The impact of urban green spaces on residents' outdoor thermal comfort – a psychological and physical approach

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Intro

Green infrastructure has the ability to improve thermal comfort in outdoor urban spaces in moderate climates. Up to now, the impact of greenery on thermal comfort, however, was only studied in physical terms, using meteorological variables and human-biometeorological indices.

Little is known about the role of green spaces on people's behaviour and generally perceived thermal comfort. Furthermore, physical thermal conditions of various parks within one city have not yet been investigated in the Netherlands.

Objective

The main objective was to get comprehensive insights into the impact of green spaces on outdoor thermal comfort from both a psychological and a physical perspective. We answered the following research questions:

1. How do people generally perceive green places in urban environments during warm summer days with respect to thermal conditions?
2. What are the physical thermal comfort conditions related to air temperature (T_a), mean radiant temperature (T_{mrt}) and physiological equivalent temperature (PET) in urban green areas (during daytime on warm summer days)?
3. Is the impact of green spaces on perceived thermal comfort consistent with the physical thermal environment?

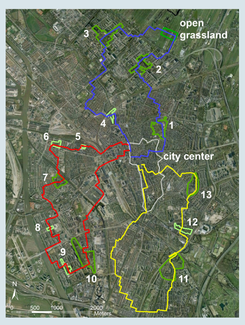
Method

Study 1 - Psychological approach (Surveys with passers-by)

- Interviews with passers-by during summer days, in 2011 and 2012 in three cities in The Netherlands: Arnhem, Utrecht and Rotterdam
- Response of 559 questionnaires (184 in Arnhem, 181 in Utrecht, and 194 in Rotterdam), response rate of 31%
- Investigating relationship between green environments and thermal comfort compared to built and water environments on the basis of recurring patterns in people's experiences[1]
- Analyses: descriptive statistics, reliability analyses, SPSS 19 (more details see[2])

Fig. 1: Interviews with passers-by in the city centre of Utrecht

Study 2 - Physical approach (Micrometeorological measurements)



- Mobile micrometeorological measurements on two summer days in 2012 in the city of Utrecht, The Netherlands
- Cargo-bicycles equipped with sensors for air temperature, wind, humidity, solar and thermal radiation and a GPS device (more details see[3])
- Loops covered 13 parks (1 - 22 ha), the city centre and an open grassland outside the north-eastern side of the city (Fig.2)
- Analyses: calculation of T_{mrt} and PET (Rayman[4]), comparison of the average values and the variance of all T_a, T_{mrt} and PET measurements (more details see[2])

Fig. 2: Location of bicycle loops in Utrecht in The Netherlands (yellow , blue and red = bicycle route, green=edge of parks, with=edge of city centre)(Aerial photograph by Google Earth)

1 Lenzholzer, S. and N. Y. van der Wulp (2010). "Thermal experience and perception of the built environment in Dutch urban squares." Journal of Urban Design 15(3): 375-401..

2 Klemm, W., B. G. Heusinkveld, et al. (2014). "Psychological and physical impact of urban green spaces on outdoor thermal comfort during summertime in the Netherlands." Building and Environment (in press).

3 Heusinkveld, B. G., G. J. Steeneveld, et al. (2014). "Spatial variability of the Rotterdam urban heat island as influenced by urban land use." Journal of Geophysical Research: Atmospheres: 2012JD019399.

4 Matzarakis A, Rutz F, Mayer H. Modelling radiation fluxes in simple and complex environments - Application of the RayMan model. International Journal of Biometeorology. 2007;51:323-34.

Results

People generally perceived urban green spaces as thermally comfortable during warm summer days (Fig. 3).

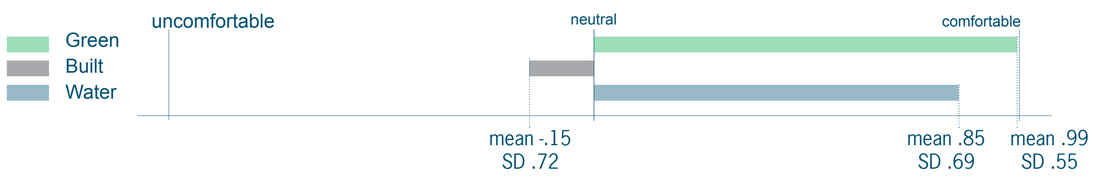


Fig. 3: Generally perceived thermal comfort in three different urban environments - Responses coded on a five-point scale from very uncomfortable (-2) to very comfortable (+2)

The experienced thermal comfort in green environments was significantely ($p < 0.001$) larger than in water and built environments (Table 1).

Table 1: Differences of generally perceived thermal comfort between urban environment types

Contrast	Mean difference	Test statistics: t-value	Significance: p-value	Effect size: Cohen's d
Green versus built	1.14	34.31	< 0.001	1.78 (r = 0.66)
Green versus water	0.14	4.68	< 0.001	0.22 (r = 0.11)
Water versus built	1.01	34.22	< 0.001	1.42 (r = 0.58)

59,4% of the 672 specific places that were indicated as thermally comfortable on warm summer days was a green environment (Fig. 4). All findings were stable across the cities of Arnhem, Utrecht and Rotterdam.

Fig. 4: Preferred thermal comfort places in three cities on warm summer days (times mentioned/ response frequency)

Measurement results demonstrate that the 13 examined parks were cool islands within the urban area (Table 2).

Table 2: Average and daily maximum T_a, T_{mrt} and PET values in 13 investigated parks, the city centre and above open grassland outside the city. Based on third order polynomial fit function of all measurement points on July 24th 2012 (12:00 - 17:00 UTC) in Utrecht, The Netherlands

	Average 12:00-17:00 UTC			Daily max		
	T_a [C°]	T_{mrt} [C°]	PET [C°]	T_a [C°]	T_{mrt} [C°]	PET [C°]
13 parks	27.4	42.7	32.3	27.7	46.4	34.0
City centre	28.2	44.4	34.2	28.5	47.6	35.1
Open grassland outside the city	27.1	56.3	37.3	27.5	60.0	39.2

There was a wide variation in ambient thermal conditions, both between different parks and inside individual parks (Fig. 5). The variance is related to tree canopy cover inside parks and up-wind vegetation cover outside parks (see [2, 3]).
The results based on measurement data from July 24th, 2012 were in accordance with the data from August 18th, 2012.

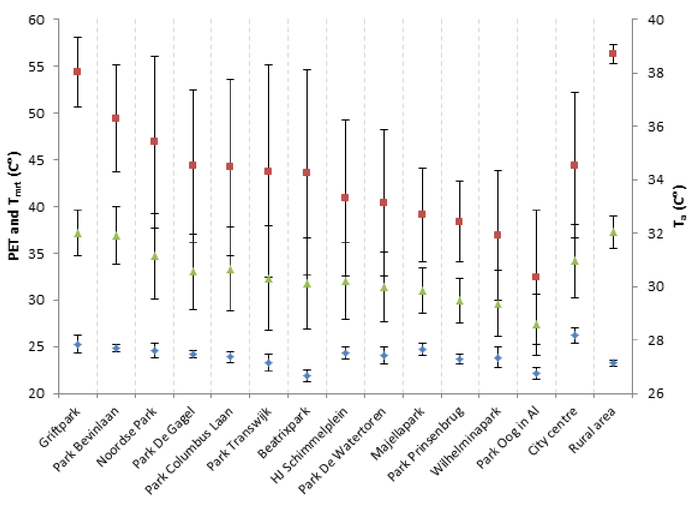


Fig. 5: Averaged T_a, T_{mrt} and PET values of 13 parks and the city centre compared to the open grassland in the rural area outside the city. Error bars represent average standard deviation of all individual measurements on July 24th 2012 (12:00 - 17:00 UTC) in Utrecht, The Netherlands

Conclusions

1. Green places within cities are perceived as thermally comfortable during warm summer days. Green environments are perceived even more thermally comfortable than built and water environments. This implies that peoples' generally perceived thermal comfort is related to spatial characteristics of the environment (green, built, water).
2. Green spaces, like parks, are cool islands within the city. On average green spaces were characterized by PET values 1.9 K lower than the city centre and 5 K lower than the open grassland out side the city indicating the best physical thermal comfort conditions.
3. The psychological impact of green spaces on generally perceived thermal comfort is consistent with the physical thermal conditions related to T_a, T_{mrt} and PET. Therefore, we recommend to use ample green spaces within urban environments in moderate climates as urban green does improve perceived and objective thermal comfort.

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