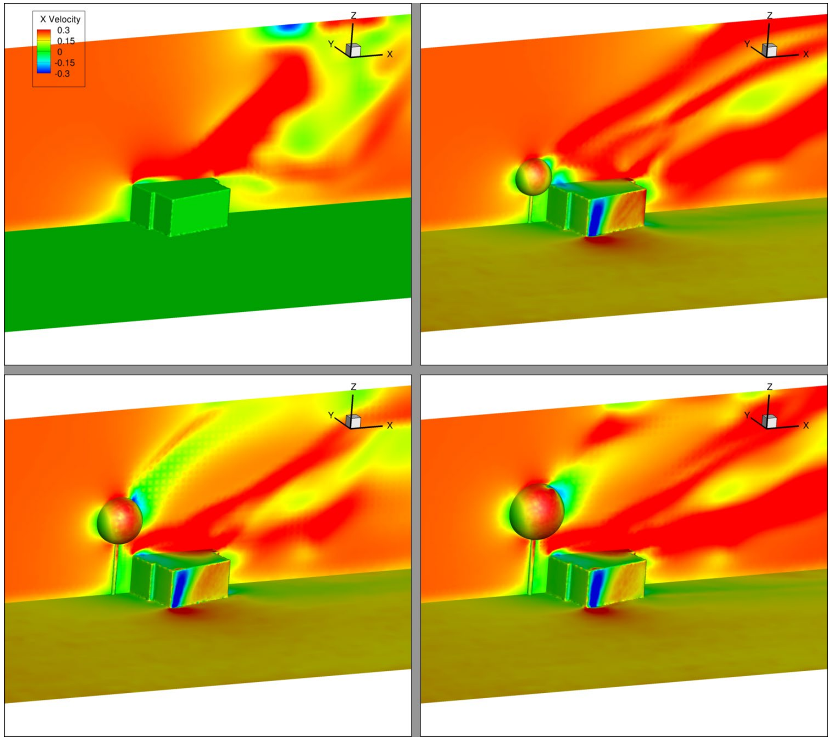


Figure 5. Comparison of x-velocity of house only (top left) and three different size trees close to the house

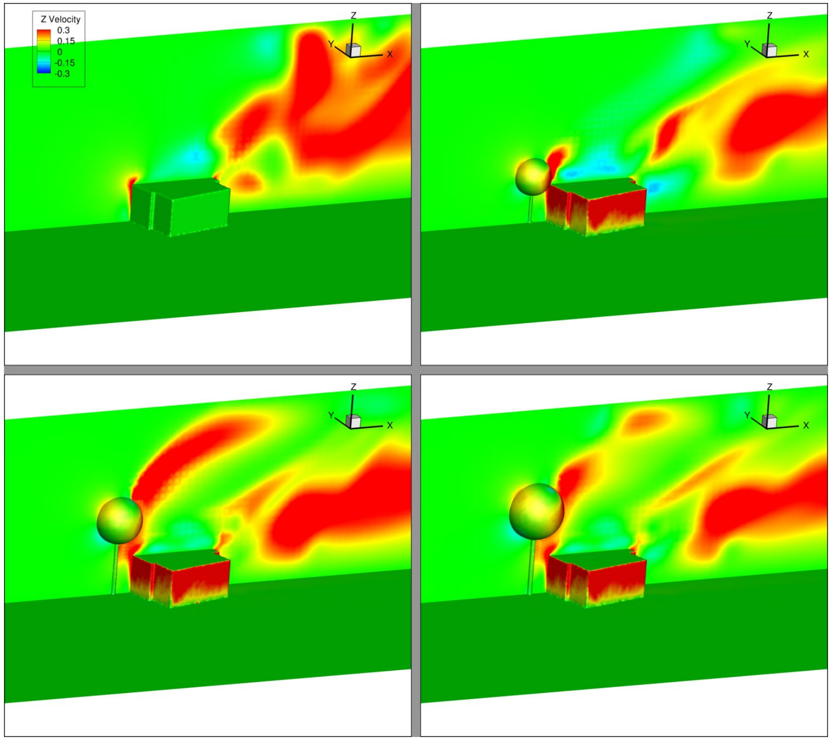


Figure 6. Comparison of z-velocity of house only (top left) and three different size trees close to the house

Evapotranspiration and Leaf Temperature

- Evapotranspiration can help to cool the microclimate around trees
- Leaf temperature (a factor that contributes to ET rate) is generally above ambient due to absorbed solar radiation, and is highly dependent on a wide range of characteristics including species, climate, weather, and solar conditions

Leaf temperature probe used to measure absolute temperature of a leaf. Note: This study relied on previously published leaf temperatures. (Image from www.envoglobal.com.)

Ansari, A., & W. Loomis, 1959. *American Journal of Botany*, 46(10), pp. 713-717.
Vogel, S., 2009. *New Phytologist* 183(1):13-26.

Estimating Tree ET

Species-specific tree evapotranspiration rates are not well studied.

Thus, the FAO Penman-Monteith equation, and FAO ET Calculator were used to estimate tree ET values for proxy species selected from the literature

$$ET = K_c ET_{ref}$$

Empirically derived equation for estimating species evaporation based on the FAO Penmen-Monteith equation reference ET ($ET_{ref\_}$) and a crop coefficient (K_C).

Allen, R., 1998. FAO Irrigation and Drainage Paper 56. Food and Agriculture Organization of the United Nations.
Food and Agriculture Organization (FAO-UN), n.d. FAO ET Calculator. Available at: http://www.fao.org/land-water/databases-and-software/eto-calculator/en/

Estimating Tree ET

ET approximations were made for representative small (crabapple), medium (ornamental pear), and large (American basswood) trees in the spring, summer, and fall.

ET (mm/day) by representative tree species/size			
Season	**Small**	**Medium**	**Large**
Spring	1.6	2.0	4.3
Summer	6.5	7.8	5.9
Fall	4.2	7.5	5.2

ET approximations for representative tree species.

Estimating Leaf Temperature

In hot and humid climates leaf surface temperatures are generally above ambient temperatures due to absorbed solar radiation (Ansari 1959; Vogel 2009).

- Based on published literature and typical weather conditions in Des Moines, leaf temperatures for tree species in the Capitol East neighbourhood were estimated to be:

May	July	September
5°C over ambient	15°C over ambient	10°C over ambient

Ansari, A., & W. Loomis, 1959. *American Journal of Botany*, 46(10), pp. 713-717.
Vogel, S., 2009. *New Phytologist* 183(1):13-26.

Conclusion, Limitations, Outlook

- CFD framework integrating evapotranspiration integrates wholistic impact of tree shading in relation to building characteristics and according to tree size and distance from the home shows distinct patterns for air movement and temperature profiles

- The potential to integrate these specifics into design configurations for this and similar neighbourhoods can provide significant benefit to reduce building interior temperature conditions in situations of extreme heat events. Thus future work in our team will now combine radiation blockage as complement to the CFD simulations.

- Current limitations of the proposed technique are related to the missing validation with actual metered energy consumption data.

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Also thanks to collaborators: Thompson, Marmur, Ganapathysubramanian, Gao, Zhou.

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