EVIDENCE FOR THE TEMPERATURE-MITIGATING CAPACITY OF URBAN BLUE SPACE – A HEALTH GEOGRAPHIC PERSPECTIVE

Sebastian Völker, Hendrik Baumeister, Thomas Classen,
Claudia Hornberg and Thomas Kistemann

With 2 figures and 2 tables
Received 16. July 2013 · Accepted 03. December 2013

Summary: Climate change is regarded as one of the greatest challenges to cities in the future. Some proposals focus on incorporating urban green space to counter the rise in temperature and ensuing public health hazards. Urban blue spaces, defined as all surface waters within a city, are regarded as a possible factor for temperature mitigation, but effects have not been quantified and so remain underrepresented in research, recommendations for action and planning. A systematic review was conducted of studies quantifying the temperature-mitigating effects of urban blue compared to other urban sites (n=27). The studies included in the review measured air temperatures at various types of urban blue space such as ponds, lakes or rivers and compared them with reference sites at defined distances or to urban reference sites in the same city. The meta-analysis suggested that a cooling effect of 2.5 K (CI 95% 1.9-3.2 K, p<0.01) during the warmest months on northern hemisphere (between May and October) can be attributed to urban blue sites when including remote sensing data. However, research on the air temperature effects of urban blue space remains sparse compared to studies on urban green. The cooling effects clearly attributable to urban blue space are limited by surrounding environmental conditions like microclimate, urban development, wind velocity, wind turbulence, wind direction, temperature and humidity. Future research is needed to help planners use urban blue space efficiently as a temperature-mitigating and health protecting and promoting factor. The temperature-mitigating capacity of urban blue can potentially reduce heat stress in urban areas. To create healthy environments in the cities of the future, a better understanding of health affecting aspects of urban blue is needed to initiate public health action.

Zusammenfassung: Der Klimawandel wird bereits heute als eine der größten zukünftigen Herausforderungen für Städte angesehen. Um resultierende Temperaturerhöhungen und die damit verbundenen Risiken für die öffentliche Gesundheit abzumildern, fokussieren viele Handlungsempfehlungen auf die zunehmende Integration stadtgrüner Räume. Stadtblaue Räume, definiert als alle Oberflächengewässer innerhalb einer Stadt, sind als möglicher Faktor für eine Temperaturabmilderung bereits anerkannt. Ihre Wirkungen wurden bislang jedoch nicht in ausreichendem Maße quantifiziert und verbleiben daher in der aktuellen Forschung und Planungspraxis sowie Handlungsempfehlungen unterrepräsentiert. Folglich wurde ein systematisches Review durchgeführt, welches Studien einschloss, die Temperaturabmilderungseffekte zwischen stadtblauen und anderen urbanen Standorten quantitativ verglichen (n=27). Studien, die in das Review aufgenommen wurden, erfassten Lufttemperaturen in verschiedenen stadtblauen Räumen, wie z.B. an Teichen, Seen oder Flüssen, und verglichen diese mit Standorten in definierten Distanzen zum stadtblauen Raum oder zu einem urbanen Referenzstandort in der gleichen Stadt. Die Meta-Analyse deutet auf einen Kühlungseffekt von 2,5 K (CI 95% 1,9–3,2 K, p<0,01) während der wärmsten Monate auf der Nordhalbkugel (zwischen Mai und Oktober) hin, welcher auf stadtblaue Standorte zurückgeführt werden kann, wenn Fernerkundungsdaten mit einbezogen werden. Die Kühlungseffekte, die eindeutig auf stadtblaue Räume zurückzuführen sind, werden durch umgebende Umweltbedingungen, wie z.B. das Mikroklima, städtebauliche Entwicklung, Windgeschwindigkeit, -turbulenz, -richtung, Temperatur und Luftfeuchte, allerdings deutlich beeinflusst. Somit bedarf dieses Themengebiet dringend weiterer Forschung, um Planern einen effizienten Einbezug von stadtblauen Räumen zur Temperaturabmilderung und als gesundheitsschützender und -fördernder Faktor zu ermöglichen. Der Kühlungseffekt von Stadtblau kann Hitzestress im urbanen Umfeld reduzieren. Für die Schaffung gesunder Lebensumwelten in der Stadt der Zukunft müssen gesundheitsrelevante Wirkungen von Stadtblau näher untersucht werden, um geeignete Public Health Interventionen zu ermöglichen.

Keywords: Urban blue space, temperature mitigation, climate change adaption, heat stress, environmental health, water bodies, urban heat island

DOI: 10.3112/erdkunde.2013.04.05 ISSN 0014-0015 http://www.erdkunde.uni-bonn.de

1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), the average global temperature is expected to increase by between 1.8 and 4.0 K by the end of the 21st century. The impacts of climate change are perceptible in the form of varying weather patterns and extreme weather events, such as windstorms, heavy rainfall, floods, droughts and heatwaves (IPCC 2007). Heatwaves affect urban areas in particular and are often associated with a significant increase in total mortality (D'Ippoliti et al. 2010). Due to the great thermal mass made up of asphalt, bricks and concrete, the dark covers of streets and roofs, low evapotranspiration, heat output by industry, households and motor vehicles, as well as the low ventilation capacity of areas with buildings, ambient air temperatures in an urban area can be 4–5 K higher than in adjacent rural areas, forming an "Urban Heat Island" (UHI) under specific conditions (Arnfield 2003; Oke 1987).

Extreme hot weather events and heatwaves represent a growing public health challenge due to increased heat-related mortality, which contributes to the global burden of disease (EEA 2012; Kováts and Hajat 2008; Comrie 2007). According to an estimated increase of mortality by 2–3% per 1 K increase in apparent temperature (Michelozzi et al. 2007), the observed mortality on heatwave days increased in European cities significantly (from 7.6% in Munich to 33.6% in Milan) (D'Ippoliti et al. 2010; Michelozzi et al. 2007). The severe heatwave that occurred in Europe in the summer of 2003 was accountable for an excess mortality estimated as varying between 25,000 and 70,000 premature deaths (Robine et al. 2008; WHO and WMO 2012).

Hot weather and heatwaves compromise everybody's comfort, well-being and, eventually, health (Smith and Levermore 2008). The human organism constantly balances individual energy heat loss and keeps the body's core temperature within the regular range of 36.1–37.8 °C. The thermal budget is strongly affected by electromagnetic waves from the sun, convection in the surrounding air and evaporation of sweat. Even a temperature rise of less than 1 K triggers a strong regulation mechanism by sweating and increasing skin perfusion. However, these thermal regulation mechanisms are stressful to the organism, especially to the cardiovascular system. Hence, excessive heat exposure can result in massive health problems varying from moderate heat rashes, heat exhaustion and heat cramps up to life-threatening heatstrokes (Kjellstrom et al. 2010; WHO 2008). Some factors in particular are specifically associated with overall morbidity and mortality during heat waves, including age, gender, premorbidity, socio-economic status and interdependencies with clinical and pathophysical factors (EEA 2012; Pauli and Hornberg 2010; Kováts and Hajat 2008; WHO 2008). Elderly people are the largest group in the vulnerable population because ageing decreases tolerance to heat. A delayed perception of thirst and a reduced sweating capacity lead to a high vulnerability amongst elderly living without care and air conditioning. The health of elderly people is further impaired by co-morbidity, physical and cognitive impairment and multiple medications (D'Ippoliti et al. 2010; Hajat et al. 2010). Infants and children, because their metabolism is not yet as efficient as that of adults, people with chronic diseases, people taking medication that affects their body's mechanisms of thermoregulation, socioeconomically deprived people, and people in occupations with heavy outdoor activity levels are also strongly affected by high temperatures (WHO 2008).

It is therefore of the utmost importance for city planners and health professionals to develop and evaluate strategies for the mitigation and adaption of climate change, particularly in urban areas (Rydin et al. 2012; Smith and Levermore 2008). Hence the distribution of the UHI effect is positively correlated with the dimensions, density and design of cities (Arnfield 2003; Oke 1987). An adaptation strategy to cool towns and cities tends to lead to 'greening' urban areas (Bowler et al. 2010a). Urban green has a high potential to ameliorate urban climate by shading, the evapotranspiration of leaves and providing areas and surfaces for water evaporation (Givoni 1991; Taha et al. 1988). Evidence of the cooling capacity of urban green being strong enough to cool down the environment on a local scale is summarised in the literature review performed by Bowler et al. (2010b). Their meta-analysis suggests a cooling effect of vegetation in urban parks by 1 K on average compared to non-green areas and reflects the results of recent studies (Li et al. 2011; Oliveira et al. 2011; Peng et al. 2012).

Studies on temperature-mitigation are performed using different research methods. Researchers make use of remote sensing data to estimate the surface temperatures of different land covers in an urban area. Remotely sensed surface temperature represents "an indirect measurement requiring consideration of the intervening atmosphere and the surface radiative properties that influence the emission and reflection of radiation within the spectral wavelengths detected by the sensor" (Voogt and Oke 2003, 372). Voogt and Oke (2003) define necessary steps for estimating temperatures: the calculation of the directional brightness temperature, the application of atmospheric effects corrections, i.e. pressure, temperature and humidity, the application of the emissivity of surface materials and the calculation of the directional radiometric temperature. Finally, not all surfaces are viewed by the remote sensor, so that a correction needs to be added, providing predictive data on parts of the land surface. A recent study identified another important limitation as it calculated an overestimation of temperatures during daytime and underestimation during night-time for remote sensing data compared to on-site measurement data (Mohan et al. 2013). Deriving data empirically from on-site measurements, normally at ground level, is conducted using calibrated thermometers either at fixed stations or with mobile devices and need standardised measurement procedures at the various locations (WMO 2010). Computer simulations and mathematical models are predictive tools for i.e. assess potential effects of interventions on urban climate (Fröhlich and Matzarakis 2012; Spronken-Smith and Oke 1999).

The used methods also implicate the use of different scales. Remote sensing data normally refer to larger scaled areas, whereas data from on-site measurements can provide data on specific local scale conditions, due to considerable expenditures in comparison (WMO 2010). These constraints have to be taken into account. In our review we included studies on remote sensing and empirically on-site measurement data to test for direct influences of urban blue spaces on ambient air temperatures. The advantage of using results from both methods is the triangulation for method and scale to derive a more sophisticated view on temperature-mitigating effects of urban blue.

Although research on the cooling capacity of parks, vegetation and vegetated areas has clearly established the heat attenuation effect of urban green by shading, transpiration and evapotranspiration, a closer look at the studies gives a rather undifferentiated picture of green areas. It is not completely evident how far the measured cooling effects can really be attributed to green areas; e.g. some studies refer to green areas as a whole without clearly characterising spatial structures (i.e. the relationship between trees, lawns and paved surfaces) and landscape elements like water bodies or fountains (Almendros Coca 1992; Chang et al. 2007; Makhelouf 2009). In other studies, the measuring points were not explicitly set, so that the effects cannot be assigned precisely to green areas or water bodies (Jáuregui 1990; Robitu et al. 2006). However, water bodies in particular are supposed to contribute to cooling down the surrounding air through evaporation (Oke 1987) and convection (Spronken-Smith et al. 2000). This provided the central question of this study: What is the cooling capacity of urban blue space?

Coutts et al. (2012) published a first compilation of studies regarding the cooling capacity of water bodies and their influence on urban climate, but their paper only discusses the capacity for water-sensitive urban design (WSUD). A systematic review was therefore conducted on the empirical evidence for the temperature-mitigating capacity of urban blue space. For our research we define urban blue as all kinds of surface water bodies in an urban area, both running (i.e. rivers, canals, streams) and standing water bodies (i.e. lakes, reservoirs, ponds). This also included wetlands and seashore lines within urban areas (Völker and Kistemann 2011; 2013).

2 Methods

A systematic review was performed to collect the best available evidence in current literature (Fig. 1) with the aim of descriptively summarising the findings in a meta-analysis and critically assessing the methods used for the studies (Petticrew and Roberts 2008). Systematic reviews are regularly applied in health research contexts and aim to compile an at most unbiased fundament of existing literature relevant to a research question. The statistical analysis in a meta-analysis can combine the results in included studies to possibly identify general patterns (Higgins and Green 2008). Before doing the literature search, subjects, interventions, outcomes and comparative sites were defined following the review on urban green by Bowler et al. (2010b). Relevant subjects were temperature measurements in urban areas throughout the world. The creation or presence of urban blue space constituted relevant interventions, the outcome was defined as a quantitative measurement of temperature. For this review comparable sites were 1) urban areas with urban blue space compared to surrounding urban areas without urban blue space; 2) the comparison of urban areas before and after the creation of urban blue space; or 3) urban blue space compared to surrounding urban green. In the following the comparative site is labelled as "urban site".

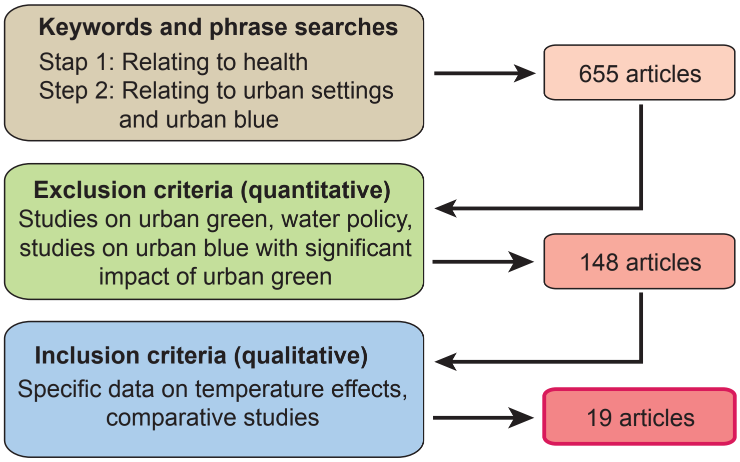

Fig. 1: Methodological steps of the systematic review and number of papers found after each step

In a comprehensive search we used relevant electronic search engines (PubMed, ISI Web of Knowledge, Science Direct) and relevant journals (Theoretical and Applied Climatology, International Journal of Climatology) to search for predefined keywords and phrases (Tab. 1). The search also included the reference lists of papers included in the study and papers written by key authors and organisations dealing with urban climate. The predefined quantitative exclusion criteria were then used to exclude all studies dealing with water policy (Deak and Bucht 2011; Nakayama and Hashimoto 2011; Takahashi et al. 2010; Walker et al. 2012) and urban green space (Bowler et al. 2010b; Oliveira et al. 2011; Upmanis et al. 1998), as well as studies not clearly differentiating urban green and urban blue space (Jáuregui 1990; Mahmoud 2011; Robitu et al. 2006).

The papers identified by the quantitative search were then screened using qualitative inclusion criteria. In order to meet these, studies were required to have measured temperature at least at ground level (air temperature at up to 2 m height or surface temperature) in an urban area and to compare temperatures at an urban blue site with a non-urban blue site. The latter was further used as a criterion for the meta-analysis. Papers on urban blue space with significant influence of urban green (Martin et al. 2012; Martínez-Arroyo and Jáuregui 2000; Wong et al. 2011) or studies modelling temperature (Fröhlich and Matzarakis 2012; Nakayama and Hashimoto 2011; Robitu et al. 2006; Spronken-Smith and Oke 1999) were not included in the review. All papers were entered into a matrix and classified by bibliographic parameters (author, title, year, journal), study site, climatic classification (Lauer and Frankenberg 1988; Lauer et al. 1996), setting scale, method, investigation period, concept/experiment design, general results, specific effects of urban blue space on temperature and, where given, the size and type of urban blue investigated.

For the meta-analysis, data from the papers was used to calculate the temperature effects of urban blue compared to non-urban blue sites. The temperature difference ΔT (=effect size) was calculated using the method proposed by Bowler et al. (2010b), which is the median of the differences in K between urban blue and non-blue urban areas:

$$\Delta T = T_{urban} - T_{blue}$$

This measure can provide a good overview of the temperature-mitigating effect size referred to urban blue space according to the different studies. The measurements of T_{urban} and T_{blue} should ideally be taken at the same time. In studies having more than two sampling points (one urban site, one urban blue site), the average temperature for all urban blue sites and the average for all urban sites were calculated. In the case of multiple points or time frames of measurements, the median of all sampling points at the urban blue site was compared to the median of all sampling points at the urban site and ΔT was calculated. If the data was obtained during different seasons, data of the warmest months on northern hemisphere (all months between May and October) was chosen for better comparability. The ΔT variation between studies was shown by indicating the minima and maxima alongside the median. Due to a lack of explicit data in the data presented in the papers confidence intervals could not be calculated for

Tab. 1: Keywords used in the search engines to identify papers relevant to temperature mitigation caused by urban blue

Keywords used for the thematic aspects:		
Climate	**Urban area**	**Urban blue space**
air, heating, cooling, evaporation, humidity, humidness, moisture, temperature, microclimate, thermal environment, urban heat island effect, heat wave, urban climate	city, urban, town, township, quarter, ward	creek, fountain, lake, pond, pool, river, stream, water

each ΔT. A paired t test was performed to underline the significance of all studies providing data for T_{urban} and T_{blue} using IBM® SPSS® Statistics 20 (n=18). Also included were possible confounders for variation in respect to climate zone (differences between Lauer/Frankenberg climate zones, e.g., tropical vs. subtropical (Lauer et al. 1996)), setting scale (size of the study area, e.g. region versus urban quarter), types of urban blue space (different size and appearance, e.g. river vs. pond), study design (longitudinal vs. cross-sectional) and method (on-site measurements vs. remote sensing data).

3 Results

In total we found 19 articles comprising 27 different studies on temperature effects of an urban blue site compared to an urban reference site (Tab. 2). Each study investigated one type of urban blue.

Regarding the geographical spread of studies (all from the northern hemisphere), most were conducted in East Asia (22 studies, 81%: China 12, Japan 8, South Korea 2). 4 studies (15%) were located in Europe and one (4%) in North America. This is also reflected by the climates of the countries where the studies were conducted. Four studies (15%) were conducted in warm moderate maritime, 20 (74%) in a subtropical climate (18 (67%) of these in a continental, 2 (7%) in maritime subtropical climate), and 3 (11%) in tropical climate.

The different setting scales used in the studies were addressed by defining a macro-, meso- and micro-scale. The macro-scale comprised studies done on a regional or entirely urban level, the meso-scale was defined as an urban district or quarter and micro-scale studies were defined as a park or square research level. Most of the studies were conducted on a meso-scale (n=14; 52%), 9 (33%) on the macro-scale and 4 (15%) on the micro-scale level. The majority of the studies had a cross-sectional study design (n=22; 81%), which dealt with specific points in time during the year, typically one or two days, only 5 studies (19%) showed longitudinal design and considered the temperature effects, i.e. during a seasonal period.

Regarding the method of retrieving temperature data, two ways of measurement were isolated: via on-site measurement (n=18; 67%) with measurements of the air temperature with mobile or static devices at the study sites or at specific distances, or via remote sensing (n=9; 33%), which used mainly satellite data to calculate surface temperatures.

To summarise different types of urban blue space on comparable scales, the following types were defined: "ocean", comprising oceans, seas and shorelines; "river", comprising rivers, canals and streams; "lake", comprising lakes and reservoirs; and "pond", comprising ponds and fish ponds.

3.1 Synthesis of the evidence

The calculated effect size, ΔT resulted from the average temperatures measured in each study (Tab. 2). Studies with on-site measurements merged the data of one or more days containing daytime and night-time measurements. The ΔT was usually positive (urban blue sites were relatively cool) during the day around the highest ambient temperatures of the city, and negative (urban blue sites were relatively warm) during the night. This is due to the specific heat, which is greater for water than for any other material, so that water cools more slowly during the night than other urban materials like concrete (Li et al. 2011; Sun and Chen 2012).

All studies found a cooling effect for urban blue space during the warmest months on northern hemisphere, particularly during heat events. If indicated in the studies, the daytime and night-time temperature effect was used for calculation (Tab. 2). The ΔT for each study ranged from 0.4 K (minimum) to 5.6 K (maximum). Calculating the median ΔT for all studies (n=27), a cooling effect of 2.5 K was found

Tab. 2: Characteristics of studies included in the review, which investigated temperature effects of urban blue compared to an urban reference site. If more than one study is presented in one article, each study in the article is assigned to a specific study abbreviation. ΔT is the median of the differences in K between urban blue and non-blue urban areas: $\Delta T = T_{urban} - T_{blue}$

No.	Author	Publication year	Study Abbr.	Study site	Climatic classification[1]	Setting scale
1	Chen et al.	2006	WB	Pearl River Delta, China	A2sh - Tropical warm semi-humid	Macro-scale
2	Chen et al.	2006	FPB	Pearl River Delta, China	A2sh - Tropical warm semi-humid	Macro-scale
3	Chen et al.	2009		Guangzhou, China	A2sh - Tropical warm semi-humid	Micro-scale
4	Han et al.	2011		Wuhan, China	B2h - Subtropical continental humid	Meso-scale
5	Hathway and Sharples	2012		Sheffield, United Kingdom	C_I3sh - Maritime warm moderate semi-humid	Meso-scale
6	Hou et al.	2009		Beijing, China	B2sh - Subtropical continental semi-humid	Macro-scale
7	Hou et al.	2013		Beijing, China	B2sh - Subtropical continental semi-humid	Macro-scale
8	Huang et al.	2008a		Nanjing, China	B2h - Subtropical continental humid	Meso-scale
9	Huang et al.	2008b		Nanjing, China	B2h - Subtropical continental humid	Meso-scale
10	Ishii et al.	1991	WP	Fukuoka, Japan	B2h - Subtropical continental humid	Micro-scale
11	Ishii et al.	1991	WU	Fukuoka, Japan	B2h - Subtropical continental humid	Meso-scale
12	Kim et al.	2008	SD	Seoul, South Korea	B2h - Subtropical continental humid	Meso-scale
13	Kim et al.	2008	SFD	Seoul, South Korea	B2h - Subtropical continental humid	Meso-scale
14	Li et al.	2011		Shanghai, China	B2h - Subtropical continental humid	Macro-scale

Urban blue site and reference site	**Investigation period**	**Daytime / Night-time**	**Methods**	**Experi-mental design**	**ΔT of urban blue [K]**
Water *compared to* built-up area	6 days throughout year	n/a	Remote sensing (RS)	Cross-sectional (CS)	3.17
Fish ponds *compared to* built-up area	6 days throughout year	n/a	RS	CS	2.58
Pond *compared to* built-up area	1 day July	Daytime (DT)	On-site measure-ment (OS)	CS	1.3
Urban river *compared to* urban block	Two days summer	DT	OS	CS	2
Urban river *compared to* urban site	Two periods May and June-July	DT	OS	CS	1.26
Urban wetlands *compared to* urban region	3 dates May/June	DT	RS	CS	5.63
Urban wetlands *compared to* residential area	1 date May	DT	RS	CS	4.83
Urban lake *compared to* city centre	July-September	DT & night-time (NT)	OS	Longitu-dinal (L)	0.9
Urban lake *compared to* city centre	July-September	DT & NT	OS	CS	0.9
Pond in park *compared to* the same park without pond	2 days in August	DT	OS	CS	0.4
1) Park with pond, 2) park without pond *compared to* built-up residential area	2 days in August	DT	OS	CS	1.16
Restored downtown stream on surface *compared to* downtown area with stream in canal	Summer	DT	OS	L	0.6
Restored downtown stream on surface *ompared to* downtown area in 200 m distance	Summer	DT	OS	L	1
Water areas *compared to* urban areas	1 date March, 1 date June	n/a	RS	CS	0.95

No.	Author	Publication year	Study Abbr.	Study site	Climatic classification[1]	Setting scale
15	Lopes et al.	2011	SLFU	Funchal, Portugal	B3sh - Subtropical maritime semi-humid	Meso-scale
16	Lopes et al.	2011	SLNU	Funchal, Portugal	B3sh - Subtropical maritime semi-humid	Meso-scale
17	Murakawa et al.	1991	CUD	Hiroshima, Japan	B2h - Subtropical continental humid	Meso-scale
18	Murakawa et al.	1991	RUD	Hiroshima, Japan	B2h - Subtropical continental humid	Meso-scale
19	Murakawa et al.	1991	RU	Hiroshima, Japan	B2h - Subtropical continental humid	Meso-scale
20	Nishimura et al.	1998	WP	Osaka, Japan	B2h - Subtropical continental humid	Micro-scale
21	Nishimura et al.	1998	WFP	Osaka, Japan	B2h - Subtropical continental humid	Micro-scale
22	Schwarz et al.	2012		Leipzig, Germany	C_I3sh - Maritime warm moderate semi-humid	Meso-scale
23	Shudo et al.	1997		Western Hokkaido Island, Japan	C_I2h - Maritime warm moderate humid	Macro-scale
24	Sun and Chen	2012		Beijing, China	B2sh - Subtropical continental semi-humid	Macro-scale
25	Sun et al.	2012	LB	Beijing, China	B2sh - Subtropical continental semi-humid	Macro-scale
26	Sun et al.	2012	RB	Beijing, China	B2sh - Subtropical continental semi-humid	Macro-scale
27	Tuller	1995		Victoria, Canada	C_I3h - Maritime warm moderate humid	Meso-scale

[1]) Climate classification after Lauer/Frankenberg is used (Lauer and Frankenberg 1988; Lauer et al. 1996). Other climate classifications lead to different classifications for individual locations, e.g. Beijing and Seoul represent critical cases, which are classified as cold moderate (III 7) by Troll/Paffen or moderate east coast (III 5) by Neef/Flohn.

for urban blue space. Using the paired t test the alternate hypothesis can be assumed. That means the sample averages of T_{urban} and T_{blue} date to different populations (ΔT=2.6 K, CI 95% 1.9-3.2 K, p<0.01, n=18).

Regarding the effect of different climate zones on temperature mitigation by urban blue space (Fig. 2), the strongest effect was observed in tropical climates. Studies in this climate zone found a cooling effect of 2.6 K. The difference in cooling effect of urban blue space between the highest median effectiveness (tropical climate) and the lowest median effectiveness (maritime, warm moderate climate) was only 0.7 K, to a rather narrow median ΔT range.

Regarding different urban blue types, wetlands showed the strongest effect (ΔT=5.2 K, min=4.8 K, max=5.6 K, n=2) and ponds the least (ΔT=1.6 K, min=0.4 K, max=4.7 K, n=6). However, the num-

Urban blue site and reference site	Investigation period	Daytime / Night-time	Methods	Experi-mental design	ΔT of urban blue [K]
Shore line *compared to* urban valley bottom in 780m distance	10 days June and August, 4 days September	DT	OS	CS	1.95
Shore line *compared to* urban area near shoreline in 75m distance	10 days June and August, 4 days September	DT	OS	CS	3.08
Urban channel *compared to* urban quarter in 400m distance	2 dates July, 2 dates September	DT & NT	OS	CS	2.54
Urban river *compared to* urban quarter in 400m distance	2 dates July, 2 dates September	DT & NT	OS	CS	2.1
Urban river *compared to* urban quarter	Whole year (14 months)	DT	OS	L	4
Water pond without fountain *compared to* park	1 day in summer	DT & NT	OS	CS	1.8
Water pond with fountain *compared to* park	1 day in summer	DT & NT	OS	CS	4.7
Water *compared to* urban area	2 days in summer	DT	RS	CS	2.5
Water (inland waters, seashore, seas) *compared to* all other land uses (man-made, agricultural, woods and forests)	Whole year (June-July)	n/a	RS, OS	L	0.5
Water bodies (excluding rivers and canals) *compared to* built-up land	1 day in summer	DT	RS	CS	3.37
Lakes/reservoirs *compared to* built-up area	1 day in summer	DT	RS	CS	3.63
Rivers/canals *compared to* built-up area	1 day in summer	DT	RS	CS	3.3
Urban waterfront *compared to* varying urban inland sites	16 days July-September	DT	OS	CS	5.4

ber of studies for wetlands was extremely low, which makes it difficult to compare ΔTs. Rivers showed a ΔT of 2.1 K (min=0.6 K, max=4 K, n=8), the unspecified urban blue space type "water" 2.5 K (min=0.5 K, max=3.4 K, n=5). Although oceans showed a lower ΔT (ΔT=3.1 K, min=2 K, max=5.4 K, n=3) than did lakes (ΔT=3.5 K, min=0.9 K, max=3.6 K, n=3), the range of ΔT indicated the higher effectiveness of oceans.

Remote sensing data yielded a higher average cooling effect (ΔT=3.3 K, min=1 K, max=5.6 K, n=9) than did on-site measurements (ΔT=1.9 K, min=0.4 K, max=5.4 K, n=18). Longitudinal study designs (ΔT=0.9 K, min=0.5 K, max=4 K, n=5) did not show as strong a cooling effect as cross-sectional studies (ΔT=2.6 K, min=0.4 K, max=5.6 K, n=22). One explanation was the inclusion of non-summer seasonal temperature data. Urban blue space cools

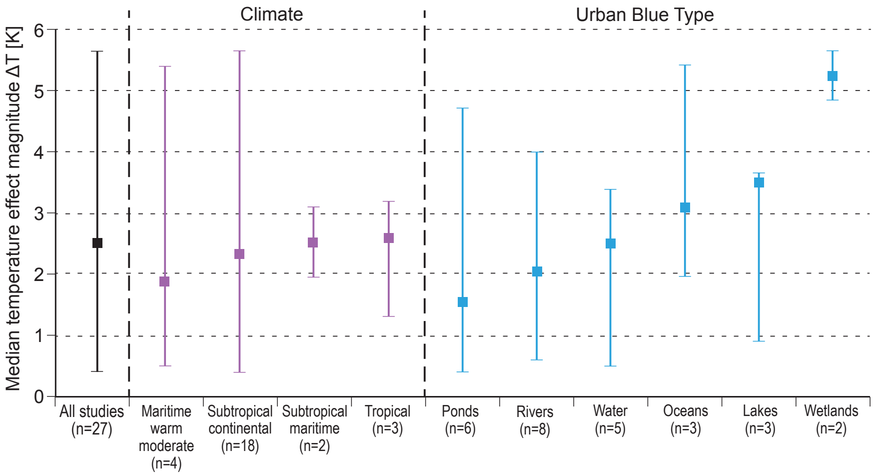

Fig. 2: Temperature mitigation effects of urban blue according to different target dimensions and subdimensions. The median temperature effect magnitude ΔT is calculated with the subtraction of urban blue temperature from the urban reference site ($T_{urban} - T_{blue}$). Therefore, a positive ΔT value in K indicates a cooling effect of urban blue. The squares represent the median, the upper and lower dots the maximum and the minimum of each category, respectively

the ambient air temperature in summertime on every scale, but the general trend was a decline from the macro (ΔT=3.3 K, min=0.5 K, max=5.6 K, n=9) over the meso (ΔT=2.1 K, min=0.6 K, max=5.4 K, n=14) and the micro-scale (ΔT=1.6 K, min=0.4 K, max=4.7 K, n=4). The studies assigned to the macro-scale were identical to the studies using remote sensing data.

4 Discussion

4.1 Determinants of the temperature mitigation capacity of urban blue space – strength of evidence

This review was undertaken to compile current evidence for temperature mitigation effects of urban blue space as a possible support for the reduction of UHI and heat stress. All the papers analysed reported a reduction of temperature at urban blue compared to urban reference sites.

However, there are still far fewer studies on urban blue than on urban green. It was therefore necessary to use the median ΔT rather than an arithmetic mean. The results of the studies were sometimes given as figures or graphs from which the data had to be extracted. Some studies had no urban reference sites, making it necessary to assign an urban reference site in the study data; i.e. Murakawa et al. (1991) measured the distribution of air temperatures at defined distances from two rivers. Although not explicitly mentioned, the farthest point of measurement represented the central part of the city, which was taken as the urban reference site. Other reference sites contained non-urban sites (Ishii et al. 1991; Nishimura et al. 1998; Shudo et al. 1997), so that the cooling effects are expected to be higher if all non-urban confounders are adjusted for. In all studies, except Hathway and Sharples (2012), no significance for ΔT was calculated. Hathway and Sharples (2012) found ΔT to be significant, above all for periods with temperatures above 20 °C.

There are multiple determinants for the temperature mitigation effects of urban blue space. Environmental conditions from neighbouring areas like wind velocity, wind turbulence, wind direction, temperature and humidity affect the cooling range of urban blue space (Chen et al. 2009; Murakawa et al. 1991; Nishimura et al. 1998; Robitu et al. 2006). Due to differences in climatic conditions, setting scales, study designs, measurement methods and types of urban blue, we conceive that the studies are not entirely comparable to each other. Compared to the review on the temperature mitigation effects of green space (Bowler et al. 2010b), a classification of blue space to date does not seem appropriate because only a few studies address this issue.

The effect size of data retrieved by remote sensing is higher than that drawn from on-site measurements, because remote sensing measures surface temperature, including such surfaces as the centre of a large lake, where temperatures are not affected as much by the surrounding area as at the edge of the lake, and urban areas with concrete surfaces are known to have a much higher capacity for heat absorption (Spronken-Smith et al. 2000). Additionally, on-site measurements indicate the temperature during a whole day (including the night). Studies using remote sensing methods concentrated on daytime measurements, often just at a specific time like 12:00 a.m., which is supposed to be the time when water reaches a high cooling capacity. This might also be the reason why ΔT derived from remote sensing data was higher than that derived from on-site measurements. Furthermore, remote sensing measures temperatures from places where people normally do not go or which they cannot reach during their everyday activities, and so cannot experience directly, thus reducing the usefulness such measuring points have for humans and human health.

The location of the reference site compared to the urban blue site strongly influences the effect size of urban blue space found by the meta-analysis. Nishimura et al. (1998) chose a location 60 m from a fountain within a park as a reference site, whereas Huang et al. (2008a, b) chose the city centre.

Comparable study conditions differed considerably, making it hard to eliminate confounders. Most of the studies were done in subtropical climates in Southeast Asia. Evidence for the cooling capacity of urban blue space in other climates and regions of the world remains weak. While the extrapolation of temperature mitigation by urban blue space from Southeast Asian climates to climates of for example, the Mediterranean is partly possible, conclusive data is yet to be found.

Most of the studies were conducted during the warmest months on northern hemisphere (between May and October). For this review, this distortion was accepted by only retrieving summer data even if the study also reported effects from other seasons. Due to the lack of research on effects of urban blue space on temperature in other seasons (i.e., winter), only summer data was deemed suitable for the meta-analysis.

Weather conditions sometimes differed greatly from day to day regarding ambient air temperature, wind speed, wind direction, humidity, cloudiness, etc. This affected not only comparability between studies, but also data within a study. Although the studies chosen did not compare the absolute temperatures of one day to another but temperature differences of an urban blue to a nearby reference site, different weather conditions could influence effect magnitude. Hathway and Sharples (2012) could clearly identify the effect size of urban blue space as being stronger on days with higher temperatures, summarised in "consecutive periods >20 °C" (Hathway and Sharples 2012, 19).

On the micro-scale, water is very stable under current weather conditions compared to concrete or lawn (Huang et al. 2008a) due to its greater thermal capacity (Hou et al. 2013), but other conditions also influence the effectiveness of urban water. ΔT is highly related to current radiation conditions. The cooling effects of urban blue space depend on how radiant energy separates into heat fluxes (Sun and Chen 2012). With increasing global solar radiation, the temperature deviation between water and urban areas is stronger (Ishii et al. 1991).

Wind speed and direction are important in spreading the cooling effect of urban blue space. Wind conditions can produce different patterns of temperature distribution, as can urban morphology (Kim et al. 2008). Urban streets that run downwind or a public square on the edge of urban blue space have better thermal conditions than do obstructive streets (Han et al. 2011; Hathway and Sharples 2012). Some studies did not consider the spread of the cooling effect from water due to the wind field or the surface character. Ishii et al. (1991) found lower temperatures on the leeward sector of urban blue space. Hathway and Sharples (2012) emphasized the importance of open spaces near urban blue sites for temperature distribution compared to enclosed or obstructive streets.

Murakawa et al. (1991) pointed out that the horizontal influence of urban blue space on the microclimate depends on the building density and the width of rivers and streets. Due to the often limited number of urban blue spaces in a city, this horizontal efficacy of cooling capacity is important. In the leeward direction of a 127,000 m² pond in Fukuoka, Japan, Ishii et al. (1991) found an influence on the surrounding areas up to a distance of 400 m. Using remote sensing data, Hou et al. (2009) calculated the mean of the maximum regulation distance of urban wetlands for the city of Beijing, China, which amounted to 267.34 m. In a later follow-up study, Hou et al. (2013) identified a 300 m milestone up to which the influence of wetlands was significant. In streets up to 100 m wide and facing a river, Murakawa et al. (1991) observed horizontal cooling from urban blue space up to a distance of 400 m. In narrower streets (10 m wide) with heavy traffic, the horizontal cooling did not reach farther than 50–150 m.

Shading of urban blue sites by trees produces lower temperatures and improves the thermal environment (Hathway and Sharples 2012; Li et al. 2011; Robitu et al. 2006). The misting of water is effective for cooling as well. Nishimura et al. (1998) examined the effects of a fountain in a park in Osaka

(Japan). They observed a significantly higher cooling effect when the fountain was turned on rather than off, above all in the leeward direction (1.8 K compared to 4.7 K).

Not all these determinants were considered in every study, researchers often only focused on those relevant to their specific research question. The complex interaction of temperature mitigation effectiveness of urban blue spaces still needs to be more thoroughly investigated.

Only two papers directly attributed thermal influence to urban blue space. Ishii et al. (1991) examined the thermal environment of a pond in the central park of Fukuoka, Japan, and could benefit from a governmental project to clean the sludge out of a pond, which induced a complete drainage. They then conducted studies in the period when the pond was drained and in the period the pool was re-filled with water. The temperatures of the water-drained case and the water-filled case were compared to urban reference sites, calculating an effect size. The subtraction of the effect sizes of water-filled and water-drained cases resulted in the isolated, absolute thermal effects of urban blue without urban green. On average, the temperature in the park with water was 0.4 K cooler than without it. Compared to the temperatures of the surrounding residential area, the park with water was 1.2 K cooler than that without.

In Seoul (South Korea), Kim et al. (2008) conducted a similar study where a channelled stream was to be restored in the central district. In this place, the UHI was normally the most intensive. Temperatures in the area were measured before, during and after the restoration of the stream over three years during August in comparison to an urban reference site. The distribution of calculated effect sizes in the central district before and after restoration could lead to a quantitative stream effect size. After restoration, the urban district was on the average 0.6 K cooler and 1 K cooler compared to the urban area 200 m distant.

To get further insights into the effect of blue spaces on ambient air temperature, research needs to focus on factors like size, depth, width, etc. This also includes considering only blue spaces without confounding green spaces. This would require a design like those used by Ishii et al. (1991) and Kim et al. (2008). The comparison of the same urban site with and without an urban blue site seems to yield the most reliable results. The impact of temperature influencing surroundings, like urban form, green space etc., is addressed in some studies (Chen et al. 2009; Hathway and Sharples 2012; Huang et al. 2008a; Katayama et al. 1991; Li et al. 2011; Schwarz et al. 2012; Sun et al. 2012), but further research is needed to derive reliable recommendations for action or instructions for urban planning and public health actors.

We propose to investigate the impact of urban blue space on urban climate in other regions of the world, such as Europe, Africa, Australia or the Americas. Due to the low number of studies originating from these regions, the temperature effects are not precisely researched. This could also solve the problem that most of the studies were conducted in a subtropical climate. Taking other regions of the world into account would also allow for investigation of variation in different climate zones. The macroscale research levels were mainly performed using remote-sensing data. In order to give improved, evidence-based answers to the effect of urban blue space, on-site measurement studies on larger scales are necessary.

Above all, under weather conditions with higher ambient air temperatures, as in an UHI, urban blue space can produce high cooling rates. In their meta-analysis of 74 papers on the temperature effects of urban green areas, Bowler et al. (2010b) found a cooling effect of 1 K. Urban blue space seems to have a higher cooling effect on ambient air temperature than urban green (ΔT=2.5 K, n=27). Even focusing on data drawn from on-site measurements while disregarding remote sensing data, which show a higher ΔT, a stronger effect is found (ΔT=1.9 K, min=0.4 K, max=5.4 K, n=18). The paired t test for n=12 on-site measurement studies providing T_{urban} and T_{blue} showed a CI 95% between 1.6 and 3.3 K ($p<0.01$). Although the data basis for the calculation of ΔT is limited, the narrow CI 95% with the very high significance, the assumption of the alternate hypothesis in the paired t test and ΔT support the assumption that urban blue space might have a greater cooling effect than urban green.

The most obvious environmental health impact is caused by temperature extremes of heat and cold. Ambient air temperatures are an important measure to depict health risks caused by urban climate (i.e. Human Thermal Comfort (HTC), Heat Stress Index (HIS), Physiological Equivalent Temperature (PET)). Although the ability of the human body to radiate heat is dependent on the ambient temperature, indices with additional factors like humidity or wind chill describe environmental stress much more accurately. Indices like the HTC or temperature humidity are commonly used by medical scientists. The strongest associations between heat and increased mortality emerge within regions where heatwaves are rare and from people with predisposing factors like cardiovascular disease (Jendritzky 1993; Meade and Earickson 2005; Robine et al. 2008).

4.2 Implications

Extreme weather events like heatwaves can cause severe stress for urban dwellers, particularly for vulnerable groups like the elderly or children. Our review provides evidence for possible interventions in urban areas. The creation, maintenance and the reshape of urban blue can result in lower stress in extreme heat exposition times and consequently can enhance human health in urban areas. Urban blue is important for the local urban climate, due to its evaporation processes consuming thermal energy from ambient air. This causes a reduction of environmental temperature especially in warmer periods. Integrating higher amounts of urban blue in a city can increase humidity and attain cooling effects. The redesign of urban blue space, i.e. reshaping water bodies or installing water dispensing facilities, can increase this effect (MUNLV NRW 2010). Additionally, as shown in some studies and not particularly considered in this review, water also has temperature-mitigating effects in winter, when surface water is warmer in relation to ambient air temperatures (i.e. Murakawa et al. 1991; Shudo et al. 1997).

Due to the difficulty of introducing and maintaining water bodies within a city, the construction of urban green seems to be an easier way of mitigating climate change effects, but the combination of urban blue and urban green space seems to feature the highest potential (Hathway and Sharples 2012; Li et al. 2011; Robitu et al. 2006). New green areas with water bodies are an important issue for the urban climatic environment. Martínez-Arrojo and Jáuregui (2000) have already suggested the construction of small water bodies distributed all over Mexico City to improve climatic conditions. Administratively, addressing challenges of climate change needs the initiation of more integrative approaches regarding isolated effects of urban surface waters as well as surrounding buildings, accompanying urban green, air lanes etc. The interdisciplinary interaction of different sectors and sciences, e.g. public health, urban planning, landscape architecture and environmental planning as well as an optimal knowledge transfer from scientific research into practice and vice versa can help to formulate consistent strategies for handling climate change in cities in the future.

5 Conclusions

Heatwaves are a major health concern in a changing climate in cities. This review focussed on studies investigating the climate mitigation effects of urban blue space. In summer, various types of urban blue space possess the capacity to cool the ambient air temperature. Extreme weather events like heatwaves, with the resulting heat stress for citizens are attenuated by urban blue space. This meta-analysis suggests an average cooling of 2.5 K for urban blue compared to urban reference sites. However some studies had limitations, namely they were based on remote sensing data, only representing the temperature of large blue areas at a specific time, thus not representing the accessible parts of the city for urban residents. The studies were carried out mainly in subtropical climates and do not represent interventional studies.

Urban blue space needs to be monitored better to provide more reliable data for meta-analyses. Forthcoming studies should be undertaken regarding the various confounding and neighbouring environmental conditions to refine data so as to refer more precisely to urban blue space and thus strengthen the evidence.

Another important question addressed by some studies concerns the effect of urban blue space on temperature according to the distance and size of urban blue space. The diffusion of different urban blue types is an important issue for urban and health planners and policy makers and should therefore be addressed in future studies.

The temperature mitigation capacity of water can reduce health risks caused by heat waves, although the higher humidity caused by urban blue space must also be taken into account as a potential health risk as well as the emergence of possible vector-borne infectious diseases. To create healthy environments in the city of the future, a better understanding of the capacity of urban blue space is needed to offer opportunities for action.

Acknowledgements

This work is part of the young professionals research group "German Healthy Urban Open Spaces". We thank the Fritz and Hildegard Berg Foundation, Essen (Germany), for funding.

References

Almendros Coca, M. A. (1992): Aspectos climaticos del parque del Retiro (Madrid). In: Estudios Geográficos 53, 217–239.

Arnfield, A. J. (2003): Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. In: International Journal of Climatology 23, 1–26. DOI: 10.1002/joc.859

Bowler, D. E.; Buyung-Ali, L.; Knight, T. M. and Pullin, A. S. (2010a): How effective is 'greening' of urban areas in reducing human exposure to ground level ozone concentrations, UV exposure and the 'urban heat island effect'? Systematic Review No. 41. Collaboration for Environmental Evidence. Bangor. http://www.environmentalevidence.org/Documents/SR41.pdf (Date 20.11.2013)

Bowler, D. E.; Buyung-Ali, L.; Knight, T. M. and Pullin, A. S. (2010b): Urban greening to cool towns and cities: a systematic review of the empirical evidence. In: Landscape and Urban Planning 97, 147–155. DOI: 10.1016/j.landurbplan.2010.05.006

Chang, C.-R.; Li, M.-H. and Chang, S.-D. (2007): A preliminary study on the local cool-island intensity of Taipei city parks. In: Landscape and Urban Planning 80, 386–395. DOI: 10.1016/j.landurbplan.2006.09.005

Chen, X.-L.; Zhao, H.-M.; Li, P.-X. and Yin, Z.-Y. (2006): Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes. In: Remote Sensing of Environment 104, 133–146. DOI: 10.1016/j.rse.2005.11.016

Chen, Z.; Zhao, L.; Meng, Q.; Wang, C.; Zhai, Y. and Wang, F. (2009): Field measurements on microclimate in residential community in Guangzhou, China. In: Frontiers of Architecture and Civil Engineering in China 3, 462–468. DOI: 10.1007/s11709-009-0066-6

Comrie, A. (2007): Climate change and human health. In: Geography Compass 1, 325–339. DOI: 10.1111/j.1749-8198.2007.00037.x

Coutts, A. M.; Tapper, N. J.; Beringer, J.; Loughnan, M. and Demuzere, M. (2012): Watering our cities the capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context. In: Progress in Physical Geography 37, 2–28. DOI: 10.1177/0309133312461032

D'Ippoliti, D.; Michelozzi, P.; Marino, C.; De'Donato, F.; Menne, B.; Katsouyanni, K.; Kirchmayer, U.; Analitis, A.; Medina-Ramón, M.; Paldy, A.; Atkinson, R.; Kovats, S.; Bisanti, L.; Schneider, A.; Lefranc, A.; Iñiguez, C. and Perucci, C. A. (2010): The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. In: Environmental Health 9, 37. DOI: 10.1186/1476-069X-9-37

Deak, J. and Bucht, E. (2011): Planning for climate change: the role of indigenous blue infrastructure, with a case study in Sweden. In: Town Planning Review 82, 669–685. DOI: 10.3828/tpr.2011.38

EEA (EUROPEAN ENVIRONMENT AGENCY) (2012): Climate change, impacts and vulnerability in Europe 2012 – an indicator-based report. European Environment Agency, Copenhagen. http://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012/at_download/file (Date 20.11.2013)

Fröhlich, D. and Matzarakis, A. (2012): Modeling of changes in thermal bioclimate: examples based on urban spaces in Freiburg, Germany. In: Theoretical and Applied Climatology 111, 547–558. DOI: 10.1007/s00704-012-0678-y

Givoni, B. (1991): Impact of planted areas on urban environmental quality: a review. Atmospheric Environment. Part B. In: Urban Atmosphere 25, 289–299. DOI: 10.1016/0957-1272(92)90015-K

Hajat, S.; O'Connor, M. and Kosatsky, T. (2010): Health effects of hot weather: from awareness of risk factors to effective health protection. In: The Lancet 375, 856–863. DOI: 10.1016/S0140-6736(09)61711-6

Han, G.; Chen, H.; Yuan, L.; Cai, Y. and Han, M. (2011): Field measurements on micro-climate and cooling effect of river wind on urban blocks in Wuhan city. 2011 International Conference on Multimedia Technology (ICMT), 4446–4449. DOI: 10.1109/ICMT.2011.6003331

Hathway, E. A. and Sharples, S. (2012): The interaction of rivers and urban form in mitigating the Urban Heat Island effect: a UK case study. In: Building and Environment 58, 14–22. DOI: 10.1016/j.buildenv.2012.06.013

Higgins, J. P. and Green, S. (2008): Cochrane handbook for systematic reviews of interventions. Chichester.

Hou, P.; Jiang, W.; Cao, G. and Luo, A. (2009): Effect of urban thermal characteristics on wetlands based on remote sensing and GIS. In: Urban Remote Sensing Event, 2009 Joint, 1–6. DOI: 10.1109/URS.2009.5137701

Hou, P.; Chen, Y.; Qiao, W.; Cao, G.; Jiang, W. and Li, J. (2013): Near-surface air temperature retrieval from satellite images and influence by wetlands in urban region. In: Theoretical and Applied Climatology 11, 109–118. DOI: 10.1007/s00704-012-0629-7

Huang, L.; Li, J.; Zhao, D. and Zhu, J. (2008a): A fieldwork study on the diurnal changes of urban microclimate in four types of ground cover and urban heat island of Nanjing, China. In: Building and Environment 43, 7–17. DOI: 10.1016/j.buildenv.2006.11.025

Huang, L.; Zhao, D.; Wang, J.; Zhu, J. and Li, J. (2008b): Scale impacts of land cover and vegetation corridors on urban thermal behavior in Nanjing, China. In: Theoretical and Applied Climatology 94, 241–257. DOI: 10.1007/s00704-007-0359-4

IPCC (2007): Fourth assessment report. Cambridge.

Ishii, A.; Iwamoto, S.; Katayama, T.; Hayashi, T.; Shiotsuki, Y.; Kitayama, H.; Tsutsumi; J.-I. and Nishida, M. (1991): A comparison of field surveys on the thermal environment in urban areas surroundings a large pond: when filled and when drained. In: Energy and Buildings 16, 965–971. DOI: 10.1016/0378-7788(91)90091-G

Jáuregui, E. (1990): Effects of revegetation and new artificial water bodies on the climate of northeast Mexico City. In: Energy and Buildings 15, 447–455. DOI: 10.1016/0378-7788(90)90020-J

Jendritzky, G. (1993): Atmospheric environment – an introduction. In: Experientia 49, 1–8. DOI: 10.1007/BF01923541

Katayama, T.; Hayashi, T.; Shiotsuki, Y.; Kitayama, H.; Ishii, A.; Nishida, M.; Tsutsumi, J.-I. and Oguro, M. (1991): Cooling effects of a river and sea breeze on the thermal environment in a built-up area. In: Energy and Buildings 16, 973–978. DOI: 10.1016/0378-7788(91)90092-H

Kim, Y.-H.; Ryoo, S.-B.; Baik, J.-J.; Park, I.-S.; Koo, H.-J. and Nam, J.-C. (2008): Does the restoration of an inner-city stream in Seoul affect local thermal environment? In: Theoretical and Applied Climatology 92, 239–248. DOI: 10.1007/s00704-007-0319-z

Kjellstrom, T.; Butler, A. J.; Lucas, R. M. and Bonita, R. (2010): Public health impact of global heating due to climate change: potential effects on chronic non-communicable diseases. In: International Journal of Public Health 55, 97–103. DOI: 10.1007/s00038-009-0090-2

Kovats, R. S. and Hajat, S. (2008): Heat stress and public health: a critical review. In: Annual Reviews of Public Health 29, 41–55. DOI: 10.1146/annurev.publhealth.29.020907.090843

Lauer, W. and Frankenberg, P. (1988): Klimaklassifikation der Erde. In: Geographische Rundschau 40, 55–59.

Lauer, W.; Rafiqpoor, M. D. and Frankenberg, P. (1996): Die Klimate der Erde. Eine Klassifikation auf ökophysiologischer Grundlage der realen Vegetation. In: Erdkunde 50 (4), 275–300. DOI: 10.3112/erdkunde.1996.04.01

Li, J.; Song, C.; Cao, L.; Zhu, F.; Meng, X. and Wu, J. (2011): Impacts of landscape structure on surface urban heat islands: a case study of Shanghai, China. In: Remote Sensing of Environment 115, 3249–3263. DOI: 10.1016/j.rse.2011.07.008

Lopes, A.; Lopes, S.; Matzarakis, A. and Alcoforado, M. J. (2011): The influence of the summer sea breeze on thermal comfort in Funchal (Madeira). A contribution to tourism and urban planning. In: Meteorologische Zeitung 20, 553–564. DOI: 10.1127/0941-2948/2011/0248

Mahmoud, A. H. A. (2011): Analysis of the microclimatic and human comfort conditions in an urban park in hot and arid regions. In: Building and Environment 46, 2641–2656. DOI: 10.1016/j.buildenv.2011.06.025

Makhelouf, A. (2009): The effect of green spaces on urban climate and pollution. In: Journal of Environmental Health Science & Engineering 6, 35–40.

Martin, J.; Kurc, S. A.; Zaimes, G.; Crimmins, M.; Hutmacher, A. and Green, D. (2012): Elevated air temperatures in riparian ecosystems along ephemeral streams: The role of housing density. In: Journal of Arid Environments 84, 9–18. DOI: 10.1016/j.jaridenv.2012.03.019

Martínez-Arroyo, A. and Jáuregui, E. (2000): On the environmental role of urban lakes in Mexico City. In: Urban Ecosystems 4, 145–166. DOI: 10.1023/A:1011355110475

Meade, M. S. and Earickson, R. J. (2005): Medical Geography, Guilford Publications Incorporated, New York.

Michelozzi, P.; Kirchmayer, U.; Katsouyanni, K.; Biggeri, A.; McGregor, G.; Menne, B.; Kassomenos, P.; Anderson, H. R.; Baccini, M.; Accetta, G.; Analytis, A. and Kosatsky, T. (2007): Assessment and prevention of acute health effects of weather conditions in Europe, the PHEWE project: background, objectives, design. In: Environmental Health 6, 12. DOI: 10.1186/1476-069X-6-12

Mohan, M.; Kikegawa, Y.; Gurjar, B. R.; Bhati, S. and Kolli, N. R. (2013): Assessment of urban heat island effect for different land use-land cover from micrometeorological measurements and remote sensing data for megacity Delhi. In: Theoretical and Applied Climatology, 112, 647–658. DOI:10.1007/s00704-012-0758-z

MUNLV NRW (MINISTERIUM FÜR UMWELT UND NATURSCHUTZ, LANDWIRTSCHAFT UND VERBRAUCHERSCHUTZ DES LANDES NORDRHEIN-WESTFALEN) (2010): Handbuch Stadtklima. Maßnahmen und Handlungskonzepte für Städte und Ballungsräume zur Anpassung an den Klimawandel. Düsseldorf. http://www.umwelt.nrw.de/klima/klimawandel/anpassungspolitik/projekte/staedte_und_ballungsraeume/projektseite_01/index.php (Date 20.11.2013)

Murakawa, S.; Sekine, T.; Narita, K. and Nishina, D. (1991): Study of the effects of a river on the thermal environment in an urban area. In: Energy and Buildings 16, 993–1001. DOI: 10.1016/0378-7788(91)90094-J

Nakayama, T. and Hashimoto, S. (2011): Analysis of the ability of water resources to reduce the urban heat island in the Tokyo megalopolis. In: Environmental Pollution 159, 2164–2173. DOI: 10.1016/j.envpol.2010.11.016

Nishimura, N.; Nomura, T.; Iyota, H. and Kimoto, S. (1998): Novel water facilities for creation of comfortable urban micrometeorogy. In: Solar Energy 64, 197–207. DOI: 10.1016/S0038-092X(98)00116-9

Oke, T. R. (1987): Boundary layer climates. London.

Oliveira, S.; Andrade, H. and Vaz, T. (2011): The cooling effect of green spaces as a contribution to the mitigation of urban heat: a case study in Lisbon. In: Building and Environment 46, 2186–2194. DOI: 10.1016/j.buildenv.2011.04.034

Pauli, A. and Hornberg, C. (2010): Sozialräumliche und gesundheitsbezogene Implikationen des Klimawandels im Kontext von Klimaschutz und Klimaanpassung. In: Verhaltenstherapie & Psychosoziale Praxis 42, 313–329.

Peng, S.; Piao, S.; Ciais, P.; Friedlingstein, P.; Ottle, C.; Bréon, F.-M.; Nan, H.; Zhou, L. and Myneni, R. B. (2012): Surface urban heat island across 419 global big cities. In: Environmental Science & Technology 46, 696–703. DOI: 10.1021/es2030438

Petticrew, M. and Roberts, H. (2008): Systematic reviews in the social sciences: a practical guide. Oxford.

Robine, J.-M.; Cheung, S. L. K.; Le Roy, S.; Van Oyen, H.; Griffiths, C.; Michel, J.-P. and Herrmann, F. R. (2008): Death toll exceeded 70,000 in Europe during the summer of 2003. In: Comptes Rendus Biologies 331, 171–178. DOI: 10.1016/j.crvi.2007.12.001

Robitu, M.; Musy, M.; Inard, C. and Groleau, D. (2006): Modeling the influence of vegetation and water ponds on urban microclimate. In: Solar Energy 80, 435–447. DOI: 10.1016/j.solener.2005.06.015

Rydin, Y.; Bleahu, A.; Davies, M.; Dávila, J. D.; Friel, S.; De Grandis, G.; Groce, N.; Hallal, P. C.; Hamilton, I.; Howden-Chapman, P.; Lai, K.-M.; Lim, C.; Martins, J.; Osrin, D.; Ridley, I.; Scott, I.; Taylor, M.; Wilkinson, P. and Wilson, J. (2012): Shaping cities for health: complexity and the planning of urban environments in the 21st century. In: The Lancet 379, 2079–2108. DOI: 10.1016/S0140-6736(12)60435-8

Schwarz, N.; Schlink, U.; Franck, U. and Grossmann, K. (2012): Relationship of land surface and air temperatures and its implications for quantifying urban heat island indicators – An application for the city of Leipzig (Germany). In: Ecological Indicators 18, 693–704. DOI: 10.1016/j.ecolind.2012.01.001

Shudo, H.; Sugiyama, J.; Yokoo, N. and Oka, T. (1997): A study on temperature distribution influenced by various land uses. In: Energy and Buildings 26, 199–205. DOI: 10.1016/S0378-7788(96)01035-3

Smith, C. and Levermore, G. (2008): Designing urban spaces and buildings to improve sustainability and quality of life in a warmer world. In: Energy Policy 36, 4558–4562. DOI: 10.1016/j.enpol.2008.09.011

Spronken-Smith, R. A. and Oke, T. R. (1999): Scale modelling of nocturnal cooling in urban parks. In: Boundary-Layer Meteorology 93, 287–312.

Spronken-Smith, R. A.; Oke, T. R. and Lowry, W. P. (2000): Advection and the surface energy balance across an irrigated urban park. In: International Journal of Climatology 20, 1033–1047. DOI: 10.1023/A:1002001408973

Sun, R. and Chen, L. (2012): How can urban water bodies be designed for climate adaptation? In: Landscape and Urban Planning 105, 27–33. DOI: 10.1016/j.landurbplan.2011.11.018

Sun, R.; Chen, A.; Chen, L. and Lü, Y. (2012): Cooling effects of wetlands in an urban region: the case of Beijing. In: Ecological Indicators 20, 57–64. DOI: 10.1016/j.ecolind.2012.02.006

Taha, H.; Akbari, H.; Rosenfeld, A. and Huang, J. (1988): Residential cooling loads and the urban heat island – the effects of albedo. In: Building and Environment 23, 271–283. DOI: 10.1016/S0378-7788(96)00999-1

Takahashi, R.; Asakura, A.; Koike, K.; Himeno, S. and Fujita, S. (2010): Using snow melting pipes to verify the water sprinkling's effect over a wide area. Sustainable techniques and strategies in urban water management, 7th International Conference Lyon.

Tuller, S. E. (1995): Onshore flow in an urban area: microclimatic effects. In: International Journal of Climatology 15, 1387–1398. DOI: 10.1002/joc.3370151206

Upmanis, H.; Eliasson, I. and Lindqvist, S. (1998): The influence of green areas on nocturnal temperatures in a high latitude city (Göteborg, Sweden). In: International Journal of Climatology 18, 681–700. DOI: 10.1002/(SICI)1097-0088(199805)18:6<681::AID-JOC289>3.0.CO;2-L

Völker, S. and Kistemann, T. (2011): The impact of blue space on human health and well-being – Salutogenetic health effects of inland surface waters: a review. In: International Journal of Hygiene and Environmental Health 214, 449–460. DOI: 10.1016/j.ijheh.2011.05.001

– (2013): "I'm always entirely happy when I'm here!" Urban blue enhancing human health and well-being in Cologne and Düsseldorf, Germany. In: Social Science & Medicine 78, 113–124. DOI: 10.1016/j.socscimed.2012.09.047

Voogt, J. and Oke, T. (2003): Thermal remote sensing of urban climates. In: Remote Sensing of Environment 86, 370–384. DOI: 10.1016/S0034-4257(03)00079-8

Walker, C.; Lampard, J.; Roiko, A.; Tindale, N.; Wiegand, A. and Duncan, P. (2012): Community well-being as a critical component of urban lake ecosystem health. In: Urban Ecosystems, online publication. http://www.springerlink.com/index/10.1007/s11252-012-0256-1 (Date: 20.11.2013)

WHO-EURO (WORLD HEALTH ORGANIZATION) (2008): Heat-health action plans guidance. Geneva.

WHO and WMO (WORLD METEOROLOGICAL ORGANIZATION)(2012): Atlas of health and climate. Geneva. http://www.who.int/iris/bitstream/10665/76224/5/9789241564526_eng.pdf (Date: 20.11.2013)

WMO (WORLD METEOROLOGICAL ORGANIZATION) (2010): Guide to climatological practices WMO-No. 100 (third edition). http://www.wmo.int/pages/prog/wcp/documents/Guidefulltext.pdf (Date: 20.11.2013)

Wong, N. H.; Tan, C. L.; Nindyani, A. D. S.; Jusuf, S. K. and Tan, E. (2011): Influence of water bodies on outdoor air temperature in a hot and humid climate. ICSDC 2011, 81–89. Kansas City, Missouri: American Society of Civil Engineers. http://ascelibrary.org/doi/abs/10.1061/41204%28426%2911 (Date: 20.11.2013)

Authors

Dr. Sebastian Völker
Prof. Dr. Thomas Kistemann
Institute for Hygiene and Public Health
RG Medical Geography & Public Health
University of Bonn
Sigmund-Freud-Str. 25
53105 Bonn
Germany
sebastian.voelker@ukb.uni-bonn.de
thomas.kistemann@ukb.uni-bonn.de

Hendrik Baumeister
Dr. Thomas Claßen
Prof. Dr. Claudia Hornberg
School of Public Health
Department 7 Environment and Health
University of Bielefeld
Universitätsstr. 25
33615 Bielefeld
Germany
baumeister@uni-bielefeld.de
thomas.classen@uni-bielefeld.de
claudia.hornberg@uni-bielefeld.de