GLOBAL HEAT HEALTH INFORMATION NETWORK

Understanding and Managing Urban Heat

Masterclass 5.1

Part 2: Framework for Understanding and Addressing Urban Heat

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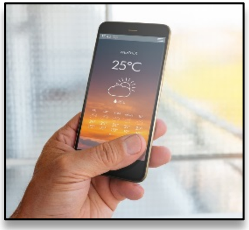
OBJECTIVES

- To understand the various metrics used to quantify heat, exposure, and outdoor thermal comfort
- To understand the basics elements and nature of outdoor thermal comfort
- To understand how climate-sensitive design can improve outdoor thermal comfort and heat exposure

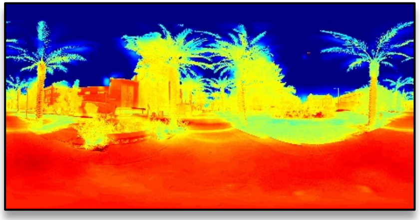
FUNDAMENTALS: Heat Metrics

Heat comes in many forms

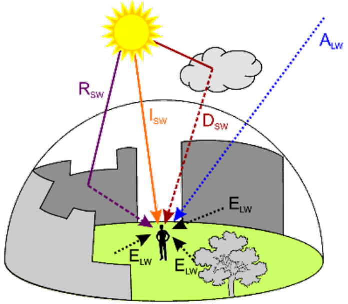
- **Air temperature (T_a)**
  - Measure of how hot or cold the air is



- **Surface temperature (T_s)**
  - Temperature of a surface



- **Mean Radiant temperature (T_{MRT})**
  - Synthetic parameter that summarizes the heat load on a person's body

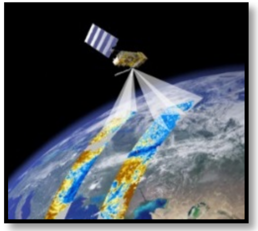


FUNDAMENTALS: Heat Sensors

Examples of Heat Sensors

- **Air temperature (T_a)**
  - Weather station, handheld thermometers


- **Surface temperature (T_s)**
  - Satellites, thermal cameras, IR guns

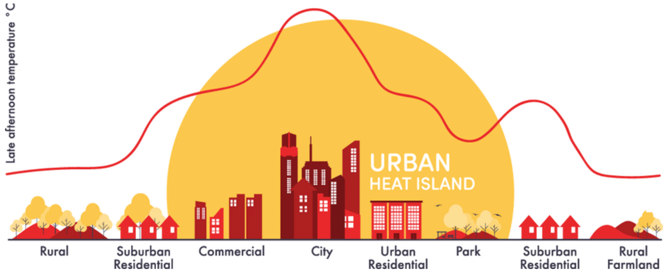


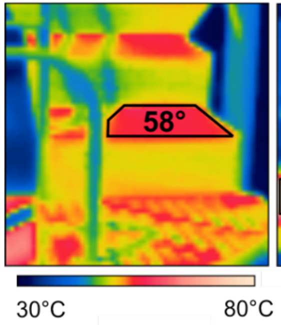
- **Mean Radiant temperature (T_{MRT})**
  - Globe thermometer,
    6-directional setup (3 net radiometers)

FUNDAMENTALS: Heat Metric Applications

When to use which metric?

- **Air temperature (T_a)**
  - Building energy use, UHI
- **Surface temperature (T_s)**
  - Surface UHI, touch-scale studies
- **Mean Radiant temperature (T_{MRT})**
  - Human thermal comfort and exposure





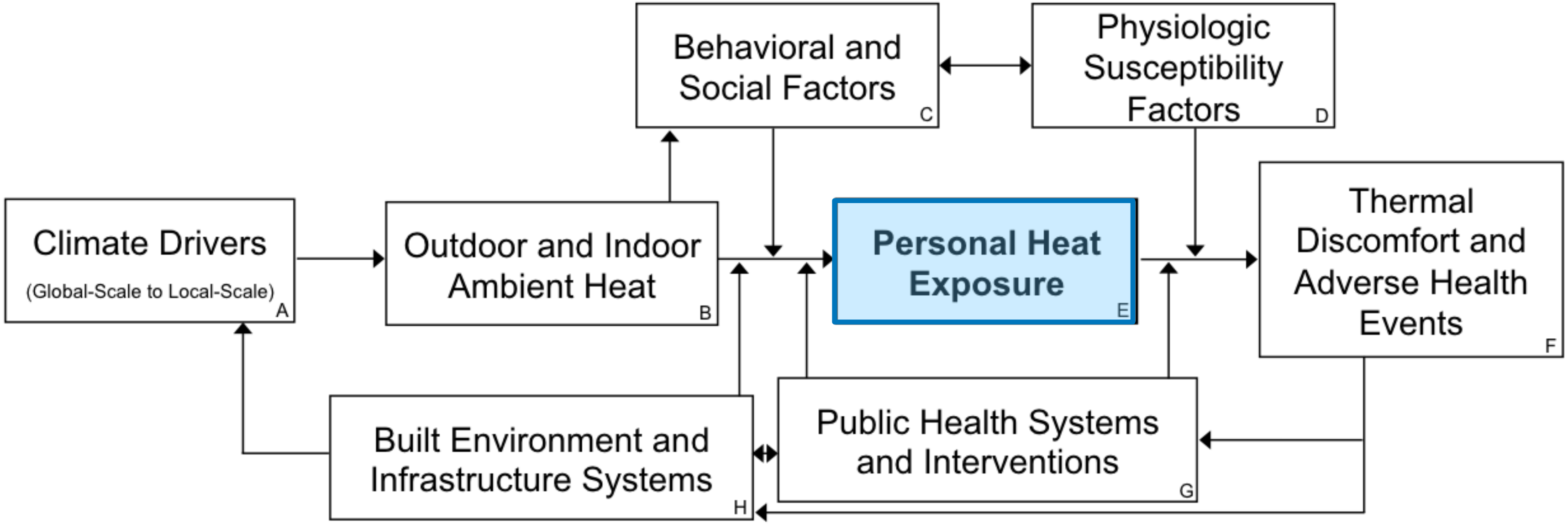
Vanos, Middel et al. LUP (2016)

Interactive Mentimeter Question:

What *other factors* besides air temperature and mean radiant temperature do you think impact thermal comfort?

How do people experience heat?
Personal Heat exposure (PHE)

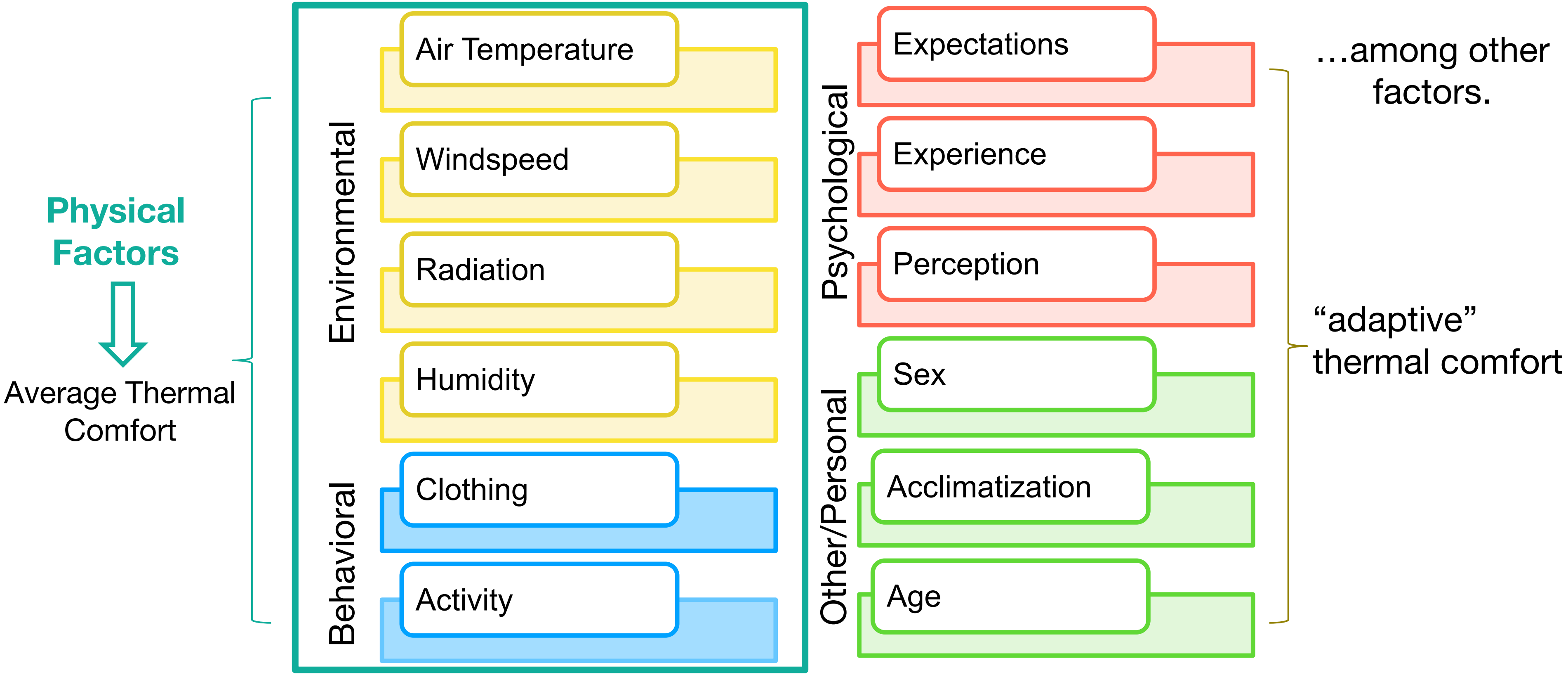
PHE "realized contact between a human and an indoor or outdoor environment in which the air temperature, radiative load, atmospheric moisture content, and air velocity collectively pose a risk of increases in body ***core temperature*** *and/or* ***perceived discomfort****"* (Kuras et al., 2018)



Kuras ER, Bernhard MC, Calkins MM, Ebi KL, **Middel, AM.**, ….. **Vanos JK**, Hondula DM, et al. Environ Health Perspectives (2018).

FUNDAMENTALS: Outdoor Thermal Comfort

Thermal comfort is *“the condition of mind that expresses satisfaction with the thermal environment”* (ASHRAE, 1966)



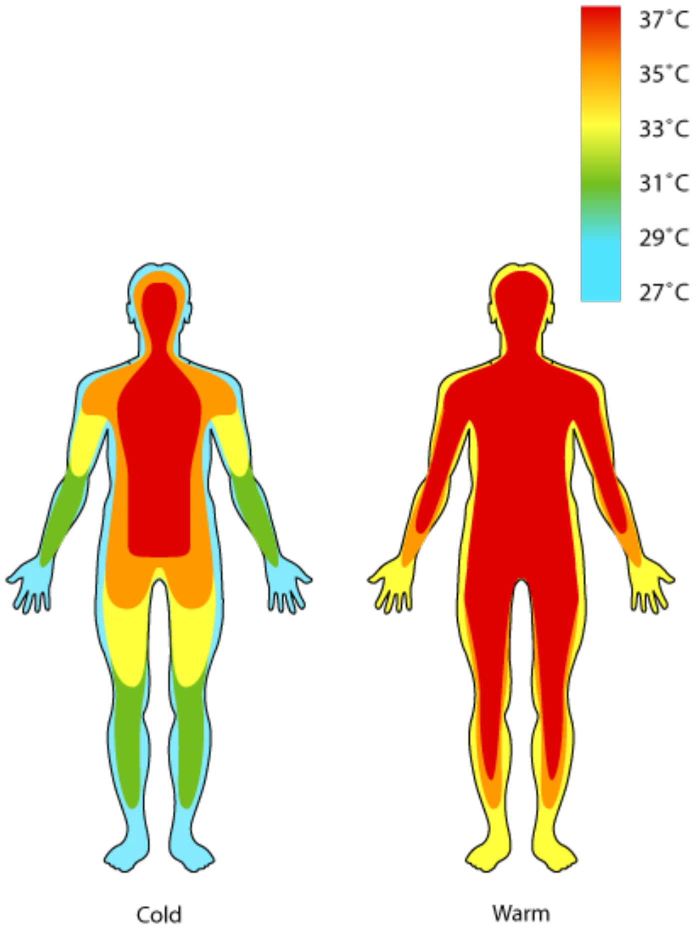
The Thermal Comfort Equation

Three main conditions for comfort

(Fanger, 1970):

1. **The body is in heat balance.**
2. Sweat rate is within comfort limits.
3. Mean skin temperature is within comfort limits.

(4th also the absence of local discomfort)

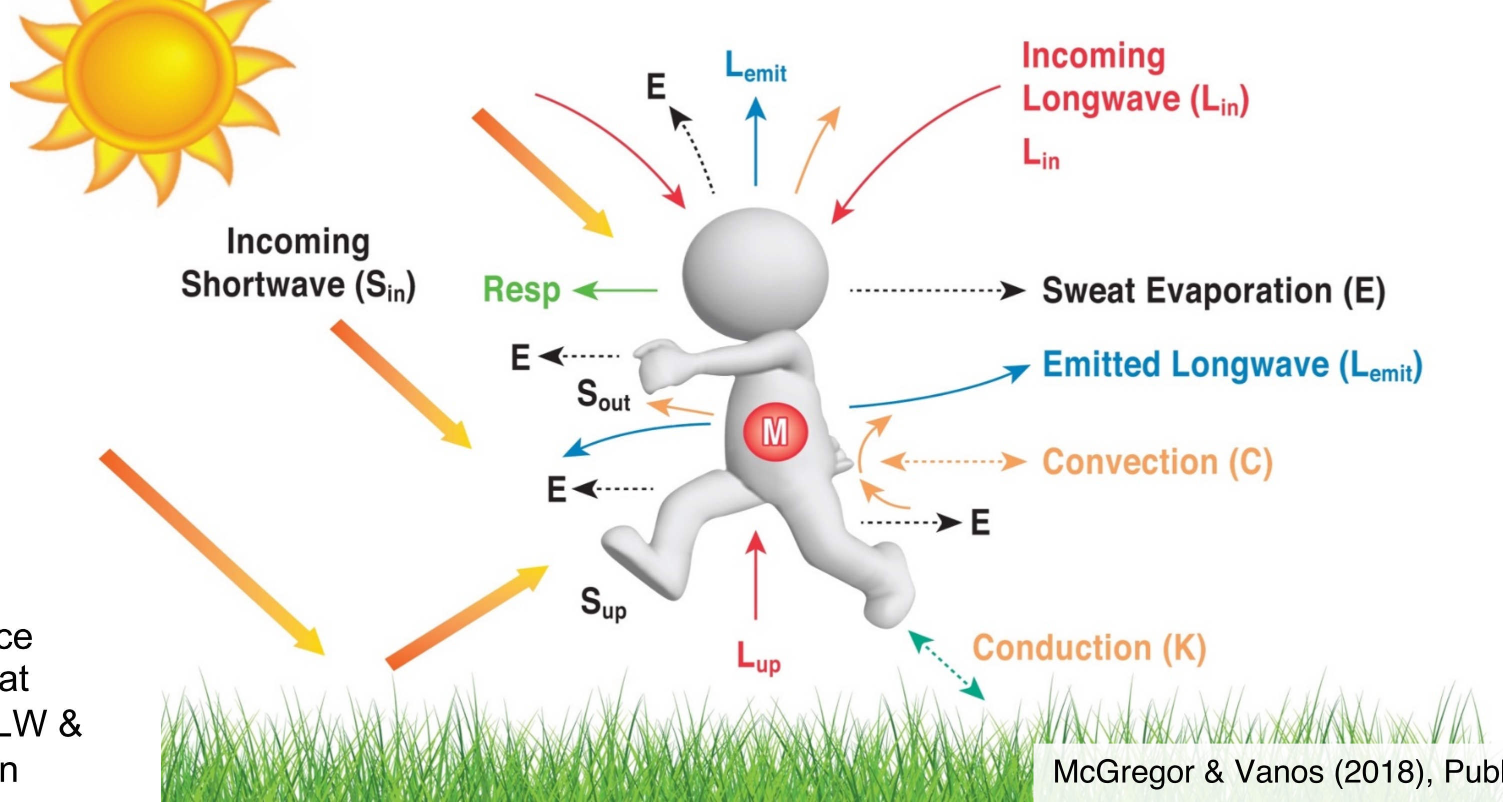


http://www.medguidance.com/images/10420742/part2.png

Fanger, P. O., 1970, *Thermal Comfort*, Copenhagen: Danish Technical Press.

Outdoor Heat Exchange
& factors used to predict thermal comfort

$$EB = M + K + R_{net} \pm C - E_{tot}$$ (W or Wm^{-2})

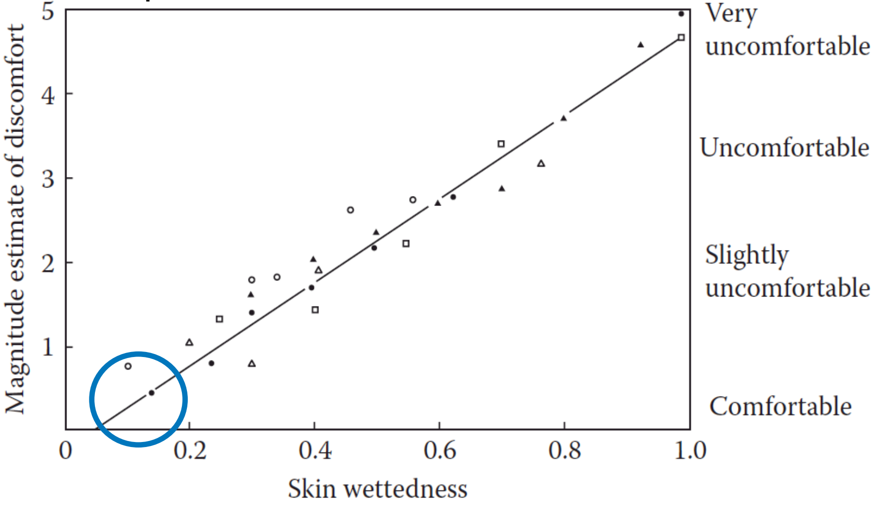


*R_{net}: balance between heat transfer by LW & SW radiation

McGregor & Vanos (2018), Public Health

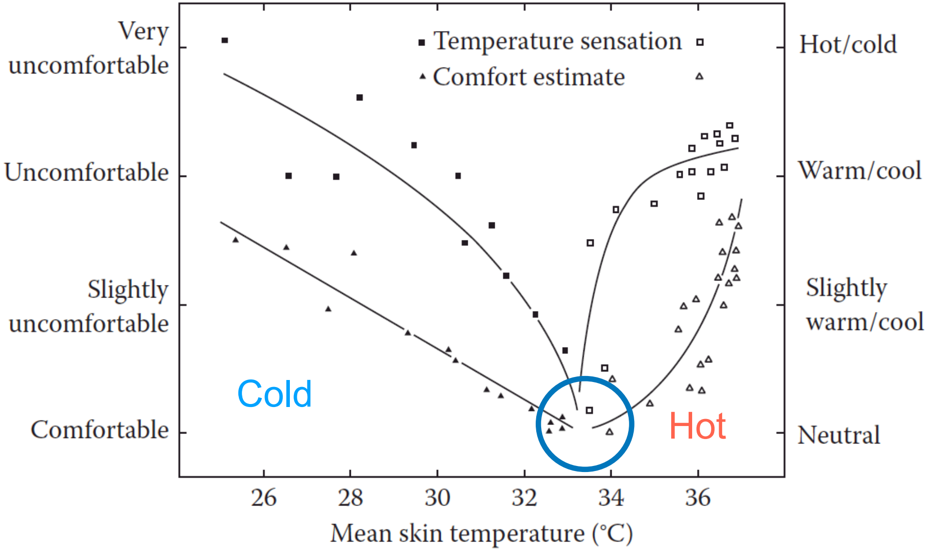
Comfort Limits of Sweat & Skin Temperature

Skin wettedness: good predictor of warm discomfort



$$\omega = \frac{E_{req}}{E_{max}}$$

Skin Temperature: relationship with comfort differs on hot & cold ends



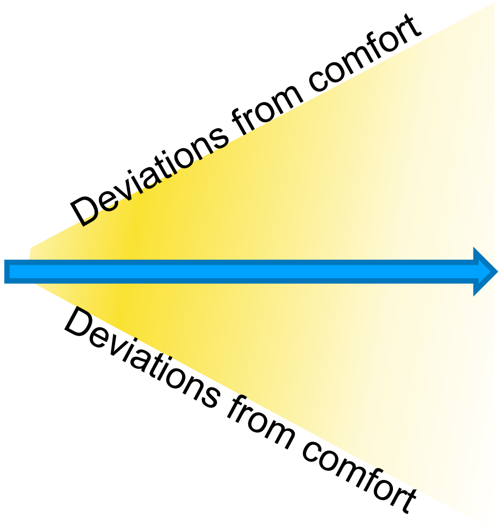
In Parsons (2014) adapted from Gonzalez, R.R. and Gagge, A.P., *ASHRAE Transactions*, 79, 89–96, 1973.

Thermal Comfort & Thermal Sensation

Thermal Comfort:
Lack of discomfort (in steady state)

Thermal Sensation: For deviations from comfort in transient conditions; function of thermal load and activity (Parsons, 2014)

Very Uncomfortable
Uncomfortable
Slightly Uncomfortable
Comfortable



Thermal Sensation Scale

Hot	+3
Warm	+2
Slightly warm	+1
Neutral	0
Slightly cool	–1
Cool	–2
Cold	–3

Subjective:

Called “Thermal Sensation Vote” (TSV), “Actual Thermal Sensation” (ATS) or perception

Thermal Sensation

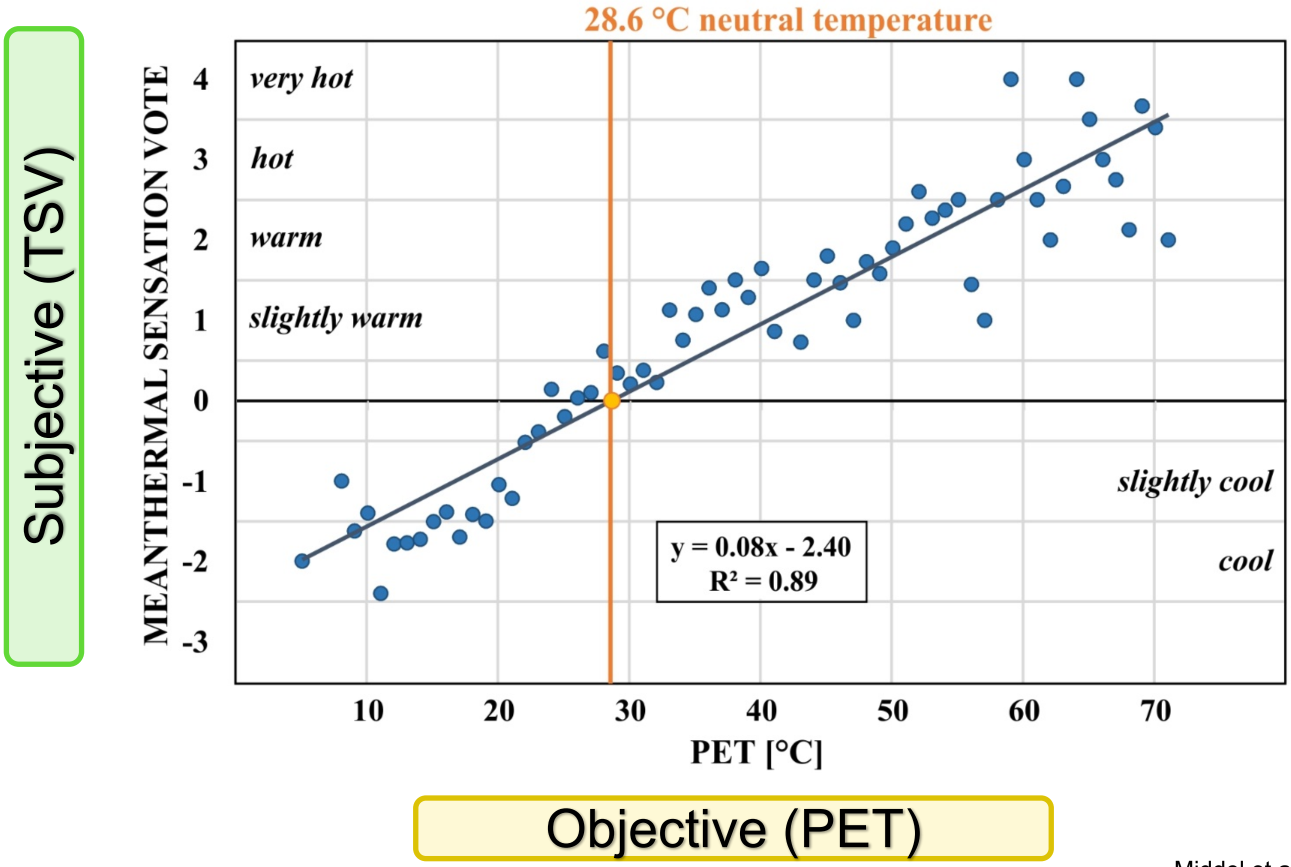
(outdoor, low/no activity)

Objective:

Output from a model (e.g., PET, UTCI, PMV, COMFA, etc.)

Thermal Sensation Scale (9-point scale)	PET (°C)	UTCI (°C)	PMV	COMFA ($W\ m^{-2}$)
-4 (very cold)	<4	< –40	< –3.5	
-3 (cold)	4–8	–40 to –27	–3.5 to –2.5	≤ –201
-2 (cool)	8–13	–27 to –13	–2.5 to –1.5	–200 to –121
-1 (slightly cool)	13–18	0 to 9	–1.5 to –0.5	–51 to –120
0 (neutral)	18–23	9 to 26	–0.5 to 0.5	–50 to 50
+1 (slightly warm)	23–29	26 to 32	0.5 to 1.5	51 to +120
+2 (warm)	29–35	32 to 38	1.5 to 2.5	+121 to +200
+3 (hot)	35–41	38 to 46	2.5 to 3.5	≥201
+4 (very hot)	>41	>46	>3.5	

Subjective versus Objective



Middel et al. (2016). Int J Biomet. 60:1849–1861

Heat Mitigation Strategies

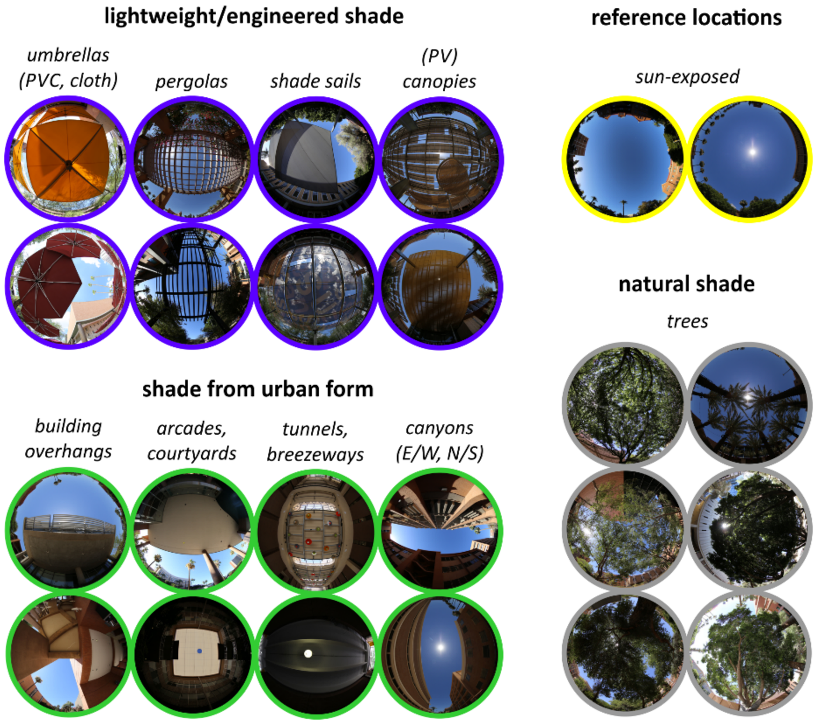
HEAT MITIGATION

- Urban Greening
- Urban Materials
- Urban Form

Case Study 1: Shade

What is the most effective shade type depending on urban context and function of space?

- Cities face challenges to meet tree canopy goals outlined in urban forestry plans
- Goal: develop guidelines and best practices—grounded in local observational data—that can be incorporated into ordinances and plans



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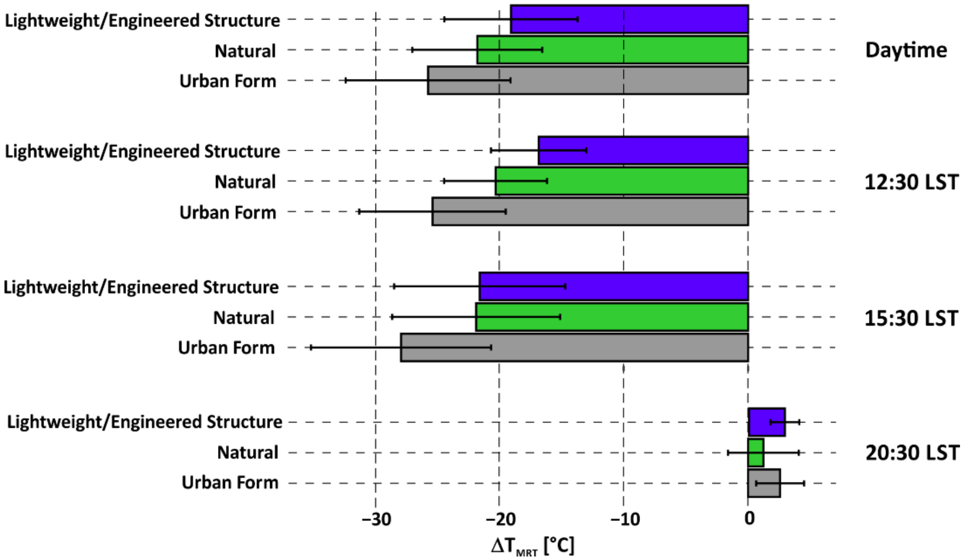
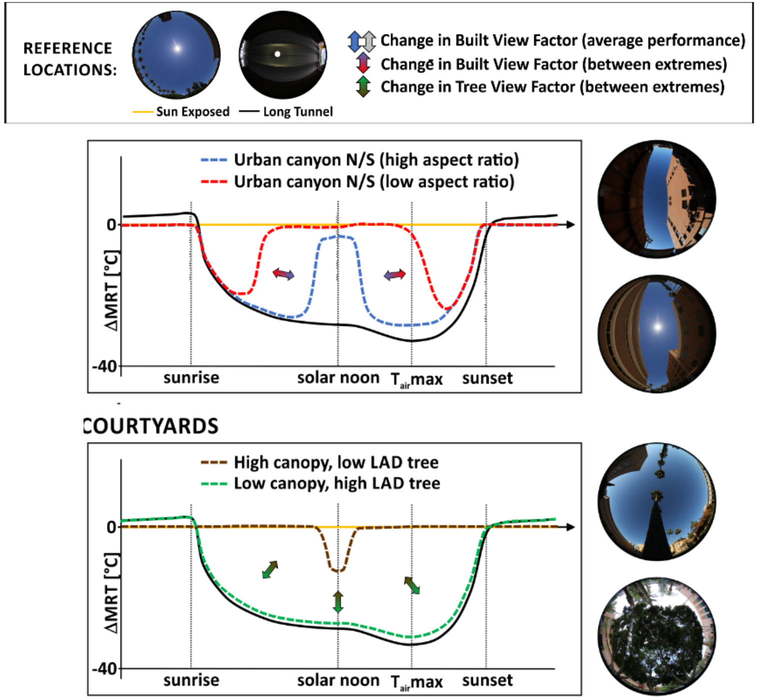




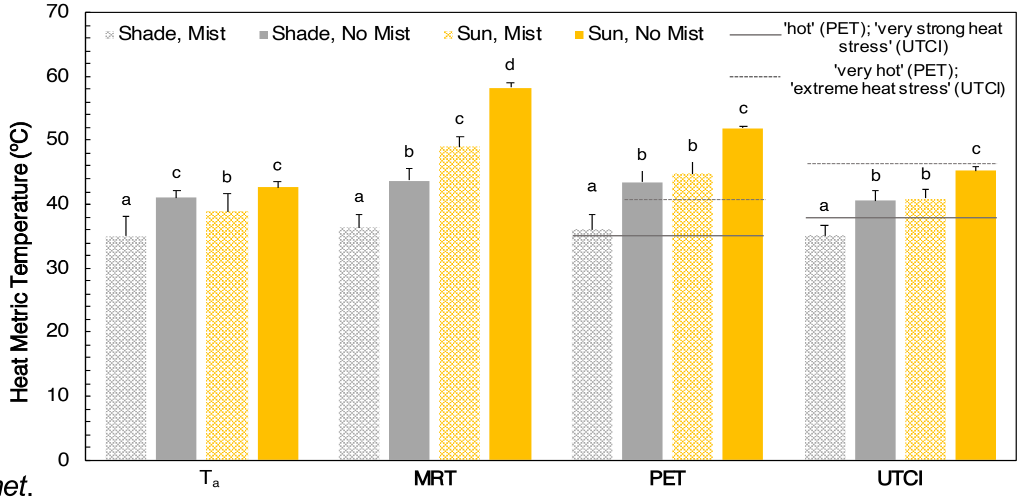
Case Study 2: Misters for Evaporative Cooling in a Hot, Dry Climate

- Misters improved thermal comfort across **all** days, sites, and exposure conditions.

- Thermal comfort was most improved using **mist + shade** — PET and UTCI were **reduced** by 15.5°C and 9.7°C ($p<0.05$)

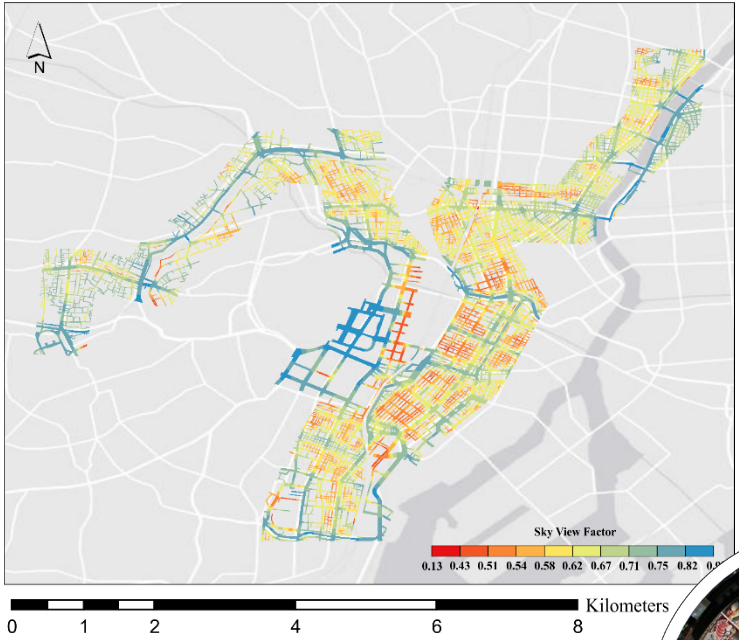
- Business managers identified customer **comfort** and **increased seating capacity** as the principal factors for mister use.

Mean T_{air} = 41°C



Vanos, Wright, Kaiser, **Middel,** Ambrose, Hondula, (2020) *Int J Biomet*.

Case Study 3: Tokyo Spectators' Thermal Comfort



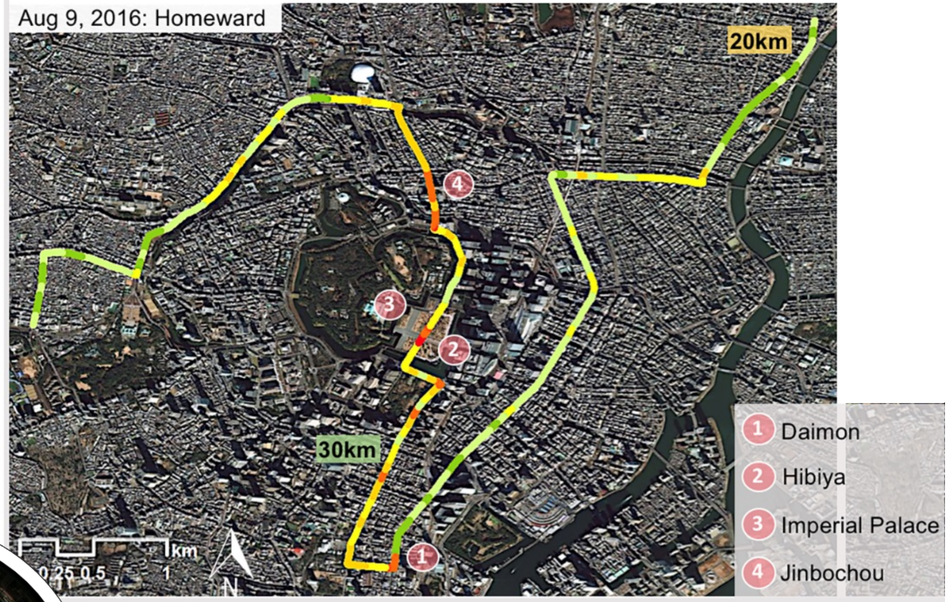
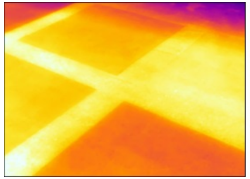


Photo Illustration by Sarah Rogers/The Daily Beast

- COMFA adaptive model
- "hot" spots indicating poor thermal comfort & high heat stress (via HSI)
- Mapped for multiple days & scenarios

Vanos, JK., Kosaka, E., Iida, A., Yokohari, M., **Middel, A.** et al. (2018) *Science of the Total Environment.* 657, 904-917.



Case Study 4: Cool Pavement

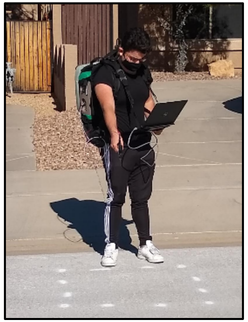
What is the impact of cool (highly reflective) pavement on urban heat?

- Holistic assessment of “Cool Seal” in City of Phoenix residential neighborhoods

Air temperature:
Thermocouples/ vehicle traverse

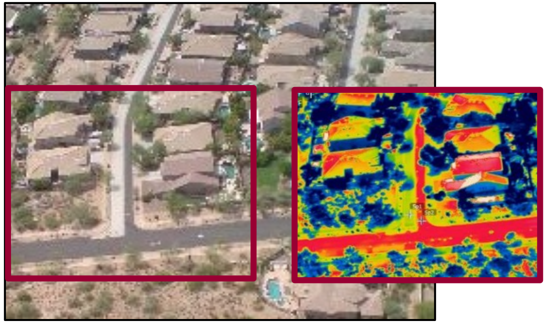
Subsurface
temperature:
iButtons

Reflectivity:
Spectrometer



MRT:
MaRTy

Surface Temperature: Helicopter
overflight/thermal photography



Phoenix neighborhood, half-coated with CoolSeal
September 10, 2020, 13:08 h
Air temperature: 32°C
Difference in surface temperature: 7.5°C

ASU: Schneider, Vanos, Middel, Sailor, Hondula, Kaloush, Campbell, Medina, Cordova
City of Phoenix: Lolly

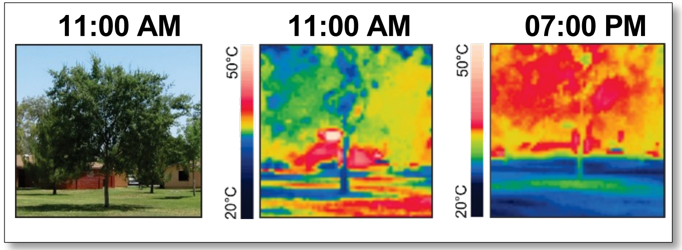
Interactive Mentimeter Question

What percent of downtown city land, on average, is used for vehicles in the United States? (parking lots, roads, etc.)

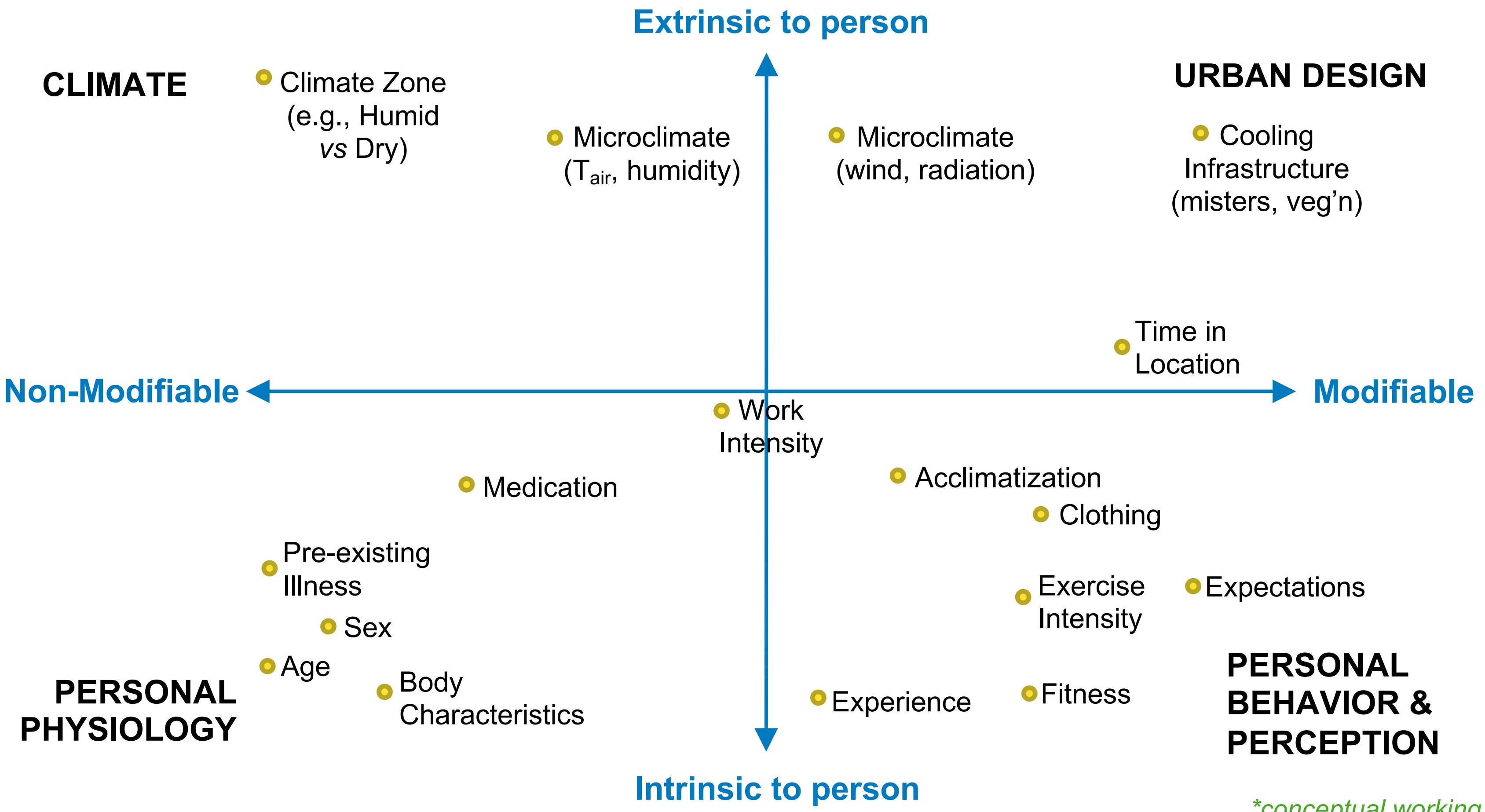
Competing Goals and Tradeoffs

No one-size-fits-all heat mitigation strategy

- Vegetation cools through shade and evapotranspiration but requires irrigation in hot dry environments
- Shade increases daytime thermal comfort, but longwave trapping/heat retention at night
- High albedo surfaces lower surface temperature but increase mean radiant temperature



Goals & Considerations for Outdoor Thermal Comfort



**conceptual working diagram*

Wrap Up & Conclusions

GLOBAL HEAT HEALTH INFORMATION NETWORK

- Urban infrastructure can **increase heat** (as discussed in Part I on UHIs) and **mitigate heat** (via vegetation, urban form, materials)
  - Sensors and models can help us quantify impacts
  - Type of metric is an important consideration
- **Thermal comfort** is complex and highly individualized
  - Important to understand the model used
- **No one size fits all** for designing thermally comfortable spaces
  - spaces should be responsive to the needs of their users and climate-specific

Thank you!

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