Urban Forestry & Urban Greening 20 (2016) 198–209

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Temporal variations in microclimate cooling induced by urban trees in Mainz, Germany

Jenny Lindén[a,*], Patrick Fonti[b], Jan Esper[a]

[a] Department of Geography, Johannes-Gutenberg University, Mainz, Germany
[b] Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

ARTICLE INFO

Article history:
Received 5 February 2016
Received in revised form 30 August 2016
Accepted 7 September 2016
Available online 9 September 2016

ABSTRACT

Global warming is likely to increase the frequency and magnitude of heat waves. As the urban geometry and material amplifies warming, city dwellers will face an intensification of heat-induced health problems and mortality. Although increased vegetation cover is frequently used in urban planning to mitigate excessive heat, temporal variations, as well as the influence of synoptic weather conditions and surrounding urban geometry on the vegetation cooling effect, are still unclear. In this study, we monitored the transpiration-induced cooling from trees over two summers in five urban settings characterized by varying levels of greenness and urban geometry in the city of Mainz (Germany). Differences in air temperature and humidity patterns were compared with estimates of tree transpiration derived from high-resolution stem size and sap flow measurements. Results from the five urban sites indicate significant cooling due to transpiration, but with large variability depending on time of day and weather conditions. The cooling effect is strongest during periods of high transpiration demand, and in the stable nocturnal boundary layer when air mixing is limited. The strongest transpiration cooling was found in an enclosed courtyard structure. These findings reveal that a few trees can substantially mitigate urban excess heat, but that the urban geometry, time of the day, and prevailing weather conditions considerably modulate this effect.

© 2016 Elsevier GmbH. All rights reserved.

1. Introduction

Heat-related health problems and mortality are expected to rise, as global warming is projected to cause more frequent and stronger heat waves (IPCC, 2014). City dwellers in particular are at risk because of the urban heat island (UHI) effect, i.e. the intensified warming caused by altered land surface properties. These modifications include an increased thermal admittance of construction materials, the restricted radiative and advective cooling due to the urban geometry, and the lowered evapotranspiration-induced cooling due to sealed surfaces and limited vegetation coverage (e.g. Arnfield, 2003; Oke, 1987). The UHI effect is strongest at night, causing a lack of adequate nocturnal relief from heat stress for the urban inhabitants which has been linked to, for example, increased urban mortality during heat waves (Clarke, 1972; Conti et al., 2005). Appropriate urban planning is thus required to mitigate the warming effects in cities. One key approach used is to increase the abundance of vegetation (Bowler et al., 2011; Norton et al., 2015; Taha, 1997) which lowers temperatures and improves the human thermal comfort, particularly during heat waves (Harlan et al., 2006).

The cooling effect of vegetation includes shading and evapotranspiration (e.g. Bowler et al., 2011). Shading from urban trees reduces heating of surfaces and depends on the three dimensional shape and the degree of vegetation permeability to solar radiation (Konarska et al., 2014). While shading can considerably increase human comfort, its effect on air temperature (TA) appears limited (Oliveira et al., 2011). More efficient for TA is the cooling by transpiration, whereby the water that transpires during the process of photosynthesis transfers sensible heat into latent (Grimmond and Oke, 1991; Taha, 1997). Slightly lower air temperatures have been found over grassy urban surfaces than above concrete (e.g. Mueller and Day, 2005). Lower air temperatures above green roofs has also been found but effect is small and very variable (e.g. Wong et al., 2003) A review by Qiu et al. (2013) showed that transpiration, especially from taller vegetation in parks can reduce urban temperatures between 0.5 and 4 °C, with time and magnitude for maximum influence depending on park type, size, and climate. Hamada and Ohta (2010) also noted an important transpiration induced cooling from urban parks in summer, but stated that further studies are needed to clarify the physiological effects influencing the transpiration of urban vegetation. Street

* Corresponding author.
E-mail address: J.Linden@geo.uni-mainz.de (J. Lindén).

http://dx.doi.org/10.1016/j.ufug.2016.09.001
1618-8667/© 2016 Elsevier GmbH. All rights reserved.

trees were found to have very strong transpiration compared to urban trees in other settings in a study by Pataki et al. (2011), but the transpiration-induced cooling from isolated trees in streets and other urban settings remain largely unknown. The rate of transpiration generally increases with atmospheric evaporative demand (often expressed as the vapour pressure deficit, VPD, Eamus et al., 2013) and depends on water availability. The influence of VPD also depend on the wood anatomy where diffuse porous taxa showed a near linear increase in transpiration with VPD (Bush et al., 2008). By using high-resolution measurements of stem size changes, King et al. (2013) showed that both meteorological conditions and soil water availability impact the diurnal cycle of tree-water relations. However, these relations are only valid as long as enough water is available in the soils (Brodribb and Holbrook, 2004; Gao et al., 2002; Gindaba et al., 2004; Ma et al., 2004; Zweifel et al., 2001).

Although numerous studies of urban climate have shown that cooler places within the city are closely connected to an increased vegetation cover (Alavipanah et al., 2015; Fan et al., 2015; Harlan et al., 2006; Lindén, 2011; Middel et al., 2012; Norton et al., 2015), the diurnal variations as well as influence of changing weather conditions on the transpiration-induced cooling are still unclear. For example, cooling was strongest in the afternoon in irrigated parks and parks in humid climates (Jonsson, 2004; Potchter et al., 2006; Spronken-Smith and Oke, 1998). However, a review by (Bowler et al., 2011) showed that cooling from urban green spaces is in general slightly stronger at nighttime and nocturnal effects also dominated in non-irrigated parks in e.g. Ouagadougou, Sacramento, and Vancouver (Lindén, 2011; Spronken-Smith and Oke, 1998).

Here we evaluate the effectiveness of transpiration-induced cooling from trees by comparing urban climate among sites with contrasting greenness and urban geometry. In particular, we aim to (1) quantify differences in seasonal and diurnal patterns of temperature and humidity among urban sites, (2) link these differences to tree transpiration as derived from continuous measurements of sap flow (SF) and stem size variations, and (3) examine the influence of atmospheric evaporative demand and extreme drought stress on the transpiration-induced cooling processes.

2. Methods

2.1. Study sites

The study has been performed in the city of Mainz in Germany (50.0°N, 8.3°E, elevation 100 m.a.s.l, Fig. 1). Mainz is an inland city with approximately 200 000 inhabitants, located in a landscape of gently rolling hills on the western side of the Rhine River. The climate is temperate and humid with an annual average TA of 10.7 °C and precipitation of 620 mm. The summers are warm and humid (June to August: 19.2 °C and 175 mm, from 1981 to 2010, www.dwd.de). The city architecture has a compact midrise structure (Stewart and Oke, 2012) with smaller parks, grassy areas, and streets with scattered trees. Soil conditions for the urban sites are varying and heavily disturbed since most structures were built on top of the rubble from the second world war.

Five sites varying in vegetation cover and building structure were selected: one suburban park of sparsely built structure according to the local climate zone (LCZ) categorization (Stewart and Oke, 2012) as well as four urban sites with different levels of greenness (with and without trees) and architectural geometry (LCZ 2 and 5) were selected (Table 1). The sub-urban forested park (hereafter Park) was chosen as a site representative of high level of greenness. The two vegetated urban sites with some mature trees but with different geometry (a closed Courtyard and an open Garden) represent the urban structure of Mainz. These were both coupled with adjacent open and sparsely vegetated urban elements (a Street and a Square, Fig. 1). Information about area average sky view factor for each site was not possible to obtain in this study, and the sites are instead described in view of vegetation cover within 30 m of the center of the area, with surrounding building structure and activity described in text (Table 1). Land cover within a similar distance was found to be most important for microclimate differences by Konarska et al. (2016a,b). For the Park, Courtyard and Garden sites, *Platanus × acerifolia* was chosen for measurement of stem radius change and Sap Flow where available, with addition of two *Tilia platyphyllos* in the Park, and one *Acer platanoides* in the Garden (where only two *Platanus × acerifolia* were available). The trees in Mainz start foliating in the beginning of April and appeared fully foliated in the beginning of June when measurements of sap flow and stem radius were initiated. The canopies of *Platanus × acerifolia* were very dense with large leaves (around 300 cm^2) in the urban sites, especially in the courtyard where pruning had taken place in 2011, and less dense in the park where trees were allowed to grow freely. Canopies of *Tilia platyphyllos* were also dense, while *Acer platanoides* was less dense. 2013 and 2014 started out similar, but in 2013 the leaves started going partly brown in the beginning of August, likely due to the warmer and drier conditions this summer. Leaf area density was not measured in this study but has previously been found to vary between 0.3 and 0.5 for unpruned *Platanus × acerifolia* (Hipps et al., 2014). *Platanus × acerifolia* has in a previous study shown a near linear increase in transpiration with VPD (Bush et al., 2008).

2.2. Monitored parameters

Spatial and temporal variations in climate and tree transpiration were assessed at a temporal resolution of 30 min during different periods between June 2013 and February 2015 (Table 1). The measurements were performed over the full period at the Park site, but the coupled urban elements were monitored during only one summer, i.e. the Courtyard-Street in 2013 and the Garden-Square in 2014. However, the climate sensors have been kept running during the whole period in the Courtyard-Street sites and for one year in the Garden—Square sites to support comparisons of seasonal patterns.

The climate was monitored at all sites by measuring **TA** and relative humidity (HR) using HOBO U23-001 Pro v2 data loggers placed in RS1 solar radiation shields (Onset, Bourne, MA, USA), at a height of approximately 3 m to avoid vandalism. This type of sensor and shielding was found to be the most reliable in comparison to other types of shielding (Da Cunha, 2015). One sensor per site was used. As commonly found in urban areas, standard guidelines for placement of meteorological instruments was not possible to follow due to the complexity of the selected study sites, but recommendations in the WMO guidelines for urban climate studies (Oke, 2008) were carefully followed when selecting sensor placement to minimize any potential bias. Due to urban activity and traffic, posts for sensor installation could not be installed. Existing posts were of different size and material, and placed at varying distance from the walls and the HOBO-sensors were instead placed on tree stems or branches on the north side of the tree, where a free airflow around the sensor could be ensured (no leaves or dense branch structure nearby). This placement reduces the risk of temperature bias from nearby heated walls and other anthropogenic materials, and as the microclimate influence of trees is the focus of the study, any potential influence caused by differences in canopy geometry of the sensor trees was determined to be small and seen as part of the aim.

Prior to installation, a comparison among the sensors located in a well ventilated rooftop for 22 days (with TA ranging from −4 °C to 18 °C and HR from 30 to 100%) showed agreement with an average difference in TA $< \pm 0.08$ K ($<2\%$ exceeding ± 0.2 K), and in HR$<0.2\%$ ($<2\%$ exceeding 1%). These measurements were then used to derive

Download English Version:

https://daneshyari.com/en/article/6461909

Download Persian Version:

https://daneshyari.com/article/6461909

Daneshyari.com