Linking shading patterns of trees in Phoenix, AZ to thermal comfort

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Central Arizona-Phoenix Long-Term Ecological Research CAP LTER

ASU Center for Integrated Solutions to Climate Challenges, Arizona State University

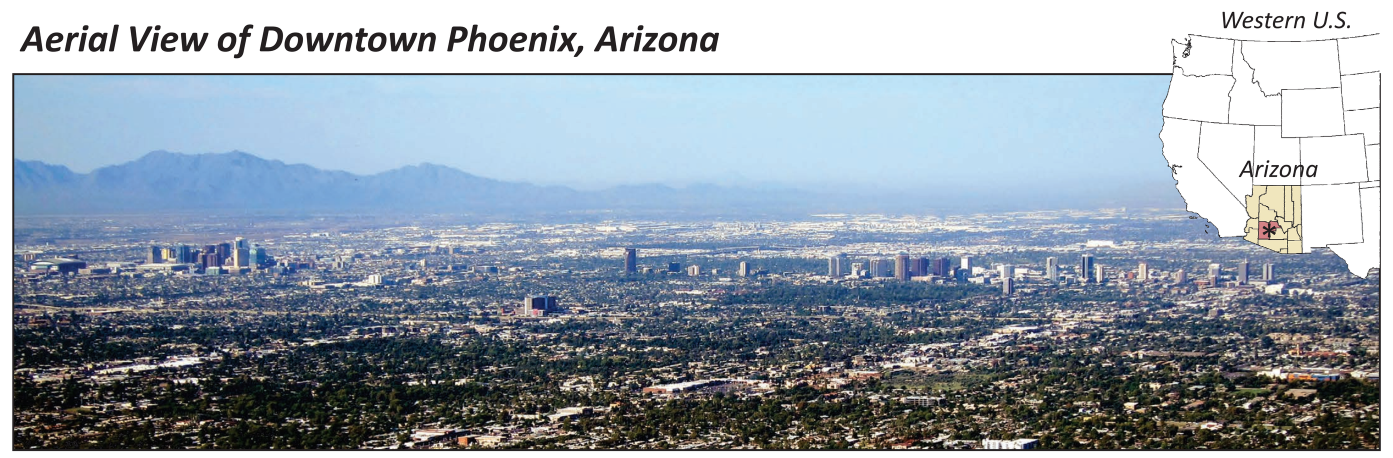
IRTG 1131

ASU Decision Center for a Desert City, Arizona State University

Introduction

- Desert cities experience high daytime air temperatures and increased solar intensity in the summer, decreasing thermal comfort and posing serious health risks to vulnerable populations, especially during heat waves
- Trees play a significant role in reducing surface and ambient temperatures through evaporation and shading, therefore mitigating heat-related health impacts
- Thermal comfort models, e.g., RayMan [1], can help quantify the thermal benefits of trees through calculation of various comfort measures based on in-situ microclimate observations

Aerial View of Downtown Phoenix, Arizona

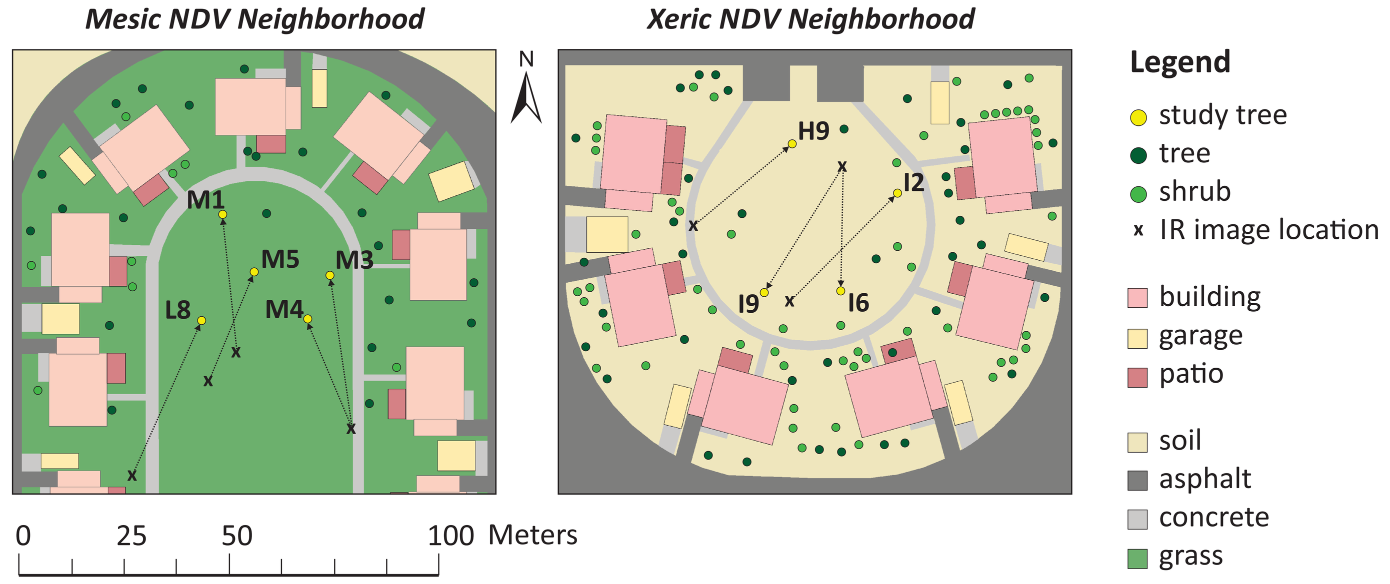


Research Goal

- Assessment of thermal benefits of tree canopy shade in semi-arid Phoenix, AZ, for a typical heat wave day during pre-monsoon summer (June 21, 2012) based on hourly meteorological observations, thermographic images, fisheye photography, and modeling
- Overarching goal: to understand how the physical dynamics of microclimate in desert environments impact thermal comfort and perceptions

Study Site

The Central Arizona-Phoenix Long-Term Ecological Research project's (CAP-LTER) North Desert Village (NDV) landscape experiment at the ASU Polytechnic campus



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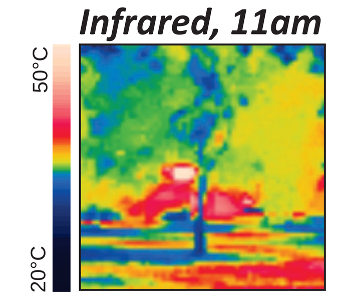
Methodology

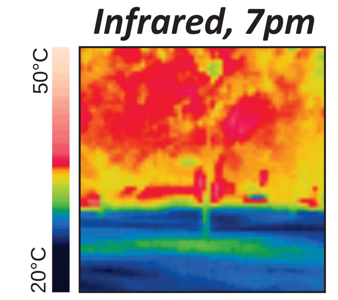
- Hourly surface temperature observations under selected trees in NDV using a FLIR i3 infrared camera (06:00am to 10:00pm on June 21, 2012)
- Correction of thermal images for emissivity
- Sky View Factor (SVF) under each tree determined using fisheye photography
- Extraction of average surface temperature for shaded and non-shaded surfaces with a region-growing algorithm
- Validation of surface temperatures using data from weather stations in the xeric and mesic NDV neighborhoods
- Air temperature correction under trees based on empirical observations
- Calculation of Mean Radiant Temperature (MRT), Physiological Equivalent Temperature (PET), and Universal Thermal Comfort Index (UTCI) with RayMan [1] based on meteorological observations, fisheye photos, and infrared images

Ulmus Parvifolia (Tree ID: L8) photo, 11am

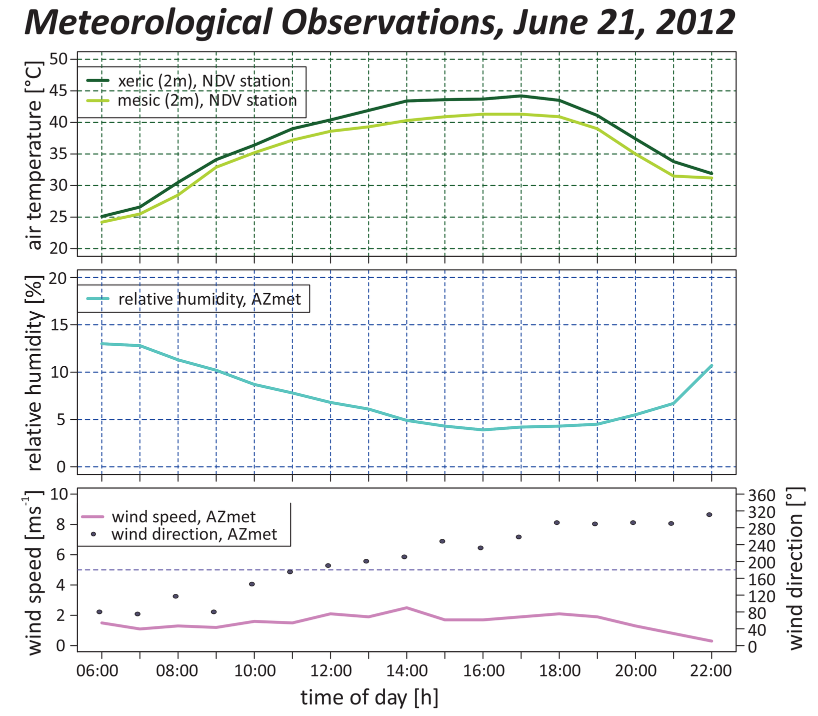
Infrared, 11am



Infrared, 7pm



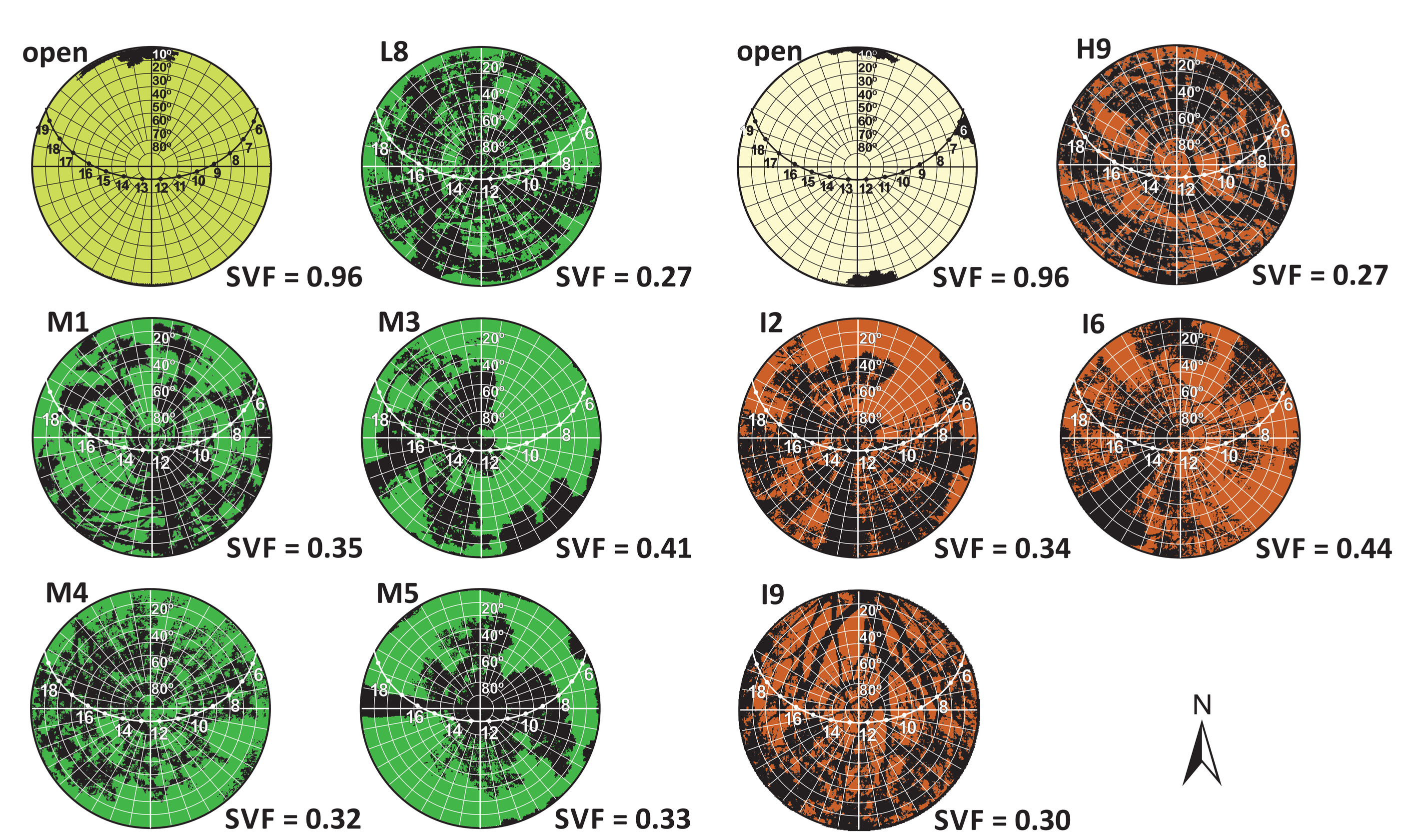
Meteorological Observations, June 21, 2012



Tree Species under Investigation

Tree ID	Species	Mesic	Xeric
L8	Ulmus parvifolia	x	
M1	Pinus eldarica	x	
M3	Brachychiton populneus	x	
M4	Ulmus parvifolia	x	
M5	Pistacia chinensis	x	
H9	Parkinsonia florida		x
I2	Eucalyptus microtheca		x
I6	Eucalyptus microtheca		x
I9	Parkinsonia florida		x

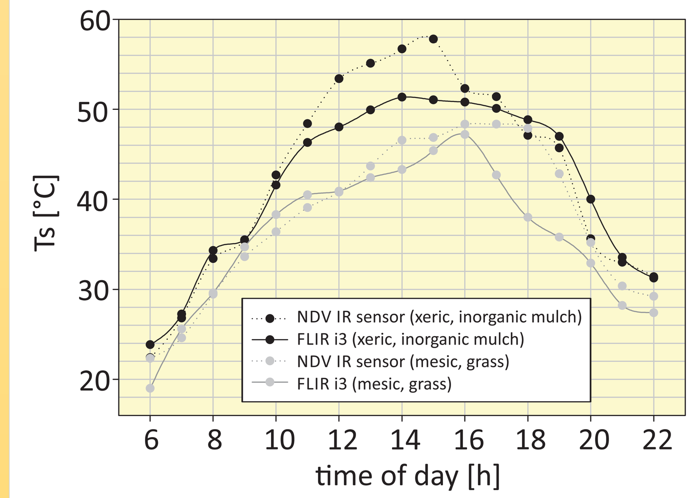
180° Fisheye Photos, Sun Orbit (June 21, 2012), and Skyview Factor (SVF) of Select Trees in the NDV



Results

Surface Temperature Validation

(observed surface temperatures from the FLIR i3 camera vs. NDV IRR-PN infrared radiometer sensors)

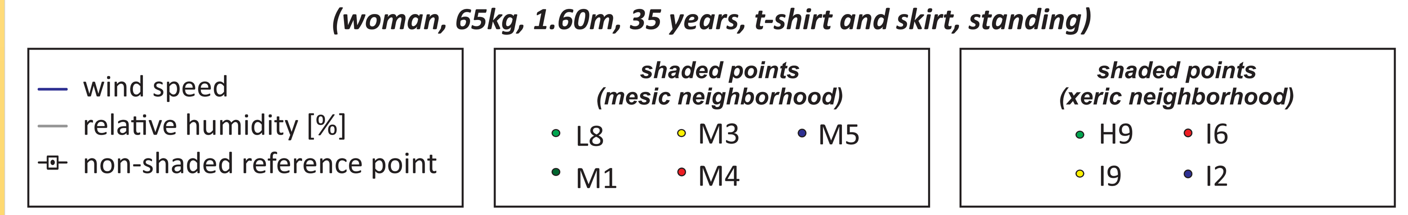


mesic		xeric	
MBE*	-1.9	MBE*	1.0
RMSE**	3.6	RMSE**	3.1
MAE***	2.6	MAE***	2.3
d****	0.95	d****	0.97
MSE***** (systematic)	4.1	MSE***** (systematic)	3.9
MSE (unsystematic)	25.8	MSE (unsystematic)	21.6
RMSE (systematic)	2.0	RMSE (systematic)	1.9
RMSE (unsystematic)	5.0	RMSE (unsystematic)	4.6

* Mean Bias Error
** Root Mean Square Error
***Mean Absolute Error
**** Index of Agreement
***** Mean Square Error

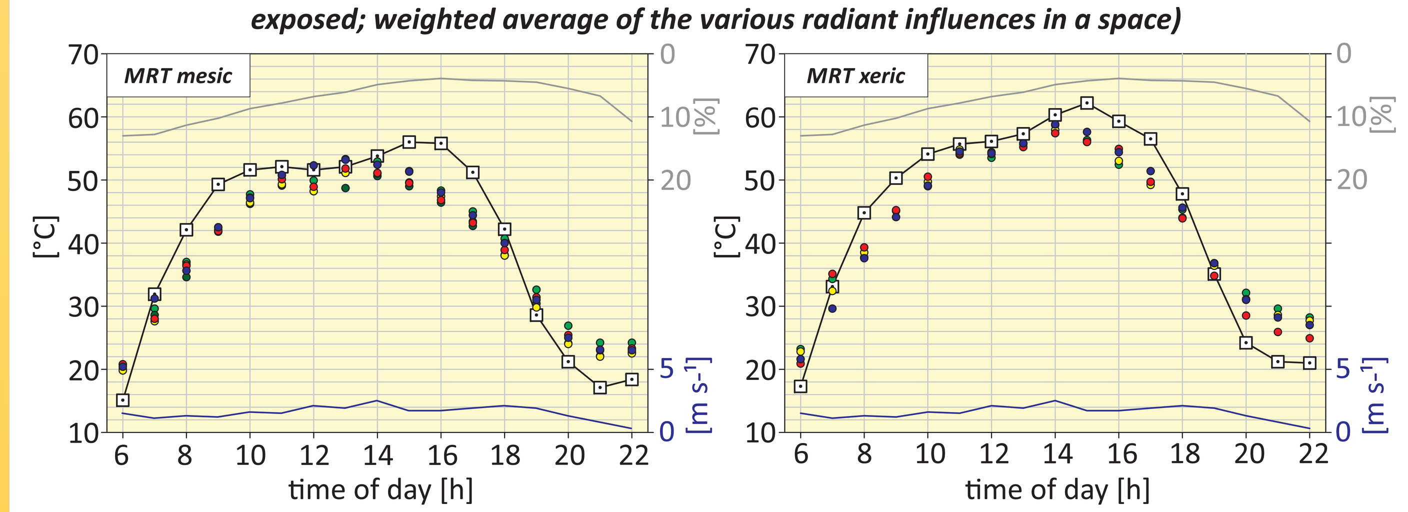
RayMan Output: Thermal Comfort Measures

(woman, 65kg, 1.60m, 35 years, t-shirt and skirt, standing)



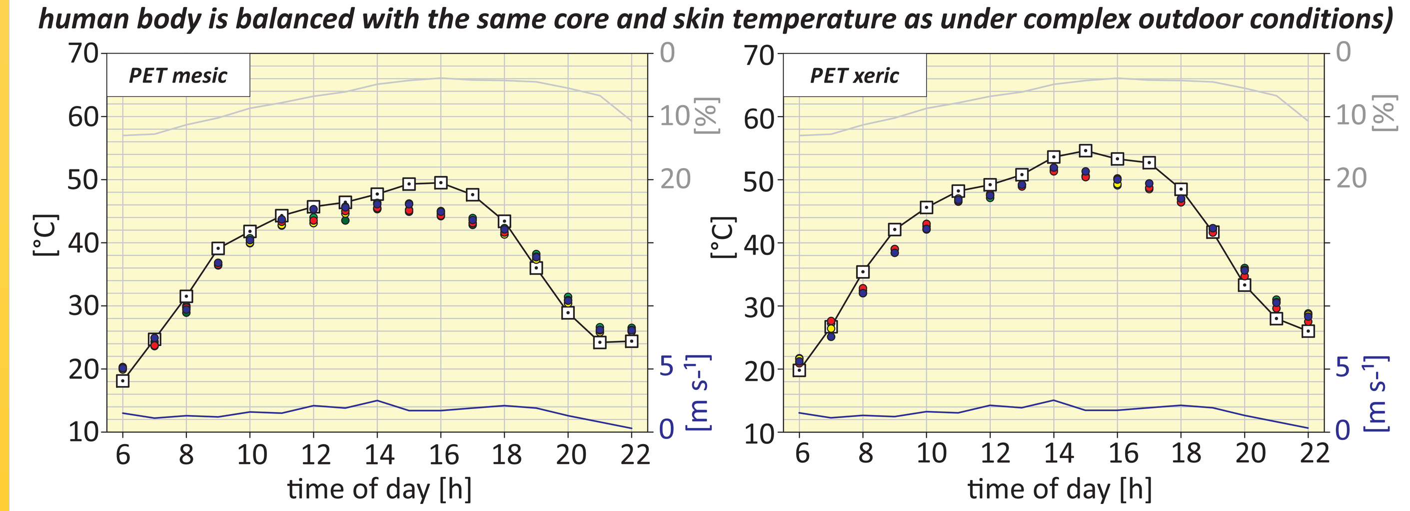
MRT

(the sum of all short- and longwave radiation, both direct and reflected, to which the human body is exposed; weighted average of the various radiant influences in a space)



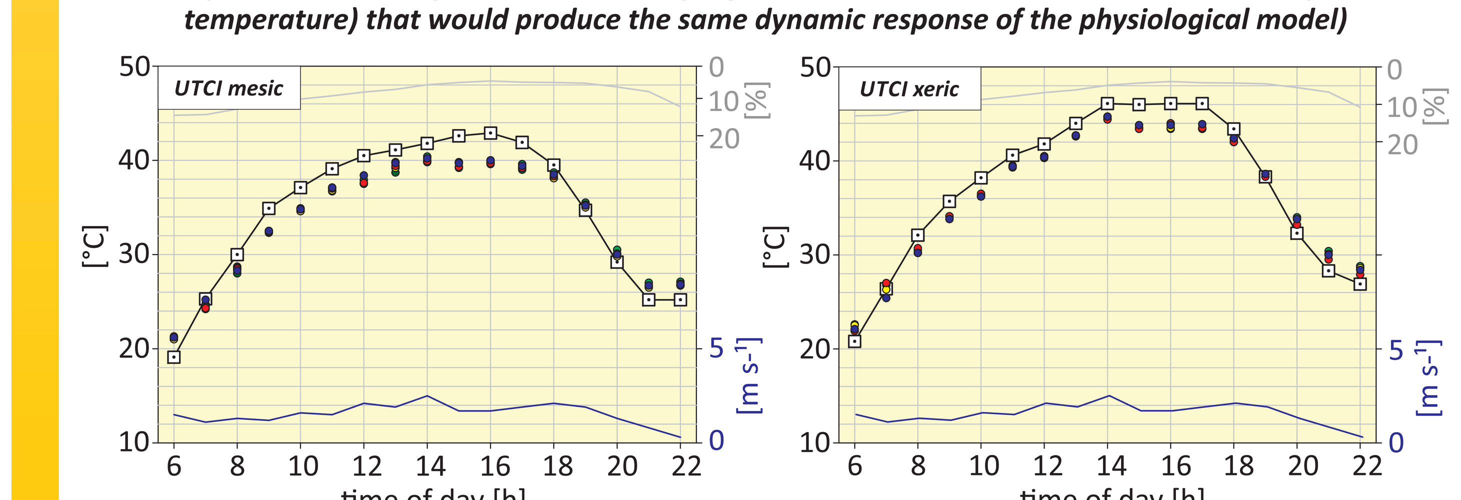
PET

(air temperature at which, in an indoor setting without wind and solar radiation, the heat budget of the human body is balanced with the same core and skin temperature as under complex outdoor conditions)



UTCI

(air temperature in the reference condition of a given microclimate (wind, radiation, humidity, and air temperature) that would produce the same dynamic response of the physiological model)



Key Findings

- Overall, the microclimate in the mesic neigborhood was more comfortable than in the xeric area, both under tree canopies and in the open
- Daytime surface temperatures of inorganic mulch were higher by at least 5 °C, even under tree canopy, than temperatures of sun-exposed grass
- Before sunrise and after sunset, surface temperatures were higher under the tree canopy than in the open, indicating that the canopies function as a trap for outgoing longwave radiation, retaining heat over both surface types on the order of 1-2 °C PET; these findings confirm the results of a previous study by Golden et al. [2] on the thermal impacts of canopies on pavement surface temperatures in Phoenix
- PET values exceeded 40 °C for 9 consecutive hours (10:00 am – 06:00 pm) on shaded grass and 11 hours (09:00 am – 07:00 pm) on shaded inorganic mulch
- In the afternoon, under-canopy PET levels were lower by up to 6 °C in the mesic area and up to 4 °C in the xeric neighborhood compared to non-shaded sites. Studies in Germany [3,4] and Tel Aviv [5] found up to 10 °C differences for similar settings, which suggests that the thermal benefit of trees in arid climates is less pronounced than in more temperate, humid regions

Merit

A comprehensive understanding of thermal comfort benefits of trees in semi-arid environments will

- help urban planners to design more comfortable and sustainable cities
- foster the development of science-based adaptation solutions to urban climate challenges in desert cities

Future Work

- Quantify the thermal benefits of shade from trees in relation to tree species, maturity/size of trees, and leaf area density
- Investigate thermal comfort benefit of trees for various tree spacing and clustering scenarios
- Seasonal assessment of tree canopy shade benefits
- Analysis of thermal comfort under trees and engineered canopy in comparison to non-shaded landcovers using a matrix of various land cover types (grass, inorganic mulch, asphalt, concrete, sand, etc.)
- Trade-off analysis for comfort benefit of tree canopy shade and water use

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