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A Review on Interdisciplinary Methods for the Characterization of Thermal Perception in Public Spaces

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Abstract. *The contemporary design of public spaces integrates frequently urban cooling installations for thermal comfort in summertime. However, the details of the thermal experience that they provide is yet partially unknown. This paper studies how methods and techniques arising from microclimatology, urban studies and sensory studies can interact for characterizing thermal comfort outdoors. We have reviewed thirteen papers using meteorological measuring instruments and assessed them according to the requirements of methods originating from social sciences and sensory studies for the public space. As a result, we discuss the potentialities and limitations of such techniques to interact through an interdisciplinary methodological design.*

1. Introduction

During recent summer periods, European citizens have witnessed the proliferation of urban installations aiming at refreshing the cities' public spaces – e.g. cooling canopies, cooling benches, misting poles, air-conditioned bubbles. Designed as permanent or ephemeral installations for commercial, public health or recreational purposes, these new urban "attractors" punctually reshape the citizens' experience of the city in terms of social practices and sensory perception.

These installations gather together techniques for both thermal comfort in outdoor open spaces (e.g. misting, ventilation, evapotranspiration) and thermal conditioning in semi-outdoor spaces (e.g. evaporative cooling, ventilation, radiation). By interweaving the urban spatial layout and the microclimatic effects, they modify practices and behaviors inherent to the public realm. For this reason, we call them "spatio-climatic devices".

Analyzing these spaces involves zooming in on research methods on the citizen's scale, to consider sensory, social and behavioral phenomena in relation to climate. Doing so involves mixing quantitative and qualitative methods arising from various disciplines, which challenges the limits of their conceptual and methodological basis. In particular, this review aims at forming a better view on how meteorological measuring techniques can be crossed with methods originating from social sciences and sensory studies for the study of thermo-spatial perception in the public space.

2. Methods for thermal comfort: a brief state of the art

2.1. Microclimatological methods for thermal comfort

Environmental-based methods, such as microclimate simulation or meteorological measurements, are applied for the characterization of thermal comfort variables. Their current limits for dealing with citizens' body scale (decimetric) are also recognized. Microclimatic simulations deal with meteorological variables obtaining acceptable results up to a decametric resolution; however, finer details require tedious geometric and physical descriptions involving numerous hypotheses [1]. Thermal comfort indexes applied outdoors are criticized for focusing on the physiological dimension in spite of the acknowledged relevance of the citizens' socio-cultural background, the diversity of activities and behaviors, the alternate sensory situations intermingling steady-state and transient-state and the physical variability of heterogeneous and asymmetric spatial and climatic conditions [2,3].

In the last few years, meteorological measuring methods have deserved increasing attention for analyzing thermal comfort variables outdoors. Authors like Johansson *et al.* [4] note their potential to consider the actual spatial and meteorological conditions, although the lack of standardization in the

field makes it difficult to compare results until now. Furthermore, the authors underline three critical aspects in the instrument choice: the influence of solar and surfaces radiation in sensors and their shields; the rapidly changing conditions of wind speed and direction; the influence of mean radiant temperature (Tmrt) in thermal comfort, especially during warm and sunny weather conditions.

Meteorological instruments for thermal comfort usually take the form of mobile instruments that allow going through a deeper understanding of processes *in situ*. According to Seidel *et al*. [5], the recent developments of positioning techniques (GNSS, inertial navigation systems), the sensors' miniaturization and their wireless connectivity are rapidly changing the field. However, the combined effect of sensor inertia, movement speed and sampling frequency conditions the data interpretation [6].

2.2. Interdisciplinary methods for studying the public space

Many authors suggest that methods of social sciences and sensory studies can complete the environmental-based approach to reach a complementary understanding of thermal comfort. Operating through person-centered approaches, these methods unveil the individual behaviors, collective practices and intimate perceptions connected to the specific microclimate of a particular space. Traditionally applied for studying the public space, they can be summarized in three approaches:

- Urban studies' methods [7] focus on how the material characteristics of the space, together with their interaction with climate, influence citizens' uses and behaviors – e.g. behavioral mapping, individual-centered tracking, activities observation. Although emerging techniques of automatic tracking through smartphones and cameras will soon contribute to these methods, they raise nowadays number of problems in terms of privacy (public realm) and precision (open space).
- Environmental psychology methods [8,9] have also been applied for thermal comfort outdoors with the aim of considering the effects of the experience temporality (instantaneous or continuous) and the citizens' knowledge of the space (short-term or long-term) – e.g. cognitive maps, semi-structured interviews.
- Site-specific methods from sensory studies [10] unveil the kinetic and synesthetic aspects of thermal perception and unveil the personal circumstances laying behind thermal perception – e.g. sensory walking, sensory surveys.

Depending on the aims of the study and the analysis procedure, these methods can lead to both quantitative and qualitative results – e.g. trajectories, movements, interactions, gestures, occupations of the space, lexical analysis and many others.

3. Meteorological measuring instruments for thermal comfort outdoors: A review of techniques

We have studied research instruments for meteorological measurements in the aim of understanding how they could integrate other interdisciplinary methods. We have reviewed 22 papers published between 2006 and 2019 in scientific journals and conference proceedings using mobile instruments for micrometeorological measurements. After obtaining the specifications, 13 instrumental configurations have been selected; the remaining 9 solutions replicated the methodological design of the previous ones.

The instrumental solutions have been characterized through the analytic descriptors listed below:

- Station format: descriptor of the form of the measuring system and the interaction of the researcher with it – wearable, backpack, compact-station, tripod-station.
- Carrying equipment: descriptor of the transportation system and the moving speed – walking, cart, mobile-tripod, motorized.
- Immersivity of the device (Im): scale from 1 to 5 analyzing the instrument's capability for being as close as possible to the actual citizens' positions and to integrate the urban scene discreetly. It considers its size and degree of mobility – 1 (clearly visible and difficult to move) / 5 (small, light and person-centered position).

- Sensor lag (Sl): scale from 1 to 5 analyzing the instrument's capability to reflect inflections and thresholds in rapidly variable situations considering the sensors' response time – 1 (smooth slow measures, average Sl <15 s.) / 5 (almost instantaneous, average Sl <2 s.).
- Spatial resolution (Sr): scale from 1 to 5 considering the minimum region of interest (described in the paper and calculated with sensors' response time and average speed) and its effect in perception – 1 (body-scale, average Sr <1 m) / 5 (urban space, average Sr> 20 m).
- Characterization degrees (Cd): scale from 1 to 5 considering the accuracy and the number of sensors for analyzing heterogeneous microclimatic conditions like gradients, asymmetries and directional of phenomena – 1 (sensors for Tair & Hr) / 5 (Tair, Hr, Tmrt, Wind speed and direction, short- and long-wave radiation by direction).

	Station format	**Carrying equipment**	**Im**	**Sl**	**Sr**	**Cd**
Boiné, K *et al*. [11]	wearable	walking	5	2	3	2
Camponovo, R *et al*. [12]	backpack	walking	3	5	5	5
Häb, K *et al*. [6]	tripod-station	motorized	1	5	5	2
Johansson, E *et al*. [4]	tripod-station	mobile-tripod	1	1	5	2
Kastendeuch, P *et al*. [13]	tripod-station	cart	1	3	5	2
Klok, L *et al*. [14]	tripod-station	cart	2	1	5	2
Lai, A *et al*. [15]	tripod-station	mobile-tripod	1	1	5	5
Le Bras, J & Masson, V [16]	backpack	walking	3	5	4	1
Mayer, H *et al*. [17]	tripod-station	mobile-tripod	1	2	5	2
Middel, A & Krayenhoff, E S [18]	tripod-station	cart	2	5	5	5
Santucci, D *et al*. [19]	wearable	walking	4	5	5	2
Thorsson, S *et al*. [20]	tripod-station	mobile-tripod	1	1	5	5
Tsin, P K *et al*. [21]	backpack	walking	4	1	1	1

Table 1. Analysis of the measuring instruments.

A classification in four groups emerges from the analysis of Table 1. Each one involves with different degrees of immersion in the fieldwork, spatio-temporal resolution and complexity of parameters characterized:

- Wearable instruments: two studies [11,19] implement sensors located close to the body's surface. They are small and little intrusive, although their accuracy and resolution are debatable. Thus, data requires important post-processing corrections. The methodological designs studied make it difficult to obtain correct measurements for wind (body's mask) and almost impossible to characterize short- and long-wave radiation.
- Portable instruments: three studies [12,16,21] propose meteorological stations integrated in a backpack to be transported by the researcher. This setup permits mounting accurate sensors, although obtaining robust measurements involves avoiding researchers or sensors radiations and masks (solar and wind). This requires separating the sensors through complementary structures, which makes the instrument heavier and more visible. In the current state of technology, bigger instruments [12] reach a more complete characterization of thermal comfort, whereas smaller solutions are less complete.
- Movable instruments: three studies [13,14,18] implement meteorological stations installed into carts. This setup offers accurate and rapid sensors, integrating a high number of meteorological variables, placed in optimum measuring conditions. The distance between the researcher and the

instrument avoids solar and wind masks. In the three cases, this leads to medium size and slightly heavy instruments, which modify the immersion conditions into the fieldwork.

– Semi-stationary instruments: four studies [4,15,17,20] explore a methodological design with meteorological stations installed in a mobile tripod setup. They are mostly used for characterizing a single space, usually with slower but more accurate sensors. Other designs use semi-stationary stations as a reference for calibrating other mobile devices [6,18]. Lastly, this setup opens new perspectives through micro sensors networks as argued by Seidel *et al*. [5].

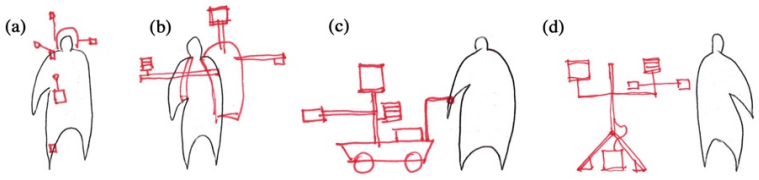


Figure 1. Representation of the instrumental configurations.

4. Potential for methodological hybridizations

A comparative analysis based on the five interdisciplinary methods and the four mobile measuring techniques explores their potential hybridizations. Table 2 summarizes the implications for the researcher (Rs), subjects (Sb), area studied (Sa) and data obtained (Do).

	Wearable (C1)	Portable (C2)	Movable (C3)	Semi-stationary (C4)
Observation (T1)	Rs: 2 people needed, 1 moves freely & interacts with citizens Sb: n/a Sa: perturbed the Rs Do: postprocessing needed to combine.	Rs: 2 people needed, 1 moves freely & interacts with citizens Sb: n/a Sa perturbed the Rs Do: direct combining.	Rs: moves freely, difficult interactions, observes Sb: n/a Sa: perturbed the Rs Do: direct, few spatial data, representative data needs 2 people.	Rs: stays away from Sa Sb: n/a Sa: perturbed depending sensors number Do: not representative unless sensors are numerous & intrusive.
Semi-structured interviews *in situ* (T2)	Rs: free to interact Sb: wears light instruments & interacts. Sa: n/a Do: postprocessing needed to combine.	Rs: almost free to interact. Sb: moves freely Sa: n/a Do: measures not taken in the citizen position.	Rs: interaction difficult, 2 people needed. Sb: moves freely Sa: n/a Do: measures not taken in the citizen position.	Rs: free to interact Sb: moves freely Sa: n/a Do: measures & interv. uncorrelated, post-pro. & hypothesis needed.
Cognitive maps *in situ* (T3)	Rs: free to interact Sb: moves freely Sa: n/a Do: measures & mapping uncorrelated, postpro. needed.	Rs: almost free to interact Sb: moves freely Sa: n/a Do: measures & mapping uncorrelated.	Rs: interaction difficult. Sb: moves freely Sa: n/a Do: measures & mapping uncorrelated.	Rs: free to interact. Sb: moves freely Sa: n/a Do: measurements interpolation needed for mapping correlation.
Sensory walking (T4)	Rs: free to interact Sb: wears light instruments & interacts. Sa: n/a Do: postprocessing needed to combine.	Rs: free to interact Sb: moves freely Sa: n/a Do: measures not taken in the citizen position.	Rs: difficult interaction Sb: moves freely Sa: n/a Do: measures not taken in the citizen position.	Rs: free to interact Sb: move freely Sa: n/a Do: measures & interv. uncorrelated, post-pro. & hypothesis needed.
Reactivated interviews *in situ* (T5)	Rs: free to interact Sb: moves freely Sa: n/a Do: postprocessing needed to combine.	Rs: free to interact Sb: moves freely Sa: n/a Do: analysis & postprocessing.	Rs: difficult interaction, 2 people needed Sb: moves freely Sa: n/a Do: analysis & postpro.	Rs: free to interact Sb: move freely Sa: n/a Do: measurements & interviews uncorrelated.

Table 2. Analysis of measuring techniques according to social sciences and sensory studies methods.

For the analysis of Table 2, we have proceeded to explore the applicability of the previous combinations in the methodological design defined by Chelkoff [22]. This work helped us to understand which of them could be more suitable. The author suggests that an interdisciplinary approach to the public space must consider at least three levels that cover the specific disciplinary approaches intimately linked between themselves:

- The first level concerns the interactions between the built environment and the microclimatic variables. The scope of the analysis is mainly the physical dimension and data is provided by spatial and meteorological measurements. We suggest combinations like T1-C3 and T1-C4.
- The second level concerns the citizens' sensory perception of the environment (form and climate). It constitutes the local specificity of the object of study and data are obtained from semi-structured interviews, cognitive maps and sensory walking. Method combinations like T2-C3, T3-C3, T4-C1 and T5-C3 contribute to this level.
- The third level concerns human behaviors and social practices, their various expressions and adjustments circumscribed within the context of the two previous points. Data are provided by observations and reactivated interviews together with interpretation and extrapolation according to theory. Combinations like T1-C3, T1-C4 and T5-C3 would help at this level.

On the contrary, some of the table 1 combinations could present methodological contradictions. In our opinion, with the aim of keeping both methods robustness, combinations like T1-C1, T1-C2, T2-C4, T4-C4, T5-C3 or T5-C4 have to be considered carefully.

5. Conclusions

This paper contributes to previous reviews on methods and instruments for thermal comfort outdoors, such as those of Johansson *et al*. [2] and Lenzholzer *et al*. [8]. Our work explores how meteorological measuring techniques can be implemented in social sciences and sensory studies methods for the study of the thermo-spatial perception in public spaces. It reveals that several methodological hybridizations for the study of thermal comfort outdoors are possible, although not all of them are appropriate. Points like the choice of sensors (response time and accuracy), the complexity of the measuring instrument, the instrument's size and mobility degree, the researcher autonomy, the interviewee mobility, and his/her degree of immersion within the studied microclimate are crucial for a robust methodological design.

We have examined 22 articles and selected 13 instrumental solutions for microclimate measurement. This work reveals that there is no one-fits-all solution useful for all the interdisciplinary methods. However, two main ways for coupling methods emerge.

On the one hand, portable and movable instruments, placed on backpacks or carts, integrate accurate sensors for characterizing a higher diversity of parameters outdoors. These configurations allow measuring vertical thermal gradients, characterizing short- and long-wave radiation in six directions as well as wind speed and direction. These are particularly influential parameters for assessing thermal comfort in warm and sunny weather conditions, which is the aim of the ANR Coolscapes project.

On the other hand, wearable instruments are particularly adapted to sensory walking and semi-structured interviews *in situ*. They are small, light, autonomous and can be nowadays wirelessly connected to cellphones, which allows almost free interactions during the experiments and measuring close to the interviewees' situation. Although the instruments analyzed give rise to questions about their accuracy and data interpretation, smart sensors become progressively more accurate and, as previously explained, we can imagine that in few years this solution would produce more robust data.

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