Meteorol. Z. (Contrib. Atm. Sci.), Vol. **32**, No. 6, 447–470 (published online September 19, 2023)

Biometeorology

Thermal loads in two different urban quarters – perspectives from mobile measurements and mental maps

Uta Moderow[1*], Astrid Ziemann[1], Valeri Goldberg[1] and Heidi Sinning[2]

[1]Technische Universität Dresden, Faculty of Environmental Sciences, Department of Hydrosciences, Chair of Meteorology, Dresden
[2]Fachhochschule Erfurt – University of Applied Sciences, Institute for Urban Research, Planning and Communication (ISP), Erfurt

(Manuscript received November 10, 2022; in revised form July 3, 2023; accepted July 6, 2023)

Abstract

The fact that different urban structures have different climatic effects and therefore differ in their thermal loads for people is well known. However, there is a lack of quantitative and qualitative surveys in specific districts that are suitable to derive accepted adaptation measures. This paper addresses the research questions where thermally stressed areas in public space are identified by mobile measurements and by mental maps and what are the causes of each, where both methods agree or disagree, and what are the benefits and the limitations of using both methods for prioritizing adaptation measures.

Mobile measurements in an urban quarter over a whole day can supply needed data for determining thermal loads of urban structures and their temporal development. Mental maps give information about the perception of urban dwellers and – based on the spatial distribution of obtained data – the user frequency. Both methods provide information concerning where and when measures should be taken in order to facilitate adaptation to heat.

The paper presents the results of mobile measurements and mental maps of two different urban quarters in Germany. Thermal loads were assessed by using the Universal Thermal Climate Index (UTCI) for three selected summer days. Results indicated that the different urban structures can differ by up to 7 K or by two stages of thermal stress during a hot summer day. Surface material with high albedo can overcompensate smaller sky view factors resulting in high thermal loads. Street trees caused changing thermal loads but reduced them on average.

Identified hot spots based on mobile measurements mostly correlated with hot spots identified by mental maps, if they were frequently used. However, hottest spots identified by measurements were not necessarily most frequently named as hot spots in the mental maps. Most often named hot spots of mental maps coincided with major traffic routes suggesting that user frequency is important. We conclude that the combination of both methods can be valuable for identifying locations with high priority for climate adaptation in cities.

Keywords: heat adaptation measures, heat stress, mental maps, mobile measurements, urban climate

1 Introduction

Today we live in a fast changing world and one of the biggest challenges is the ongoing climate change and related consequences whereas projections indicate a continued global warming (IPCC 2021). Hot spells have intensified and this climate risk to cities – amongst others – will increase in the future (IPCC 2012, 2021, 2022). Adapting cities to future climatic conditions is an important task, but the resources available to fulfil this task are very often limited. Therefore, it is useful to know where adaptation measures concerning heat should be taken. In order to identify hot spots as well as suited adaptation measures within a city modelling (e.g. Shashua-Bar et al., 2010; Goldberg et al., 2013, Gross, 2017; Taleghani and Beradi, 2018) and measurements (e.g. Upmanis, 1998; Heusinkveld et al., 2014; Chatzidimitrou and Yannas, 2015; Tsin et al., 2016, Samad and Vogt, 2020) are commonly used, whereby different aspects are addressed (e.g. effects of water bodies, of urban green in general, of buildings itself). Obtained results supply information where unfavourable thermal areas are located and which measures might be useful for a specific situation based on the determined effects of the physical environment. However, they do not contain any information on the behaviour of residents with regard to places or routes that must be used preferentially or necessarily in their everyday life. Here, one established method, which recently received more attention are mental maps (Lynch, 1960; Downs et al., 1982). It can be used to obtain information about the spatial behaviour and perception of space by residents.

Studies addressing thermal comfort in cities by using both measurements and/or modelling and mental maps are increasing but still rare (Lenzholzer, 2010; Lehnert et al., 2021a, 2021b; Mittermüller et al., 2021).

---

[*]Corresponding author: Uta Moderow, Technische Universität Dresden, Faculty of Environmental Sciences, Department of Hydrosciences, Chair of Meteorology, 01062 Dresden, Germany, e-mail: uta.moderow@tu-dresden.de

DOI 10.1127/metz/2023/1175

Gebrüder Borntraeger Science Publishers, Stuttgart, www.borntraeger-cramer.com

Lehnert et al. (2021a) compared areas with high surface temperatures in two Czech cities with the results of mental maps aiming to identify hot spots as perceived by residents. They obtained surface data by using satellite data und mental maps by utilizing online questionnaires. Their results indicated notable differences between the location of hot spots identified via surface temperatures and those identified by the citizen participation via the survey, the latter one being dependent on how often certain areas were frequented. Following Stewart et al. (2021), we hypothesize that the reported mismatch between surface temperature (satellite data) and survey results is due to the fact that satellite based surface temperature cannot capture the information of all surrounding surfaces. Therefore, the thermal load cannot be adequately described with this variable alone. Mittermüller et al. (2021) combined GIS-analysis of urban vegetation and density parameters (tree coverage, percentage of sealed area), simulation of mean radiant temperature (model SOLWEIG, Lindberg et al., 2008) and mental maps in order to identify areas where adaptation measures should be taken first. The authors concluded that geo-statistical analysis and modelled mean radiant temperature alone do not provide sufficient information to identify areas where action should take place. Accessibility of green spaces, their design and quality and stress factors related to traffic (e.g. noise) turned out to be important factors in perceiving benefits of green urban infrastructure. Lenzholzer (2010) compared microclimate perception obtained via mental maps with results of microclimate measurements for Dutch urban squares but mainly focused on wind. Lehnert et al. (2021b) recorded microclimatic data using fixed stations at six different locations with blue infrastructure (five squares and one park) in different Czech cities and compared obtained values of two different bioclimatic indices with thermal sensation as indicated by mental maps. They concluded that sustainable urban planning to mitigate heat stress should take into consideration the behavioural patterns of the residents.

The reported studies found a disagreement between surface temperature and bioclimatic indices, respectively, concerning location and strength of heat stress. Other aspects like user frequency, accessibility of green spaces, their design and quality and stress factors related to traffic (e.g. noise) were named as important factors in shaping the perception of thermal conditions and should not be neglected in urban planning (Lehnert et al., 2021a, 2021b; Mittermüller et al., 2021).

The current paper combines (a) a metrological based approach and (b) a participatory planning approach based on subjective perception with the aim to prioritise locations where adaptation measures should be taken. For the metrological approach we used backpack measurements in order to obtain information about the experienced heat load of pedestrians in terms of a bioclimatic index UTCI (Universal Thermal Climate Index, Błażejczyk et al., 2010; Jendritzky et al., 2012; Bröde et al., 2012). Here, backpack measurements allow a direct, metrological and objective assessment of heat stress of urban residents in open space on typical routes through the neighbourhood. Furthermore, backpack measurements allow the recording of environmental conditions at high spatial resolution along ways and tracks, where pedestrians typically move, and which are often not accessible by other mobile measurement platforms (e.g. cars). The use of a bioclimatic index takes into account that human heat stress is dependent on several environmental variables.

For the participatory approach, we used mental maps which were obtained via outdoor in person interviews during different summer days. The coupling of the backpack measurements with mental maps provides additional information that cannot be obtained with purely physical measurements, such as the perception of places or frequency of use of certain places by city dwellers. Both investigations (backpack measurements and mental maps) took place within the framework of the HeatResilientCity project (http://heatresilientcity.de/).

Based on these data the following questions are addressed:

1. Where are thermally stressed areas in public space identified by backpack measurements and what are the causes?
2. Where are thermally stressed areas in public space identified by located mental maps and what are the causes?
3. Where do both methods agree or disagree and what is the benefit of using both to prioritize adaptation measures?

2 Material and methods

2.1 Investigated urban areas

The project HeatresilientCity (http://heatresilientcity.de/, accessed 23 June 2023) focuses on two urban areas of different characteristics situated in two different cities of Germany, Dresden (51°.05 N, 13°.73 E) and Erfurt (50°.97 N, 11.03 E). We present measurement results for a summer day with high radiation (clear sky conditions, both cities) and a summer day with lower radiation (cloudy day, only Dresden-Gorbitz).

Dresden-Gorbitz

The investigated area of Dresden was established in the late 1980s and is an area of prefabricated houses made of concrete. Most houses have a height between 15 and 20 m along the measurement route. The area is characterized by generously sized vegetated courtyards and a number of public green spaces. It is situated at a gentle slope facing easterly directions. The height above sea level increases from about 135 m to 175 m from East to West.

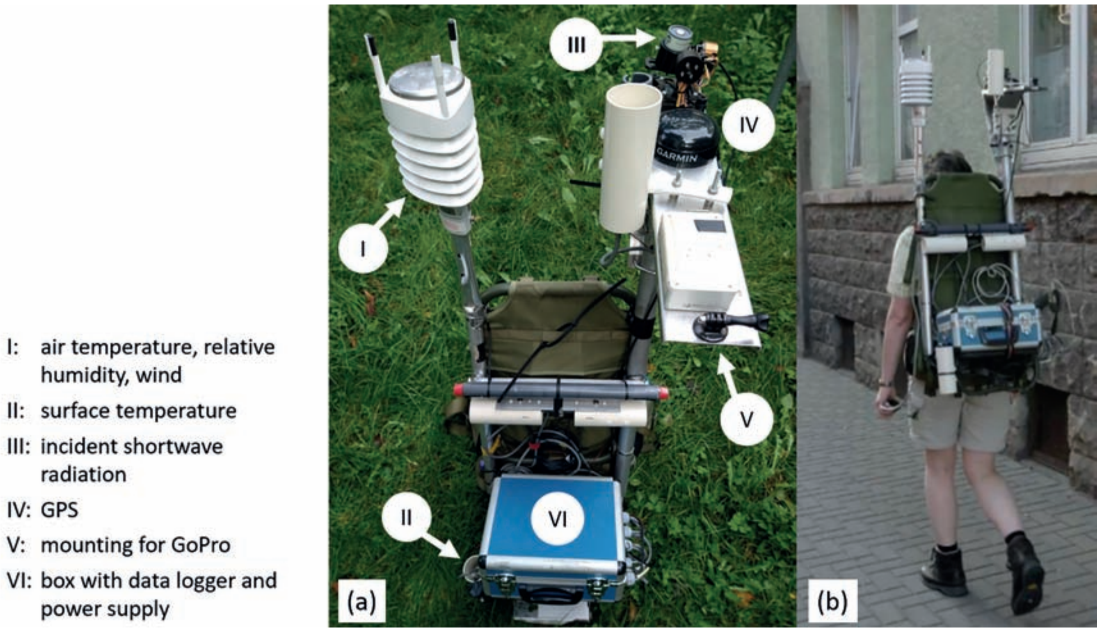

Figure 1: Subplot (a): Backpack with mounted measurements devices for mobile measurements, only used measurements devices are noted, GoPro not mounted, the thermocouple was mounted below the pyranometer but is not visible in this picture. Subplot (b): Mobile measurements in the city of Erfurt (Photo, V. Goldberg, TU Dresden).

Table 1: Information about used measurement devices.

Measured variable	Measurement device	Manufacturer
Air temperature	Weather Transmitter WXT 520[§]	Vaisala, Vantaa, Finnland
Relative humidity	Weather Transmitter WXT 520[§]	Vaisala, Vantaa, Finnland
Wind speed	Weather Transmitter WXT 520	Vaisala, Vantaa, Finnland
Shortwave radiation[#]	Pyranometer SKS 1110	Skye Instruments, Llandrindod Wells, UK
Longwave radiation	Infra-red Remote Temperature Sensor IR120[§,$]	Campbell Scientific, Logan, USA
Position and Time	GPS16X-HVS	Garmin Ltd., USA

[§] used with radiation shield
[$] directed towards the ground, field of view 20°
[#] incident on a horizontal plane

Erfurt-Oststadt

The investigated area of Erfurt was mainly built on during the Wilhelminian period approximately between 1890 and 1920. A smaller part (northern edge of the project area) was subject to redevelopment in the 1960s. The perimeter blocks mostly have a height between 10 m and 20 m. The area is densely built and lacks public green spaces. However, many streets do have street greenery, including older trees with larger crowns, which provide a lot of shade, as well as recently planted trees with small crowns providing only little shade. The area itself is flat with a height of approximately 195 m above sea level.

2.2 Mobile measurements

Instrumentation

For the measurements, a backpack was used (Fig. 1) to which measurement devices were mounted in order to assess the thermal stress of pedestrians in different urban environments. Table 1 indicates the applied measurement devices for measuring air temperature, relative humidity, wind velocity, solar radiation and thermal radiation of the surrounding. A GoPro camera was used to record the conditions of the lower and upper hemisphere along the measuring route. The GoPro camera was not available during the measurements in Dresden.

All measurements were synchronized in time via a GPS receiver (GPS16X-HVS). Measurements were logged every 1 s during measurements in Dresden-Gorbitz in summer 2018. In the case of Erfurt measurements were logged every 2 s in order to obtain a more stable GPS signal. Still, the quality of the GPS signal was sometimes poor or even absent resulting in an uneven distribution of measurement points along the measuring route. All data were combined and stored using a data logger (CR 1000X, Campbell Scientific, Logan, US). It should be noted that the measurement height also depends on the person carrying the backpack.

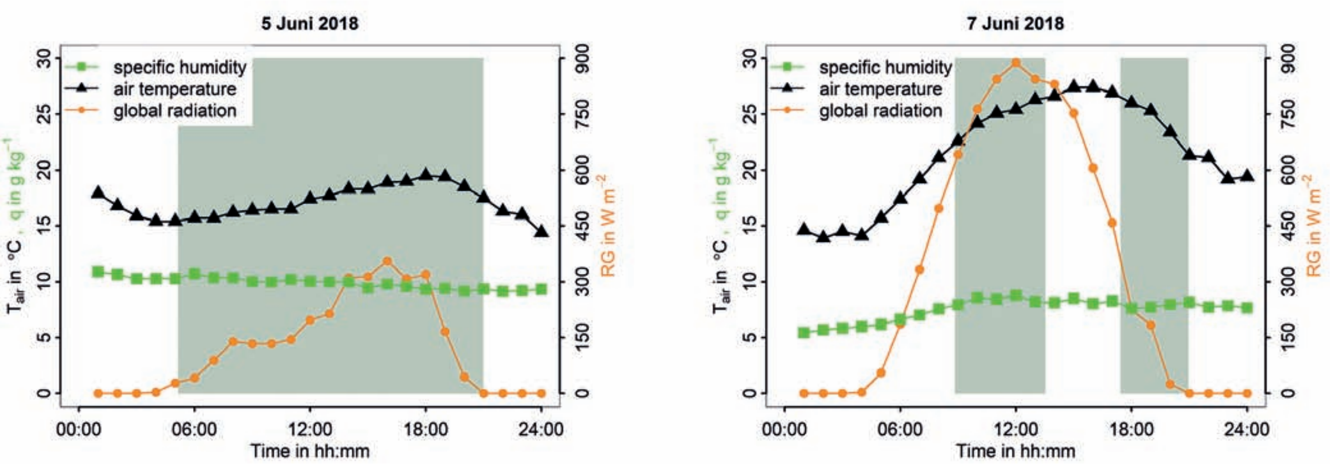

Figure 2: General meteorological conditions (air temperature T_{air}, global radiation RG and specific humidity q) on the 5th and 7th of June 2018. Time refers to Central European Time (CET). Grey shaded background indicates time range where the measurements took place. Data source: German Weather Service (DWD), station Dresden-Klotzsche.

The accuracy of the employed instruments are as follows as denoted by the respective manufacturer: air temperature ±0.3 K at 20 °C (WXT 520); relative humidity ±3 % at 0–90 % (WXT 520); wind speed ±3 % at $10\,\mathrm{m\,s^{-1}}$ (WXT 520); surface temperature ±0.2 °C at 50 °C (IR 120); shortwave radiation ±5 % (SKS 1110), position accuracy < 3 m (GPS16X-HVS).

As all structures of a measurement walk were sampled by the same instruments we can therefore exclude differences due to different instruments. However, we acknowledge that radiation errors might have been larger for those time intervals with higher radiation than for time intervals with lower radiation input.

Measurement walks and selected structures at Dresden-Gorbitz

Presented measurement walks at Dresden-Gorbitz took place on the 5th and 7th of June 2018. Fig. 2 gives an overview of the general climatic conditions for these two days using data of the German Weather Service (DWD) station Dresden-Klotzsche (51.12 N, 13.75 E). Generally, the daily mean temperature and received shortwave radiation increased from the 5th of June to the 7th of June.

Fig. 3 shows the general route of the measurement walks together with information about the urban structure. On the 5th of June 2018 12 complete measurement walks were recorded. It took approximately one hour to cover the whole route. On the 7th of June 2018, there was a data loss due to storage failure between late morning and late afternoon. Therefore, data of five measurement walks were available of which two were incomplete. However, the first walks of this day indicated a day with high thermal load.

Seven subsections of the measurement route were selected, which represent different urban structures. Urban structures with a high proportion of urban greenery and structures with high radiation exposure and low proportion of urban greenery were selected in order to investigate different structures of different thermal loads. Table 2 gives an overview about these seven subsections, which are indicated in Fig. 3 as yellow lines.

Measurement walks and selected structures at Erurt-Oststadt

Measurement walks at Erfurt-Oststadt took place on the 23rd of August 2019. Fig. 4 gives an overview of the general climatic conditions for Erfurt for this day using data of DWD station Erfurt-Weimar (50.98 N, 10.96 E). The 23rd of August was almost a perfect radiation day.

Nine measurement walks were recorded on this day. As in the case of Dresden-Gorbitz, it took approximately one hour to cover the whole route. Out of the different measured urban structures, we selected eight for which we analysed obtained data more in detail. Table 3 and Fig. 5 provide information about the selected structures.

Calculation of presented values for selected structures

At first all measurement walks were loaded into a GIS (QGIS 3.16) software and visually checked in order to evaluate whether the quality of the GPS signal for the respective measurement walk would allow an accurate spatial assignment of the respective data to the different selected structures. Data of the investigated structures were then selected from obtained measured data according to their coordinates. In order to achieve this, rectangles around each structure to be investigated were defined. These rectangles differed in size with respect to the given structure. Data points were selected for a certain structure when they fall within the respective rectangle according to their coordinates in order to account for spatial uncertainty of GPS data.

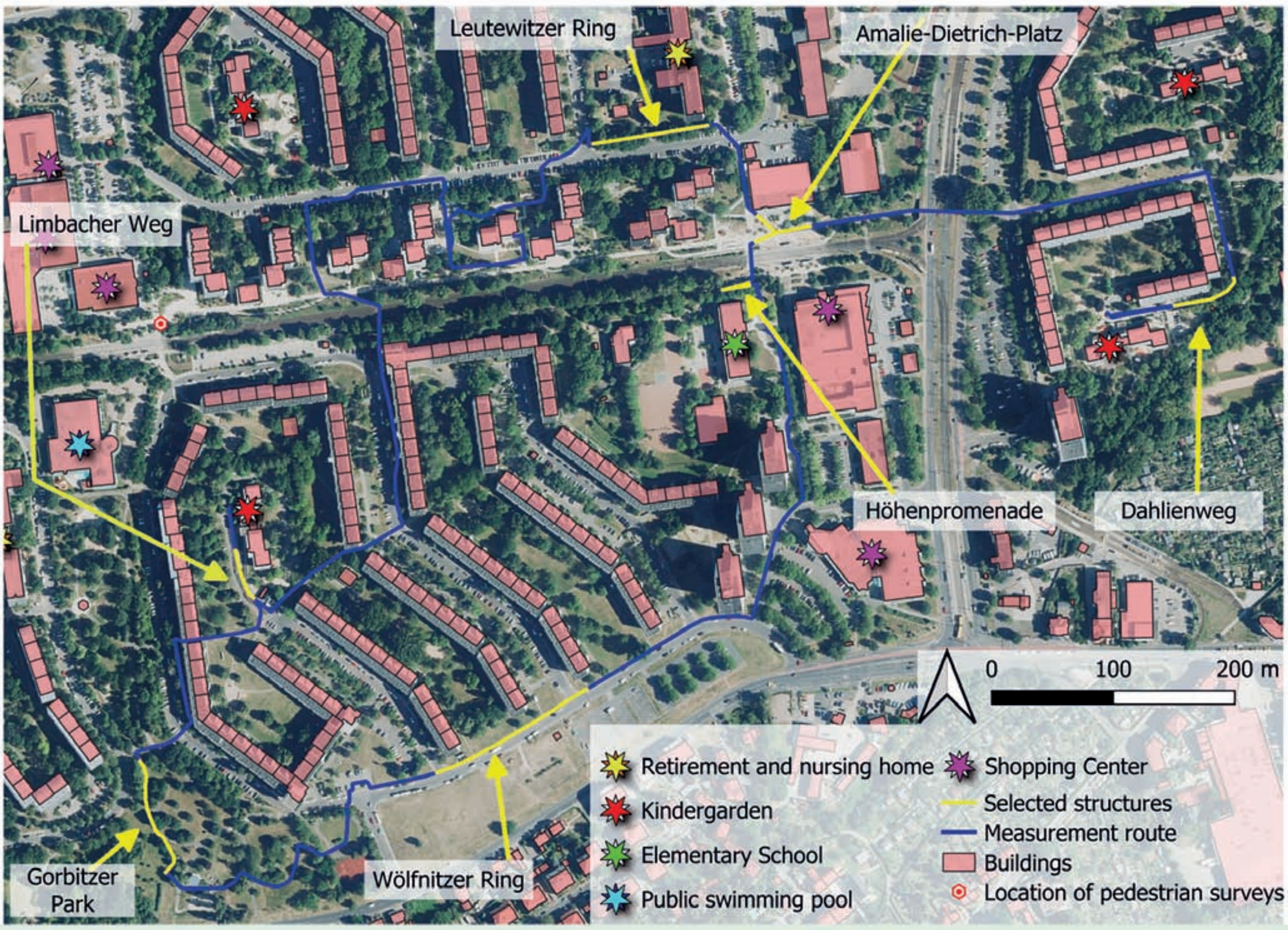

Figure 3: Investigated area of Dresden. Map base: Digital surface model, buildings, orthophotos: Open geo data of the Free State of Saxony (Germany), Source: © GeoSN, dl-de/by-2-0. The border of the whole project area is given in Fig. 11.

Table 2: Description of selected urban structures – Dresden. Descriptions of streets refer to the side of the street which was assessed by measurements.

Nr	Name	Description
1	Höhenpromenade	Pavement with established trees on both sides
2	Amalie-Dietrich-Platz	Open square, sealed surface, mainly concrete
3	Dahlienweg	Street with established dense trees on both sides
4	Leutewitzer Ring	Street running from East to West with established evenly spaced street trees on both sides
5	Limbacher Weg	Street running from North to South, pavement without directly adjacent street trees
6	Gorbitzer Park	Park, trees and lawn alternate
7	Wölfnitzer Ring	Street running from North-north-east to South-south-west without street trees

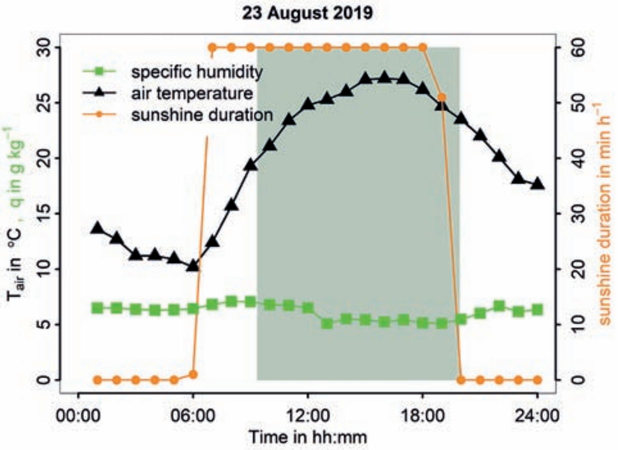

Figure 4: Same as Fig. 2 but for general meteorological conditions on the 23rd of August 2019. No radiation measurements were available. Therefore, sunshine duration is shown. Time is in Central European Time (CET). Data source: German Weather Service (DWD), station Erfurt-Weimar.

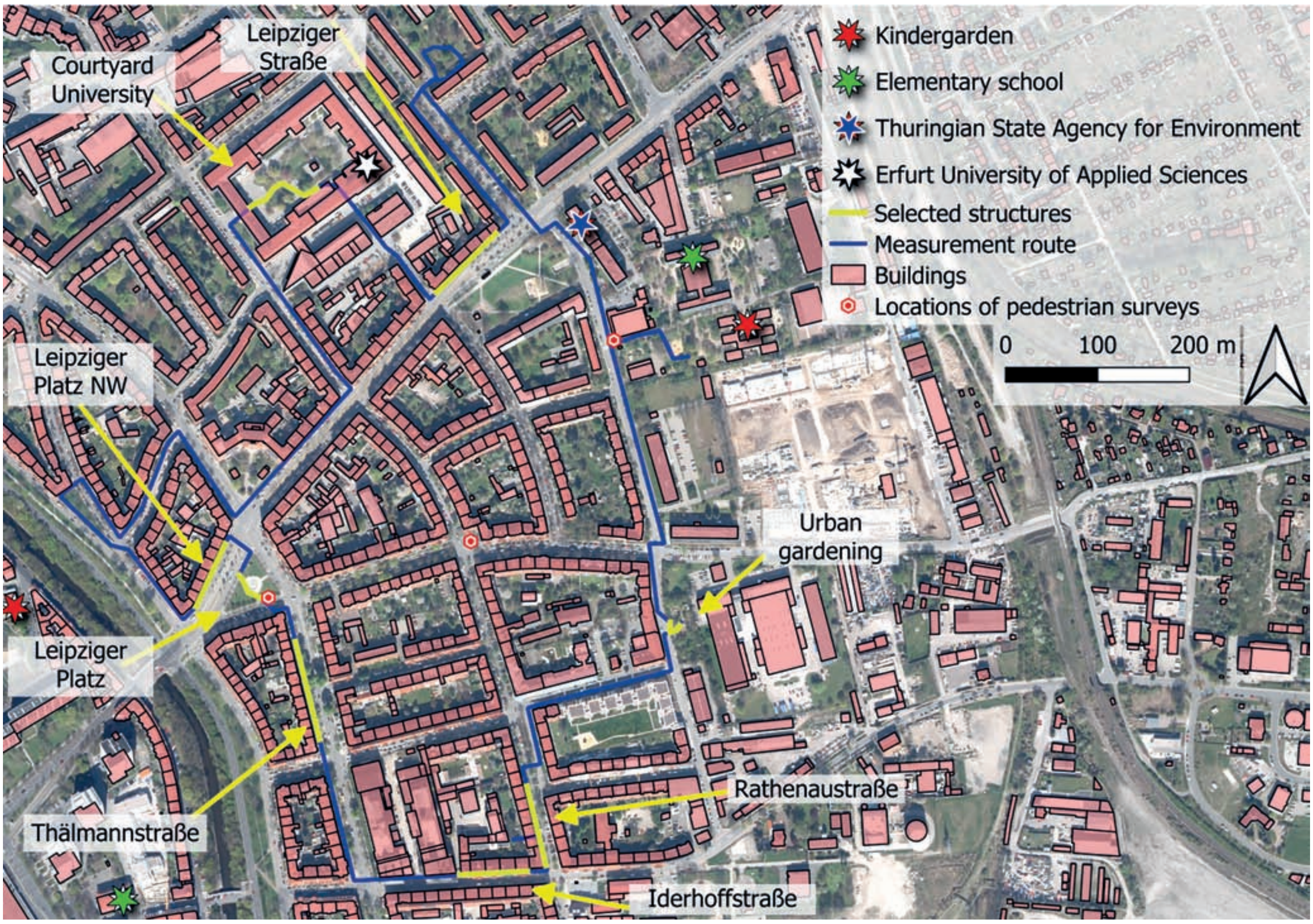

Figure 5: Investigated area of Erfurt. Map base: Buildings, orthophoto: Open geo data of the Free State Thuringia (Germany), © GDI-TH, dl-de/by-2-0. The border of the project area is given in Fig. 12.

Table 3: Description of selected urban structures – Erfurt. Descriptions of streets refer to the side of the street which was assessed by measurements.

Nr	Name	Description
1	Urban gardening	Urban gardening area with established trees, canopy not closed
2	Rathenaustraße	Street running from South to North, with established trees, buildings on both sides of the street
3	Iderhoffstraße	Street running from East to West, pavement with a few young trees with small crowns, buildings on both sides of the street
4	Thälmannstraße	Street running from South to North, with established trees, buildings on both sides of the street
5	Leipziger Platz	Open square with lawn beside the pavement and a fountain in the middle
6	Leipziger Platz NW	Northwestern edge of Leipziger Platz, unevenly spaced street trees, adjacent buildings in northwest only, open square adjoins to the south-east
7	Courtyard University	Large courtyard with sealed surfaces, trees and lawn, enclosed by buildings on all sides
8	Leipziger Straße	Street running from south-west to north-east, unevenly spaced street trees, adjacent buildings in northwest only, open square adjoins to the south-east

In the following, values recorded while crossing a selected structure were used for the analysis. For each crossing, the corresponding mean value and standard deviation were calculated to assess the variation within a chosen structure. Data obtained in this way were related to the midpoint of the time period, when a certain structure was crossed.

Commonly, mobile measurements do not allow to measure all points of given route at the same time. We detrended air temperature to account for this fact for comparison reason only, i.e. if not stated otherwise, all presented values are not trend corrected. The trend-corrected value of a temperature measurement n was calculated as difference of the mean value of air temperature calculated over the respective entire measurement walk minus the temperature measurement n. This difference was divided by two and then the value of temperature measurement n was added back.

As mentioned earlier, the GPS-signal was sometimes absent and resulted in an uneven distribution of measured data points along the measurement route. If at least 6 data points could be collected for the crossing of a structure, mean and standard deviation were calculated accordingly. In the case of Leipziger Platz (open square at Erfurt-Oststadt) data coverage was sometimes sparser. Information about the number of available data points per structure and measurement walk can be found in Table A1, A2 (Dresden-Gorbitz) and A3 (Erfurt-Oststadt) of the Appendix.

Calculation of UTCI

We used the Universal Thermal Climate Index (UTCI; Błażejczyk et al. (2010), Jendritzky et al., 2012; Bröde et al., 2012), to evaluate the thermal stress of human beings. It is given in degree Celsius and is divided in different stages of thermal stress. Błażejczyk et al. (2010, p. 94) state that the "UTCI is the air temperature which would produce under reference conditions the same thermal strain as in the actual thermal environment." Please refer to Błażejczyk et al. (2010); Havenith et al. (2012); Bröde et al. (2012) and Jendritzky et al. (2012) for more detailed information about the UTCI.

RayMan Pro 2.2 (Matzarakis et al., 2010) was utilised to calculate UTCI. Following variables were used to obtain the UTCI (°C), global radiation ($\mathrm{W\,m^{-2}}$), air temperature (°C), relative humidity (%), Wind ($\mathrm{m\,s^{-1}}$) and infrared temperature (°C) of the ground. RayMan 2.2 applies a regression equation for the UTCI (Bröde et al., 2012 and therein cited online resources). Independently of this, the UTCI values were compared with UTCI values determined with a self-written Fortran code. The values from RayMan were confirmed.

The recorded wind speed of a moving person is always influenced by the walking speed of the person itself. Therefore, general wind conditions were analysed when the measuring person remained stationary for some time and did not walk. The locations where the backpack carrier stopped for a few minutes and where wind speed was measured are representative of the urban structures studied. These values were averaged for each inspected day and resulted in average values of $0.8\,\mathrm{m\,s^{-1}}$ (05.06.2018 at Dresden), $0.9\,\mathrm{m\,s^{-1}}$ (07.06.2018 at Dresden) and $0.5\,\mathrm{m\,s^{-1}}$ (23.08.2019, 24.08.2019 at Erfurt). These values were used for the calculation of UTCI for each respective day. Although this might alleviate differences in thermal conditions to a certain degree we are convinced that the main characteristics are preserved as the UTCI most strongly depends on mean radiant temperature. Wind speed was generally low at the inspected days. Therefore, its influence on thermal conditions can be assumed to be of minor importance. This assumption is supported by the findings of Novak (2013), who investigated typical conditions for the Czech Republic. Novak (2013) showed only weak dependency of the UTCI on wind speed for air temperatures above 25 °C when wind speeds were larger than $2\,\mathrm{m\,s^{-1}}$.

2.3 Mental maps

In summer 2018, surveys were conducted in the neighbourhoods of Gorbitz in the City of Dresden and of the Oststadt, in the City of Erfurt which addressed heat related aspects. As part of these surveys, hot spots (places and paths that are unpleasant during hot days) and cool spots (pleasant places and paths during hot days) were identified (Baldin and Sinning, 2019a; 2019b).

The method of mental maps (Lynch, 1960; Downs et al., 1982) was used in order to obtain data where residents locate cool and hot spots. The basic concept is based on perceptual and behavioural geographic research approaches. According to those, different types of perception shape a subjective, selective image of spaces (Lynch, 1960; Downs et al., 1982). A notable advantage of mental maps is that residents are not confronted with a selection of ready-made answers but reproduce the most important spatial elements by themselves and evaluate them (e.g., Kranepuhl and Ziervogel, 2007).

The data used for creating mental maps were exclusively obtained through a pedestrian survey. Residents were asked to mark hot and cool spots in a map, which are accessible to the public. This map showed areas of the city neighbourhoods of Dresden-Gorbitz (Fig. 11) and Erfurt-Oststadt (Fig. 12), respectively. The corresponding area is marked by a by red-dashed line in these Figures. Each interviewee could indicate several hot and cool spots in this map according to own experience and subjective evaluation. This was always done in a face-to-face situation, which offered the possibility to help residents if there were concerns regarding drawing errors, correct orientation or needed additional information (Baldin and Sinning, 2019a; 2019b). All passers-by who passed by the survey stands and thus passed through the corresponding neighbourhoods could fill in mental maps. This means that not only residents of Dresden-Gorbitz (Erfurt-Oststadt), but also residents from other parts of Dresden (Erfurt) participated in the survey as they also used the neighbourhoods and public spaces.

In Dresden, surveys took place on seven days in July and August 2018. Air temperature maxima of these days varied between 19.5 °C and 35.2 °C with 4 days having maximum temperatures greater or equal to 30 °C (Data source: German Weather Service (DWD), station Dresden-Klotzsche). The survey was located at various places near Merianplatz (Fig. 3) and took place during different daytimes in order to reach different groups of residents. Based on these surveys, 139 mental maps were completed (Baldin and Sinning, 2019a).

The age structure of the respondents at Dresden shows some deviations with respect to the general age structure of the neighbourhood of Gorbitz as a whole. The groups of 18 to 24 year-olds and 25 to 44 year-olds were encountered less frequently but the oldest age group (65 years and older) is more represented than in the statistical reports of the city of Dresden (Baldin and Sinnig, 2019a). This can be attributed to the fact that the area of Dresden-Gorbitz, where the survey took place is an area of older residents in general (Baldin and Sinnig, 2019a). Thus, the survey especially reflects the subjective location of older people to some degree, which is a group more vulnerable to heat stress.

In Erfurt, the surveys took place on ten days in July and August 2018. Air temperature maxima of these days varied between 16.9 °C and 36.5 °C with 5 days having maximum temperatures greater or equal to 30 °C (Data source: German Weather Service (DWD), station Erfurt-Weimar). As during the surveys in Dresden, the location and time of the surveys varied from day to day in order to reach different groups of residents The locations of the pedestrian survey are marked in Fig. 5. Based on these surveys, 139 mental maps were completed (Baldin and Sinning, 2019b).

The age structure of the respondents in Erfurt reflects the age structure of Erfurt's Oststadt with minor deviations. Only the 45–64 age group was encountered less frequently in the pedestrian surveys and the group of 25 to 44 year-olds is slightly more represented than in the statistics of the City of Erfurt (Baldin and Sinning, 2019b). Thus, one can assume that the obtained mental maps of Erfurt-Oststadt reflect the resident's view reasonably.

The spatial distribution of hot spots and the spatial distribution of cool spots were separately analysed by using GIS (Baldin and Sinning, 2019a; 2019b). The used Add-on 'Spatial Analyst' of ArcGIS (ESRI) uses Kernel density estimates (KDE). Kernel density estimation enables a statistical investigation of the spatial distribution of variables (events; in this study: locations, which were marked as hot or cool, respectively, by the interviewees). The general concept assumes that the relevant variable (event) pattern has a density at any location in the area of interest and not only at locations where an event is, which allows the construction of continuous surfaces of density estimates. For further information about spatial analyses using KDE we kindly refer to (e.g.) De Smith et al. (2007). The resulting maps for hot and cool spots were subtracted from each other (hot spots minus cool spots) in order to obtain the final map.

3 Results

3.1 Mobile measurements Dresden-Gorbitz

Radiation Day – Dresden-Gorbitz

Fig. 6 shows obtained UTCI values of the selected structures for the 7 June 2018, which was almost a perfect radiation day. Mean values and corresponding standard deviation are shown. For each structure it took some time to cross it. The shown mean values were related to the midpoint of the respective time period. Due to the chosen route some urban structures were crossed two times within a measurement walk. This holds for Limbacher Weg, Amalie-Dietrich-Platz and Dahlienweg. As Dahlienweg and Limbacher Weg were crossed two times within a short time (maximum time gap 6 minutes), all respective data points were used to obtain the respective average value.

Highest thermal loads were obtained during midday and lowest in the late afternoon. Differences between the investigated structures were largest in the late morning and during midday and smallest in the late afternoon. Although shown UTCI values of each walk were not referred to a reference point in time, the available data illustrate that differences between different structures can be as large as 7 K and almost 10 K concerning UTCI during times of high thermal load. This means the different urban structures differed by one stage of thermal stress for our investigations. In the early evening, obtained UTCI indicated conditions of no thermal stress for all investigated structures.

Standard deviations of obtained UTCI for each structure crossed were smallest in the evening and largest during times of high thermal stress. Largest variations were found for urban structures with trees but incomplete canopy closure, i.e., Leutewitzer Ring (street with trees), Gorbitzer Park (park with groups of trees and lawn), Höhenpromenade (pathway with established trees on both sides) and Limbacher Weg (street with established trees on both sides in the vicinity of a beck). It indicates that sunlit areas and shadowed areas alternate and thus thermal conditions. During times of high thermal load, standard deviation of UTCI was smallest for structures offering almost no shade i.e., Wölfnitzer Ring (street running from north-north-east to south-south-west with no street trees), Amalie-Dietrich-Platz (open square with only a very few small trees) and Limbacher Weg (running from North to South). These are also those structures with high thermal load, i.e., a person crossing these structures experience a high thermal stress, which additionally varies only little.

Cloudy Day – Dresden-Gorbitz

In contrast to 7 June 2018, 5 June 2018 was very cloudy day. Fig. 7 shows obtained UTCI values of the selected structures for this day. Again structures with a larger proportion of urban greenery and large crowned trees offered conditions of lower heat stress compared to structures with no or only very few small trees. The relative course of differences between the selected urban structures follow a similar pattern as for 7 June 2018 (day with high radiation). Largest differences between urban structures were found in the early afternoon with a maximum value of 7 K concerning UTCI. However, gener-

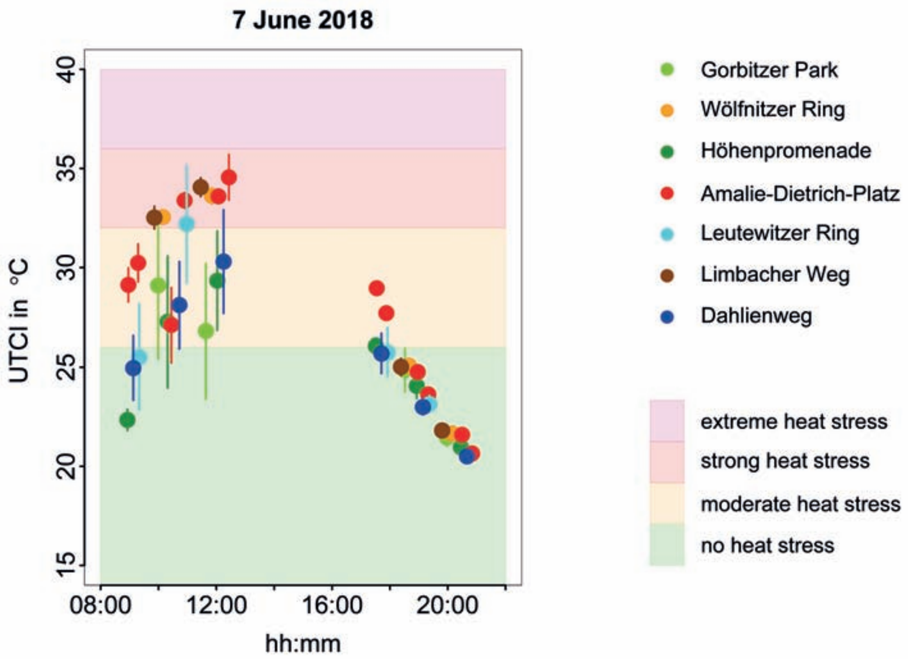

Figure 6: Obtained UTCI-values of the different urban structures. Filled circles denote the mean values averaged over all values obtained when the respective structure was crossed. Vertical lines denote standard deviation. Background colours denote the different stages of thermal strain. Each mean value is composed out of six measurements points at least.

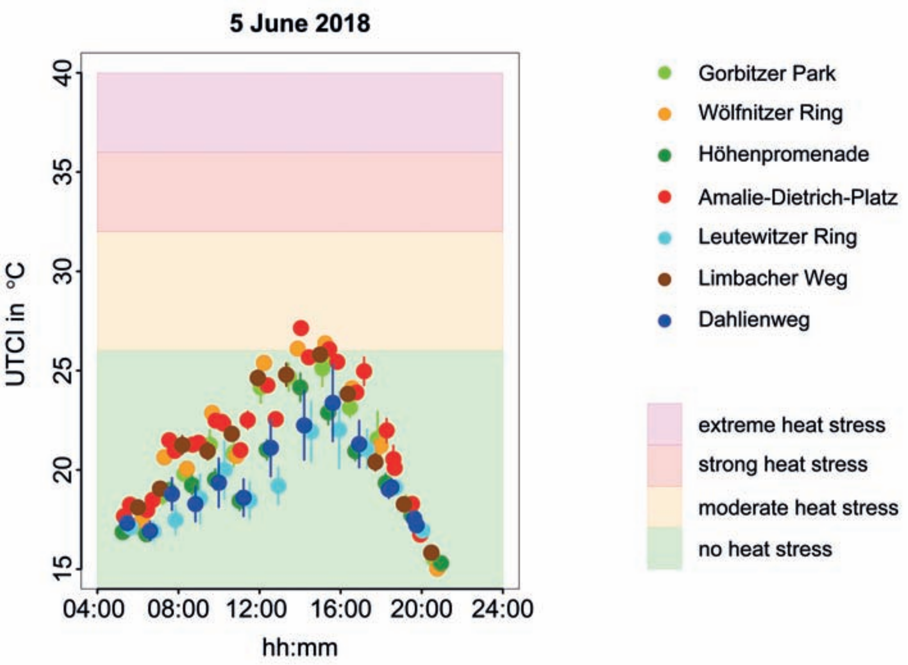

Figure 7: As Fig. 6 but for 5 June 2018.

ally differences were smaller than for the day with high radiation. Only during midday, moderate heat stress occurred. Although, differences were somewhat alleviated among different structures, they can differ in terms of stages of thermal strain by one stage. The magnitude of standard deviations changed less over the day than for the high radiation day suggesting that differences in radiation gain were generally smaller.

On both days, UTCI was closely related to mean radiant temperature and thus follows the relative course of this variable (Fig. 8). However, UTCI values at comparable T_{mrt} values are higher on 7 June than on 5 June due to higher air temperatures on 7 June. The higher temperatures on 7 June more than compensate for the lower humidity and slightly higher wind speed on this day compared to 5 June.

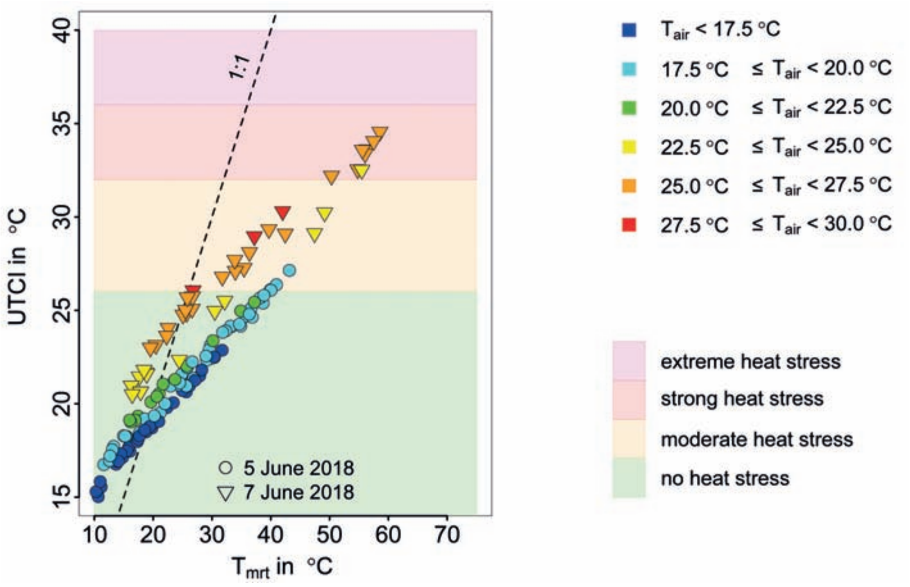

Figure 8: Relation between mean radiant temperature Tmrt and UTCI for the two investigated days and all investigated structures. Dashed line denotes 1:1 line.

Although, specific humidity was higher on 5 June 2018 (between 8.6 g kg^{-1} and 9.9 g kg^{-1}) than 7 June 2018 (between 6.8 g kg^{-1} and 8.6 g kg^{-1}), there was no clear dependency of UTCI on specific humidity on either day.

For both measurement days, structures, which have no or only little urban green, i.e. their overall appearance is not determined by urban greenery, exhibit larger thermal loads than those, with a good provision with urban green. According to the results of the micrometeorological measurements, an implementation of heat adaptation measures should be prioritised at the following locations (descending order): Amalie-Dietrich-Platz, Limbacher Weg, Wölfnitzer Ring.

3.2 Mobile measurements – Erfurt-Oststadt

Fig. 9 presents the UTCI-values of the different structures investigated in the case of Erfurt-Oststadt for 23 August 2019. During this very warm day, the measuring persons experienced heat stress, which varied from no heat stress to strong heat stress. Strongest heat stress was recorded in case of Iderhoffstraße (red filled circles in Fig. 9). This is a remarkable result as the heat stress at Iderhoffstraße was even larger than at Leipziger Platz (brown filled circles in Fig. 9), which is a large open square with rather few trees. Variables, which determine thermal stress, were investigated in order to identify possible causes for the differences between these two structures.

In the case of air temperature, it turned out that both structures differed in air temperature only very slightly. In the case of the measuring walk from 14:00 to 14:53 pm, air temperature differences along the route were not larger than 1 K. However, air temperature at Iderhoffstraße was lower and belonged to 10^{th} percentile of all measured air temperatures for this walk. This pattern in air temperature could be especially observed between 12:45 pm and 16:00 pm but generally holds for all other measurements walks. This did not change, when air temperature was detrended in order to account for the fact that the different points of the measurement route cannot be measured at the same time. The sky view factor (SVF) at Iderhoffstraße was lower than at Leipziger Platz (Iderhoffstraße: 0.31, Leipziger Platz: 0.72; based on fisheye photos and estimated using RayMan Pro 2.2 Matzarakis et al., 2010). Therefore, other factors than air temperature and a large SVF must have contributed to the high thermal load at Iderhoffstraße. A comparison of received incident shortwave radiation and recorded surface temperature (T_{surf}) showed that both variables were consistently larger in the case of Iderhoffstraße than in the case of Leipziger Platz during hours of high thermal loads (Fig. 10). This resulted in higher T_{mrt} at Iderhoffstraße than at Leipziger Platz. The larger T_{mrt} at Iderhoffstraße indicated a higher radiation load. This might be explained by the general orientation of Iderhoffstraße, which runs from West to South and therefore the northern side of the street receives full sun light during hours of highest radiation but this could be also stated in the case of Leipziger Platz. However, the houses at the northern side of Iderhoffstraße are mainly of very light (white) colour and therefore probably reflect a considerable part of the incident shortwave radiation thus enlarging the radiation load for pedestrians. We hypothesize that the colour of the buildings in concert with characteristics of the surface material overcompensated the smaller SVF at Iderhoff making this the hottest spot at Erfurt-Oststadt. The fact that light colours of buildings have an unfavourable effect on thermal load is also described in other studies (Chatzidimitrou and Yannas, 2015; Salata et al., 2015; Yuan et al., 2017).

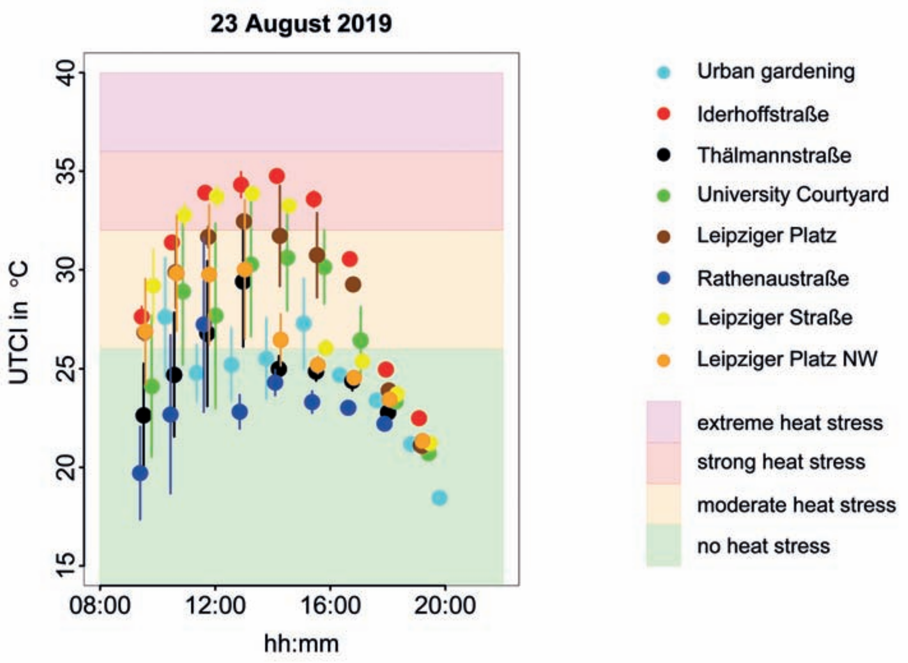

Figure 9: Obtained UTCI-values of the different urban structures. Filled circles denote the mean values averaged over all values obtained when the respective structure was crossed. Vertical lines denote standard deviation. Background colours denote the different stages of thermal strain. Each mean value is composed out of six measurements points at least. In the case of Leipziger Platz data coverage was sometimes sparser.

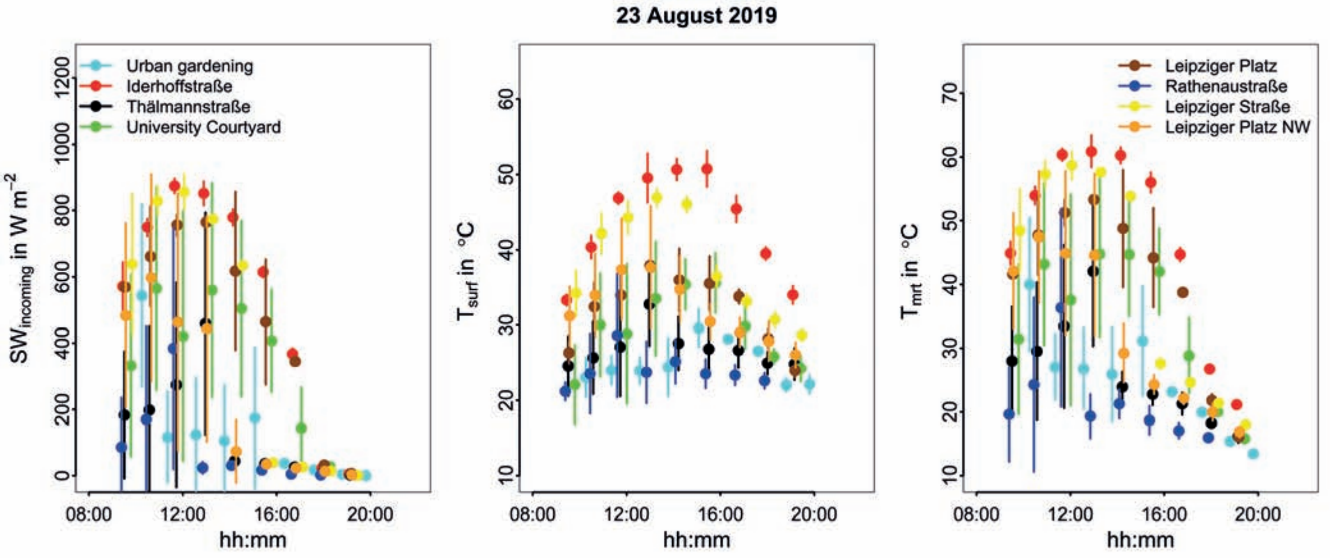

Figure 10: Obtained values for shortwave incoming radiation (SW_{incoming}), surface temperature (T_{surf}) and resulting mean radiant temperature (T_{mrt}) of the different urban structures. See Fig. 9 for further information.

A further area with high thermal load is Leipziger Straße. As for Iderhoffstraße the buildings are also of light colour (reflection enhances radiation load), which is especially relevant in the morning hours. Additionally, surface materials seem to favour high surface temperatures (second largest T_{surf}). However, trees at this street are bigger providing more shade (larger standard deviation) and the street is shaded by buildings after 15 pm (drop in UTCI, smaller standard deviation). A similar behaviour is found in case of Leipziger Platz NW, although not as pronounced as for Leipziger Straße. Rathenaustraße and Thälmannstraße are streets, which run from southerly to northerly direction. Each have trees on both street sides but measurements were only taken at the easterly pedestrian walk way of each street. However, Rathenaustraße is narrower than Thälmannstraße and there is no greenery between the buildings and the pedestrian walkway. Therefore, the easterly side of Rathenaustraße benefits from being in the shade longer in the morning and earlier in the shade in the afternoon. It mostly receives less shortwave radiation, shows smaller surface temperatures and showed a tendency to marginal lower air temperatures compared to Thälmannstraße. Consequently, Rathenaustraße experiences less heat stress compared to Thälmannstraße for most of the day. All three investigated streets show a marked decrease in standard deviation as soon as they lie in shade after midday indicating that street trees make the microclimate more variable for sunlit hours. This is also true in case of the urban gardening site, which provides one of the most comfortable conditions on average during the whole day due to its trees and their shading but it also benefits from the shadow of buildings from the late afternoon onwards.

The inner courtyard of the University of Applied Sciences Erfurt, which is open to public, shows a comparatively high thermal load but also a strong scatter (large standard deviation). This is due to the fact that during the measurements in this courtyard, different surface conditions (lawn, trees, sealed surfaces, different distances to surrounding buildings) were recorded within a short distance. Thus variable conditions were measured. As these conditions vary comparatively strongly this might also enhance the problem of unevenly distributed data points as the different conditions are not evenly measured in every case. However, its comparatively large SVF is reflected in higher thermal loads until late afternoon. Surface temperatures as well as shortwave incident radiation show smaller values compared to Iderhoffstraße and Leipziger Platz and result in conditions of mainly moderate heat stress.

Highest thermal loads and largest differences between selected structures were obtained over midday and in the early afternoon. The available data show that differences between different structures can be as large as 7 K and almost 10 K concerning UTCI during times of high thermal load, which is comparable to differences obtained between structures as for Dresden-Gorbitz. This means the thermal load between different urban structures differed by up to two stages of thermal stress in Erfurt-Oststadt. This is one stage more as in Dresden-Gorbitz. However, one should take into account that no values were recorded in Dresden-Gorbitz from late morning to early afternoon for the day with high radiation load (7 June 2018). Thus, this difference between Erfurt-Oststadt and Dresden-Gorbitz might be an effect of missing values.

In the early evening, obtained UTCI indicated conditions of no thermal stress for all investigated structures, which was also found in the case of Dresden-Gorbitz.

Standard deviations of obtained UTCI for each structure crossed were smallest in the evening and largest during times of high thermal stress. As for Dresden-Gorbitz, largest variations were found for urban structures with trees but incomplete canopy closure, i.e. Thälmannstraße and Rathenaustraße but also structures that are themselves structurally diverse (University of Applied Science). During times of high thermal load, standard deviation of UTCI was smallest for structures offering almost no shade i.e. Iderhoffstraße (street running approx. from East to West) and partly Leipziger Platz. As noted already in relation to Dresden-Gorbitz, these are structures with high thermal load, i.e. a person crossing this structures experience a high thermal stress, which additionally varies only little, especially in the case of Iderhoffstraße.

Based on the measurement results the following structural aspects tend to favour high thermal loads for pedestrian during day: no or only little urban green, adjacent buildings of light color, unfavorable orientation to the sun (streets running from westerly to easterly direction), large sky view factors. Generally, this confirms existing literature (Ali-Toudert and Mayer, 2006; Erell et al., 2014; Wang and Akbari, 2014; Erlwein et al., 2021). All the aforementioned aspects are characteristics of the hottest spots according to Fig. 9 (UTCI). According to the results of the micrometeorological measurements, an implementation of heat adaptation measures should be prioritised at the following locations (descending order): Iderhoffstraße, Leipziger Straße, Leipziger Platz.

3.3 Mental maps – Dresden-Gorbitz

Fig. 11 shows the differences between the mentions of hot and pleasant places, i.e. places more often termed as “hot” than as “pleasant” (yellow, orange, red) and places which are were more often termed as “pleasant” than as “hot” (blue colours). Two hot spots stand out in particular, Amalie-Dietrich-Platz and Merianplatz. Both sites are open sites with limited urban green and high degree of sealing, adjacent shopping facilities, parking areas and tram stops. In the case of Merianplatz there is also an adjacent public indoor swimming pool. Both places provide uncomfortable microclimate conditions due to its building characteristics and amount of urban green, which is supported by micrometeorological measurements (see Sections 3.1 and 3.2) in the case of Amalie-Dietrich-Platz. Both places must be passed by the residents to absolve obligations of everyday lives (go to school, shopping, use of public transport in order to get to work, go for swimming) and therefore are busy places. When residents wait for public transport at the tram stops, they inevitably have to stay longer in uncomfortable conditions. Both places are not used for leisure. A third hot spot is located at Gorbitzer Ring. It is related to a supermarket with an adjacent parking area. There is no direct access to public transport. The parking area is sealed and there are only some younger trees (no large crowns), i.e. the amount of shade is limited. As in the case of Amalie-Dietrich-Platz and Merianplatz, this is a location, which has to be used by the residents in their daily life and it is therefore more frequently passed than other places. There are also other large parking areas with similar characteristics at Dresden-Gorbitz but with no adjacent shopping facility. Probably due to

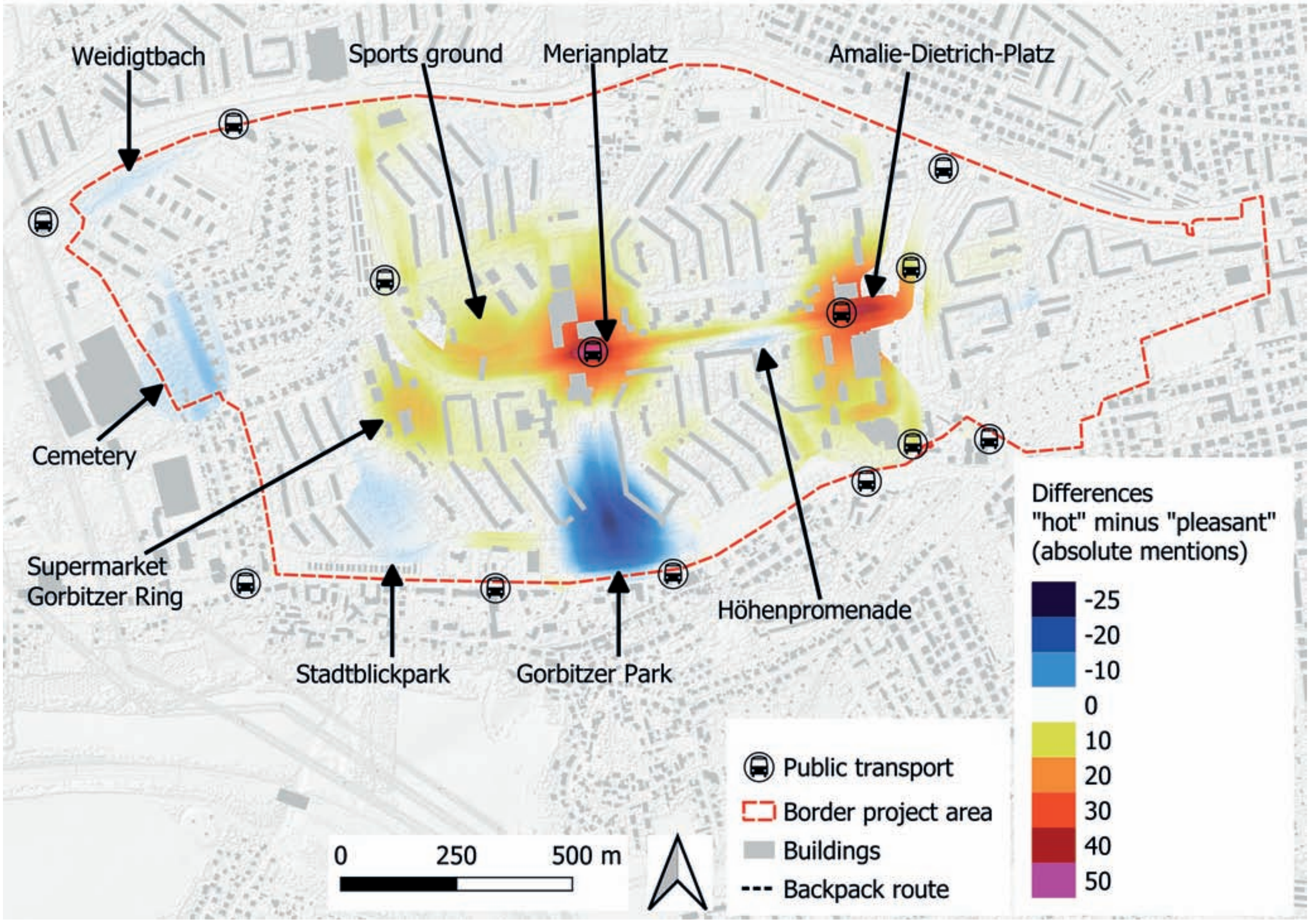

Figure 11: Dresden-Gorbitz, differences in "hot" and "pleasant" characteristics of the absolute mentions of the residents, multiple answers by residents possible. Red, yellow and orange refer to places which were more often termed as "hot" than as "pleasant". Blue colours refer to places, which were more often termed as "pleasant" than as "hot". Building data, digital surface model: Open geo data of the Freestate Saxony (Germany), Source: GeoSN, dl-de/by-2-0.

lower user frequency, these parking areas are not mentioned as "hot" as often as the parking area at the supermarket. Comparing the area of the supermarket at Gorbitzer Ring to Amalie-Dietrich-Platz and Merianplatz, it suggests that access to public transport and related higher user frequency contributes to the fact that places of these characteristics are even more often named as hot. Furthermore, it might be possible that residents must stay in unfavourable conditions when waiting for public transport. Therefore, exposure time might also play a role concerning whether a place is subjectively remembered as hot or pleasant (c.f. Nikolopoulou and Steemers, 2003). A relevant area is also the sports ground at Omsewitzer Ring, which is more often perceived as hot than as pleasant. As this is a sports ground, it also has a higher user frequency and the user additionally strain their bodies through sport. Probably, it was less often named as "hot" spot compared to Merianplatz und Amalie-Dietrich-Platz as sport is not part of everyone's daily life. It is therefore likely, that the purpose of use and the frequency of use (mainly favoured by access to public transport and shopping facilities) play a role whether a certain place, which objectively exhibits hot conditions, is often named as "hot" or not.

Places that were assessed as most thermally stressed by the respondents (Merianplatz, Amalie-Dietrich-Platz) are also characterized by an average high noise pollution (>65 db(A) tramway noise; EU Noise Mapping 2017; EU Directive 2002/49/EC; map viewer: https://gis.uba.de/maps/resources/apps/laermkartierung/index.html?lang=de&land=de, accessed 18 June 2023). This value is critical to health (Umweltbundesamt, 2019) if there is a permanent exposure. However, it can be assumed that most people stay in the aforementioned areas only temporarily and not for a longer period of time. Therefore, it can only be stated that noise pollution exists in addition to thermal stress. Whether noise increases or change the perception of heat stress cannot be stated unequivocally on the basis of available data, but it certainly represents another stress factor.

Gorbitzer Park (public urban park) stands out as the place most often termed as "pleasant". This is the largest public park in this area with established trees, meadows, shaded benches and playgrounds. Although, the spaces between prefabricated buildings are commonly well provided with landscaped urban greenery (meadow, established trees) they are less often named as pleasant, because they are probably more semi-public places

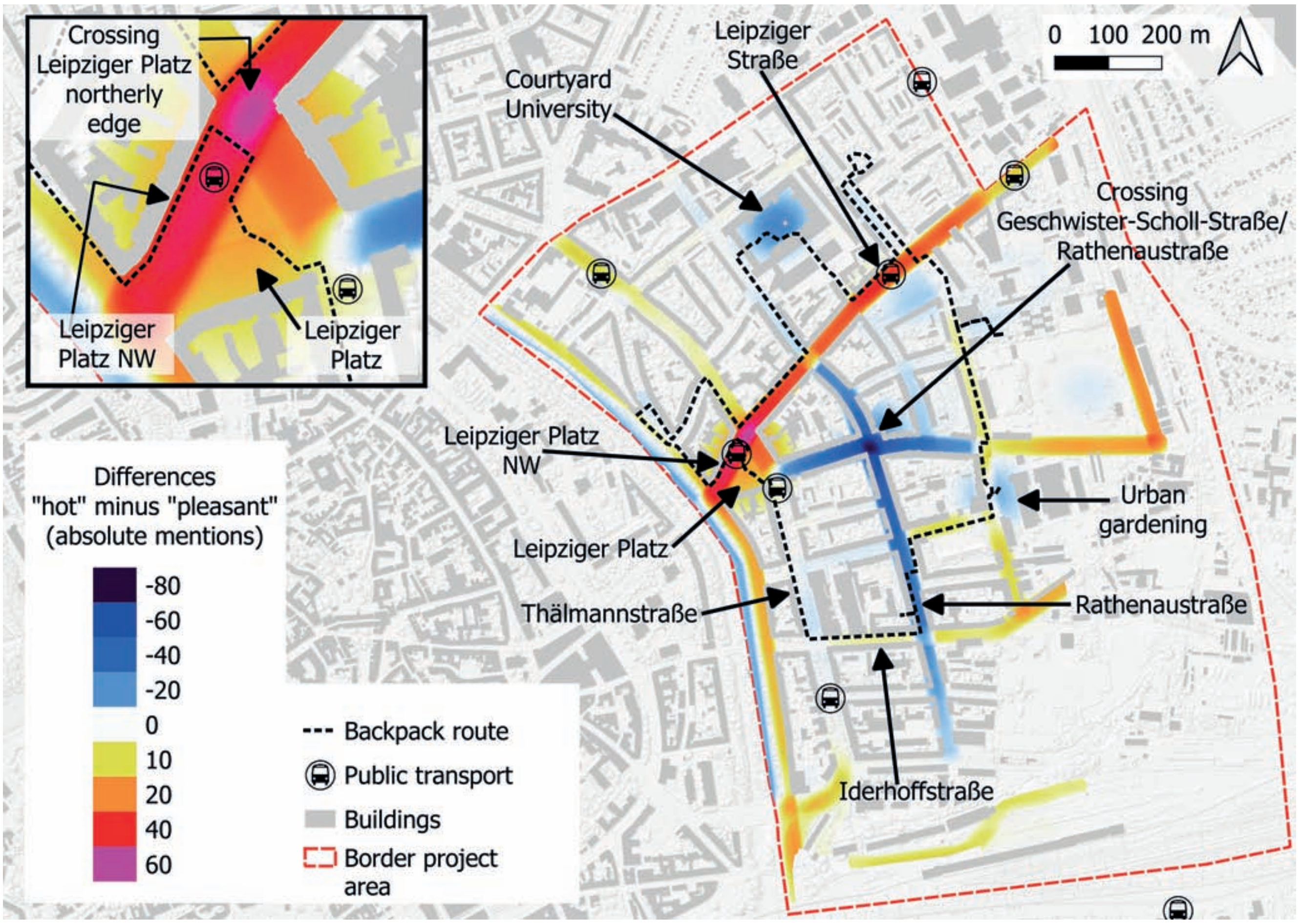

Figure 12: Erfurt-Oststadt, differences in "hot" and "pleasant" characteristics of the absolute mentions of the residents, multiple answers by residents possible. Red, yellow and orange refer to places which were more often termed as "hot" than as "pleasant". Blue colours refer to places, which were more often termed as "pleasant" than as "hot". Building data, digital surface model, noise data: Open geo data of the Freestate Thuringia (Germany), Source: GeoSN, dl-de/by-2-0.

and therefore mainly used by the tenants of the adjacent buildings. Gorbitzer Park probably attracts more people from a wider area for social activities. The area second most indicated as "pleasant" is Forsythienstraße with street trees on both sides and an adjacent cemetery (Obergorbitzer Friedhof) with established trees. A third larger area more often termed as "pleasant" than as "hot" is Stadtblickpark (public urban park). However, compared to Gorbitzer Park, it is mainly characterized by meadows and less by older (large-crowned) trees, i.e. less shade is provided and the park is therefore less often termed as "pleasant" Results suggest that public accessible places, which have a sufficient amount of urban green (especially established trees) are more often termed as pleasant. This also holds for a section of Höhenpromenade and Weidigtbach (small stream). Furthermore, this result is in accordance with Mittermüller et al. (2021), who stated that the accessibility of urban green is important for its appreciation.

3.4 Mental maps – Erfurt-Oststadt

Fig. 12 shows the mental map results concerning hot and pleasant spots in Erfurt-Oststadt. Areas, which are most referred to as being "hot" are the northwestern edge of Leipziger Platz, a section of Leipziger Straße and a crossing adjacent to Leipziger Platz (north of it). All these areas are passed by the residents in order to get to work or to return home as there are locations of public administration and the University of Applied Science, where many people work. However, in contrast to Dresden there are no larger shopping facilities.

At first we have a look at the northwest edge of Leipziger Platz. Residents locate hot spots more at the northern edge and at the corresponding sidewalk than at the middle of the street, where the tram and bus stop is located. Whether this is an effect of a fuzzy spatial location or whether residents perceive the sidewalk itself as hot remains unclear. Similarly, the spot most often termed as hot is located right at the middle of the crossing north of Leipziger Platz. This is somewhat unexpected as this area is very probably passed in a very short time when crossing the street. Possibly, the crossing as a whole should be marked as residents experience heat stress on different sides of the crossing over the day. Leipziger Straße is also quite often described as being a hot spot. This might be due to the fact that there are adja-

Table 4: Ranking of three hottest areas based on measurements and mental maps results for Dresden-Gorbitz and Erfurt-Oststadt. Areas and/or structures that were assessed by both methods are highlighted in grey. Crossing north of Leipziger Platz (Erfurt-Oststadt) was only partly assessed by measurements (lightgray background).

	Dresden-Gorbitz		Erfurt-Oststadt	
Rank	Measurements	Mental Map	Measurements	Mental Map
1	Amalie-Dietrich-Platz	Merianplatz	Iderhoffstraße	Crossing north of Leipziger Platz
2	Limbacher Weg	Amalie-Dietrich-Platz	Leipziger Straße	Leipziger Platz NW
3	Wölfnitzer Ring	Supermarket	Leipziger Platz	Leipziger Straße

cent buildings only at one side of the street and therefore less shade, especially during midday.

The area most referred to as pleasant is located at the crossing of Geschwister-Scholl-Straße and Rathenaustraße. This is a small area with established trees and a popular fast food restaurant. There is no direct access to public transport but it is not far away from Leipziger Platz. However, the aspect of frequent use is also apparent here but probably more in conjunction with leisure activities. Rathenaustraße with established trees on both sides is also quite often termed as pleasant. It is mainly a residential area with almost no shopping facilities. Therefore, noise pollution is likely to be less than in Thälmannstraße, which is also accompanied by street trees on both sides but is not as often named as pleasant as Rathenaustraße. A third spot, which is quite often perceived as pleasant, is the courtyard of the Erfurt University of Applied Science although it is a comparatively large and open area. However, its design is characterised by various greening, different sitting areas, sealed surfaces, a little pond and it is free of permanent noise sources. It is publicly accessible and used by residents for recreation.

Summarized, based on mental map results, places most named as hot are the crossing north of Leipziger Platz, the northwest edge of Leipziger Platz and Leipziger Straße. The crossing at Rathenaustraße/ Geschwister-Scholl-Straße was most often termed as pleasant by the residents followed by Rathenaustraße and the courtyard of the University of Applied Science.

As in the case of Dresden-Gorbitz, places that were assessed as thermally stressed (Leipziger Platz NW, Leipziger Straße, crossing northwest of Leipziger Platz) by the respondents are also characterized by an average high noise pollution (EU Noise Mapping 2017; EU Directive 2002/49/EC; map viewer: https://gis.uba.de/maps/resources/apps/laermkartierung/index.html?lang=de&land=de, accessed 18 June 2023). However, as in the case of Dresden-Gorbitz, it can only be stated that noise pollution exists in addition to thermal stress but no connection with the perception to heat stress can be established.

3.5 Comparison of mental maps results and measurements results

The presented mental maps identify places, that are more often perceived as hot (unpleasant) than other places but they do not contain any quantitative information concerning the intensity of heat stress. Therefore, we next compare the residents' ranking with the ranking based on measurements. It should be noted that the measurement walks only covered a part of the area of the mental maps. Table 4 lists the hottest places for both quartiers as determined by mental map result and measurements.

For each of the two cities, there is only one structure that stands out as a hot spot, both in the mental map and measurement results, namely Amalie-Dietrich Platz (Dresden-Gorbitz) and Leipziger Straße (Erfurt-Oststadt). Both places have in common that they are used frequently (e.g. from/to work) and have direct access to public transport. However, both areas were not the area most often to be named as hot. In the case of Dresden-Gorbitz, Merianplatz was most often named to be hot in mental map results but does not turn up in measurement results as it was not assessed during presented measurement campaigns. Therefore, the main reason for this deviating result between both methods is probably a spatial mismatch between measurements and mental map results. This is also partly true for the crossing north of Leipziger Platz (Erfurt-Oststadt), which is prominent in mental map results but was not selected to be investigated more in detail based on measurements. For this structure, limited measurements only are available for the northwestern edge of this crossing but confirm very strong heat stress from late morning until midday.

A spatial mismatch might also cause the difference in the ranking of Leipziger Platz NW between mental map results and measurements results (Erfurt-Oststadt). Measurements indicated that Leipziger Platz NW exhibits large thermal loads until late midday, which were commonly lower than Leipziger Platz, Iderhoffstraße and Leipziger Straße on average. However, the tram bus/stop right in the middle of the street, where shade is very limited, was not assessed by measurements. Possibly, interviewees referred to the bus/tram stop in the mental maps rather than to the north-western part of Leipziger Platz itself.

The structure 'Supermarket' ranked 3rd in mental maps results (Dresden-Gorbitz) but does not appear in measurement results as it was not assessed by measurements (spatial mismatch between both methods).

For each of the two cities, there are structures that stands out as a hot spot based on measurement results

Table 5: Ranking of three coolest and pleasant, respectively, areas based mental maps results for Dresden-Gorbitz and Erfurt-Oststadt. Areas/structures assessed by both methods are highlighted in grey. There were no ambiguous ranking concerning the three places with lowest thermal load based on measurements at Dresden-Gorbitz Therefore a corresponding listing is missing here.

	Dresden-Gorbitz	Erfurt-Oststadt	
Rank	Mental Map	Measurements	Mental Map
1	Gorbitzer Park	Rathenaustraße	Crossing Rathenaustraße/-Geschwister-Scholl-Straße
2	Cemetery	Urban Gardening	Rathenaustraße
3	Stadtblickpark	Thälmannstraße	Courtyard University of Applied Science

but appear not in the top three hot spots of corresponding mental maps. In the case of Iderhoffstraße (Erfurt-Oststadt) and Wölfnitzer Ring (Dresden-Gorbitz) an explanation could be that this is due to lower user frequency by residents caused by various reasons (limited shopping facilities, no public institutions, possibly less attractive environment to walk). In contrast to these two structures, Limbacher Weg (Dresden-Gorbitz) provides access to a public institution (kindergarden) but is also not very prominent in the mental map results. A possible reason lies in the mental map sample. The age group 65 years and older is over represented whereas age groups typically having little children are less represented compared to census data. Another reason might be that the presence time in this structure is probably short.

Leipziger Platz (Erfurt-Oststadt) is ranked 3rd based on measurement results but does not appear in the top three based on map results. This was a somewhat unexpected result as Leipziger Platz is an open square with a comparatively large sky view factor and therefore receives full sunlight during most of the day. However, the square provides a fountain. Leipziger Platz could be less prominent in the mental map results because residents might use the fountain and its droplets to cool themselves down. Therefore, it is not remembered to be extremely hot. This suggests that the perception of residents of whether a place is “hot” or “pleasant” might be inadvertently influenced by adaptation measures taken. Furthermore, this perception is probably conditioned by a psychological component, i.e. the mere presence of the fountain, possibly leads to feeling cooler.

There is no ambiguous ranking concerning the three places with lowest thermal load based on measurements at Dresden-Gorbitz, when considering the whole measurement days whereas a ranking for both methods was possible in the case of Erfurt-Oststadt (Table 5).

If one inspects Table 5 it is apparent that the difference in the ranking by both methods is partly due to different spatial coverage (Cemetery, Stadtblickpark in the case of Dresden-Gorbitz; Crossing Rathenausstraße/-Geschwister-Scholl-Straße in the case of Erfurt-Oststadt). However, mental map results strongly indicate that supplied public green is valued and apparently used. Even small green areas which offer a pleasant environment are used and valued in an environment, which is poor in public green otherwise (Erfurt-Oststadt).

There is good accordance between mental map results and measurement results concerning Rathenausstraße (Erfurt-Oststadt). Rathenaustraße exhibited lowest thermal load of all structures investigated based on measurements and is also valued as a pleasant (cool) area by residents.

Gorbitzer Park (Dresden-Gorbitz; public park) was named most often by residents to be “pleasant”, but it does not stand out as a place of low or high thermal load either based on measurements. One reason might be that the residents use the park in a different way compared to the measuring person, which just crossed the park and experienced alternating sunlit and shaded areas. It is very likely that residents deliberately go to shaded areas and stay there longer. Therefore, the perception of the residents is already influenced by an adaptation measure taken (stay in shade). Additionally, this is likely to be done during leisure time when it can be anticipated that stress levels are generally lower. It is very likely that the same reasons lead to the result that the courtyard of the University of Applied Science is highlighted as a pleasant place in the mental map, where, additionally, residents might take advantage of a little pond to cool themselves down. Measurements denote that the urban gardening area (Erfurt-Oststadt) is an area of reduced thermal stress (no thermal stress or only moderate heat stress) but it is less prominent in the mental map results. One hypothesis might be that urban gardening is more often pursued by people with higher education (Berges et al., 2014; Winkler et al., 2019). It further might be that the area implies not to be open to the public and/or that this area is less known among the interviewees (interviewees must live in Erfurt but not necessarily in Erfurt-Oststadt). Measurements show that Thälmannstraße (Erfurt-Oststadt) offers slightly more favourable thermal conditions than other inspected measured structures but is seldom named by residents to be “pleasant” concerning heat. This might be due to street noise (c.f. Chapter 3.4).

4 Summary and conclusion

The presented study discusses two different methods for analysing thermal discomfort in cities, the participatory approach of mental mapping and the expert tool of mobile measurement. The two cases of Dresden and Erfurt

Table 6: Comparison of mental maps and mobile measurements regarding methodological similarities and differences.

	Mental maps	Mobile measurements
Expertice and perspective	layperson expertise (based on personal perception of residents)	microclimate or micrometeorological expertise (based on measurements of meteorological quantities)
Type of assessment of thermal load	mix of quantitative and qualitative[#]	quantitative
Repeatability	limited (differences in the sample not unlikely)	limited (unlikely that measurements could be repeated under exact same weather conditions)
Survey/evaluation of space	punctiform/areal	linear
Quality of spatial localization	could be blurred (depends on the memory and spatial orientation of the interviewees, but also on aid to orientation on the map)	precise
Reference to time	not precise (Statements are made based on previous experiences during the summer season in general apart from the implicit temporal reference 'summer', the reference period and its length is undetermined and can vary from interviewee to interviewee.)	precise
Influence of other stressors on the localization and stated/determined strength of heat loads	yes, generally possible (e.g. noise pollution, recent thermal history of interviewee, meteorological conditions during the interview or overall)	no
Statements for different age groups	yes, generally possible (depends on sample)	very limited
Statements about frequency of use	yes, generally possible	no

[#] only qualitative statements in this study

are situated in Germany and represent cities of about 200.000 and 500.000 inhabitants. The study provides empirical data that show which are of relevance for local adaptation to climate change.

The method of mental maps has already been applied in previous studies and compared to measured heat stress from micrometeorological measurements (Lenzholzer, 2010; Lehnert et al., 2021a, 2021b; Mittermüller et al., 2021). The current paper combines mental maps and a bioclimatic index to describe heat loads of human beings. Concerning the identification of thermally pleasant and unpleasant places and methodological aspects, there are some relevant differences between both methods (Table 6).

Based on the study it can be concluded that there is reasonable agreement between mental map and mobile measurement results concerning the location of hot spots when the corresponding area is frequently used by residents. This corresponds with results of Lehnert et al. (2021a) who also reported a positive relationship between the location of hot spots and user frequency for mental maps obtained in their research.

Nevertheless, the comparison also identifies differences in the location of most heat stressed areas between mobile measurements and mental maps. Generally, these can be related to user frequency, to different ways of staying in or crossing a certain structure (e.g. Gorbitzer Park), but also to different spatial coverage of the two methods. The results confirm results of the study of Lehnert et al. (2021a) that the behavioural patterns of the residents and already applied adaptation measures should be taken into account in order to achieve a comprehensive picture. Furthermore, the research has shown that for mobile measurement the routes should be adapted to user behaviour if possible to reach better results.

The importance of longer residence duration in heat stressed areas on the perception of heat by residents is somewhat reduced when there are options for limiting personal heat stress (e.g. shadow or water droplets of a fountain). This means that taken adaptation measures or the access to urban green influence the perception of heat in areas, which, however, objectively exhibit considerable heat stress. This result is somewhat in contradiction to the results of Lehnert et al. (2021b), who found a higher probability for TSV-related heat stress near sprayed water mist (TSV, thermal sensation votes, obtained via questionnaires). This might be an indication that obtained results are rather site specific and depend on specific site characteristics.

Results further suggest that lower stress levels during leisure time might alter the perception of heat. Noise polluted areas generally coincided with areas most often named to be hot. However, the data of the study do not allow further interpretation on the relationship of noise and heat perception.

Overall, the research concludes, that both methods, mental maps and mobile measurement, provide valuable results for local adaptation strategies. If co-creation and implementation of measures are prior goals of the local transformation approach, mental maps offer a respective methodology by making citizens become an active partner of the analysis and conceptualisation process and help municipalities to identify fields of action of climate adaptation with high benefit for the citizens.

Results show the benefits of the combined use of mental maps and meteorological measurements, yet there are points that should be addressed in further work. Backpack measurements offer the advantage that all measured areas were measured with the same measurement devices, but the measurement uncertainty can change, e.g. with the radiation conditions (radiation error). Therefore, the uncertainty of the measured meteorological variables should be estimated in further work. For this purpose, the Monte Carlo simulation method can be used to apply uncertainties (within justified limits) to the individual measured values. A sufficiently high number of simulations would then lead to reasonable statements on the uncertainty of the measured values. An unsolved problem and thus a subject of further possible research is the determination of the uncertainties of mental maps and their comparison with uncertainties of meteorological measurements.

Additionally, further efforts should focus on including both methods into a mixed methods approach of local climate adaptation respecting the strengths and weaknesses of both and benefitting from synergies. Furthermore, the potential of innovative digitalisation needs to be explored and reflected to be applied and optimize the methods (e.g. use of apps to lower the effort and increase the participation of mental mapping as it was experienced in other participation processes in Dresden and Erfurt in the HeatResilientCity-project (Grossmann et al., 2021; Grossmann and Sinning, 2021). However, face-to-face questionnaires should remain part of the methodology to avoid digital divide-restrictions.

Acknowledgments

Presented work took place within the framework of the project HeatResilientCity, funded by the Federal Ministry of Education and Research of Germany (Funding references: 01LR1724, 01LR2011F). We are grateful to the anonymous reviewers for their valuable comments, which helped to improve the manuscript accordingly.

Appendix

Table A1: Information about number of obtained data points per structure for Dresden-Gorbitz, 5 June 2018. The variation coefficient was calculated as standard deviation divided by the mean value and is given in percent.

Investigated structure	Time (midpoint) in CET+1	Number of obtained data points	Difference in time between first and last data point in s	UTCI (Mean value) in °C	Standard deviation in °C	Variation coefficient in %
Gorbitzer Park	07:05:33	88	87	17.1	0.3	1.7
	08:11:23	78	77	18.7	0.4	2.3
	09:17:28	71	70	19.8	0.3	1.8
	10:32:51	113	137	21.3	0.7	3.5
	11:43:27	86	85	20.8	0.6	2.9
	11:45:17	29	28	20.9	0.1	0.3
	13:03:33	335	334	24.2	0.8	3.2
	14:26:08	190	189	24.7	0.7	2.8
	16:05:42	89	88	25.1	0.9	3.6
	16:07:30	11	16	25.6	0.1	0.3
	17:27:16	156	155	23.1	0.5	2.2
	18:49:26	86	85	21.6	1.4	6.3
	20:13:12	91	90	18.3	0.5	2.6
	21:34:47	98	97	15.5	0.3	1.8
Wölfnitzer Ring	07:12:13	103	102	17.5	0.1	0.6
	08:18:10	106	105	20.6	0.2	0.9
	09:25:03	114	113	20.1	0.1	0.7
	10:39:36	115	114	22.9	0.1	0.6
	11:51:24	119	118	20.7	0.2	0.9
	13:12:58	122	121	25.4	0.2	0.7
	14:52:44	108	107	26.1	0.2	1.0
	16:14:23	120	119	26.4	0.1	0.5
	17:34:03	114	113	24.1	0.2	0.6
	18:57:57	115	114	21.2	0.8	3.9
	20:21:23	119	118	18.2	0.1	0.6
	21:45:41	158	157	15.0	0.1	0.7
Höhenpromenade	06:14:50	216	274	16.9	0.2	0.9
	07:25:32	141	140	16.8	0.1	0.9
	08:31:17	77	76	19.0	0.4	2.0
	09:40:18	80	79	19.2	0.5	2.5
	10:48:16	117	119	19.5	0.5	2.7
	12:01:00	149	148	18.4	0.5	2.6
	13:21:22	91	90	21.0	0.5	2.4
	15:00:28	118	117	24.2	0.7	2.9
	16:23:00	74	73	22.9	0.6	2.7
	17:43:09	217	216	20.9	0.5	2.2
	19:13:25	217	216	19.3	0.5	2.4
	20:29:16	127	126	17.7	0.2	1.2
	21:56:40	173	172	15.3	0.1	0.6
Amalie-Dietrich-Platz	06:18:53	118	121	17.7	0.4	2.2
	06:36:40	49	48	18.2	0.1	0.3
	07:27:22	39	38	18.0	0.1	0.4
	07:43:42	50	49	18.5	0.2	0.8
	08:48:44	46	45	21.0	0.1	0.5
	09:41:42	29	28	21.3	0.1	0.5
	09:59:29	239	238	21.4	0.2	1.1
	08:32:48	40	39	21.5	0.0	0.2
	10:50:01	43	42	22.5	0.1	0.5
	11:08:12	6	6	22.4	0.4	1.6
	11:12:33	79	94	22.3	0.1	0.6

Table A1: continued

Investigated structure	Time (midpoint) in CET+1	Number of obtained data points	Difference in time between first and last data point in s	UTCI (Mean value) in °C	Standard deviation in °C	Variation coefficient in %
Amalie-Dietrich-Platz	12:03:07	44	43	21.0	0.1	0.3
	12:24:50	400	399	22.5	0.4	1.9
	13:23:09	48	47	24.3	0.1	0.5
	13:47:45	626	625	22.6	0.2	1.1
	15:02:28	65	64	27.1	0.2	0.6
	15:25:45	537	536	25.7	0.3	1.0
	16:25:42	52	51	26.1	0.1	0.3
	16:49:49	369	368	25.4	0.2	0.9
	17:45:57	51	50	23.9	0.1	0.6
	18:09:07	759	758	25.0	0.7	2.8
	19:15:56	35	34	22.0	0.6	2.7
	19:35:51	9	8	20.5	0.7	3.3
	19:39:39	36	35	20.1	0.1	0.7
	20:30:59	40	39	18.3	0.1	0.3
	20:55:26	515	518	16.7	0.3	2.0
Leutewitzer Ring	06:38:55	87	86	17.1	0.4	2.4
	07:46:21	71	70	16.9	0.5	2.9
	08:50:50	71	70	17.5	0.7	4.2
	10:03:43	88	93	18.5	1.2	6.7
	11:16:14	142	141	20.0	1.5	7.3
	12:30:48	103	102	18.5	0.9	5.0
	13:55:30	100	99	19.2	0.9	4.8
	15:32:43	85	84	21.9	1.5	7.0
	16:55:26	98	97	22.0	1.9	8.7
	18:17:30	81	106	21.1	1.0	4.6
	19:41:50	72	71	19.1	0.4	1.9
	21:02:03	80	79	17.0	0.1	0.8
Limbacher Weg	06:59:42	63	232	18.1	0.3	1.9
	08:05:35	59	244	19.1	0.3	1.4
	09:11:22	81	266	21.3	0.4	2.1
	10:25:59	83	190	21.0	0.4	2.0
	11:37:32	69	187	21.8	0.2	1.1
	12:54:54	79	190	24.6	0.4	1.6
	14:18:51	70	260	24.8	0.6	2.3
	15:58:59	79	251	25.8	0.3	1.2
	17:21:06	73	174	23.8	0.2	1.0
	18:42:44	70	266	20.4	0.4	2.1
	20:06:57	70	226	18.3	0.1	0.7
	21:28:09	76	259	15.8	0.2	1.0
Dahlienweg	06:28:12	88	356	17.3	0.4	2.1
	07:35:27	95	314	16.9	0.5	2.9
	08:40:37	83	315	18.8	0.8	4.3
	09:50:01	115	283	18.3	0.9	4.8
	10:59:14	95	348	19.4	1.2	6.3
	12:12:27	105	344	18.6	0.9	5.0
	13:33:02	98	398	21.1	1.4	6.8
	15:11:58	104	405	22.2	1.7	7.8
	16:36:31	108	442	23.4	1.9	8.3
	17:54:38	101	310	21.3	1.2	5.5
	19:22:21	47	46	19.0	0.4	2.3
	19:29:59	45	44	19.1	0.4	2.0
	20:37:25	56	55	17.5	0.1	0.7
	20:44:35	54	53	17.2	0.2	0.9

Table A2: Information about number of obtained data points per structure for Dresden-Gorbitz, 7 June 2018. The variation coefficient was calculated as standard deviation divided by the mean value and is given in percent.

Investigated structure	Time (midpoint) in CET+1	Number of obtained data points	Difference in time between first and last data point in s	UTCI (Mean value) in °C	Standard deviation in °C	Variation Coefficient in %
Gorbitzer Park	10:59:15	127	134	29.1	3.7	12.6
	12:38:22	526	540	26.8	3.4	12.7
	19:31:03	162	171	24.9	1.1	4.4
	20:58:34	401	400	21.5	0.4	2.0
Wölfnitzer Ring	11:09:07	143	142	32.5	0.3	0.9
	12:50:51	122	121	33.6	0.4	1.3
	19:39:37	130	129	25.1	0.3	1.2
	21:09:12	137	136	21.7	0.2	0.8
Höhenpromenade	09:55:30	143	142	22.3	0.5	2.4
	11:18:59	172	171	27.3	3.3	12.1
	13:01:56	132	137	29.3	2.5	8.5
	18:30:51	127	126	26.1	0.4	1.4
	19:55:42	128	127	24.1	0.6	2.6
	21:27:11	208	207	21.0	0.3	1.5
Amalie-Dietrich-Platz	09:57:27	41	40	29.1	0.9	3.0
	10:17:44	43	42	30.2	1.0	3.2
	11:26:40	703	702	27.1	1.9	6.9
	11:54:06	39	38	33.4	0.4	1.2
	13:04:14	51	50	33.6	0.3	1.0
	13:26:04	39	38	34.6	1.2	3.3
	18:32:41	39	38	29.0	0.1	0.2
	18:52:38	48	47	27.7	0.3	1.1
	19:57:38	53	52	24.8	0.1	0.3
	20:19:33	56	55	23.6	0.1	0.5
	21:29:46	54	53	21.6	0.1	0.6
	21:50:29	39	38	20.7	0.1	0.6
Leutewitzer Ring	10:20:05	83	82	25.5	2.7	10.4
	11:58:25	238	256	32.2	3.0	9.3
	18:55:13	95	94	25.7	1.2	4.8
	20:22:06	91	90	23.1	0.4	1.8
Limbacher Weg	10:51:18	79	368	32.5	0.6	1.7
	12:27:32	77	281	34.1	0.5	1.4
	19:23:06	82	289	25.0	0.4	1.7
	20:48:32	81	227	21.8	0.3	1.3
Dahlienweg	10:07:35	96	417	25.0	1.6	6.5
	11:43:12	112	462	28.1	2.2	7.8
	13:15:01	118	464	30.3	2.6	8.6
	18:42:30	96	400	25.7	1.0	3.9
	20:08:32	112	459	23.0	0.4	1.7
	21:40:07	109	411	20.5	0.2	1.0

Table A3: Information about number of obtained data points per structure for Erfurt-Oststadt, 23 August 2019. The variation coefficient was calculated as standard deviation divided by the mean value and is given in percent.

Investigated structure	Time (midpoint) in CET+1	Number of obtained data points	Difference in time between first and last data point in s	UTCI (Mean value) in °C	Standard deviation in °C	Variation Coefficient in %
Urban Gardening	10:15:37	165	604	27.6	3.0	10.9
	11:21:03	359	1034	24.8	1.4	5.8
	12:33:34	308	1414	25.2	1.8	7.2
	13:46:13	275	1206	25.5	2.0	8.0
	15:04:15	304	1272	27.3	2.3	8.4
	16:19:33	372	1322	24.7	0.2	0.9
	17:36:24	309	1246	23.4	0.3	1.3
	18:48:04	320	1320	21.2	0.4	1.8
	19:47:23	38	164	18.4	0.2	1.2
Iderhoffstraße	09:26:22	20	52	27.6	0.5	1.9
	10:29:16	12	50	31.4	0.4	1.1
	11:38:44	11	20	33.9	0.2	0.7
	12:53:22	8	46	34.3	0.6	1.9
	14:08:04	11	48	34.8	0.3	0.9
	15:25:08	10	50	33.6	0.4	1.2
	16:40:08	12	52	30.5	0.3	1.0
	17:55:30	17	50	25.0	0.1	0.6
	19:04:36	16	48	22.5	0.2	0.8
Thälmannstraße	09:30:09	23	70	22.6	2.6	11.6
	10:33:45	29	80	24.7	3.1	12.7
	11:42:55	19	70	26.8	3.7	13.7
	12:57:29	7	68	29.4	3.3	11.1
	14:11:58	16	76	25.0	0.7	2.6
	15:29:32	18	78	24.9	0.5	1.9
	16:45:07	18	74	24.4	0.5	2.0
	17:59:43	9	56	22.8	0.2	0.9
	19:08:35	9	70	21.1	0.3	1.5
Courtyard University	09:46:47	18	60	24.1	3.6	14.8
	10:51:49	12	58	28.9	3.7	12.8
	11:59:49	10	56	27.7	4.7	16.9
	13:13:45	24	66	30.3	3.6	12.1
	14:29:20	12	66	30.6	2.7	8.8
	15:46:23	14	54	30.1	1.9	6.2
	17:02:29	21	72	26.4	1.7	6.3
	18:15:24	15	56	23.3	0.1	0.5
	19:24:13	12	76	20.7	0.2	1.0
Leipziger Platz	09:31:39	8	14	26.8	0.2	0.8
	10:36:33	17	64	29.9	1.8	6.0
	11:44:19	8	22	31.7	0.5	1.7
	12:58:54	2	2	32.5	0.1	0.2
	14:13:40	7	12	31.7	2.5	8.0
	15:31:13	11	20	30.7	2.1	7.0
	16:46:29	2	2	29.3	0.1	0.2
	18:00:53	10	24	23.9	0.3	1.2
	19:09:41	5	14	21.1	0.2	0.7
Rathenaustraße	09:22:10	28	262	19.7	2.4	11.9
	10:25:33	25	238	22.7	4.0	17.6
	11:34:52	32	314	27.2	4.4	16.2
	12:49:44	17	216	22.8	0.9	3.8
	14:03:41	19	312	24.3	0.6	2.7
	15:20:47	15	310	23.3	0.6	2.4
	16:36:02	16	282	23.0	0.3	1.3
	17:51:34	11	244	22.2	0.2	1.1

Table A3: continued

Investigated structure	Time (midpoint) in CET+1	Number of obtained data points	Difference in time between first and last data point in s	UTCI (Mean value) in °C	Standard deviation in °C	Variation Coefficient in %
Leipziger Straße	09:49:26	7	44	29.2	1.9	6.4
	10:54:20	15	42	32.8	0.6	1.7
	12:02:06	16	56	33.7	0.6	1.7
	13:16:07	7	36	33.9	0.2	0.5
	14:32:23	15	66	33.2	0.2	0.5
	15:49:04	19	62	26.0	0.2	0.9
	17:05:32	6	52	25.4	0.2	0.8
	18:17:47	12	52	23.7	0.2	0.7
	19:26:30	25	52	21.2	0.1	0.6
Leipziger Platz NW	09:32:49	12	36	26.9	2.7	10.0
	10:38:01	17	50	29.8	2.9	9.8
	11:45:47	11	48	29.8	3.5	11.9
	13:00:04	18	48	30.0	3.5	11.7
	14:14:53	18	52	26.5	1.3	4.9
	15:32:16	11	60	25.2	0.4	1.7
	16:48:02	13	50	24.5	0.3	1.1
	18:01:58	7	36	23.4	0.4	1.6
	19:10:29	21	52	21.3	0.3	1.2

References

Ali-Toudert, F.H. Mayer, 2006: Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. – Build. Env. **41**, 94–108, DOI:10.1016/j.buildenv.2005.01.013.

Baldin, M.-L., H. Sinning, 2019a: HeatResilientCity Hitzeresiliente Stadt- und Quartiersentwicklung in Großstädten – Ergebnisbericht zur Befragung 2018 in Dresden – Institut für Stadtforschung, Planung und Kommunikation der Fachhochschule Erfurt, Erfurt, https://www.db-thueringen.de/receive/dbt_mods_00046114 (accessed at 09.08.2023).

Baldin, M.-L., H. Sinning, 2019b: HeatResilientCity Hitzeresiliente Stadt- und Quartiersentwicklung in Großstädten – Ergebnisbericht zur Befragung 2018 in Erfurt. – Institut für Stadtforschung, Planung und Kommunikation der Fachhochschule Erfurt, Erfurt https://www.db-thueringen.de/receive/dbt_mods_00045614 (accessed at 09.08.2023).

Berges, R., I. Optiz, A. Piorr, T. Krikser, A. Lange, K. Bruszewska, K. Specht, C. Hennerberg, 2014: Urbane Landwirtschaft – Innovationsfelder für die nachhaltige Stadt? – Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF) e. V., Müncheberg, https://digital.zlb.de/viewer/resolver?urn=urn:nbn:de:kobv:109-1-8337101 (accessed at 29.10.2022).

Błażejczyk, K., P. Broede, D. Fiala, G. Havenith, I. Holmér, G. Jendritzky, B. Kampmann, A. Kunert, 2010: Principles of the New Universal Thermal Climate Index (UTCI) and its Application to Bioclimatic Research in European Scale. – Misc. Georg. **14**, 91–102, DOI:10.2478/mgrsd-2010-0009.

Bröde, P., D. Fiala, K. Błażejczyk, I. Holmér, G. Jendritzky, B. Kampmann, B. Tinz, G. Havenith, 2012: Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). – Int J. Biometeorol. **56**, 481–494, DOI:10.1007/s00484-011-0454-1.

Chatzidimitriou, A., S. Yannas, 2015: Microclimate development in open urban spaces: The influence of form and materials. – Energ Build. **108**, 156–174, DOI:10.1016/j.enbuild.2015.08.048.

De Smith, M.J., M.F. Goodchild, P.A. Longley, 2007: Geospatial analysis a comprehensive guide to principles, techniques and software tools, 2nd ed. – Matador, Leicester

Directive 2002/49/EC, 2022: Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise – Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise. – Official Journal L 189, 18/07/2002 P. 0012–0026 Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002.

Downs, R.M., D. Stea, R. Geipel, D.W. Steadman, 1982: Kognitive Karten: Die Welt in unseren Köpfen. – Harper & Row, New York.

Erell, E., D. Pearlmutter, D. Boneh, P.B. Kutiel, 2014: Effect of high-albedo materials on pedestrian heat stress in urban street canyons. – Urban Climate **10**, 367–386 2014, DOI:10.1016/j.uclim.2013.10.005.

Erlwein, S., T. Zölch, S. Pauleit, 2021: Regulating the microclimate with urban green in densifiying cities: Joint assessment on two scales. – Build. Env. **205**, 108233, DOI:10.1016/j.buildenv.2021.108233.

Goldberg, V., C. Kurbjuhn, C. Bernhofer, 2013: How relevant is urban planning for the thermal comfort of pedestrians? Numerical case studies in two districts of the City of Dresden (Saxony/Germany). – Meteorol. Z. **22**, 739–751, DOI:10.1127/0941-2948/2013/0463.

Gross, G. 2017: Some effects of water bodies on the environment – numerical experiments. – J. of Heat Island Inst. **12**, 1–11

Grossmann, L., H. Sinning, 2021: HeatResilientCity – Bürgerbeteiligung zur hitzeresilienten Platzgestaltung. Wissenschaftlicher Ergebnisbericht zur Intervention und Online-Befragung „Platz nehmen – auch bei Hitze!“ 2020 in der Erfurter Oststadt. – ISP-Schriftenreihe, Vol. 17, Erfurt, https://isp.fh-erfurt.de/fileadmin/Dokumente/ISP/Publikationen/ISP_Schriftenreihe_Band_17.pdf (accessed 25 October 2022)

Grossmann, L., K. Brüggemann, H. Sinning, 2021: HeatResilientCity – Bürgerbeteiligung zur hitzeresilienten

Gestaltung von Haltestellen. Wissenschaftlicher Ergebnisbericht zur Online-Befragung „Heiß, heißer, Haltestellen?“ 2020 in Dresden-Gorbitz. – ISP-Schriftenreihe, Vol. 16, Erfurt, https://isp.fh-erfurt.de/fileadmin/Dokumente/ISP/Publikationen/ISP_Schriftenreihe_Band_16.pdf (accessed 25 October 2022)

Havenith, G., D. Fiala, K. Błazejczyk, M. Richards, P. Bröde, I. Holmér, H. Rintamaki, Y. Benshabat, G. Jendritzky, 2012: The UTCI-clothing model Int J. Biometeorol **56**, 461–470, DOI:10.1007/s00484-011-0451-4.

Heusinkveld, B.G., G.J. Steeneveld, L.W.A. van Hove, C.M.J. Jacobs, A.A.M. Holtslag, 2014: Spatial variability of the Rotterdam urban heat island as influenced by urban land use. – J. Geophys Res Atmos **119**, 677–692, DOI:10.1002/2012JD019399.

IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G. -K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (Eds). – Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, B. Zhou (Eds) – Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp, DOI:10.1017/9781009157896.

IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Pörtner, H.-O., D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (Eds). – Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., DOI:10.1017/9781009325844.

Jendritzky, G., R. de Dear, G. Havenith, 2012: UTCI – Why another thermal index? – Int J. Biometeorol **56**, 421–428, DOI:10.1007/s00484-011-0513-7.

Kranepuhl, S., D. Ziervogel, 2007: Mental Maps als Instrument der Bürgerbeteiligung? Erfahrungen aus einem Pilotprojekt in Leipzig. – Published online, DOI:10.25673/86220.

Lehnert, M., J. Geletié, J. Kopp, M. Brabec, M. Jurek, J. Pánek, 2021a: Comparison between mental mapping and land surface temperature in two Czech cities: A new perspective on indication of locations prone to heat stress. – Build. Env. **203**, 108090, DOI:10.1016/j.buildenv.2021.108090.

Lehnert, M., M. Brabec, M. Jurek, V. Tokar, J. Geletié, 2021b: The role of blue and green infrastructure in thermal sensation in public urban areas: A case study of summer days in four Czech cities. – Sustain. Cities Soc. **66**, 102683, DOI:10.1016/j.scs.2020.102683.

Lenzholzer, S., 2010: Engrained experience – a comparison of microclimate perception schemata and microclimate measurements in Dutch urban squares. – Int J. Biometeorol. **54**, 141–150, DOI:10.1007/s00484-009-0262-z.

Lindberg, F., B. Holmer, S. Thorsson, 2008: SOLWEIG 1.0 – Modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings. – Int J. Biometeorol **52**, 697–713, DOI:10.1007/s00484-008-0162-7.

Lynch, K., 1960: The image of the city. – The M.I.T. Press, Cambridge Massachusetts, 194 pp.

Matzarakis, A., F. Rutz, H. Mayer, 2010: Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. – Int J. Biometeorol **54**, 131–139, DOI:10.1007/s00484-009-0261-0.

Mittermüller, J., S. Erlwein, A. Bauer, T. Trokai, S. Duschinger, M. Schönemann, 2021: Context-specific, user-centred: Designing urban green infrastructure to effectively mitigate urban density and heat stress. – Urban Plan **6**, 40–53, DOI:10.17645/up.v6i4.4393.

Nikolopoulou, M., K. Steemers, 2003: Thermal comfort and psychological adaptation as a guide for designing urban spaces, Energ. Build. **35**, 95–101, DOI:10.1016/S0378-7788(02)00084-1.

Novak, M., 2013: Use of the UTCI in the Czech Republic. – Geogr. Polonica **86**, 21–28, DOI:10.7163/GPol.2013.3.

Salata, F., I. Golasi, A. de L. Vollaro, R. de L. Vollaro, 2015: How high albedo and traditional buildings' materials and vegetation affect the quality of urban microclimate. A case study Energ. Build. **99**, 32–49, DOI:10.1016/j.enbuild.2015.04.010.

Samad, A., U. Vogt, 2020: Investigation of urban air quality by performing mobile measurements using a bicycle (MOBAIR). – Urban Climate **33**, 100650, DOI:10.1016/j.uclim.2020.100650.

Shashua-Bar, L., O. Potchter, A. Bitan, D. Boltansky, Y. Yaakov, 2010: Microclimate modelling of street tree species effects within the varied urban morphology in the Mediterranean city of Tel Aviv, Israel. – Int. J. Climatol. **30**, 44–57, DOI:10.1002/joc.1869.

Stewart, I.D., E.S. Krayenhoff, J.A. Voogt, J.A. Lachapelle, M.A. Allen, A.M. Broadbent, 2021: Time Evolution of the Surface Urban Heat Island. – Earth's Future **9**, e2021EF002178, DOI:10.1029/2021EF002178.

Taleghani, M., U. Berardi, 2018: The effect of pavement characteristics on pedestrians' thermal comfort in Toronto. – Urban Climate **24**, 449–459, DOI:10.1016/j.uclim.2017.05.007.

Tsin, P.K., A. Knudby, E.S. Krayenhoff, H.C. Ho, M. Brauer, S.B. Henderson, 2016: Microscale mobile monitoring of urban air temperature. – Urban Climate **18**, 58–72, DOI:10.1016/j.uclim.2016.10.001.

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

Umweltbundesamt (Ed.), 2019: WHO-Leitlinien für Umgebungslärm für die Europäische Region. Lärmfachliche Bewertung der neuen Leitlinien der Weltgesundheitsorganisation für Umgebungslärm für die Europäische Region. – Published online, https://www.umweltbundesamt.de/publikationen/who-leitlinien-fuer-umgebungslaerm-fuer-die (accessed 26.06.2023).

Wang, Y., H. Akbari, 2014: Effect of sky view factor on outdoor temperature and comfort in Montreal. – Env. Eng. Sci. **31**, 272–287, DOI:10.1089/ees.2013.0430.

Winkler, B., A. Maier, I. Lewandowski, 2019: Urban gardening in Germany: Cultivating a Sustainable Lifestyle for the Societal Transition to a Bioeconomy. – Sustainability **11**, 801, DOI:10.3390/su11030801.

Yuan, J., K. Emura, C. Farnham, 2017: Is urban albedo or urban green covering more effective for urban microclimate improvement? A simulation for Osaka. – Sustainable Cities Soc. **32**, 78–86, DOI:10.1016/j.scs.2017.03.021.