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Qualitative methods to explore thermo-spatial perception in outdoor urban spaces

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ABSTRACT

To be able to design thermally comfortable urban spaces, designers require design guidelines that respond to people's thermal and spatial perception. This thermo-spatial perception is influenced by a range of dimensions: the nature and scale of spatial contexts, the kinetic state of the people and the time scale of their perception ('now' or 'the past'). Recently, novel qualitative methods have been developed to link thermal and spatial information of people's perception. To attain an overview of these methods we conducted an extensive literature review. The results show that these qualitative methods respond to the different dimensions by combinations of momentary and long-term thermal perception research in stationary mode and in motion in varying spatial environments. These qualitative methods deliver explicit combination of thermal and spatial information. Based on that evidence, new knowledge relevant to urban design of thermally comfortable urban spaces can be generated.

1. Introduction: Concepts and methods in outdoor thermal perception research

Careful climate-responsive design of urban spaces is needed to solve existing urban climate problems and face the challenges induced by climate change. To design thermally comfortable urban environments, designers need design guidelines that combine thermal and spatial matters. Such guidelines should be based

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on evidence about how urban spatial characteristics (e.g. shapes of buildings and open spaces, materials, distribution and type of vegetation) affect human thermal perception. Methods to study this connection between thermal and spatial perception are novel and need to be discussed and compared. Hence, the main aim of this paper is to give an overview of the new methods to investigate outdoor thermal perception and cast light on their usability for different research objectives.

Since the 1920s studies were conducted on human thermal environments (Houghten and Yaglou, 1923) and different thermal indices (mainly based on air temperature and relative humidity) were developed. A classical concept to describe thermal perception was given by Fanger in the 1970s. He described 'thermal comfort' as 'the human satisfaction with its thermal environment'. Fanger defined this concept for indoor environments and also developed a physiological index (PMV) to describe 'thermal comfort' quantitatively (Fanger, 1972). Since that time, various other physiological indices, e.g. the physiological equivalent temperature PET (Matzarakis et al., 1999; Mayer and Höppe, 1987) and lately the universal thermal climate index UTCI (Höppe, 2002), were developed to describe 'thermal comfort' (also see the reviews of Chen and Ng (2012) and Knez et al. (2009)). All studies that dealt with these indices included micrometeorological measurements of the thermal environments and human physiological responses.

Auliciems (1981) critically discussed these physiological thermal indices and decided to sharpen the use of terms. He described the physiological responses of the human body to thermal states with 'thermal sensation' (p. 110) and argued that the common use of the term 'thermal comfort' in the literature is not apt to describe uncomfortable thermal stimuli that humans are often exposed to. Moreover, he called for an adequate consideration of psychological influences (e.g. expectations, climate accommodation, etc.) in the description of thermal experience. He suggested a neutral and inclusive term to describe physiological and psychological influences together: 'thermal perception' (p. 119). We will use Auliciems' terminology throughout this paper because his work was seminal for the approaches to thermal perception and gained increasing acceptance throughout the past decade. Nikolopoulou et al. further questioned the purely physiological approach. They demonstrated that a physiological approach only accounts for about 50% of the variation between objective and subjective outdoor thermal perception (Nikolopoulou et al., 2001). The other part of the variation is mainly influenced by psychological factors (Nikolopoulou et al., 2001; Nikolopoulou and Lykoudis, 2006; Nikolopoulou and Steemers, 2003). Apart from that, Aljawabra and Nikolopoulou (2010) as well as Knez and Thorsson indicated that many other factors such as culture or the climate people are used to, affect thermal perception (Knez and Thorsson, 2006; Knez et al., 2009).

Rohles (1980), Auliciems (1981) and later also Nikolopoulou and Steemers introduced concepts from environmental psychology into the discourse to describe outdoor thermal perception. One major concept that relates to the temporal and ephemeral character of urban climate concerns the duration of experience: short- and long-term memory. They described how short-term experience was involved in thermal perception: "Short-term experience is related to the memory and seems to be responsible for the changes in people's expectations from one day to the following" (Nikolopoulou and Steemers, 2003, p. 97). Later on Knez and his colleagues specified the interpretation of 'short-term' and 'memory', introducing the scale of the long-term perception. It seems meaningful to differentiate momentary and longer term experience (Knez et al., 2009) (Fig. 1).

Momentary experience describes thermal perception at a specific moment in a specific place ('here and now'). The duration of such experience is in the range of seconds (Knez et al., 2009). A person could, for example, express momentary thermal perception this way: 'I feel cold right now, here in the shade of the building'. Typical studies on this momentary thermal perception entailed interviews of people in outdoor spaces such as the studies of Nikolopoulou et al. on the 'Actual Sensation Vote' (Nikolopoulou et al., 2004; Nikolopoulou and Lykoudis, 2006). An indirect way to acquire insights into people's immediate behavioral response to a thermal environment was the use of observations in urban spaces (Kántor and Unger, 2010; Katzschner, 2004; Katzschner et al., 2002). Based on Nikolopoulou's indications (Nikolopoulou and Steemers, 2003; Aljawabra and Nikolopoulou, 2010), Knez et al. (2009) and Lenzholzer (2010b) extended the concept of thermal perception to longer time scales based on so-called 'perception schemata'. These schemata are either based on experiencing a repetition of similar stimuli or they can sometimes also be biased through salient incidences that get 'engrained' in people's memory (Eysenck, 2006; Lenzholzer, 2010b; Neisser, 1976; Nikolopoulou and Steemers, 2003). Perception schemata help to 'pre-sort' information on

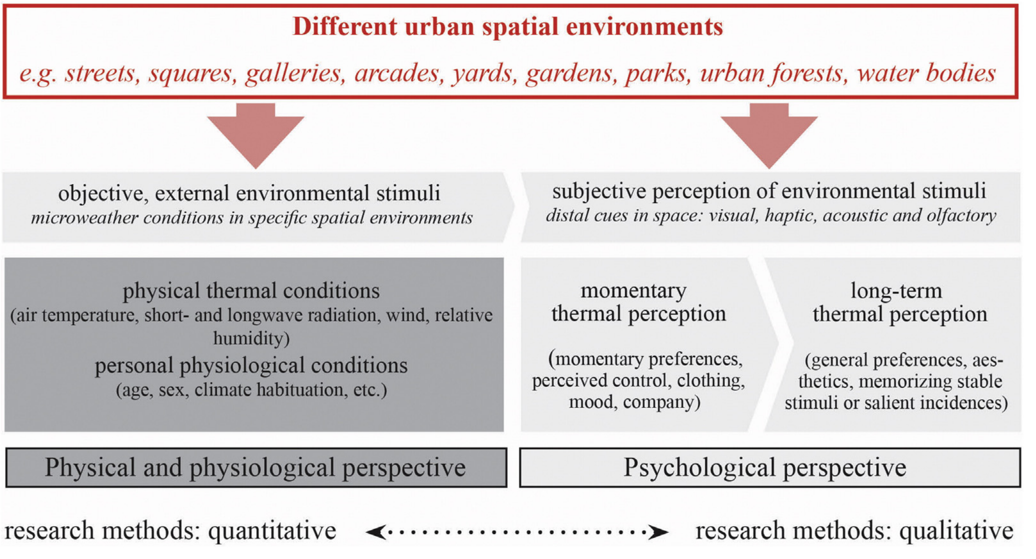

Fig. 1. Concepts and aspects of outdoor thermal perception and related research approaches.

environmental stimuli and help people to respond adequately. Such perceptual schemata were also described to relate to spatial circumstances (Brewer and Treyens, 1981). A person would talk about long-term thermal perception by expressing the longer duration of the experience clearly, for example: ‘It's always too windy over here’.

Besides the duration of experience (momentary or long-term), also the spatial and material characteristics of the environment have an influence on thermal perception. Rohles had already indicated, that ambiance and materialization of rooms influence indoor thermal perception (Rohles, 1980). His study indicated that people experience the air temperature in a room as ‘warmer’ when the room had ‘warm’ colors and furnishing, although objectively speaking, this did not have an influence on temperature (also see Greene and Bell, 1980, in: Heijs and Stringer, 1988). Griffiths et al. (1987) introduced ‘naturalness’ as one part of thermal perception in a spatial environment and the parameter was adopted by various researchers (Nikolopoulou and Lykoudis, 2006; Nikolopoulou and Steemers, 2003; Eliasson et al., 2007). According to Griffiths ‘naturalness’ is ‘the degree of artificiality’ of an environment and can thus have spatial connotations (e.g. greening areas, creating views on landscape (Nikolopoulou and Steemers, 2003)), but it is not very distinct to guide urban design decisions. To provide distinct knowledge for urban design professions, more specific space-related evidence of thermal preferences was needed.

Studies in environmental psychology brought forward that certain urban characteristics (e.g. building configuration, colors, greenery, building materials, etc.) strongly influence human synesthetic experience and behavioral response (e.g. Herzog et al., 1976; Herzog, 1992; Lindal and Hartig, 2013; Smardon, 1988). These considerations of human synesthetic spatial experience guided constituting design guidelines for ‘good urban design’ (e.g. Gehl, 1987; Carmona, 2010). But it is necessary to acquire more specific knowledge about how the spatial environment influences thermal perception as part of the synesthetic experience (Lenzholzer, 2010a; Vasilikou, 2014; Klemm et al., 2015a). The spatial environment (its dimensions, proportions and materials) can be changed through design interventions, whereas other personal factors of thermal perception such as people's clothing, mood, company, etc. cannot be influenced. Therefore it is crucial to understand how spatial environments affect thermal perception. To study the relation of spatial characteristics and thermal perception, existing methods had to be extended and new qualitative methods had be developed that go beyond existing methods from environmental psychology.

Closely linked to the momentary and long-term thermal perception as well as the spatial environment is the kinetic state of the human body - if it is stationary or in movement. It is known that human spatial perception differs significantly in a steady state and in movement (Gibson, 1979). This kinetic state (standstill or movement) can affect thermal perception in space (also see Chen and Ng, 2012, p. 119). For instance, the momentary thermal perception has to relate to a specific point in time and space ('here and now') whereas long-term experience can make up for a larger array of experiences. These experiences can entail the 'adding up' of thermal perceptions in smaller scale, but also in larger scale spatial environments and eventually form an engrained mental 'schema' (see Fig. 2). For urban design, it makes a difference if a space needs to be designed for thermal comfort of people in movement (pedestrian environments) or for people in steady state (e.g. places made for sojourn). Hence, it is essential to study outdoor thermal perception in different kinetic states in space. There have been no earlier studies on these relations and new, especially qualitative methods had to be developed recently to study thermal perception in different kinetic states and different urban spaces.

In the following section we give an overview of such recent qualitative methods to study thermal perception. We attempt to answer the following research question: Which research methods can be used to investigate thermal perception in relation to the spatial environment? We describe the qualitative methods using the parameters of temporal and spatial experience in different kinetic states related to thermal perception. Based on that review we reflect on the aptness of the different methods for different research assignments.

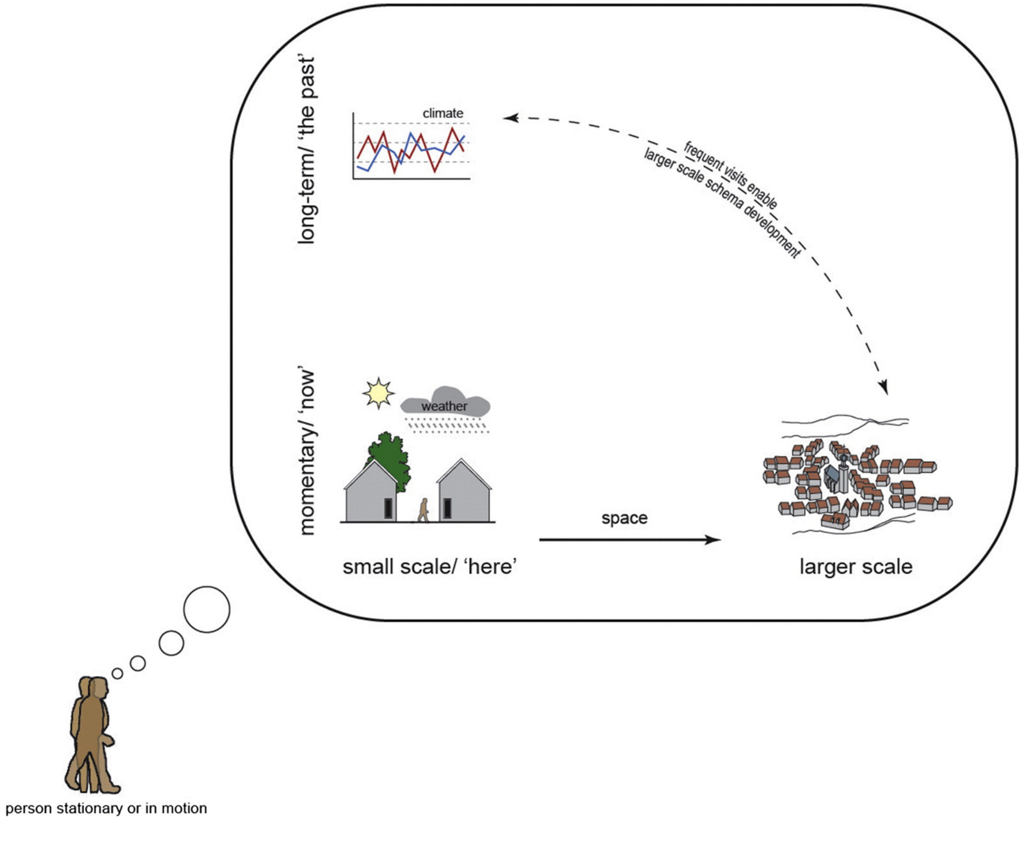

Fig. 2. Spatio-temporal aspects of thermal perception.

2. Method and results: Literature review on methods to study spatial aspects of thermal perception

In order to identify methods to investigate thermal perception in relation to space we reviewed the literature (English language only). We selected publications on their content based on our research question: Which research methods can be used to investigate thermal perception in relation to the spatial environment? The first step in the literature search consisted of consulting relevant review papers on outdoor thermal perception explicitly (Chen and Ng, 2012, 2006; Johansson et al., 2014; Nikolopoulou, 2011) or implicitly (Blocken and Carmeliet, 2004; Rupp et al., 2015). In these reviews we searched for studies that deal with outdoor thermal perception and spatial aspects and that combined qualitative (e.g. interviews) and quantitative studies (e.g. micrometeorological measurements of physical parameters or with numerical modelling) in order to get a balanced view of the objective and subjective aspects of thermal perception. This first part of the literature study yielded studies that clearly related the spatial setup of a range of urban spaces or sub-spaces with thermal perception (Ahmed, 2003; Eliasson et al., 2007; Lenzholzer and Koh, 2010; Lenzholzer and van der Wulp, 2010; Mahmoud, 2011). It also yielded some studies about thermal perception in different urban spaces, but these did not elaborate on the impact of the spatial environment explicitly (e.g. Thorsson et al., 2007a; Tsitoura et al., 2014; Yahia and Johansson, 2014). As a second step, we conducted a literature search in Scopus, combining a range of search terms in 'Article titles, abstracts and keywords' that explicitly address spatial connotations. The search terms and relevant yields were the following: "outdoor thermal perception" AND space: 0 relevant yields; "thermal perception" AND outdoor AND spatial: 0 relevant yields; "thermal perception" AND outdoor AND space: 0 relevant yields; "thermal experience" AND space: Lenzholzer and van der Wulp, 2010; "outdoor thermal comfort" AND spatial: Klemm et al., 2015a; "thermal comfort" AND outdoor AND space: Lenzholzer and Koh, 2010; "thermal comfort" AND outdoor AND spatial: Klemm et al., 2015a, Lenzholzer and Koh, 2010; "thermal comfort" AND urban AND space: Klemm et al., 2015a, Lenzholzer and Koh, 2010. Obviously the literature search eventually kept yielding the same results for various search terms and parts of them were already derived from consultation of the general reviews in the first step. In fact, the first two steps of the literature search did not bring forward all the relevant publications known to us. So we terminated the literature search and added other relevant publications known to us to the review such as: Böcker et al. (2015), Katzschner (2004), Katzschner et al. (2010), Klemm et al. (2015b), Vasilikou (2015), Vasilikou and Nikolopoulou (2016), Vasilikou and Nikolopoulou (submitted), Klemm et al. (submitted).

In Table 1, we provide an overview of all the relevant studies and the crucial parameters guiding the research methods. The parameters relate to the spatial context and scale. When we describe spatial scale as small, this ranges between a few square meters up to a hectare (e.g. around a building, a small street), medium scale concerns areas above a hectare (e.g. a neighborhood or a medium sized square) and large scale refers to the whole city. Furthermore we differentiate the time-scale of memory and kinetic state of people. Then we sketch the methods used to investigate these parameters (e.g. interviews, cognitive maps, 'thermal walks'). In the subsequent sub-sections we will describe the different studies in detail in the order of publication year.

2.1. Thermal perception study in different urban outdoor spaces in tropical Dhaka

The study of Ahmed (2003) was one of the first studies that addressed the possible relation between subjective thermal perception and different spatial surroundings. It was conducted in the tropical climate of Dhaka, Bangladesh and aimed at generating a 'thermal outdoor comfort zone' graph (similar to the graphs provided by Olgyay and Olgyay (1963) for other climates). The study was also supposed to provide urban designers in tropical regions with design guidelines for thermally comfortable outdoor spaces and building configurations. As a consequence, the author was particularly interested in the specific relations of urban configurations and their effect on people's thermal perception and the micrometeorological effects. About 1500 people were interviewed in three different areas of the city that represented different local urban climate zones: one area with low building density and abundant greenery, one area that had intensive land use with tall buildings and no vegetation as well as a zone that had high density urban fabric with smaller buildings close to the river. Within these local climate zones six types of spaces on a small scale were identified in which the interviews took place: street canyon, under an arcade or awning, on a covered gallery, under an overhead canopy, in an open square and an open riverbank space. The interviews held in the different locations considered personal factors (age, sex, clothing level, etc.) and a personal thermal sensation vote of the interviewee on a seven level scale. Parallel with the interview study, microclimate measurements were taken in strategic spots but it is unclear if these spots were situated in the different types of urban spaces or elsewhere. The results of the inquiry are represented as descriptive statistics for some parts of the set of interview data. The measurement data are not translated into a thermal perception index. Instead, a 'comfort temperature', based on the interviewees' votes is set in relation to air temperature and globe temperature for the different spatial types. But the data that directly relate people's comfort vote to the spatial surroundings were not shown. The study did not include a comparison between the 'objective' measurements and the subjective comfort votes because this study attempted to set a first 'thermal outdoor comfort zone' index for Dhaka only. Apart from that the author explicitly refrained from setting narrow indices: "It is not essential to establish a single comfort value in the context of outdoor spaces as it has been found that comfort perception outdoors is a dynamic phenomenon and a person's comfort preference, keeping within a range, continually adjusts to ambient situations [...] defining comfort for outdoor situation may not be considered a tall order [...] comfort perception is a synergistic phenomenon." (p. 109). Still, the results allowed some comparison between comfort votes and the spatial categories. For instance, overhead covers were found more comfortable at midday and the more open spaces were considered more comfortable in the late afternoon. Given the high loads of solar radiation that affects the human body during midday in the tropics people's evaluations of the different urban space types make sense and indicate a plausible relation between spatial experience and micrometeorological conditions.

2.2. Thermal perception in different spots on urban squares

An investigation of momentary thermal perception in two different squares in Kassel, Germany (Katzschner, 2004) within the RUROS project (also see Nikolopoulou et al., 2004) aimed to produce a strategy for urban design that focuses on the microclimate improvement of the respective places. Field surveys were done in summer and autumn, including combined measurements (air temperature, solar radiation, humidity, dry and wet-bulb temperature, globe temperature, wind speed) and interviews. The interviews focused on how people experienced the thermal environment on a 5 point Likert scale (very cold - very hot) and specific questions dealt with the experience of sun, wind and humidity. As opposed to earlier interview studies, the exact location of the interviews (in stationary mode) and related measurements were recorded. This allowed a precise and comprehensive spatial representation in GIS after completion of the fieldwork. Moreover, microclimate simulations were done in Envi-Met for the microclimate in similar weather conditions. The studies were represented in different sets of maps, showing the places where most people stayed (standing or sitting) and their thermal perception (see Fig. 3). Apart from that, the microclimate simulations were represented in maps. Since the study did not focus on the comparison of the objective climate data with the subjective thermal perception data no conclusions were drawn about the match between objective and subjective data.

2.3. Nordic urban places and climate perception

Eliasson and colleagues conducted a study in different Swedish urban outdoor places of local scale, such as a courtyard, an urban square, a waterfront and an urban park (2007). People's perceptions were studied via structured interviews. In the interviews people were asked about their perception of the weather at that moment and of that specific day, which makes it a study that focuses on a rather short time interval in people's memory, but according to one of the authors of the study these should actually range under 'long(er)-term' perception (Knez et al., 2009). The interviews also comprised questions about people's perception of the place in terms of its microclimate (e.g. calm-windy, cold-warm) as well as the perception of the place (e.g. ugly-beautiful, unpleasant-pleasant, windy-calm and cold-warm). The interview questions did not address spatial information relevant for urban design. However, the study made a statistical connection between the different types of outdoor places in which the interviews were held and the interview outcomes on thermal perception. This allowed to address relations between the influence of the respective urban space on thermal perception.

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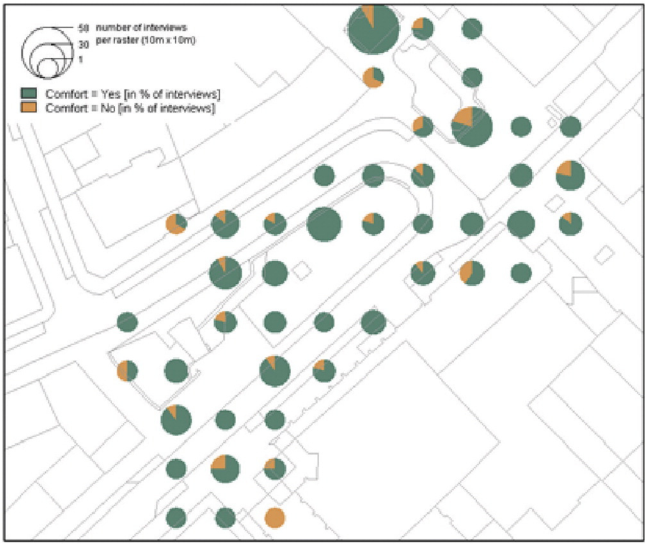

Fig. 3. Locating spots of thermal comfort and discomfort on the Florentiner Platz, Kassel (Katzschner, 2004).

The interview results were represented textually and analyzed by means of statistics. Micrometeorological measurements of air temperature, relative humidity, long- and short wave radiation as well as wind-direction and speed were measured at human body height in intervals of few minutes. The thermal perception in the three places was generally better when the micrometeorological situation was rather calm. One exception was the positive perception of the water front, although it is very windy. This was explained with the ‘naturalness’ of the place, also see (Nikolopoulou and Steemers, 2003). But in general, the matches of the microclimate measurements and people's thermal perception were very plausible.

2.4. Spatial microclimate perception in Dutch squares

The study of Lenzholzer and Koh (2010) focused on people's thermal perception in urban squares and how this relates to different types of spaces in which people stay (e.g. street entrances, middle of the square, etc.). The scale of the study covered mid-sized squares that people could overlook, so the scale addressed was medium. To respond to the knowledge gap about thermal perception in relation to space, this study employed research methods that were used in other studies about people's spatial memory (e.g. orientation, choices for spaces to stay): cognitive maps. Cognitive or ‘mental’ maps were invented by the urban design scholar Lynch (1960) as a means to represent people's perception of space. This spatial perception often differs from geographical description of space and meanings are assigned to space which cannot be made quantifiable. Lynch sparked the development of a whole range of different mental and cognitive map techniques (e.g. Downs and Stea, 1973; Kaplan, 1973; Kitchin, 1994). More recently, cognitive maps have been described as people's spatial schemata of their environment that are shaped by long-term experience and interaction with this environment (Heft, 2013; Kitchin and Blades, 2002; Kitchin, 1994). To study these schemata pertaining to microclimate and space perception, it was necessary to find respondents who knew the respective places for a longer time because of regular visits. Interviewees were selected accordingly. Eventually, hundreds of respondents on three squares (average $N = 232$ per square) were asked to draw different zones on a map to which they assign certain thermal perceptions. In case the respondents found it difficult to draw on a map, they alternatively pointed out the areas to which they assigned these perceptions and the interviewers drew them on the map. Additionally, respondents were asked to give an explanation for

Table 1
Overview of reviewed literature according to relevant criteria to categorize qualitative methods.

Authors	Spatial context	Spatial scale	Time-scale of memory	Kinetic state	Investigation methods	Representation of investigation	Match with quantitative data
Ahmed (2003)	Different spatial urban configurations	Small	Momentary	Stationary	Interviews, microclimate measurements	Textual, statistics	Only partly comparable, but plausible
Katzschner (2004)	Urban square	Medium	Momentary	Stationary	Interviews, microclimate measurements	Textual, statistics, maps	Unknown, no comparison
Eliasson et al. (2007)	Courtyard, square, urban park, urban waterfront	Medium	Momentary and short-term	Stationary	Interviews, microclimate measurements	Textual, statistics	Good, with exception water front
Lenzholzer and Koh (2010)	City squares	Medium	Long-term	Stationary	Cognitive mapping, microclimate measurements	Collective cognitive maps	Good
Lenzholzer and van der Wulp (2010)	City squares	Medium	Momentary	Stationary	Interviews, microclimate measurements	Textual, statistics	Good, with exception interpretation of colors
Katzschner et al. (2010)	Neighborhood and square	Medium	Momentary	Stationary	Interviews, microclimate simulations	Maps with GPS data of interviewees	Match for 'heat areas' good, other areas partly show differences
Mahmoud (2011)	Different zones in urban park	Small	Momentary	Stationary	Interviews, microclimate measurements	Textual, statistics, RayMan simulations	Good
Klemm et al. (2015a)	City	Large	Long-term	Stationary	Interviews, cognitive maps, microclimate measurements	Textual, statistics	Good
Klemm et al. (2015b)	Street	Small	Momentary	Stationary	Interviews, microclimate measurements	Textual, statistics	Good, with few exceptions
Klemm et al. (2015b)	Street	Small	Long-term	Stationary	Cognitive maps, microclimate measurements	Textual, impossible to produce coll. cognitive maps	Difficult to draw conclusions
Böcker et al. (2015)	City	Large	Momentary	In motion	Interviews, weather data for the city	Textual, statistics	Good
Vasilikou and Nikolopoulou (2014)	Urban street and square sequences	Small and medium	Momentary and long-term	In motion	Interviews, walks, observations, maps, microclimatic measurements	Verbal, statistics, thermal notation (maps)	Good
Vasilikou (2015)	Street and square sequences	Small and medium	Momentary and long-term	In motion	Interviews, microclimate measurements, observations, walks	Textual, statistics, thermal notation (maps)	Good
Klemm et al. (submitted)	Urban parks	Medium	Momentary	Stationary	Interviews	Textual, statistics	Good

this perception ("What are the reasons for this thermal comfort or discomfort: e.g. sun, shade, shelter, wind?").

This approach resulted in one individual 'cognitive microclimate map' per interviewee that reflects the interviewee's microclimate perceptions of sub-areas (see Fig. 4, left). All the individual 'cognitive microclimate maps' were transferred into GIS, overlaid and summarized into common 'cognitive microclimate maps'. These maps depict the generalized perception of the interviewees that were representative for the local population (see Fig. 4, right).

The collective cognitive microclimate maps have proven to offer very explicit insight into people's spatial memory and when compared to the measurement results and general urban physics (e.g. concerning wind and shadow patterns), the match between maps and measurements was good.

2.5. 'Ambiance' and thermal perception in urban squares

Lenzholzer and van der Wulp (2010) intended to gain specific information about the descriptors of 'ambiance' in relation to thermal perception for Dutch urban squares. This 'ambiance' entails various spatial parameters that can be influenced by urban design interventions such as a space's proportions or colors. This study was conducted on three Dutch urban squares of medium scale.

The study comprised semi-structured interviews about the square's spatial properties in relation to momentary thermal perception. In a test-run, respondents seemed to find it difficult to relate thermal and spatial perception directly. Therefore, separate questions were posed for thermal perception and for spatial perception. Interview questions were: "How do you experience the proportions of this square (too wide/good/too narrow)? What do you think about the openness of this square? (I like it/no opinion/I do not like it) and if you don't like it- what would you change in the spatial setup (open question)? Which of the materials used in this square, in the facades, furniture, the floor, etc. in your opinion have a warm and which have a cold appearance?" These descriptors were related to people's momentary thermal perception based on a 5-point Likert scale from 'very cold' to 'very hot'. The interview outcomes of the study were represented in statistics (ANOVA) and compared to quantitative measurement results and shadow simulations (SketchUp). It appeared that people's thermal perception in relation to the measurements and simulation outcomes made sense. The only exception was that peo-

Fig. 4. Example of an individual (left) and a collective (right) cognitive microclimate map for Spuiplein, The Hague (Lenzholzer and Koh, 2010).

ple experienced materials with warm colors (e.g. certain colors of plaster of brick stones) as 'thermally comfortable'. However, not all of these materials have the physical properties to really feel thermally comfortable.

2.6. Thermal perception maps in German neighborhoods

Within a research project on climate adaptation strategies, studies were conducted about people's momentary thermal perception in specific spots in the Vauban neighborhood in Freiburg and the Opera square in Kassel (Katzschner et al., 2010). The aim of this study was to set an example how reliable data can be generated to inform design decisions on improvement of thermal conditions in these urban places. The scale of the study was situated on a medium scale. To acquire spatially explicit information, the momentary thermal perception of people in the outdoor spaces was studied via short interviews during hot days. The outcomes were related to spatial GPS data of the place where the respondents gave this interview. Based on these data, GIS maps were generated that showed the respondent's thermal perception in space and these could be interpolated in GIS into a collective map of people's thermal perception. To compare these perception maps with objective data, BOTworld© (dynamic) and ENVI-met (static) simulations were done for the respective places. The simulations represented hot weather situations in line with the circumstances during the interview series. A comparison between the simulation and interview results shows that there can be some local differences, but the most important areas that need adaptation - the hot zones - show a good match between the thermal maps based on interviews and the simulation results.

2.7. Thermal perception study in different urban park spaces in Cairo

In order to extend the hitherto scarce research regarding outdoor thermal perception in hot and arid climate regions the study by Mahmoud (2011) was conducted in different zones of an urban park in Cairo. The author also tried to gain evidence of the effects of layouts of sub-spaces on outdoor thermal perception. These sub-spaces ("Peak, Spine, Entrance, Fountain, Lake, Canopy, Pavement, Seating, Cascade") were distinct small scaled zones that were expected to have different microclimates. About 300 interviews were conducted in summer and winter in the park (interview numbers evenly distributed over all park zones) and the main aim was to identify people's individual thermal sensation votes in the respective spatial zones. Simultaneous with the individual interviews microclimatic measurements were conducted. Additionally, RayMan simulations were generated for the spatial zones to visualize the respective Sky view factors. The survey results were represented through descriptive and correlational statistics between PET and thermal sensation vote for the different spatial zones in summer and winter. The statistical relation of PET and mean thermal sensation vote indicated that in the different zones studied in the park rather high percentages of discomfort was experienced. A close statistical relationship between the PET and mean thermal sensation vote could be identified for most of the park zones analyzed. Pertaining to the spatial setup of these zones, close relationships were found between thermal votes and the influence of the sky view factor, wind speed and albedo, based on the microclimatic influence of landscape elements such as the presence of vegetation and fountains. But the author also emphasized that other aesthetical factors might be influential and that the physical factors of microclimate "cannot completely describe the heat balance of the human body of users" (p. 2655).

2.8. Thermal perception of urban green infrastructure on city scale

Klemm et al. (2015a) examined outdoor thermal perception in open, and especially green urban spaces in the Netherlands. They investigated how people perceive these spaces during warm summer days with respect to thermal conditions in urban green spaces (during daytime on warm summer days). To study people's perceptions, semi-structured interviews with pedestrians were conducted in three Dutch cities on warm summer days. In total 559 questionnaires were completed with citizens who were well-acquainted with the city. The interviews had three focuses. First, the evaluation of the thermal effect of green environments was measured by respondents' opinion on the statements “A green environment is: a) nice, b) important, c) essential, d) convenient for my thermal comfort on hot summer days”. Secondly, respondents described long-term thermal perception in green, water and built environment types (garden, rural area, forest and park for green environments; shopping street, square, terrace or parking lot for built environments; beach lake, swimming pool and canals for water areas), by answering the question “Please indicate how thermally comfortable you feel on hot summer days in each of the four types of outdoor environments.” (based on a 5-point-Likert scale from “very uncomfortable” to “very comfortable”). The questionnaires were analyzed and results were represented by means of descriptive statistics, reliability analysis and statistical hypothesis testing. Thirdly, people's long-term perception of thermally comfortable spaces in urban environments was studied by employing cognitive microclimate maps (Lenzholzer, 2008). Respondents were asked to indicate urban spaces that they prefer because of their thermal conditions on hot summer days on a map (Fig. 5, above). A combination of all thermally comfortable urban spaces is shown in collective cognitive microclimate maps (Fig. 5, below). Additionally, the study comprised micrometeorological measurements using bicycles equipped with meteorological sensors for pedestrian levels. Those measurements were conducted in 13 parks in the city of Utrecht. This study demonstrated a positive influence of green spaces on long-term thermal perception and that long-term perception is consistent with the physical thermal circumstances: respondents generally assessed green spaces as more thermally comfortable than water and built environments on hot summer days. This matches well with the ‘park cool islands’ effect that was indicated by the micrometeorological measurements.

2.9. Street greenery and momentary thermal perception

The study by Klemm et al. (2015b) addressed aspects of momentary thermal perception. The research question: ‘What is the impact of street greenery on momentary thermal perception and how is that related to air temperature and mean radiant temperature?’ was studied with semi-structured interviews with pedestrians ($N = 108$) in the nine streets. Respondents were asked to evaluate single meteorological parameters (air temperature, sun, humidity and wind) and the overall experience of thermal comfort in the specific street (‘How do you experience the microclimate at this moment at this place?’) based on a five-point Likert scale from ‘very uncomfortable’ to ‘very comfortable’. Additionally to the interviews, micrometeorological measurements at pedestrian level were conducted. The results generally matched well with people's momentary perception; for example streets without street greenery showed the highest values of mean radiant temperature and also were evaluated by interview respondents as

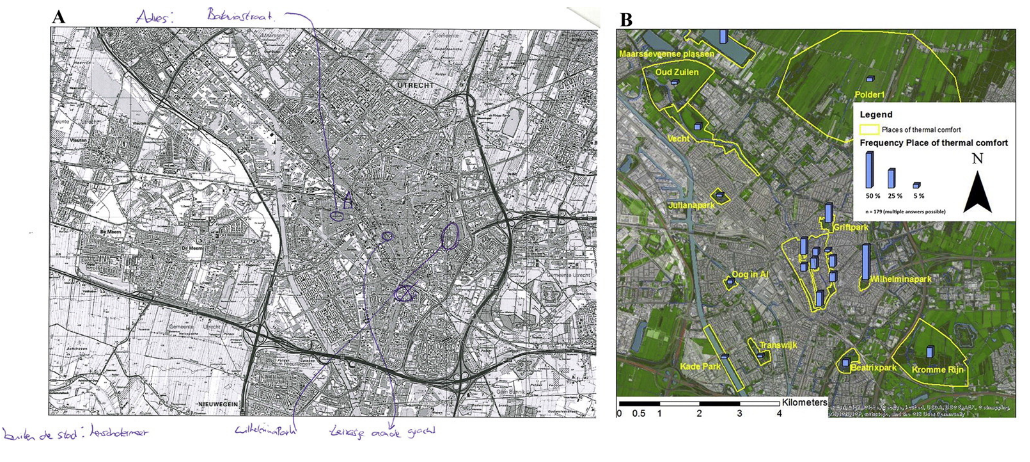

Fig. 5. above: Typical example of an individual cognitive map, Utrecht; below: collective cognitive map of places that people experience as thermally comfortable (Drost, 2013).

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the least comfortable of all street types. However, people preferred streets with front gardens and small trees over streets with tall trees. This is surprising, because streets with tall trees showed lower mean radiant temperature and thus more thermal comfort than streets with smaller trees and front gardens.

The other research question: 'How does momentary thermal perception relate to the evaluation of green street design in terms of aesthetic appreciation?' was investigated in the interviews by asking the respondents: 'How do you experience the green design of this street?' evaluated through a five-point Likert scale from 'dislike very much' to 'like very much'. Additionally, people were asked for possible improvements of the green design in an open question. Interview results for both research questions were represented with statistics. Even though respondents strongly valued the presence of street greenery (which was also expressed by the answers on improvement of green street design), there was no significant relationship between aesthetic appreciation of street greenery and momentary thermal perception due to the low number of respondents.

2.10. Street greenery and long-term thermal perception

Parts of the study by Klemm et al. (2015b) also focused on benefits of street trees and front gardens for thermally comfortable streetscapes in nine Dutch residential streets. They investigated physical thermal conditions and thermal perception of pedestrians in streets with similar spatial setup (e.g. aspect ratio, orientation towards the sun, materials) and varying amounts and distribution of street greenery. They inquired the impact of street greenery on long-term thermal perception through cognitive mapping techniques and conducted measurements of micrometeorological conditions (air temperature and solar radiation, wind speed and relative humidity) in the same period. Respondents were asked "Can you indicate zones of thermal comfort and discomfort in the street that you have experienced over longer time?" and were invited to motivate their indications. Respondents and interviewees stood in one of the streets to be investigated with a wide view of the rather small street canyon. From this spot respondents could point to comfortable or uncomfortable subspaces in the street or indicate them on the map that was part of the interview materials. It appeared unfeasible for respondents to locate their long-term thermal perception in the residential street on a map; the majority of respondents (73%) had 'no preferences for specific zones of thermal comfort' or they had 'no idea'. Interestingly, even though respondents could not locate thermal perception zones on the map, they were able to motivate their thermal perception: it appeared that people were aware of microclimate diurnal and seasonal variance (shade patterns). The comparison with the micrometeorological data showed that these evaluations of the diurnal patterns was correct, but no further comparison was done because it was impossible to generate collective cognitive maps.

2.11. Place experience and thermal conditions related to different transport modes

Transportation modes (on foot, bicycle, car, etc.) that citizens choose can largely differ, but some of the reasons for that choice of transport mode were not very clear. Hence, Böcker et al. (2015) studied transport mode choices of citizens in relation to weather, people's thermal perception and spatial experience of the routes traveled (amongst other variables that are not relevant in the context of this review). To do so, they conducted a travel diary survey during half a year amongst a panel of hundreds of respondents ($N = 11,759$ individual trips). During their travels, respondents reported about their experiences of the microclimate conditions in situ. They described their thermal experience with a 9-point Likert scale from very cold to very hot. The aesthetic evaluation of the places encountered and route comprised the following factors that were evaluated on a 5 point Likert scale: very little green - very green, sheltered - open, beautiful - ugly, lively - boring/monotonous, very busy - very quiet, very little wind - very windy. The respondent' routes were also traced in GPS, so that they could be directly related to place evaluations. Apart from that, the authors gathered measured weather data of the KNMI (the Royal Dutch Meteorological Institute) dating from the study period for further comparison. The results were analyzed and represented with multivariate statistical modelling techniques. This wealth of data enabled the authors to show that warmer thermal subjective experiences have a positive effect on place evaluation. The relation of people's thermal perception and the weather data showed a relatively good match (Böcker et al., 2016).

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2.12. 'Thermal walks' in streets and squares

Vasilikou commenced to investigate the variation in thermal perception between spaces of different geometrical characteristics that form part of a larger pedestrian route (Vasilikou, 2015; Vasilikou and Nikolopoulou, submitted) in three European locations. The study aimed to identify the change in thermal perception of participants as they are moving between interconnected spaces, but also to identify the thermal perception of people in movement. The scale of the studies ranged from small to medium urban spaces, including streets and squares of different density and geometrical qualities. People's momentary thermal perception was investigated in the form of 'thermal walks' (Vasilikou and Nikolopoulou, 2014). The core of the 'thermal walk' finds its roots in the technique of sensewalking, initially developed by Southworth (1969) on studies of the sonic environment. Sensewalking is a systemic approach with the aim to investigate and analyze the way people understand, experience and utilize urban space. The approach may focus on multi-sensory experiences that are site-specific (Lucas and Romice, 2008) or to particular sensory experiences that enable participants to express their subjective perception of an environmental aspect (Henshaw et al., 2009). A limited number of examples investigating thermal aspects of the urban environment through walks have been identified, but have generally excluded people surveys during walks and were based solely on the researcher's own observations on the thermal perceptions of specific urban routes (Ouameur and Potvin, 2007; Potvin, 2000).

To engage in a thermal walk, participants would consent to the longitudinal nature of the study, reiterating the walk between times of day, days and seasons. Walk participants were asked to assess their thermal sensation and comfort on a 5-point Likert scale for specific points of the walk ('how do you experience the thermal environment at this precise moment?' and 'how thermally comfortable do you feel at this precise moment?'). During the walk participants also evaluated changes in their thermal perception and were asked to explain the reasons of a potential change in their thermal perception (e.g. why do you think this thermal variation exists?). The effect of movement and spatial variation was assessed by the question 'is there anything different in the spatial characteristics around you?' and further questions concerning microclimatic aspects in each space. These interviews were combined with in situ measurements of microclimatic data and recording of spatial data. Results were interpreted with thermal mapping techniques (Vasilikou and Nikolopoulou, 2014). To facilitate communication of collected data during fieldwork, a design tool of data representation was developed specifically for 'thermal walks', called 'thermal notation' (see Fig. 6). The novelty of 'thermal notation' lies in the combination of both qualitative (people's responses) and quantitative (microclimatic) data in the same diagrammatic depiction, making the collected data readily accessible by designers during the early design stage of a project. The results match well with microclimatic measurements. The outcomes of thermal walks show that subtle variations in microclimatic conditions between interconnected spaces result in significant changes in the thermal perception of pedestrians for the duration of the walk. Wind speed, turbulence and mean radiant temperature had the most significant impact on the momentary thermal perception. In addition, at street level, ground-floor spaces that use active microclimatic control (such as air-conditioning or heating devices) in semi-open spaces created 'cool' or 'hot spots'. Finally, participants distinguished different prevailing thermal sensations between streets and connected squares. Most of the participants evaluated the general thermal experience of walking on the basis of specific points of the walk that were highlighted by a distinct experience of thermal comfort or discomfort. The degree of variation and spatial complexity allowed for more opportunities of thermally diverse urban experience.

2.13. Long-term thermal perception studies of people in movement

Within the 'thermal walks' method Vasilikou and Nikolopoulou also applied a different approach that focused on the long-term perception of people. They conducted a study of the thermal perception of people using outdoor urban sequence in the city centers of Rome and London, thermal perception at the scale of the urban sequence and the overall experience of the walk. The study took place during summer and winter, using the same participants between seasons. The study covered urban sequences of approximately 500 m in length. The method was based on thermal walks to inquire people's perception with structured questionnaire

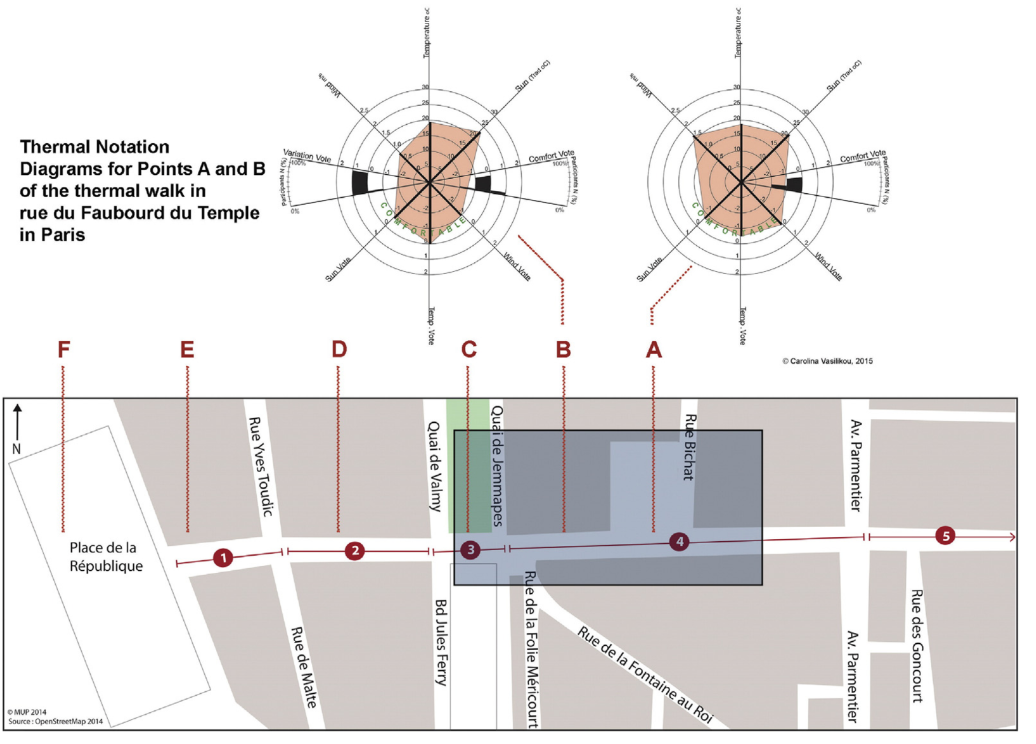

Fig. 6. Mapping example of thermal walk assessment for rue du Faubourg du Temple in Paris, using the 'thermal notation' tool to compare the variation in thermal perception between different spatial characteristics (Vasilikou, 2014).

completion, in terms of the microclimatic conditions as well as spatial perception and quality of walk that were relevant to urban design practices. Participants were invited to respond to questions in relation to the thermal perception of the whole walk (based on an 5-Likert scale), to identify places of thermal pleasantness and unpleasantness after the completion of the walk and to provide an evaluation of their change in thermal and spatial perception during the walk. The results of the thermal walks were presented with descriptive statistics and mapping analysis. An aspect of long-term memory (where frequent visits seem to enable large scale schemata) was addressed through the longitudinal nature of the study, which included the same thermal walks participants walking along the same route during different times of year (and different times of the day). The effect of walking activity was assessed with questions regarding the overall walk evaluation and thermally-pleasant and -unpleasant parts of the walk. Participants were asked to draw points of perceived thermal variations on the map of the walk. This approach results in building a database of thermal perceptions, identifying for example a pattern of a particular thermal 'identity' in a specific street or square according to seasonal conditions and microclimatic characteristics accredited to interconnected spaces based on a comparative analysis. Here, again participants' responses can be represented graphically through mapping tools, such as 'thermal notation' maps, used for the mapping analysis in Fig. 6.

2.14. Impact of summer and tropical weather on park visitors' momentary thermal perception

The study by Klemm et al. (submitted) focused on park user's behavior and thermal preferences on summer and tropical days (Ta max > 25 °C and >30 °C, respectively). Amongst other factors they examined park visitors' preferred resting locations and momentary thermal perception under these warm and tropical conditions. The study areas were two public parks of medium scale in two Dutch cities. Semi-structured interviews were conducted to investigate people's momentary thermal perception and spatial preferences. Resting park visitors ($N = 317$) were asked how they experience thermal conditions at the moment of the

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interview and why they chose this specific place. Park visitors' momentary thermal perception was examined by asking them 'How do you experience the microclimate conditions at this moment in this place?'. The evaluation of overall thermal perception and of single parameters (air temperature, sun, wind and humidity) was evaluated based on a five-point Likert scale from very uncomfortable to very comfortable. Air temperature data of the conditions during the fieldwork days were gained from official weather stations in the vicinity of the two cities. Daily means and hourly data at the moments of observations (11:00, 13:00, 15:00 and 17:00) were analyzed. The results were represented through descriptive statistics. The interview results indicated the essential role of microclimate for people's choice of resting locations in parks. In particular solar exposure and shade appeared to be most influential. On tropical days respondents clearly preferred shady to sunny places. Resting park visitors generally perceived a high level of momentary thermal comfort during all days; however overall thermal comfort was evaluated slightly more comfortable on summer than on tropical days. Largest differences in thermal perception of individual thermal comfort parameters were found for humidity and wind velocity, followed by air temperature and solar radiation.

3. Overview of different qualitative methods in relation to spatial and temporal scales

As a next step in our review the different studies were configured in a matrix that is organized according to dimensions most relevant to generate urban design relevant evidence: the spatial scales and the time scale of people's thermal perceptions as well as their kinetic state (Fig. 7). This matrix maps the current state of the art. It shows the different methods used in the studies discussed above and enables a discussion of the suitability of the methods related to scale and time dimensions and people's kinetic states.

4. Discussion and conclusions: Which method when?

Our review resulted in a range of studies that investigated people's thermal perception in relation to spatial environments in stationary or in motion mode. In this section we reflect on the results of the review in general and on which kind of knowledge should be generated for which spatial and time scales. We discuss which methods are apt for which type of research focus, limitations of certain methods and provide outlooks into future research.

4.1. Spatial aspects

A very striking pattern occurs in the overview (Fig. 7): there is a large number of studies about the small or middle scale of urban squares, parks or streets and most of the studies are based on interviews about momentary perception. Probably this is related to the fact that most of these studies aimed at generating knowledge that was not in the first place related to spatial aspects but rather to acquire knowledge about thermal perception per se. The focus on small scale studies might also relate to the fact that urban microclimates can best be influenced through urban design on the smaller scale (Brown and Gillespie, 1995, p. 46). On a medium scale mapping techniques (GPS mapping and cognitive maps) can provide a general picture of thermal perception but also allow to show how smaller partial areas are perceived. So they can actually also provide additional small scale information. Yet, mental mapping techniques may be less applicable in streets were people only move from one place to the other without much attention to the entire space, as was shown in the study of Klemm et al. (2015b). We could identify only two studies that address larger scale thermal perceptions. However, the implications of large scale studies can also be a valuable basis for climate-responsive urban planning (e.g. 'heat refuge areas' with bigger forests or waterfronts in- and outside the cities) and therefore, future research should address thermal perception on larger scales more prominently.

To inquire the spatial aspects on all scale levels we suggest to use spatially explicit methods, especially mapping techniques. For future research, it is not only important to represent knowledge in maps (planar projection), but also to represent the vertical dimensions (e.g. profiles, sections) and 3D visualizations. A first step towards such representations was made by (Klemm et al., 2015a) where perception of street greenery was represented in profiles. Recently this representation was extended and 3D perspective views were used in 'visual interviews' on thermal perception (Tang et al., 2016). We suggest ample use of such 3D representations in the future. Future use of three-dimensional GIS also has interesting potentials. In three-dimensional GIS,

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spatial properties (e.g. proportions, materials, etc.) can be analyzed and the expected human thermal perceptions can be assigned. Such data that directly predict the thermal perceptions enable direct interaction with urban design processes.

4.2. Temporal aspects

Another very striking pattern in the overview (Fig. 7) concerns the large amount of studies on momentary perception. As mentioned above, this is probably due to the fact that most research up to now aimed at thermal perception per se. Most studies on momentary thermal perception also comprised parts on generating actual sensation votes for a certain climatic region or to calibrate existing thermal perception indices. Research on both, momentary and long-term thermal perception was conducted on all scale levels. As opposed to the momentary perception, long-term experiences are more independent from the 'here and now', but all studies on long-term experience needed to presuppose that participants are well acquainted with the locality of the study through frequent visits during various points in time.

In a few cases collective cognitive maps were used to represent long term experience, in two cases the interview results of momentary experience were shown in a GIS map and in another case results were shown in maps of thermal sequence notation. The collective cognitive maps studies provided fundamental knowledge on how people assign thermal perception to spatial typologies. For purposes related to climate-responsive urban design (e.g. to generate design guidelines) studies on long-term perception can be more useful because the spatial setup of the city does not change as quickly as momentary thermal perception does. But more attention should be given to seasonal and diurnal changes or the most problematic urban climate situations in future research by tapping respondent's long-term memory on these aspects and represent them in spatially explicit ways.

4.3. Kinetic state

There are many studies that consider people's thermal perception in stationary mode and only a few very recent studies focus on thermal perception in motion. However, we need to add a critical note on our subdivision of the studies into 'stationary mode' and 'in motion'. Our review indicated that there are various studies on people's thermal perception in stationary mode, both on their momentary and their long-term thermal perception. These methods employ people's knowledge that is taken at specific points in time. In the studies we ranged under 'in motion' people stopped to fill their diary (Böcker et al., 2015) or groups of interviewees

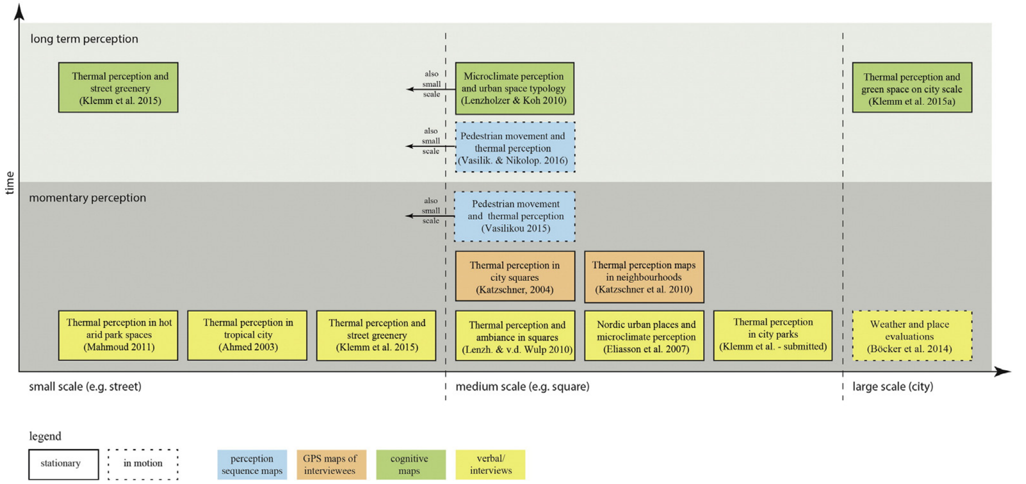

Fig. 7. Matrix of the qualitative methods to study thermal perception.

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paused during their walks to fill in questionnaires (Vasilikou, 2015; Vasilikou and Nikolopoulou, 2016). Very strictly speaking, these could also be called inquiry techniques in stationary mode. But since these studies are explicitly part of the 'in-motion' experience, we decided to differentiate these from the inquiries of typical stationary kinetic states in the overview matrix.

When the research is focused on places where people tend to stay and rest, e.g. urban squares, yards or gardens, it is advisable to use methods that represent steady state perception. When these spaces (squares, gardens, etc.) become part of a larger urban sequence, then hybrid methodologies should be used, which take into consideration both sedentary activities and dynamic movement. Here, mental mapping techniques can offer useful data on long-term spatial and thermal perception of the environment. However, in some cases, respondents seemed to find it difficult to directly relate thermal perception and spatial perception (Lenzholzer and Koh, 2010; Klemm, 2015b). To tackle this problem, conscientious pre-testing of the methods is required. During the communication with respondents careful explanation of terms in non-scientific vocabulary is necessary as well as explanation of maps to assist people with orientation. It can be useful to use additional observation methods (see Katzschner, 2004; Klemm et al., submitted). When urban areas where people tend to move such as roads or shopping streets should be represented, it is advisable to employ methods that represent people's perception in motion, and then preferably methods that record perceptions in real time when people are moving. We found only one study that focuses on the long-term perception in motion. But studying people's daily routes (e.g. cycling to work, walking for errands, etc.) and how they are perceived in terms of thermal and spatial conditions on a long-term basis is useful because these daily experiences make up for a large part of our experience of our daily environments. Hence, this should be a field of research that should be extended. Moreover, when people's perceptions in motion are to be studied, inquiry techniques should accurately represent experience simultaneously with people's thoughts. We see valuable future use of such methods, for instance by simultaneous recordings of verbalized thoughts (Kitchin and Blades, 2002, p. 196–197; Vasilikou and Nikolopoulou, submitted).

4.4. Relation between quantitative and qualitative methods

In almost all cases the results of the qualitative methods used in the studies showed a good 'match' and plausible relation with the quantitative data raised. This indicates a close relation between the 'objective' measurable and 'qualitative' subjective reality. Still, some space types or spatial attributes were identified that received a different evaluation than the quantitative data would suggest. For instance, people assessed the objectively thermally uncomfortable water fronts in Sweden positively and people in the Netherlands assigned materials with a 'warm' color with 'thermally comfortable' associations although there were no objective reasons for that. Another example on street scale showed that visual perception may influence thermal perception, independent from the micrometeorological evidence (Klemm et al., 2015b). The fact that urban design has to respond to both 'realities': the functional physical environment and how people subjectively experience it demands for appropriate representation of both. We suggest that the objective reality should be studied through quantitative methods (e.g. microclimatic measurements, simulations) and the human experience through qualitative methods that represent people's synesthetic experience of urban space. These qualitative methods should address the perception of spatial dimensions, of proportions and materials in relation to the thermal environment. Successful design of urban spaces has to address all these factors integrally and thus depends on this qualitative evidence.

4.5. General considerations

A large part of the studies discussed in this review concerned fundamental research on momentary thermal perceptions in different spaces and often the main purpose was to generate knowledge about thermal indices in the first place. Thermo-spatial experience was of secondary importance. Most of these studies employed statistics to show the interview results, although in some cases the amount of interviews was not sufficient for very reliable statistics (e.g. ANOVAs, descriptive statistics). Statistics based on interviews were also used in some studies about long-term perception, in movement and stationary and for different scale levels. This indicates the great flexibility of such representations and explains the broad use. However, the downside of such purely verbal and quantitative descriptions is that it they are often not specific about spatial configuration and exact localizing. And such spatial knowledge is needed when the synesthetic

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experience of the urban environment is pivotal in the research or when conclusions about urban design such as design guidelines should be drawn from the research. Spatially explicit ways of representing thermal experience in maps, 'thermal notations' or other spatial representations (e.g. Katzschner, 2004; Klemm et al., 2015a; Lenzholzer and Koh, 2010; Vasilikou, 2015) are very useful for urban design related research. Future research should deliver even more specific recommendations on the use of suitable methods for different types of urban spaces (e.g. open and enclosed spaces), but such methodological research would require a larger set of spatially explicit qualitative studies than hitherto conducted. Therefore, we hope that future research on thermal perception will involve more qualitative methods that provide spatially explicit results.

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