# Microclimate Effects of Photovoltaic Canopies: Ongoing Research Projects


A. Middel[1,2], N. J. Selover[1,2], N. Chhetri[1,3], B. Hagen[2], B. Mackowski[1], C. J. Sisodiya[1]

[1]Julie Ann Wrigley Global Institute of Sustainability, Arizona State University, PO Box 875402, Tempe AZ 85287-5402
[2]School of Geographical Sciences and Urban Planning, Arizona State University, PO Box 875302, Tempe AZ 85287-5302
[3]Consortium for Science, Policy & Outcomes, Arizona State University, PO Box 875603, Tempe AZ 85287-5603


ASU LightWorks ARIZONA STATE UNIVERSITY
ASU JULIE ANN WRIGLEY GLOBAL INSTITUTE of SUSTAINABILITY ARIZONA STATE UNIVERSITY
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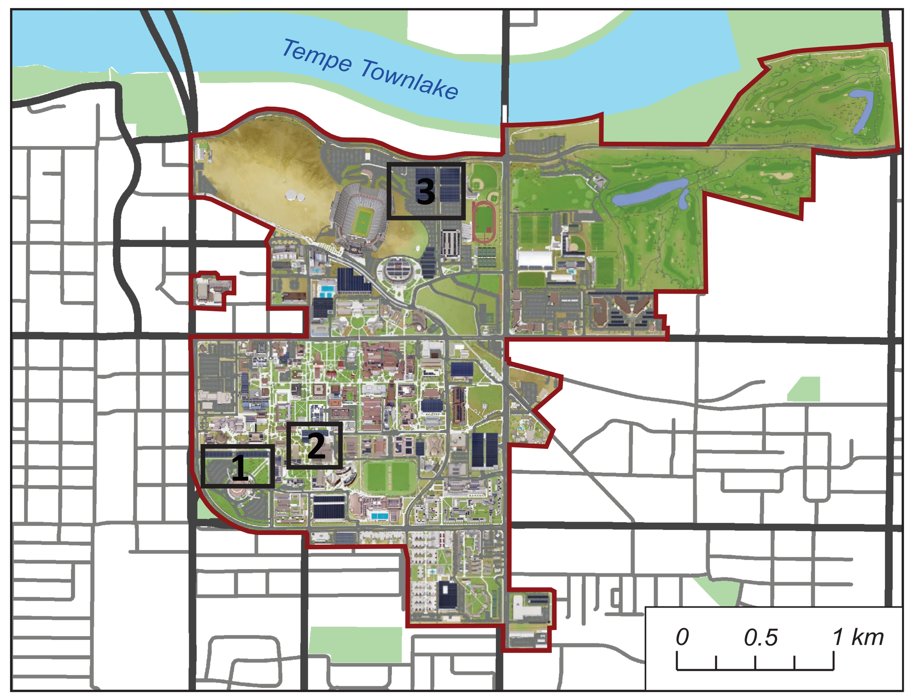
## About this Research

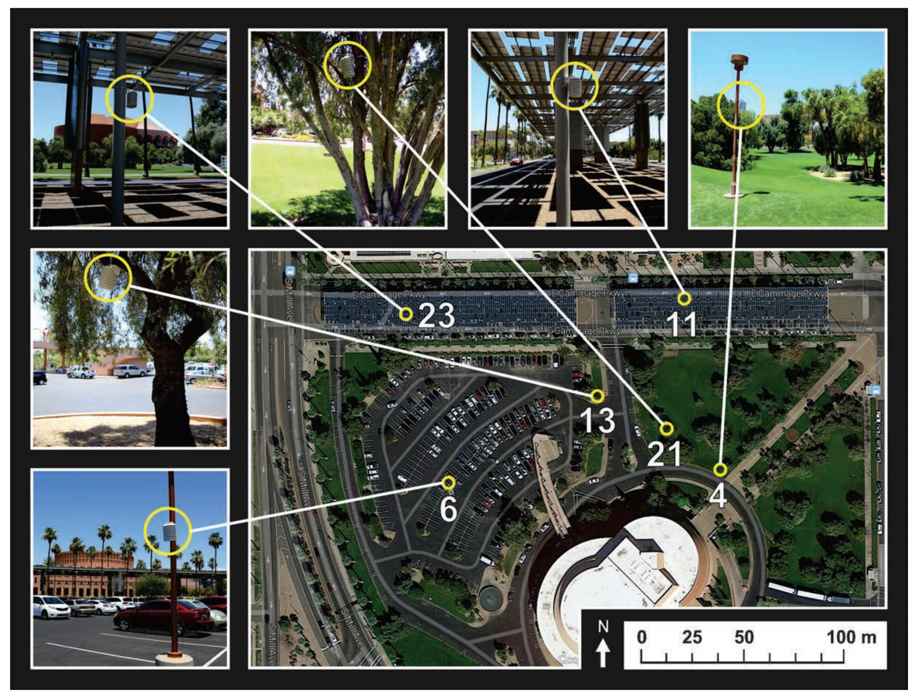
- Shade is important for designing comfortable, pedestrian-friendly outdoor spaces in desert urban environments
- To improve pedestrian thermal comfort through shading, Arizona State University (ASU) installed several photovoltaic (PV) canopy structures on its Tempe campus
- ASU's solar panels are 10 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*

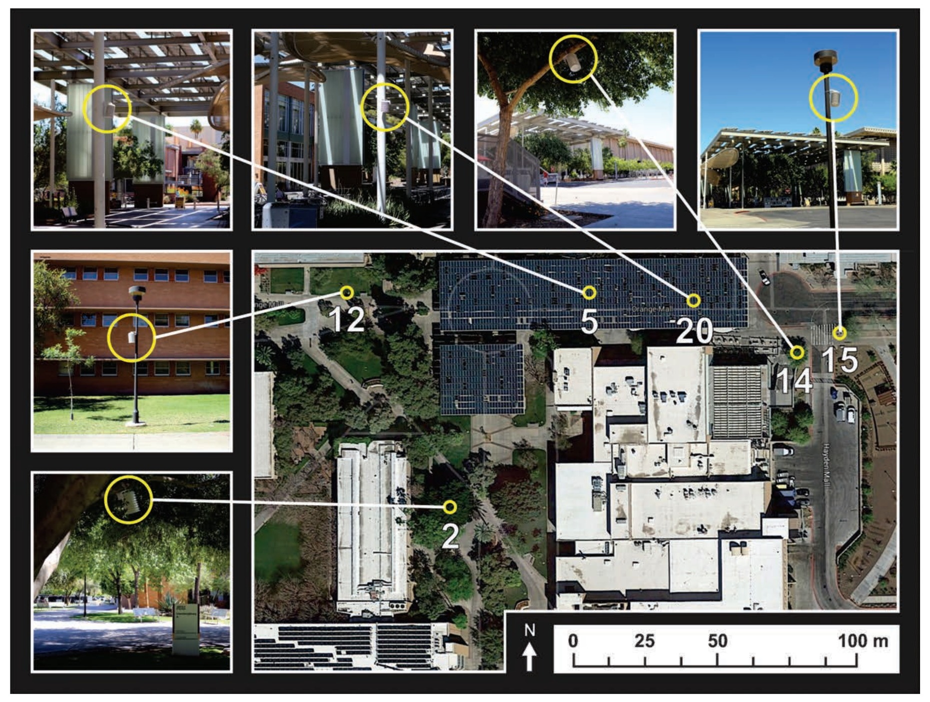
## Study Areas



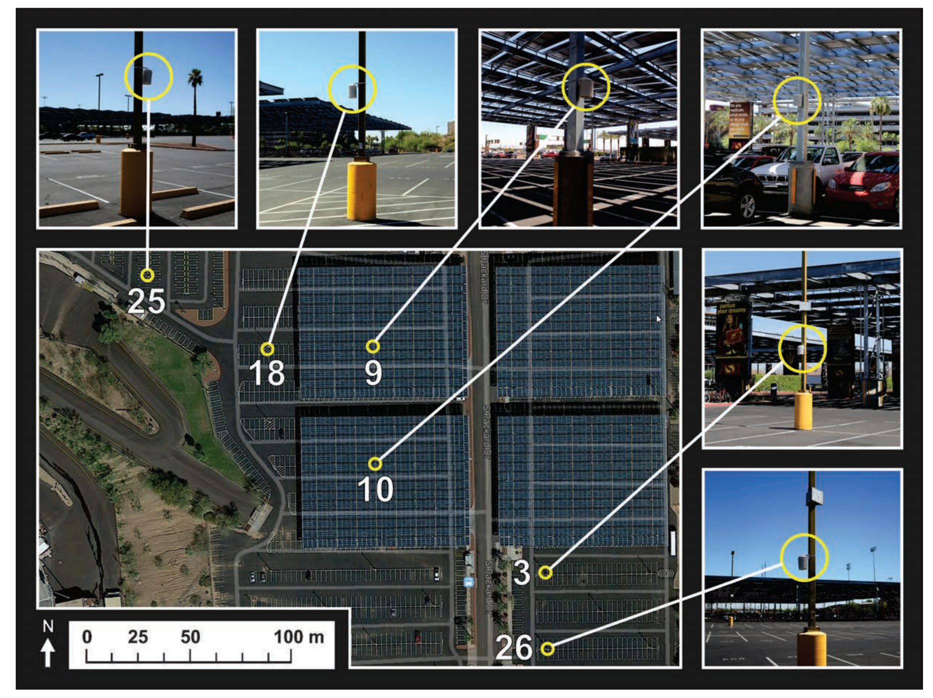

ASU's Tempe Campus




(1) Gammage Auditorium




(2) Memorial Union



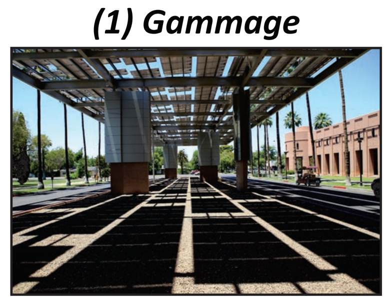

(3) Lot 59

## 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

*PV canopy structures on ASU's Tempe campus*

*(1) Gammage*



*(2) Memorial Union*

*(3) Lot 59*

*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 |


### Acknowledgements

This research was supported by ASU Lightworks, ASU's Wrigley Institute, Strategic Solar Energy LLC, and the Earnhardt car dealership. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the sponsoring agencies.


## 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

### Research Methods

- **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[2,3]

### 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

## Project 2: Lot 59 [4]

*Impact of Solar Shade Structures on Automobile's Interior Temperatures*

### Research Goals

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

### Research Methods

- **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

### Analysis

- 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 categories

## Future Work

### Memorial Union [5]

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

### Lot 59

- 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 summer

### Gammage Auditorium, Memorial Union, Lot 59

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

*Shaded parking on Lot 59*

### 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.