Microclimate Effects of Photovoltaic Canopies: Ongoing Research Projects A. Middel^{1,2}, N. J. Selover^{1,2}, N. Chhetri^{1,3}, B. Hagen², B. Mackowski¹, C. J. Sisodiya¹



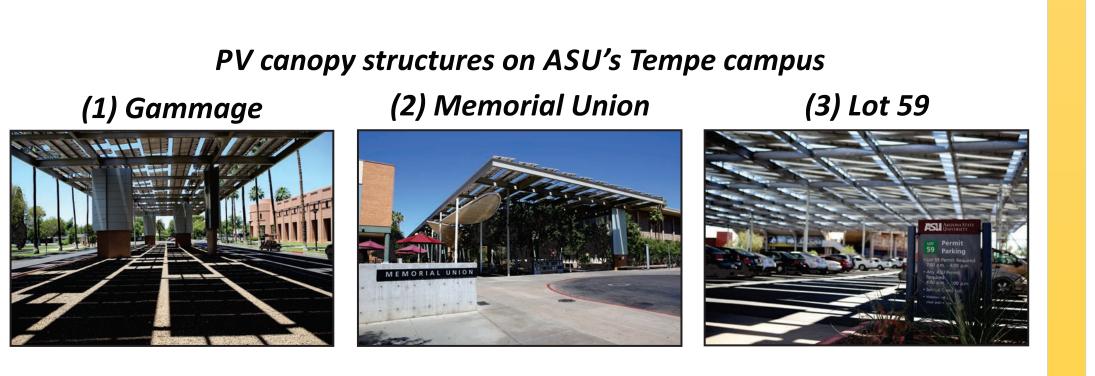
About this Research

- Shade is important for designing comfortable, pedestrian-friendly outdoor spaces in desert urban environments
- To improve pedestrian thermal comfort through shading, Arizona State University (ASU) installed several photovoltaic (PV) canopy structures on its Tempe campus
- ASU's solar panels are 10 m above ground, providing shade to the campus community and generating energy

This suite of research projects investigates the impact of ASU's PV canopies on microclimate and thermal comfort for different seasons and times of day

Microclimate Observations

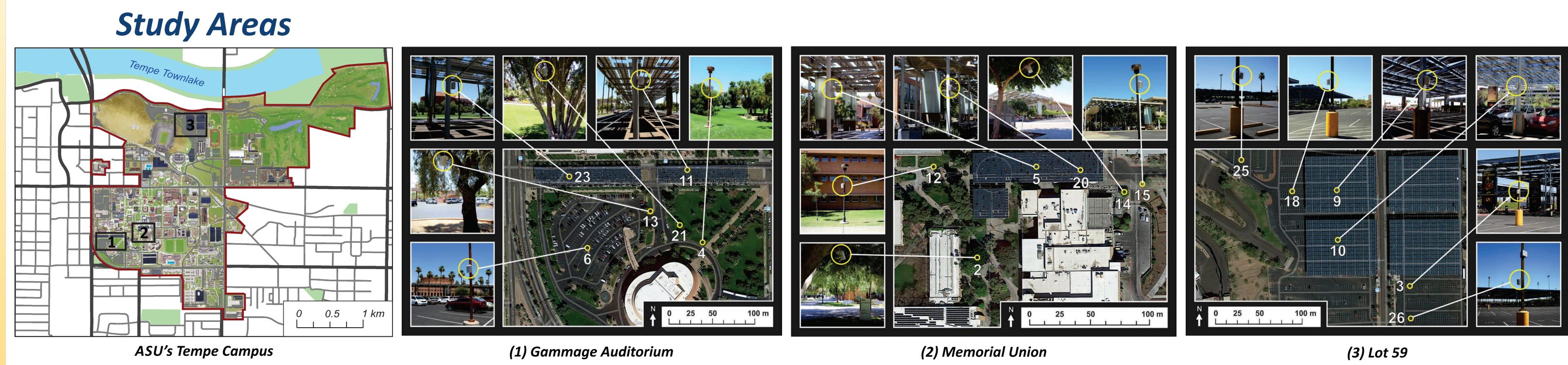
- 18 shielded air temperature/humidity sensors on ASU's campus (see study areas):
 - (1) near the Gammage Auditorium
 - (2) at the Memorial Union
 - (3) on Lot 59
- At each site, two sensors were mounted underneath the PV canopy structure; four sensors were deployed nearby in sun-exposed locations and under tree canopy
- Stationary sensors continuously monitor at five-minute intervals for a full year (start date: June 4, 2014)
- Additional transect observations are conducted on a typical day each season at the Memorial Union, using a Kestrel weather meter, a net radiometer, and a DeltaTRAK infrared gun



Sensor Specifications				
Sensor	Variable(s)	Range	Accuracy	Height
LASCAR electronics EL-USB-2+ (shielded)	temperature	-35° to +80°C	± 0.3°C	2.6 m
	humidity	0% to 100% RH	± 2.0% RH	
Kestrel 4400	temperature	-10° to +55°C	± 0.5°C	1.1 m
	humidity	0% to 100% RH	± 3.0% RH	
	globe temperature	-10° to +55°C	± 1.4°C	
	WBGT	see temperature	± 0.7°C	
	wind speed	0.6 to 60.0 ms ⁻¹	larger of 3% of reading, least significant digit or 20 ft/min	
DeltaTRAK15002	surface temperature	-40° to 510°C	± 2.0°C	1.1 m

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Research Methods

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Project 1: Memorial Union^[1]

Outdoor Thermal Comfort under Photovoltaic Canopy Structures

Research Goals

• Assess outdoor thermal comfort under photovoltaic canopies and in unshaded locations for different times of day during pre-monsoon summer

 Investigate the relationship between measured and perceived comfort

• Explore the determinants of thermal sensation, including non-climatic factors

• Instantaneous measurements under each stationary sensor through mobile transects

- June 10 & 19, 2014, 07:00 AM to 10:00 PM (hourly)
- Air temperature, humidity, wind speed, globe temperature, WBGT (Wet Bulb Globe Temperature), solar radiation, surface temperature

• Survey questionnaire

- Structured interviews, quasi-experimental design (subjects were not completely randomly chosen), transversal (each person only participated once)
- Survey questions covered location and time, general personal information, level of adaptation, thermal comfort, thermal perception, short-term thermal history, perceived control factor, clothing, activity level, and air temperature estimate (shade and sun)

• Thermal comfort modeling

 Physiological Equivalent Temperature (PET) calculations for shaded and unshaded locations using Rayman^{12,3}

Analysis

• Survey responses (thermal sensation votes and perceived comfort) are statistically linked to the observed thermal environment and modeled comfort

• Relative significance of environmental, personal, and psychological factors is investigated

Research Goals

Research Methods

Analysis

- categories

Project 2: Lot 59^[4]

Impact of Solar Shade Structures on Automobile's Interior Temperatures

 Quantify and compare shaded and unshaded vehicle interior air temperatures and temperature changes on hot sunny days

• Simulated one-hour shopping trips on Lot 59 (June 25 - July 11, 2014, 09:00 AM to 05:00 PM)

• Three matched pairs of light-colored vehicles (sedan, van, economy) were parked in the sun and under the PV canopy structure, windows up



• Interior air temperatures were continuously recorded at one-minute intervals, using a LASKAR temperature and humidity sensor

• At the start and end of each "trip", interior air temperature and surface temperatures were recorded (dashboard, steering wheel, seat)

• After one hour, shaded vehicles were moved to the sun; all vehicles were cooled to 85°F interior air temperature or until equilibrium temperature was reached; time required for cooling was recorded

• three vehicles were moved back into the shade, and process was repeated

• Heating and cooling rates of vehicle interior air temperatures for shaded and unshaded parking and different vehicle categories

• Maximum air and surface temperatures (dashboard, steering wheel, seat) inside vehicles after one-hour shopping trip

• T-test to determine differences in mean interior air and surface temperatures for vehicles parked in the sun vs. under the PV canopy structure and for different vehicle

Memorial Union¹⁵¹

Lot 59

summer

Gammage Auditorium, Memorial Union, Lot 59

across seasons



References and Future Presentations

[1] Ariane Middel, Nancy J. Selover, Nalini Chhetri, Björn Hagen, Outdoor Thermal Comfort under Photovoltaic Canopy Structures – A Field Study at Arizona State University. *Sixth Conference on Environment and Health, AMS* conference, Phoenix, Arizona, January 4-8, 2015.

[2] Andreas Matzarakis, Frank Rutz, Helmut Mayer, 2007, Modelling radiation fluxes in simple and complex environments—application of the RayMan model. *International Journal of Biometeorology*, 51(4), 323–334. doi: 10.1007/s00484-006-0061-8

[3] Andreas Matzarakis, Frank Rutz, Helmut Mayer, 2010, Modelling radiation fluxes in simple and complex environments: Basics of the RayMan model. International Journal of Biometeorology, 54(2), 131–139. doi: 10.1007/s00484-009-0261-0

[4] Nancy J. Selover, Ariane Middel, Nalini Chhetri, Ben Mackowski, Chhatrapalsinh Jaydevsinh Sisodiya, Impact of Solar Shade Structures on Automobile's Interior Temperatures. AAG Annual Meeting, Chicago, Illinois, April 21-25, 2015.

[5] Ariane Middel, Nancy J. Selover, Nalini Chhetri, Björn Hagen, Outdoor thermal comfort under photovoltaic canopies – a seasonal field study at Arizona State University, 9th International Conference on Urban Climate *(ICUC9)*, Toulouse, France, July 20-24, 2015.





Future Work

 Seasonal assessment of microclimate and thermal comfort under PV canopies and in sun-exposed locations



• Cooling time for interior temperatures of commercial vehicles (refrigerated trucks and trailers) that are parked in the sun and under PV canopy structures in the

• Intercomparison of diurnal microclimate and Urban Heat Island (UHI) implications at the three study sites

Shaded parking on Lot 59