New qualitative methods to explore thermal perception in urban spaces

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1. Introduction: A phenomenological approach to thermal perception

The concept of 'outdoor thermal comfort' has been treated as a purely physiological concept for a long time. Fanger (1970) defined thermal comfort as the human satisfaction with its thermal environment. Since that time, various indices such as PMV (Fanger, 1970), PET (Matzarakis et al., 1999; Mayer and Höppe, 1987) and lately UTCI (Höppe, 2002), were developed to describe thermal comfort based on micrometeorological conditions such as air temperature, humidity, wind and solar radiation. However, 'comfort' or 'human satisfaction' are psychological concepts that cannot be solely expressed by physiological parameters.

Nikolopoulou and Steemers (Nikolopoulou et al., 2001; Nikolopoulou and Steemers, 2003) questioned this purely physiological approach and opted for a more inclusive, phenomenological approach to the concept of thermal comfort. Nikolopoulou's extensive work on outdoor thermal comfort showed that other factors such as 'thermal history', expectations, the presence of company and other non-physical factors strongly influence thermal perception (Nikolopoulou et al., 2001; Nikolopoulou and Lykoudis, 2006; Nikolopoulou and Steemers, 2003). Also Knez and Thorsson indicated that many other factors such as culture or the climate people are used to can have an effect on thermal perception (Knez and Thorsson, 2006; Knez et al., 2009).

Yet, these earlier studies did not focus on the impact of the spatial environment on thermal perception. The investigated factors influencing thermal perception were rather non-spatial, such as thermal history or expectations. However, more specific space-related information regarding human's thermal preferences is needed to develop design guidelines for the disciplines which create and transform human outdoor environments (such as urban design, architecture and landscape architecture) in order to make them more thermally comfortable. For indoor spaces, Rohles (1980) had already indicated that the ambiance and materialization of rooms influence thermal perception. One could assume that ambiance and materialization (which can be influenced by design), would affect outdoor thermal perception as well. But to test this assumption, novel research methods relating perception of spatial characteristics with thermal perception were required.

The inspirations from Nikolopoulou and Rohles were used to develop novel methods to investigate the relation between characteristics of outdoor spaces and thermal perception. The crucial questions in developing these methods were: how can this relation between thermal perception and spatial characteristics of urban outdoor spaces be studied and how can the outcomes provide tangible, applicable results for urban designers? Physical quantitative measurements alone would not suffice to describe the influence of urban spatial arrangements and elements. Individual perceptions of thermal conditions outdoors in relation to spatial patterns and elements needed to be investigated. Analyzing these human thermal perceptions can eventually result spatial adaptation guidelines that respond to these perceptions.

Lenzholzer (2008, 2010) started such investigations by studying the ambiance and materialization, but also proportions and degree of openness of outdoor spaces and their influence on thermal perception. Later, the influence of green elements and spaces in the built environment (Klemm et al., 2015a; Klemm et al., 2015b) and of spatial variation in the urban morphology (Vasilikou and Nikolopoulou, 2013; Vasilikou, 2015) on thermal perception were studied. This paper describes these novel methods in more detail and illustrates them with examples. By describing the methods we hope to contribute to the existing body of knowledge in research methods for outdoor thermal perception that could be applied in various climatic zones.

2. Overview of novel methods to explore thermal perception in urban spaces

To investigate individual perception of urban outdoor spaces in relation to the thermal environment, qualitative methods were employed that were inspired by analysis methods in urban design, environmental psychology and human geography. All methods are based on interviews/ surveys with people in urban environments who disclose their ideas concerning the spatial and the thermal environment. The different methods respond differently to three major aspects in thermal perception: the spatial scale of the environment (city, park, square, street), the temporal scale of thermal perception (long-term and short-term) and the role of motion (stationary and walking).

Thermal perception was studied on different urban scale levels; varying from city scale (Klemm et al., 2015a) to the scale of a square (Lenzholzer, 2008; Lenzholzer and van der Wulp, 2010), to the scale of a spatial sequence that combines a series of interconnected streets and squares (Vasilikou, 2014, 2015; Vasilikou and Nikolopoulou, 2013) and to the scale of a single street (Klemm, 2015b).

Thermal perception concerns either long term (i.e. general) or short term (i.e. momentary) experience. Long term experience is either based on a repetition of similar circumstances or on salient incidences that get 'ingrained' in people's memory, also described as 'perception schemata' (Neisser, 1976). When such experiences concern spatial information, they can shape 'mental' or 'cognitive' maps (Kaplan et al., 1998). Long term thermal perception connects spatial and temporal information with thermal conditions, for example *'Large squares without shade are always too hot during warm summer days'* or *'At the foot of high-rise buildings it's always very windy.'* In contrast, momentary thermal perception relates to an experience at a specific moment in a specific place. For instance, during an interview, respondents' thermal perception would relate to the specific thermal and spatial conditions, like *'I feel cold right now, as I am standing in the wind and in the shade of a building'*. Logically, such momentary thermal experiences can only be related to a specific small scaled site. Long-term experiences can be connected to various scale levels.

Relating motion to thermal perception and space, there are two distinct strands: first, interviews can be conducted with people observing a space assessing its thermal environment while stationary, and second, interviews may be conducted while walking. Stationary interviews are used to depict both- long- and short term thermal perceptions and conditions of various scale levels. Interviews taken while walking are mainly used to analyse urban sequences of interconnected spaces and may provide an understanding of the thermal environment of an urban layout (Potvin, 2000; Vasilikou and Nikolopoulou, 2013) as opposed to a single urban space.

In all surveys we discuss in this paper, respondents' individual, behavioral and psychological aspects were also considered as they affect thermal perception (long or short term, depending on the respective study). Individual aspects, like gender and age, were taken into account in all interviews. Additionally, behavioral aspects were recorded in relation to momentary thermal perception. Those included clothing levels, level of activity and time spent in the specific place. Respondents were only selected for interviews on momentary thermal perception when they had been outdoors for at least 10 minutes to reach their metabolic equilibrium (ACSM, 2013).

In all studies, additional micrometeorological measurements were taken to compare the qualitative information from the interviews with quantitative data describing the physical conditions. The measurements either depicted the long term thermal situation (longitudinal measurement campaigns) or the situation at the moment and place when the interviews were taken. Since such measurement methods have been amply described elsewhere, we will not focus on these, but the novel qualitative methods to explore thermal perceptions in urban spaces. In the following, we will describe a range of these methods.

2.1. Interviews about perception of the spatial environment in relation to thermal perception

Studies with interviews on people's spatial perceptions of the urban environment are numerous (Herzog et al., 1982), but they never related to people's thermal perception. In 2010 Lenzholzer and van der Wulp (Lenzholzer and van der Wulp, 2010) introduced interviews in which thermal and spatial perceptions on urban squares were addressed. This approach was developed further for other urban spaces and elements, e.g. green elements at street level (Klemm et al., 2015b) and spatial sequences (Vasilikou, 2015).

Within the interviews people were asked to describe their perceptions of the spaces according to different spatial design parameters or elements and their thermal perception. In some questionnaires the questions directly related the spatial to the thermal experience and in other interviews they were not related.

In the study by Lenzholzer and van der Wulp (2010) on people's thermal perception on Dutch squares the interview questions did not directly relate thermal and spatial perception because pre-tests showed that people found it hard to directly connect these perceptions. The answers were correlated later in statistical analyses. Typical questions concerned momentary thermal perception (based on a 5-point Likert scale from 'very cold' to 'very hot' and if the respondents were feeling comfortable) on the one hand. Spatial perception, on other hand, was addressed in questions such as: How are 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? 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? Where do you see these materials?

Concerning long term thermal perception Klemm et al. (2015a) asked respondents to assess their perceived level of thermal comfort on hot summer days in three different types of urban spaces, being green, water and built environments. The question was: How thermally comfortable do you feel in one of the following urban spaces on a hot summer day (based on a 5-point-Likert scale)? Similarly momentary thermal perception was investigated in streets with different amounts of street greenery (Klemm et al., 2015b) through asking: How do you experience the microclimate at this moment at this place (based on a 5-point Likert scale)? In the latter study, the experience of the quality of the green street design had to be assessed by respondents separately from the thermal perception. Here the question was: How do you experience the spatial set-up of this street/ the green design of this street?' What do you think about the amount of greenery in this street? Additionally, respondents were asked for possible improvements of the street design.

2.2. Cognitive microclimate maps

Another type of survey was done with people in urban spaces who shared their long term thermal perceptions while standing in an urban space: cognitive mapping. Cognitive or 'mental' maps were invented by the urban design scholar Lynch (1960) as a means to represent people's perception of space. This perception often differs from geographical description of space and meanings are assigned to space which cannot be made quantifiable or 'measurable'. Lynch sparked the development of a whole range of different mental and cognitive map techniques (Kaplan, 1973; Downs and Stea, 1973; Kitchin, 1994) and social value mapping (Tyrväinen et al., 2007; Mäkinen and Tyrväinen, 2008).

Based on these earlier positive experiences with cognitive maps, they were considered to be useful to depict people's long term perceptions or engrained 'schemata' of microclimates (Lenzholzer, 2008; Lenzholzer and Koh, 2010) and were later also used in other studies (Klemm et al., 2015a; Klemm et al., 2015b).

To generate individual cognitive microclimate maps, local people were asked to share their long term knowledge about microclimates in the respective urban space. Respondents 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 assign these perceptions and the interviewers drew them on the map. Additionally, respondents were asked to give an explanation for this perception (e.g. What are the reasons for this thermal comfort or discomfort: e.g sun, shade, shelter, wind?). This approach results in individual 'cognitive microclimate maps' that reflect the interviewee's microclimate perceptions of sub- areas (see fig. 1, left). A large amount of such maps can be overlaid and be summarized into common 'cognitive microclimate maps' that depict the generalized perception of the local urban population (see fig. 1, right).

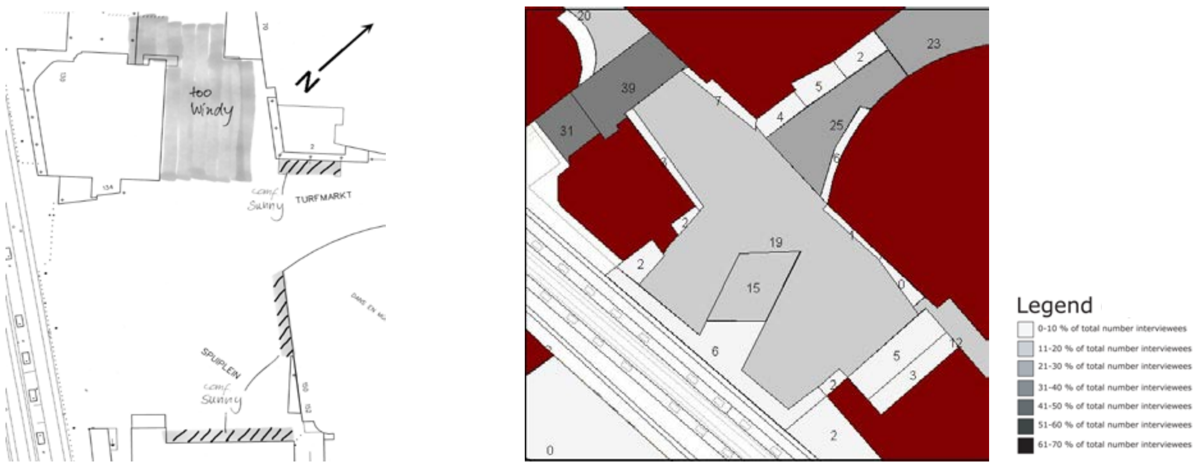

Fig. 1 Example of an individual and a common cognitive microclimate map for Spuiplein, The Hague (Lenzholzer and Koh, 2010)

2.3. Sensewalking: thermal walks

Surveys with groups of people evaluating their momentary thermal perception in motion were conducted in the form of 'thermal walks', addressing the simultaneous monitoring of microclimatic conditions and their experience by pedestrians. This approach was based on point-to-point evaluation of the thermal perception and included the combination of measuring objective microclimatic and spatial data with subjective responses by pedestrians in three walking routes of approx. 500 m in length.

The core of the methodology 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 analyse 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 (Potvin, 2000; Ouameur and Potvin, 2007).

The development of thermal walks (Vasilikou, 2015) contributes to the understanding of variations in thermal perception during movement and change in morphological characteristics between spaces. 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. 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 and microclimatic characteristics accredited to interconnected spaces based on a comparative analysis. The participants' responses can be represented graphically through qualitative design tools (see figure 2).

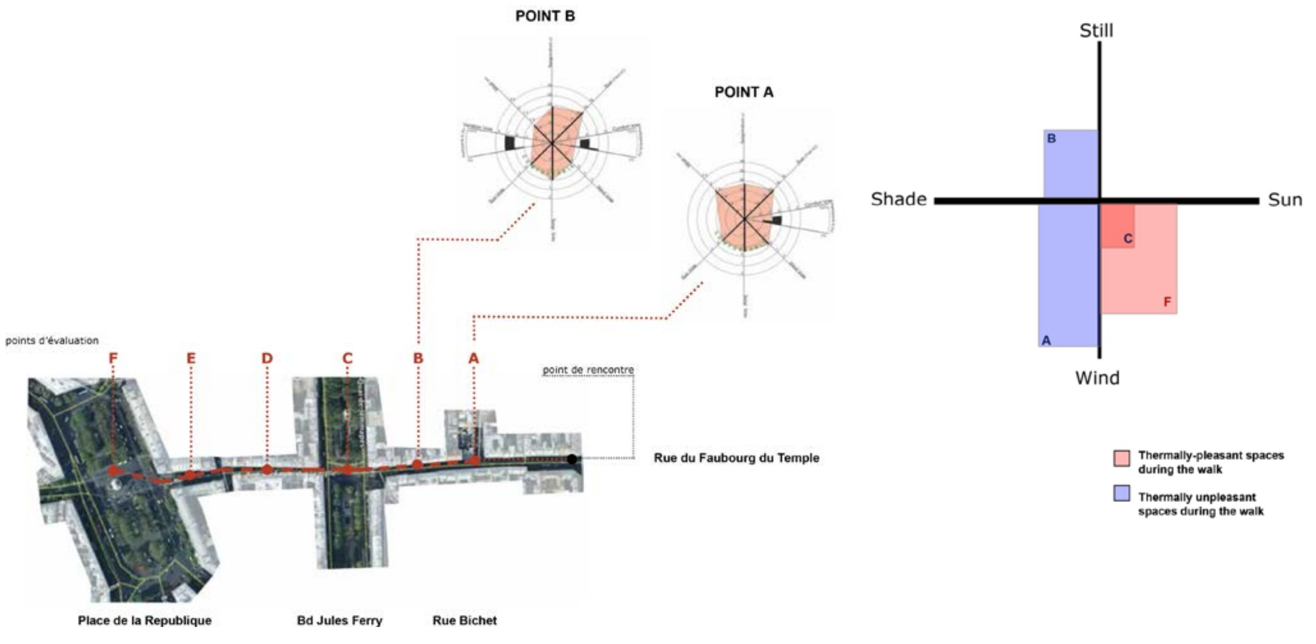

Fig. 2 Mapping example of thermal walk assessment for rue du Faubourg du Temple in Paris (Vasilikou, 2014)

3. Typical outcomes of the qualitative methods and relation to measurements

The outcomes of the **interview series** clearly related the thermal perceptions and spatial perception of people. The latter includes spatial characteristics like proportions, openness, materialization of the spatial set-up of the streets or distribution, size or green types related to greenery. In general, the common physical thermal conditions of space (proportions, materials, etc. of the environment studied) and people's thermal perception matched well. On city scale respondents generally assessed green spaces more thermally comfortable spaces than water and built environments on hot summer days- which matches the 'park cool islands' stated by measurements. On a smaller scale of urban squares, people considered open squares and surroundings of tall building to be too windy- fitting the patterns of wind dynamics. But interestingly, the relation of colours of the built environment and thermal perception was not clearly related to 'factual' effects. Spaces or elements with colours of the red spectrum were considered 'warmer' although such colours have no influence on the actual thermal conditions. Here, probably other meanings assigned to these colours (e.g. the warm sun or fire) played a role in assigning such 'labels'.
On street scale, streets with the highest amount of street greenery (street trees combined with front gardens)

were evaluated more thermally comfortable than other street types with less or without street greenery. Perception of greenery seems to influence people's long and short term thermal perception. Again, those perceptions matched well with the measurements taken in these areas.

The outcomes of the **cognitive thermal maps** indicated that many people assign similar microclimate properties to certain spaces. For instance, many people considered open squares or wider streets to be draughty. And may people defined green urban spaces as thermally comfortable on hot summer days. The micrometeorological measurement results matched well with these assessments of squares or green spaces at city scale. On the other hand, at street level respondents found it difficult to mark their long term thermal perceptions on a map. Respondents were asked which spaces of a particular street they find thermally comfortable or uncomfortable. Most of the respondents did not know that or replied that this was depending on the specific moment of the day or even of the year. Probably, the small scale and limited spatial variance of the symmetrically designed street canyons made it difficult for respondents to define thermal perception in specific sub-spaces. In contrast to this study, cognitive maps of larger urban configurations have yielded clear results which show that people assign certain types of spaces to certain microclimates (Lenzholzer, 2008; Klemm et al., 2015a).

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. Specific measured microclimatic parameters determined thermal perception and comfort during movement between spaces of increased variation in morphological indicators. In particular, wind speed, turbulence and mean radiant temperature had the most significant impact on the momentary thermal perception. The main parameters influencing thermal perception were variations in wind speed, solar radiation and morphological characteristics that allowed the ventilation of spaces. 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 opportunities for '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.

4. Reflection and conclusion

Applying these novel methods, we noticed some limitations. First of all, the concept of thermal perception is sometimes difficult to understand for laymen and relating spatial and thermal perception directly in interviews, is impossible. Often, some extra explanation is needed during interviews. Another issue is the possible influence of unpredictable factors on interviewee's answers. For instance, a person might find a space thermally comfortable because of fond memories of an incidental nice event in that space which had nothing to do with microclimate.
In some interview series, the outcomes were less usable as design guidelines as expected. They yielded more 'don'ts' than 'do's'. So, generating clear design guidelines involved extra steps or other types of further research (e.g. Research Through Designing, see also Klemm et al. elsewhere in the proceedings of this conference).

But the potentials of these methods prevail. Especially the methods that directly depict thermal perception spatially (cognitive microclimate maps and thermal walk maps), have great potentials to generate useful design guidelines for thermally comfortable urban spaces to be easily implemented in urban design practices (Lenzholzer, 2008; Lenzholzer and Koh 2010; Vasilikou and Nikolopoulou, 2013; Klemm et al., 2015a; Vasilikou, 2015). The combination with quantitative methods has increased the reliability of the results. But in case common 'cognitive microclimate maps' are based on surveys with hundreds of respondents, they might even allow to draw generalized conclusions about the effect of spatial configurations based on people's thermal perceptions and can replace measurement campaigns in some cases.

More research has to be done to further correlate the perceptions of spatial configurations and thermal perception. If the research community has a sufficient database at their disposal in the future that directly relates spatial patterns to thermal perceptions, then we can probably generate automated predictions about spatio-thermal perception through the use of 3D GIS. In 3D GIS, the spatial properties (e.g. proportions, materials, etc.) can be analyzed and the expected human thermal perceptions can be assigned. Such data that directly and interactively predict the thermal perceptions would enable direct interaction with urban design processes.

References

ACSM, 2013, ACSM's guidelines for exercise testing and prescription, Lippincott Williams & Wilkins.
Downs, R. M., Stea, D., 1973, Image and environment: Cognitive mapping and spatial behavior, Transaction Publishers.
Fanger, P. O., 1970, Thermal comfort : analysis and applications in environmental engineering, s.n., Copenhagen, pp. 244.

Henshaw, V., Adams, M., Cox, T., 2009, Route planning a sensory walk, in: Royal Geographical Society Annual Conference, Manchester.
Herzog, T. R., Kaplan, S., Kaplan, R., 1982, The prediction of preference for unfamiliar urban places, Population and Environment 5(1):43-59.
Höppe, P., 2002, Different aspects of assessing indoor and outdoor thermal comfort, Energy and Buildings 34(6):661-665.
Kaplan, R., Kaplan, S., Ryan, R. L., 1998, With people in mind : design and management of everyday nature, Island Press, Washington [etc.].
Kaplan, S., 1973, Cognitive maps in perception and thought, in: Image and environment-cognitive mapping and spatial behavior (R. M. Downs, D. Stea, eds.), Aldine, Chicago, pp. 63-78
Kitchin, R. M., 1994, Cognitive Maps - What Are They and Why Study Them, Journal of Environmental Psychology 14(1):1-19.
Klemm, W., Heusinkveld, B. G., Lenzholzer, S., Jacobs, M. H., Van Hove, B., 2015a, Psychological and physical impact of urban green spaces on outdoor thermal comfort during summertime in The Netherlands, Building and Environment 83:120-128.
Klemm, W., Heusinkveld, B. G., Lenzholzer, S., van Hove, B., 2015b Street greenery and its physical and psychological impact on thermal comfort, Landscape and Urban Planning 138:87-98.
Knez, I., Thorsson, S., 2006, Influences of culture and environmental attitude on thermal, emotional and perceptual evaluations of a public square, International Journal of Biometeorology 50(5):258-268.
Knez, I., Thorsson, S., Eliasson, I., Lindberg, F., 2009, Psychological mechanisms in outdoor place and weather assessment: towards a conceptual model, International Journal of Biometeorology 53(1):101-111.
Lenzholzer, S., 2008, Microclimate perception analysis through cognitive mapping, in: PLEA 2008 – 25th Conference on Passive and Low Energy Architecture (P. Kenny, V. Brophy, J. O. Lewis, eds.), Dublin, pp. PLEA proceedings 2008 (on CD and online).
Lenzholzer, S., 2010, Designing atmospheres: research and design for thermal comfort in Dutch urban squares, Wageningen University, Wageningen.
Lenzholzer, S., Koh, J., 2010, Immersed in microclimatic space: Microclimate experience and perception of spatial configurations in Dutch squares, Landscape and Urban Planning 95:1-15.
Lenzholzer, S., van der Wulp, N. Y., 2010, Thermal experience and perception of the built environment in Dutch urban squares, Journal of Urban Design 15(3):375-401.
Lucas, R., Romice, O., 2008, Representing sensory experience in urban design, Design Principles and Practices: An International Journal 2(4):83-94.
Lynch, K., 1960, The image of the city, s.n., Cambridge (Mass.), pp. 194.
Mäkinen, K., Tyrväinen, L., 2008, Teenage experiences of public green spaces in suburban Helsinki, Urban forestry & urban greening 7(4):277-289.
Matzarakis, A., Mayer, H., Iziomon, M. G., 1999, Applications of a universal thermal index: physiological equivalent temperature, International Journal of Biometeorology 43(2):76-84.
Mayer, H., Höppe, P., 1987, Thermal Comfort of Man in Different Urban Environments, Theoretical and Applied Climatology 38(1):43-49.
Neisser, U., 1976, Cognition and reality : principles and implications of cognitive psychology, Freeman, San Francisco, pp. XIII, 230 p;.
Nikolopoulou, M., Baker, N., Steemers, K., 2001, Thermal comfort in outdoor urban spaces: Understanding the human parameter, Solar Energy 70(3):227-235.
Nikolopoulou, M., Lykoudis, S., 2006, Thermal comfort in outdoor urban spaces: Analysis across different European countries, Building and Environment 41(11):1455-1470.
Nikolopoulou, M., Steemers, K., 2003, Thermal comfort and psychological adaptation as a guide for designing urban spaces, Energy and Buildings 35(1):95-101.
Ouameur, F., Potvin, A., 2007, Urban microclimates and thermal comfort in outdoor pedestrian spaces, in: ASES Solar Cleveland.
Potvin, A., 2000, Assessing the microclimate of urban transitional spaces, in: PLEA 2000 - 16th Conference on Passive and Low Energy Architecture, Cambridge.
Rohles, F. H., 1980, Temperature or temperament- a psychologist looks at thermal comfort, in: ASHRAE transactions, pp. 541-551
Southworth, M., 1969, The sonic environment of cities, Environment and behavior.
Tyrväinen, L., Mäkinen, K., Schipperijn, J., 2007, Tools for mapping social values of urban woodlands and other green areas, Landscape and urban planning 79(1):5-19.
Vasilikou, C., 2014, Le confort thermique de la marche, in: La place de la marche dans le fonctionnement de la rue du Faubourg du Temple a Paris, etude par le Groupe MUP pour la Mairie de Paris (J. Monnet, E. Hernandez, eds.), Labex Futurs Urbains, Universite Paris-Est, Paris.
Vasilikou, C., 2015, The role of urban morphology and pedestrian movement in the perception of thermal comfort in historic city centres, in: Architecture & Planning, University of Kent, Canterbury: .
Vasilikou, C., Nikolopoulou, M., 2013, Thermal walks: identifying pedestrian thermal comfort variations in the urban continuum of historic city centres, in: PLEA 2013 - 29th Conference on Passive and Low Energy Architecture, TUM, Munich.