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Psychological and physical impact of urban green spaces on outdoor thermal comfort during summertime in The Netherlands

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ABSTRACT

Green infrastructure can improve thermal comfort in outdoor urban spaces in moderate climates. The impact of green spaces on thermal comfort is often exclusively investigated through meteorological variables and human-biometeorological indices. Yet, studies on perceived thermal comfort are scarce. As thermal comfort is a property of human perception of the thermal environment, this knowledge is crucial for understanding the relationship between green spaces and thermal comfort.

We investigated inhabitants' long-term perception of thermal comfort on warm summer days in three Dutch cities by means of questionnaires. Additionally, we examined the daytime cooling effect of green spaces in Utrecht, in order to find physical evidence to verify thermal comfort perception. To this end we used bicycles equipped with micrometeorological sensors. We compared thermal conditions of 13 parks with thermal conditions in the city centre and in the open grassland outside the city. And we analysed dependences between thermal conditions and spatial variables of parks (size, tree canopy, upwind vegetation cover).

Our results demonstrate that green infrastructure improves generally perceived thermal comfort. People evaluated green urban spaces as the most thermally comfortable spaces which was in line with the physical thermal investigations. Physiological equivalent temperature (PET) in parks on average was 1.9 K lower than in the city centre and 5 K lower than in the surrounding grasslands during the hottest period of the day. Thermal variance between parks was significantly influenced by tree canopy cover (mean radiant temperature $p = 0.00005$) and upwind vegetation cover (air temperature $p = 0.013$), not significantly for park size.

1. Introduction

The Netherlands has a temperate climate influenced by the North Sea, with moderate temperatures throughout the year. However, hot summer days in which temperatures rise above 30 °C, do occur and will occur more frequently in future due to climate change [1]. Particularly in urban areas, this may have adverse consequences for human health and outdoor thermal comfort. In addition, future densification and extension of urban areas may further increase thermal discomfort and negative health impacts. The most vulnerable groups are elderly, young children and people with cardiovascular diseases [2,3]. But also amongst other citizens sleep, the ability to concentrate and work productivity are affected [4].

It has been demonstrated that green infrastructure within cities has the ability to effectively reduce heat and improve outdoor thermal comfort [5–9] besides other ecosystem services [10,11]. Urban green infrastructure is an accumulation of green elements and green spaces within the built environment [7–9] which can be differentiated into various vegetation types (e.g. grass, trees, green facades, parks, urban forests) [5,6]. This study focusses on urban green spaces such as parks.

The impact of urban green spaces on thermal comfort during warm summer periods up to now was predominately studied from a physical perspective. Thermal comfort studies focused on

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meteorological variables and human-biometeorological indices that represent objective thermal conditions within the urban environment. Meteorological variables include air temperature (T_a), humidity, wind speed and short- and long-wave radiation, and the measurement or modelling of the mean radiant temperature (T_{mrt}). An often applied human-biometeorological index is the physiological equivalent temperature (PET), which is a measure of thermal comfort based on the energy balance of the human body [12]. T_{mrt} and PET are considered key human-biometeorological variables for outdoor thermal comfort during Central European weather conditions [13,14].

Thermal performances of urban green spaces depend on certain spatial characteristics of the park itself and its built surrounding. Studies demonstrated a decrease of T_a along with an increase of size of parks [5,15]. Thermal comfort conditions were also improved through an increase of tree canopy cover within green spaces [5] or within built environments [16,17]. Furthermore, the nocturnal urban temperature is affected by upwind land use characteristics, most notably by vegetation cover within the upwind direction [8].

How people perceive thermal comfort related to urban green spaces depends on complex interactions of physical, physiological, behavioural and psychological factors [18]. Particularly, the psychological impact of urban green spaces on people's perceived thermal comfort is yet a relatively unexplored domain of research. In general, ample evidence exists to demonstrate that urban green spaces are positively related to health and well-being [19–21]. Also, people generally prefer green compared to non-vegetated urban environments, on the basis of sensory (predominately visual) information and symbolically assigned values [20,22].

A few studies have demonstrated that the perception of thermal comfort is related to naturalness, aesthetical appreciation and positive experience of the environment [23–25]. Other studies indicated that people's perceived thermal comfort is affected by their perception of spatial environments [26,27]. Lenzholzer et al. [27] suggested that green spaces could improve perception of places and perceived thermal comfort. The question however remains how people actually perceive thermal comfort related to urban green spaces?

In this study we used an interdisciplinary approach to examine outdoor thermal comfort related to green spaces from a psychological and a physical perspective. Our study 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?
   a. How do people evaluate the thermal comfort effect of green places?
   b. How do people experience thermal comfort in green compared to other places?
   c. Are green places more frequently preferred than other places when people seek thermal comfort?
2. What are the physical thermal comfort conditions in urban green spaces (during daytime on warm summer days) and what are the dependences with spatial variables of specific sites?
   a. To what extent differ air temperature (T_a), mean radiant temperature (T_{mrt}) and physiological equivalent temperature (PET) in urban parks from those in the city centre and open grassland outside the city during daytime, on warm summer days?
   b. What is the influence of (1) the size of urban green spaces, (2) the tree canopy cover inside green spaces and (3) the upwind land use characteristics of the built surrounding on physical thermal comfort conditions?
3. Is the impact of green spaces on perceived thermal comfort consistent with the physical thermal environment?

We aimed at gaining novel insights into the impact of urban green spaces on generally perceived thermal comfort on warm summer days. Additionally, we gathered evidence for the physical cooling effect of green spaces and its variance on city scale. Our study was conducted as part of the Dutch Climate Proof Cities program [28] contributing to develop strategies on urban climate adaptation in The Netherlands and other moderate climates.

2. Methods and materials

Our research design consisted of two separate studies, which are linked on a conceptual level. Study 1 investigated psychological impacts of urban green spaces on perceived thermal comfort through interviews. Study 2 examined physical thermal comfort conditions of green spaces compared to other urban locations within the city through micrometeorological measurements. We discussed both studies and compared their results to answer research question 3.

2.1. Psychological study

2.1.1. Background analysis

When contemplating the concept of perception (i.e., the conscious experience of the world ‘out-there’ [29]), it is important to make a distinction between momentary perception and general or long-term perception. Momentary perception is a mental state at a particular moment. For example, people can experience a particular place as thermally comfortable at a certain moment. General perception refers to a permanent mental disposition and psychological schemata. For example, people can perceive green places as thermally comfortable in general. General perception is constituted by repetitive patterns in momentary perceptions [29] and is thus influenced by characteristic events that become engrained in people's memory [27]. If people repeatedly experience thermal comfort in green environments relative to non-green environments, this series of momentary perceptions accumulates into a general perception. Thus, people might infer a relationship between green elements and thermal comfort on the basis of recurring patterns in their experiences. This inferred relationship might become a general perception of green environments as being thermally comfortable. As momentary thermal comfort perception was addressed in previous research [17], the present study focusses on general perception, as an attempt to seek complementary knowledge.

2.1.2. Variables

In order to operationalize the abstract concept (i.e., theoretical construct) of general perception of thermal comfort in green environments into psychological self-report measures (i.e., measures that use people's linguistic expressions as a proxy of their experiences or opinions), it needs to be translated into more concrete concepts. As indicated in the research questions 1a–b, we operationalized perceived thermal comfort in relation to green environments into three concepts: (1) evaluation of the thermal comfort effect of green environments, (2) generally experienced thermal comfort in different environment types, and (3) preferred thermal comfort places.

(1) The first concept is the evaluation of the thermal comfort effect of green environments: If people repeatedly experience green environments as thermally comfortable. We expect that this effect would be evaluated positively. For the