Exploring Tree Shade: Cooling Effects and Skin Temperature Recovery in Urban Environments

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Urbanism

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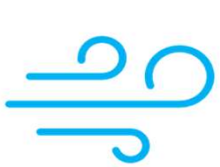
Ministerie van Binnenlandse Zaken en Koninkrijksrelaties

Cooling effects of a tree



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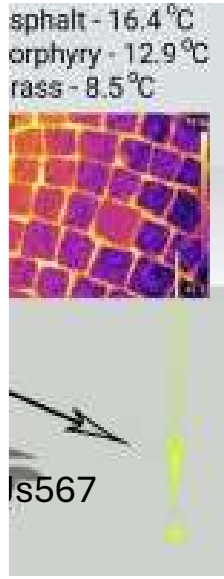
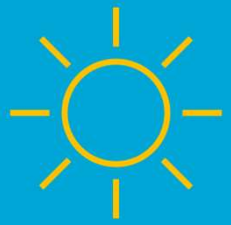


How does human skin temperature respond to urban heat and recover under tree shade?

Work Packages

1) How hot is it in the sun?



Urban **heat** measurement

2) How cool is it in the shade?

Tree **shade** measurement

3) How fast does skin temperature recover from sun to shade?

Human **skin** measurement

Workflows

3 tree species

Planatus x hispanica

Tilia x europaea

Betula pendula

8 Dutch municipalities

Amsterdam
Rotterdam
Utrecht
Den Haag
Groningen
Dordrecht
Dijk en Waard
Hendrik-Ido-Ambacht

2 boundary conditions

3 Urban green spaces

(Not used)

3 E-W street canyons

7-hour measurement campaign in 6 groups

6 Groups

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3 males
3 females

Municipality
3 males
3 females

One group selected for human experiments

1 Crown sensor

(Not used)

Air temperature
Relative humidity

2 Ground sensors

Air temperature
Relative humidity
Globe temperature
Wind speed

16 Cutaneous sensors

Skin temperature

Data analysis – **one tree**

Tree morphology
(height, crown volume)

Cooling effects
(Variability in air temperature and humidity, reduction in the tree shade compared to the sun)

Heat recovery analysis

Data analysis – **two subjects**

Skin response
(Skin temperature recovery, duration)

Metabolic rate
(Heart rate, standing position)

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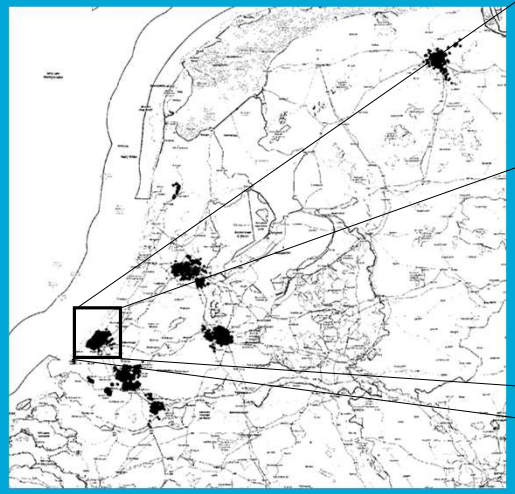
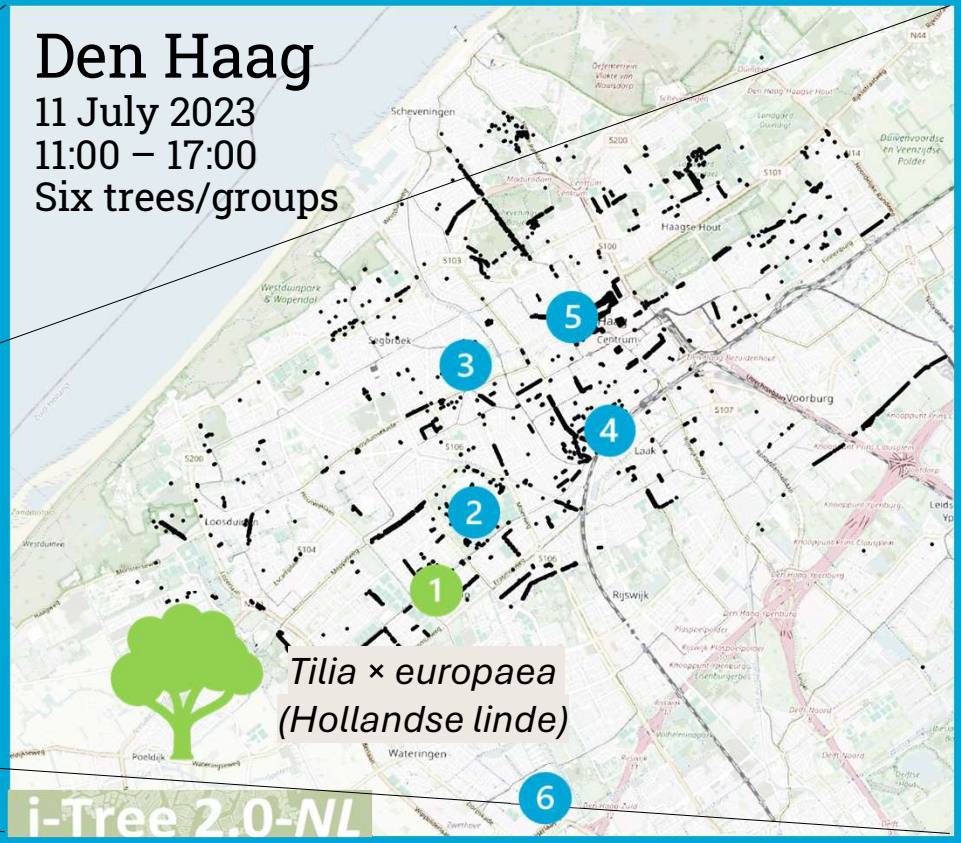
Measurement campaigns

Amsterdam
Rotterdam
Utrecht
Den Haag
Groningen
Dordrecht
Dijk en Waard
Hendrik-Ido-Ambacht

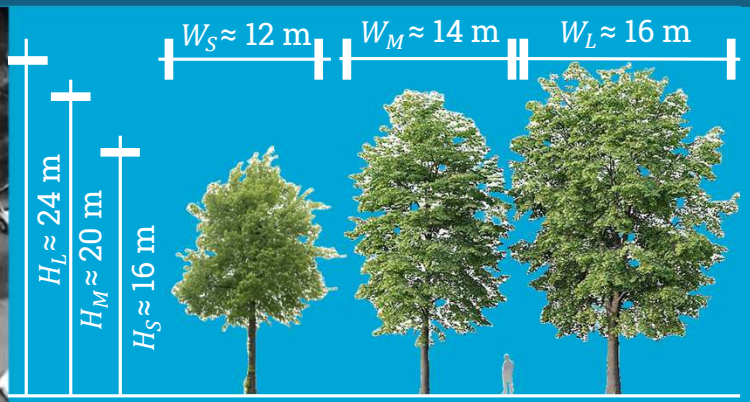
8 Dutch cities

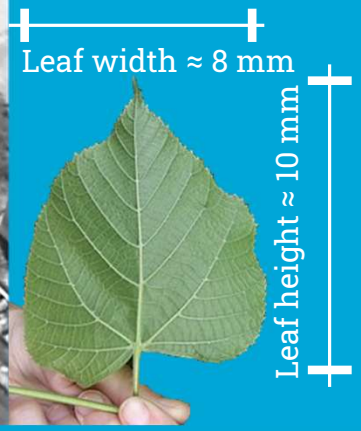


Cfb
Köppen-Geiger climate classification



Tilia × europaea (Hollandse linde)

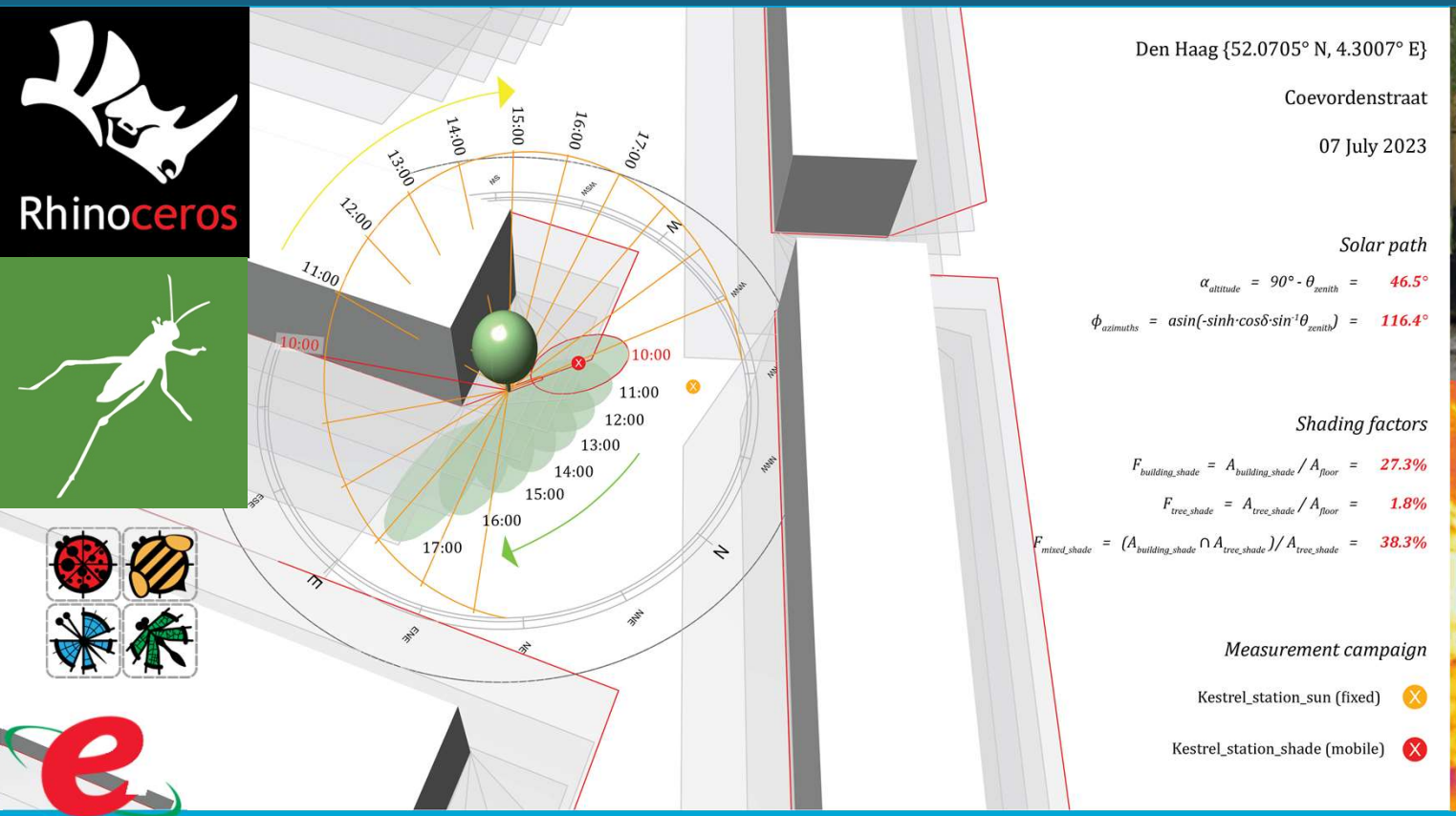




Leaves calendar

Month	Defoliation	Month	Defoliation
Jan	100%	Jul	0%
Feb	100%	Aug	0%
Mar	100%	Sep	10%
Apr	50%	Oct	50%
May	0%	Nov	80%
Jun	0%	Dec	100%

Pre-campaign numeric/field simulations



Den Haag {52.0705° N, 4.3007° E}

Coevordenstraat

07 July 2023

Solar path

$\alpha_{altitude} = 90° - \theta_{zenith} = 46.5°$

$\phi_{azimuths} = asin(-sinh \cdot cos\delta \cdot sin^{-1}\theta_{zenith}) = 116.4°$

Shading factors

$F_{building\_shade} = A_{building\_shade} / A_{floor} = 27.3\%$

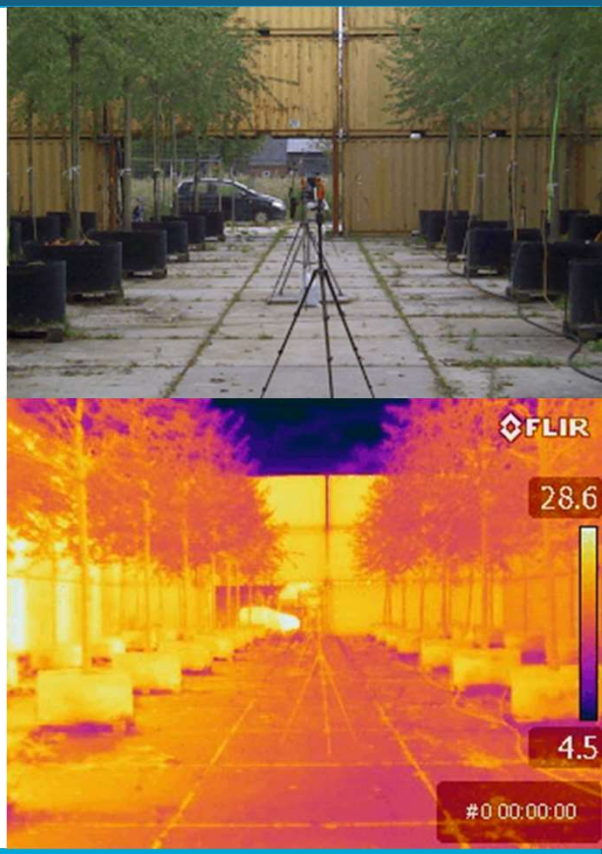
$F_{tree\_shade} = A_{tree\_shade} / A_{floor} = 1.8\%$

$F_{mixed\_shade} = (A_{building\_shade} \cap A_{tree\_shade}) / A_{tree\_shade} = 38.3\%$

Measurement campaign

Kestrel_station_sun (fixed) X

Kestrel_station_shade (mobile) X



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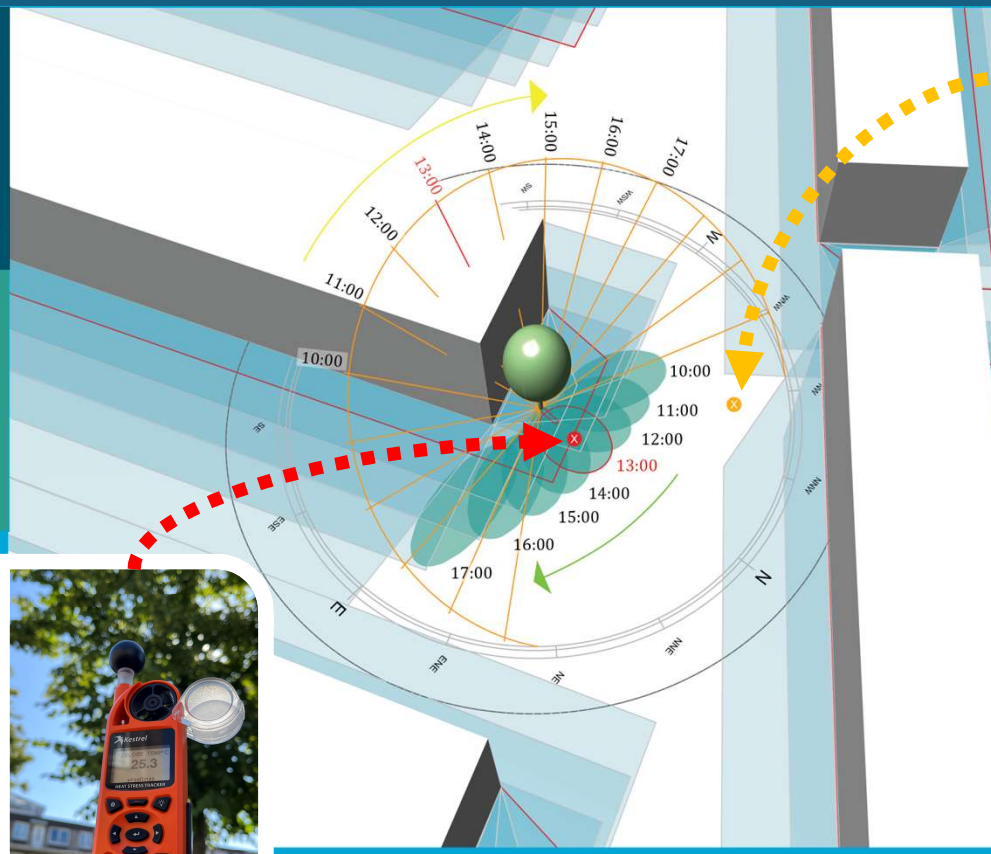
Weather stations deployment



{52.0705° N, 4.3007° E}

Coevordenstraat

07 July 2023

Solar path

$\alpha_{altitude} = 90° - \theta_{zenith} = 60.4°$

$\phi_{azimuths} = asin(-sinh \cdot cos\delta \cdot sin^{-1}\theta_{zenith}) = 185.8°$

Shading factors

$F_{building\_shade} = A_{building\_shade} / A_{floor} = 20.7\%$

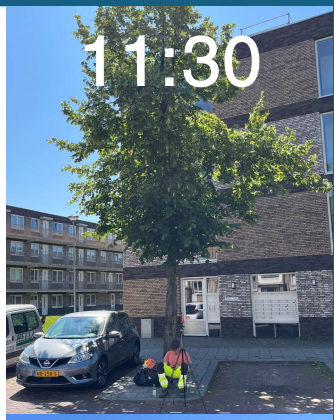
$F_{tree\_shade} = A_{tree\_shade} / A_{floor} = 1.4\%$

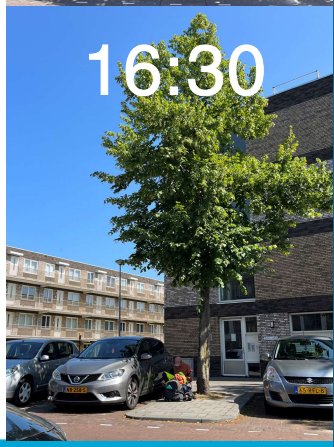
$F_{mixed\_shade} = (A_{building\_shade} \cap A_{tree\_shade}) / A_{tree\_shade} = 45.8\%$

Measurement campaign

Kestrel_station_sun (fixed)

Kestrel_station_shade (mobile)



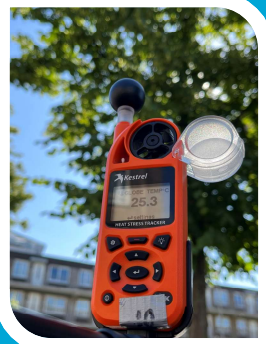


Protocols of relay

Participant A

Swap to the shade every 10 mins

Kestrel station 2 in the shade (fixed)



Kestrel station 1 in the sun (fixed)

Swap to the sun every 10 mins

Participant B

Metrics

Tartarini, F., Schiavon, S., 2020. pythermalcomfort: A Python package for thermal comfort research. SoftwareX 12, 100578. https://doi.org/10.1016/j.softx.2020.100578

Static

Universal Thermal Climate Index (UTCI)

`thermalcomfort.models.utci.utci(tdb, tr, v, rh, units='SI', return_stress_category=False, limit_inputs=True)` [source]

Static

Physiological equivalent temperature (PET)

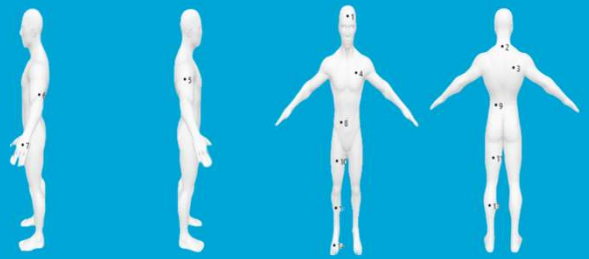
`pet_steady(tdb, tr, v, rh, met, clo, p_atm=1013.25, position=1, age=23, sex=1, weight=75, height=1.8, wme=0)` [source]

Dynamic

ISO 8-pt mean skin temperature (Tmskin)

$$T_{mskin} = (T\_forehead \times 0.07) + (T\_right\_scapula \times 0.175) + (T\_left\_chest \times 0.175) + (T\_right\_deltoid \times 0.07) + (T\_left\_elbow \times 0.07) + (T\_left\_hand \times 0.05) + (T\_right\_thigh \times 0.19) + (T\_left\_gastrocnemius \times 0.2)$$

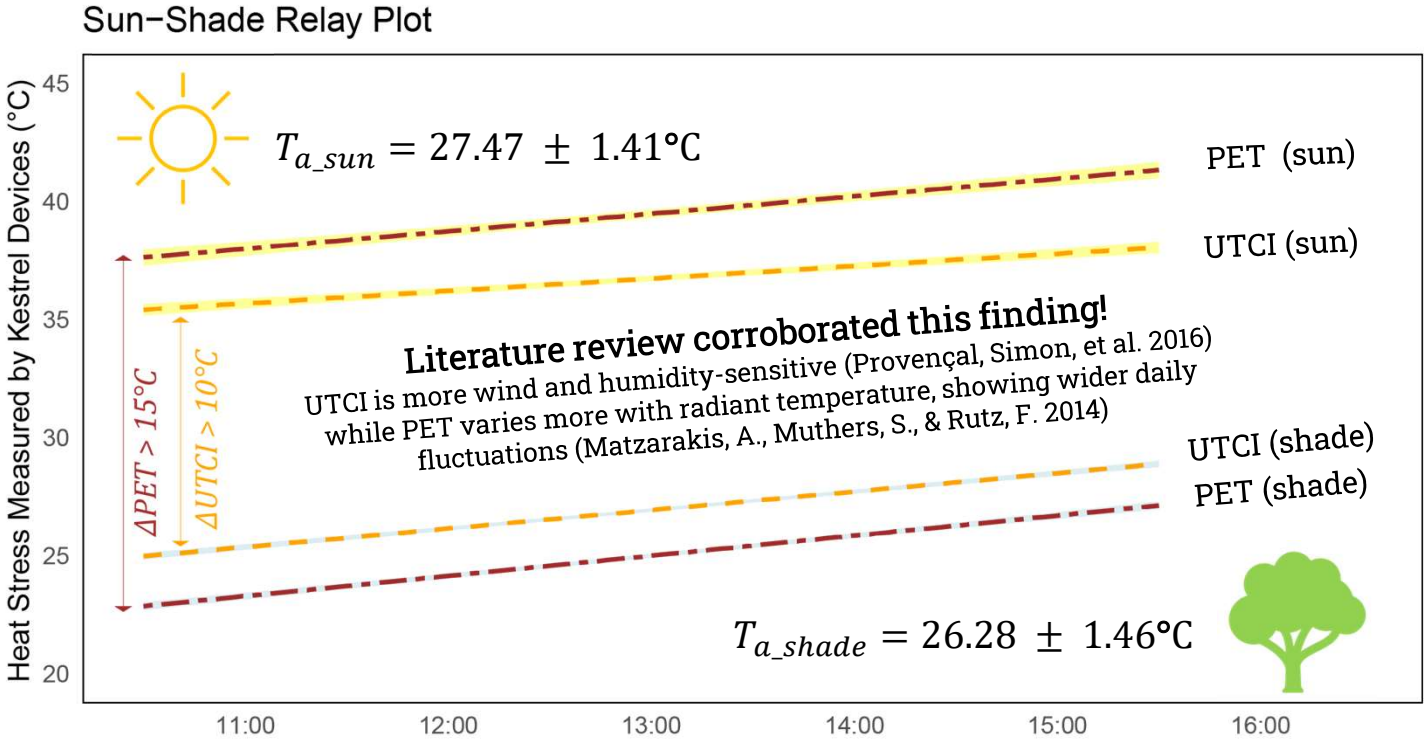
Personal parameters



Results

Kestrel (sun)

Kestrel (shade)



Results

- Gender: Male
- Age: 31
- BMI: 24
- Clo: 0.5

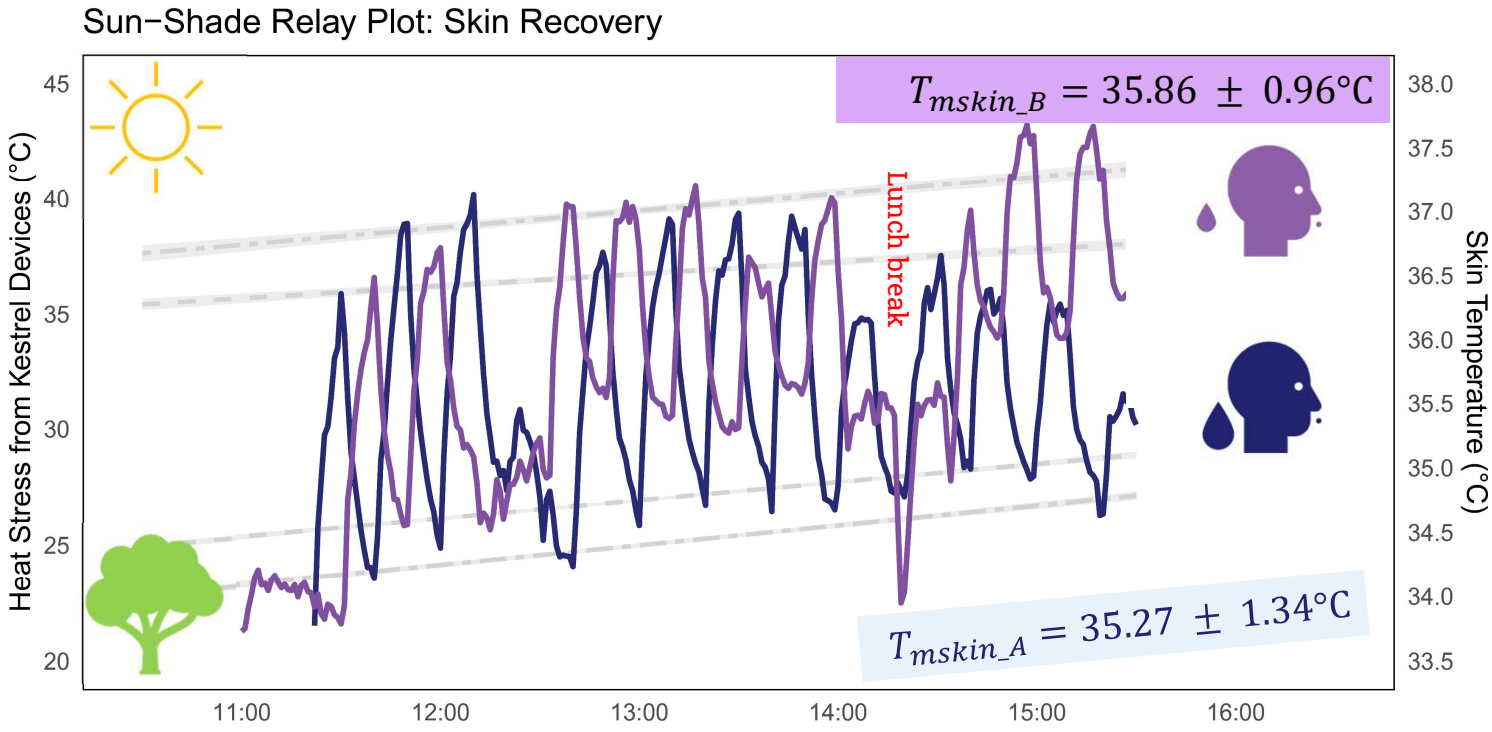
Participant A

Every 10 mins

Every 10 mins

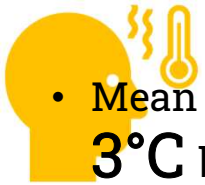
- Gender: Male
- Age: 23
- BMI: 21
- Clo: 0.5

Participant B

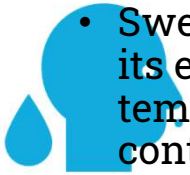


Takeaways

- **PET** in the shade of a Hollandse linde can be up to **15°C** lower than in the sun, compared to **1.2°C** in air temperature difference.



- Mean skin temperature varied up to **3°C** between sun and shade.



- Sweating reduces skin temperature, but its effect on improving skin temperature sensitivity to thermal contrast remains unclear.

- Limitations: insufficient sample size in human subjects, insufficient 10-min acclimatisation -> need 20 mins. Lack of skin wetness measurement, Lack of core temperature measurement

- Future studies in biometeorology: dynamic tree cooling-effect indicator (dPET), thermal alliesthesia/pleasure (dTmskin/dt)

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Team I-Tree 2.0 & Team Field Lab Haarlemmermeer

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Thank You

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