The Influence of Vegetation and Built Environments on Midday Summer Thermal Comfort

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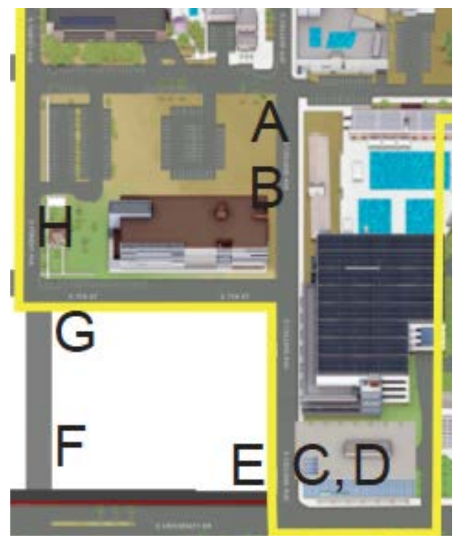
Background

- Increasing thermal comfort can increase walkability, which in turn can increase pedestrian activity and potentially take cars off the road.
- Uncomfortably hot Phoenix summers: over the 1981-2010 period in Tempe, average high temperatures in July peak at 41ºC, falling in September to 38ºC[1], the month of study.
- Weather station KAZTEMPE48, 0.8 miles south of the study area, recorded daily temperatures plateauing between roughly noon and 5pm every day in 2015[1].
- This study will inform efforts to mitigate thermal discomfort.

Research Questions

- **How does shade from vegetation alleviate midday thermal discomfort during Phoenix summers?**
- **How does the built environment, represented by the Sky View Factor, impact thermal comfort?**

Data Collection



Site Locations:

- Nine sites, labelled A, B, C, D, E, F, G, H, I
- located on the north side of ASU campus, Tempe, Arizona. *See left.*
- All sites are located on sidewalks within an area 300 meters by 150 meters. *See left.*

Data Collection:

- September 2015: 18, 19, 20, 23, 24, 25, 27, 29
- Used Kestrel 4400 meter at a height between 1.0m and 1.2m. *See left.*
- Collected air temperature (Ta), wet bulb globe temperature (WBGT), globe temperature (GT), humidity, and wind speed measurements. For data *see Results 1.*
- One collection per site, 2:30pm - 4:15pm, during the period of peak heat or "midday"
- 180° fish eye photos used to calculate Sky View Factor (SVF). *See right.*

Site **A**
Sunny at midday
SVF: 0.950

Site **B**
Sunny at midday
SVF: 0.769

Site **C**
Sunny at midday
SVF: 0.233

Site **D**
Shady at midday
SVF: 0.127

Site **E**
Shady at midday
SVF: 0.184

Site **F**
Sunny at midday
SVF: 0.630

Site **G**
Sunny at midday
SVF: 0.456

Site **H**
Shady at midday
SVF: 0.077

Site **I**
Sunny at midday
SVF: 0.208

Thermal Comfort Indices

- Mean radiant temperature (MRT) measures the heat effect of the radiation flux densities absorbed by people, and is considered the most important parameter used to measure the human energy balance during the summer seasons[2].
- MRT is a function of air temperature, globe temperature, & wind speed.
- The index Physiological Equivalent Temperature (PET) at any location is defined as the indoor air temperature that would cause the same core and skin temperatures of a human at standard conditions as the conditions at that location[3].
- Air temperature, relative humidity, vapor pressure, wind speed and estimated MRT can be entered into the RayMan model to get the PET, from which the average PET for all the days can be calculated.

Results

1) Statistical descriptives of mean physical measurement values.

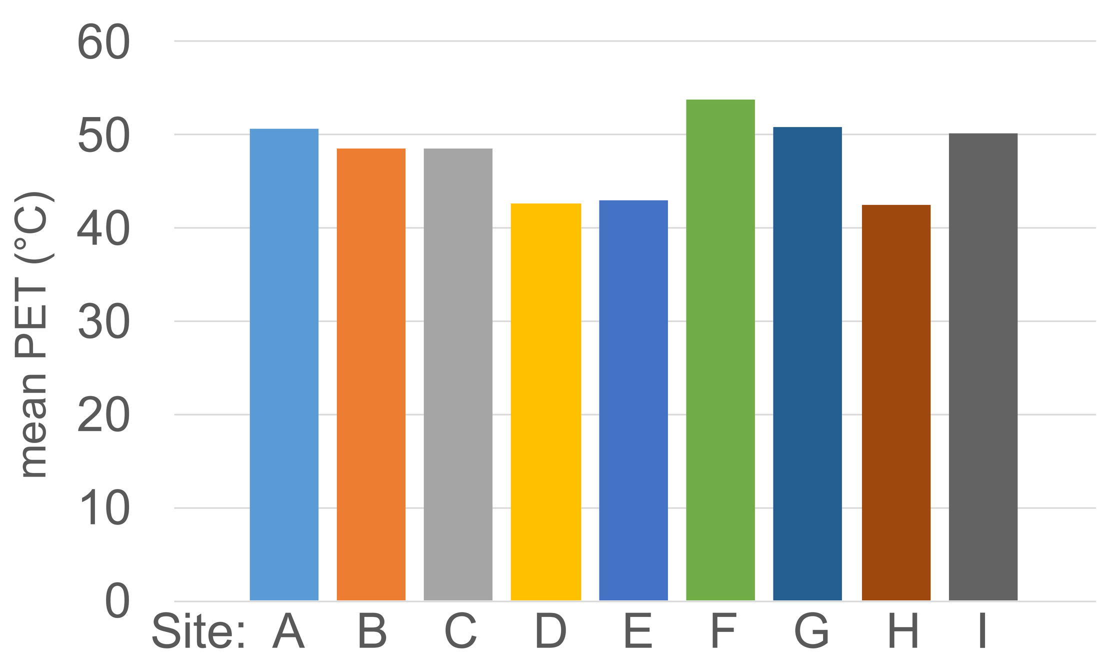
	Mean	Min	Max	σ
Temperature (°C)	39.0	37.5	41.5	1.4
WBGT (°C)	29.8	27.4	32.0	1.6
Globe Temp. (°C)	46.7	41.6	52.2	3.9
Relative Humidity (%)	19.7	16.8	21.3	1.4
Dew Point (°C)	12.7	11.9	13.6	0.6
Wind Speed (m/s)	0.6	0.4	0.9	0.2

This table, particularly the mean temperature 39°C (102°F), highlights the uncomfortable quality of these September summer conditions.

2) a. Framing PET

The most widely used PET evaluation scale, developed by Matzarakis and Mayer[4] in Germany, classifies any PET value over 41°C as "very hot." **All mean PET values in this study exceed 41°C.**

2) Mean PET values at each site (observed)



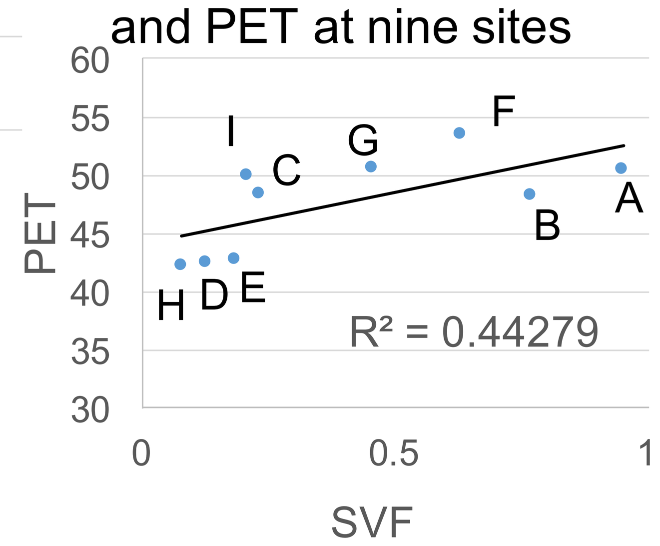
- Sites D, E, and H were shaded by trees, esp. H
- Sites C and I were under trees but exposed to sun
- Sites A, B, F, and G were not near trees

The maximum recorded PET value was taken at site I, on September 20: it was 62.9°C (145°F).

2) c. Comparing SVF to PET values

In the plot below Sky View Factor shows reliability as a predictor of PET. Note that the three shaded sites, D, E, and H, form a group, which suggests SVF could follow sun/shading at midday.

Correlation between SVF and PET at nine sites



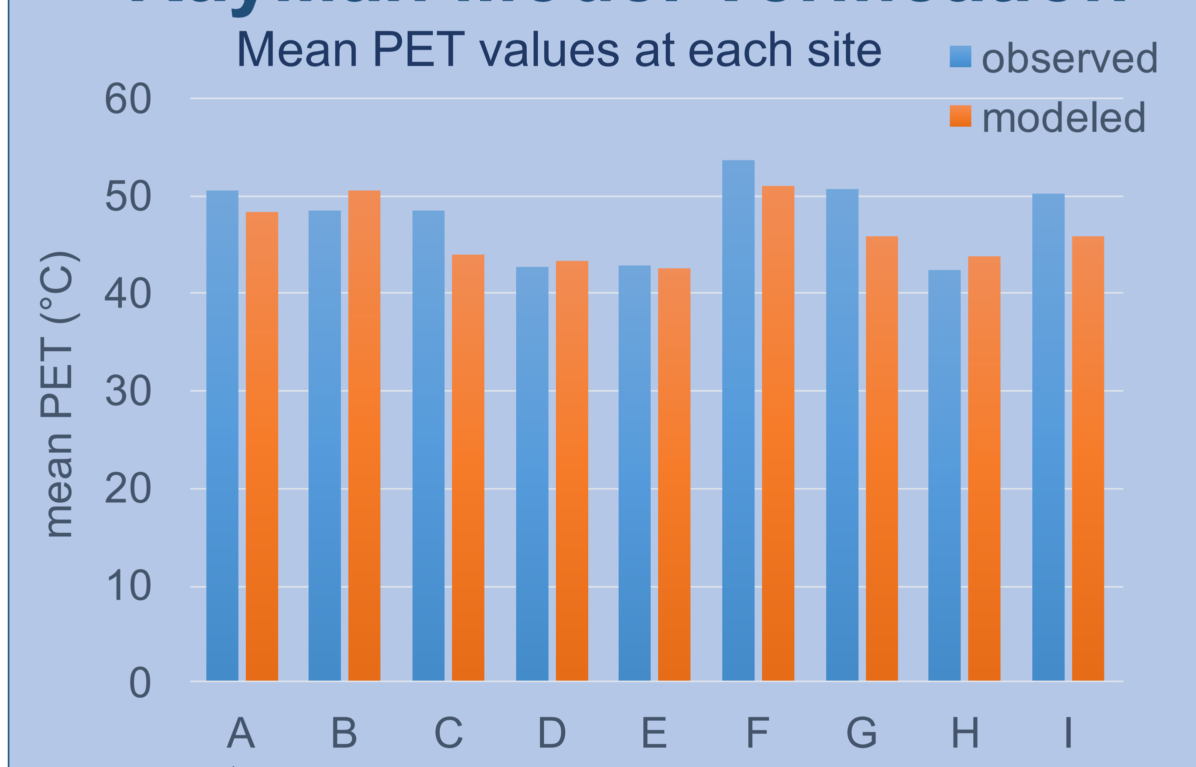
2) b. Sun/Shade Analysis of PET values

The mean of PET values from sites shaded by trees (Sites D, E, and H) was 7.7°C, over two levels of heat stress[4]. Sunny sites exhibited more variation, likely due to wider variation in built form from place to place. *See right.*

	n	Mean PET	σ	SME
Shade	3	42.5	0.225	0.130
Sun	6	50.3	1.905	0.778

1. A t-test showed that shading reduces PET by 7.7 °C with a 95% confidence interval [5.7, 9.7]
2. SVF correlates with PET at a moderately reliable R^2 value of 0.443, Kendall-tau correlation coefficient value of 0.611.

RayMan Model Verification



Difference measure	Value
N	9
MBE	-1.65
sd2	7.27
RMSE	3.03
MAE	2.58
d	0.82
r2	0.576

To model PET values, the RayMan software estimates MRT values. With time and location coordinates of the data collection, it uses a fisheye photo of a site's sky to identify where the sun had been. It can then simulate radiation patterns and estimate MRT. This RayMan MRT (modelled) was validated using MRT derived from GT (observed).

Difference measures:

- MBE indicates that RayMan underestimated
- **Index of agreement "d" indicates a strong match**, backed by relatively small RMSE

Conclusions

In the context of summer midday Phoenix area conditions,

- Trees significantly improve thermal comfort by shading walkways from the sun.
- Trees improve thermal comfort by shading walkways from shortwave radiation. The impact of other urban features on thermal comfort could not be determined, because this study used too few sites, with too much variation in other urban features.
  - Future study to investigate sun/shade vs SVF as determinant of thermal comfort is suggested.
- PET is a useful quantification of thermal comfort when comparing sites or days locally. PET fails when comparing disparate climates.
- RayMan is an acceptable model for simulation and analysis of thermal comfort scenarios in parallel urban environments.

References

[1] University Park Weather | Personal Weather Station: KAZTEMPE48 by Wunderground.com | Weather Underground. (2013). University Park Weather. N.p., n.d. Web.

[2] Matzarakis, A., Rutz, F., & Mayer, H. (2007). Modelling radiation fluxes in simple and complex environments—application of the RayMan model. *International Journal of Biometeorology*, *51*(4), 323–334.

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[4] Mayer H, Matzarakis A. Impact of street trees on thermal comfort. *Merchavim* 2006, 285-300

[5] Willmott, C.J. (1981). On the validation of models. *Physical Geography*. 2, 184-194.