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Xenia Stavropulos-Laffaille, Ignacio Requena-Ruiz, Céline Drozd, T. Leduc, Myriam Servières, et al.. Urban cooling strategies as interaction opportunities in the public space: a methodological proposal. Journal of Physics: Conference Series, 2021, 2042 (1), pp.012128. 10.1088/1742-6596/2042/1/012128 . hal-03445642

HAL Id: hal-03445642

<https://hal.science/hal-03445642>

Submitted on 31 May 2024

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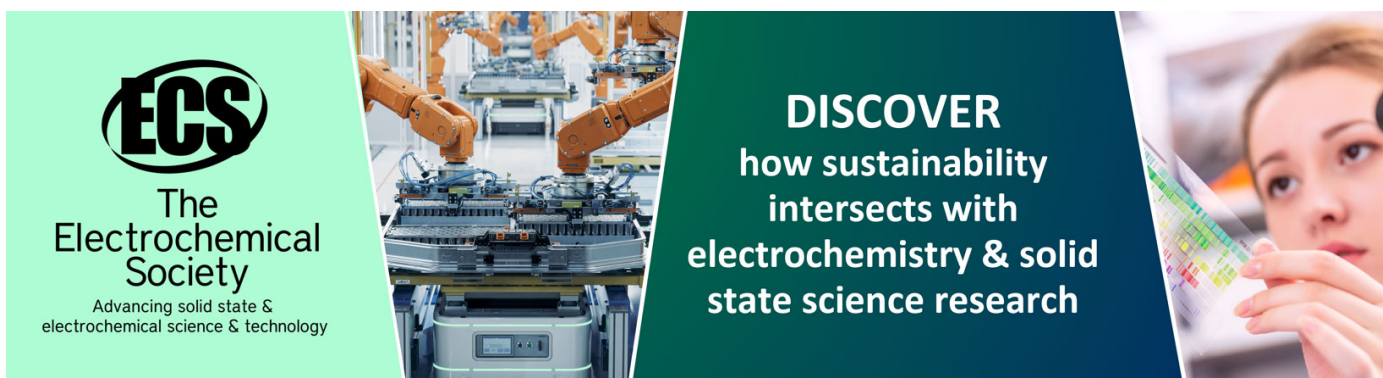
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To cite this article: X. Stavropoulos-Laffaille *et al* 2021 *J. Phys.: Conf. Ser.* **2042** 012128

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Urban cooling strategies as interaction opportunities in the public space: a methodological proposal

X. Stavropoulos-Laffaille, I. Requena-Ruiz, C. Drozd, T. Leduc, M. Servières & D. Siret

CRENAU - AAU UMR 1563 CNRS/ECN/ENSAG/ENSAN, ENSA Nantes, 6 Quai François Mitterrand, BP 16202, 44262 Nantes (France)

ignacio.requena@crenau.archi.fr

Abstract. In the context of global warming, cities promote temporary or permanent public space designs based on the integration of various cooling techniques, hereafter called spatio-climatic devices, to locally cool down the atmosphere and preserve urban liveability. Such public spaces create interaction opportunities for citizens to seek thermal pleasure outdoors. To inform about the citizens' thermal experience of these spaces, this paper explores fieldwork and data analysis methods at the crossroads of urban climatology, environmental psychology and urban design. Four spatio-climatic configurations are investigated in the 'Extraordinary Garden' in Nantes (France) through mobile microclimate measurements and ethnographic observations. By applying an 'urban transect' approach, preliminary selected microclimate, behavioural and activity observation data is displayed together with spatial information. This allows to highlight thermal situations induced by urban design and to link them to specific citizen-environment interactions. As a result, this approach contributes to a better characterization of urban cool spots as a strategy for more resilient public spaces.

1. Introduction

The potential of public space design to deal with citizens' thermal sensation, especially in summer, is crucial to preserve urban health, socio-economic activity and life quality [1,2]. During recent years, temporary and permanent urban cooling techniques have increasingly appeared in the public realm as short-term adaptation strategies to deal with rising temperatures. They present manifold adaptive opportunities for citizens to seek thermal pleasure outdoors – e.g. shading by artificial or vegetated canopies, absorbing corporal heat by urban cooling furniture or misting by misting systems. Although various studies [3,4] analyse the influence of the climate configurations created by public space design on urban life, especially in social and recreational activities, the underlying mechanisms of individuals to seek thermal comfort in the urban environment is still less known [5].

This paper focuses on the study of citizens' thermal sensation when experiencing urban places, which punctually cool down the atmosphere. Hereafter called 'spatio-climatic devices', such public places are short-term adaptation strategies to climate change combining spatial layouts and cooling techniques. The central hypothesis is, that they could be perceived by citizens as cold-inducing affordances in periods when cooling opportunities are appreciated and, consequently, they promote specific modes of citizen-environment interactions.

The theoretical foundations of this paper are grounded on the notions of 'environmental affordance' and 'adaptive thermal comfort'. The first one comes from environmental psychology and is frequently applied in design studies to intersect physical and immaterial aspects of spatial design with their perception by users [6]. With the term 'environmental affordances' researchers refer to the citizens'



functional and behavioural opportunities afforded by the spatial design. The perception of these opportunities is influenced by the citizens' knowledge, intentions or action abilities. Interaction happens when their characteristics "are matched in meaningful relations with the environmental features" [7].

The thermal comfort adaptive approach considers citizens to be free to "interact with the environment in ways that ensure their comfort" [8]. The perception of control, or the opportunity to act and change an uncomfortable state, becomes crucial in the tolerance of physiological discomfort. Researchers point out three main adaptation strategies [5,9]: i) behavioral adaptation through direct personal changes (e.g. drinking, physical activity); ii) self-act adaptation through self-actions in space (e.g. posture choice, location choice) and iii) spatial-act adaptation involving a perceptible spatial change of the environment, such as direct interactions with the urban environment.

The following sections of this paper present the details of an interdisciplinary experimental approach to data acquisition and data analysis with the aim of creating a better understanding of citizens' interactions with the spatio-climatic devices in public space.

2. Data acquisition methods

With the aim of analysing individuals' thermal experiences, this paper combines three scientific approaches: microscale mobile monitoring of urban climate (microclimatology), unobtrusive observation of urban activities (urban ethnography) and observation of individual behaviours in public spaces (design ethnography). These methods are grounded in a spatial approach: microclimate measurements are coupled with the positioning through a foot-mounted inertial sensor, whereas ethnographic methods rely on mapping approaches with a GIS portable support. Furthermore, the experimental campaign was preceded by a study of climate relevant spatial and material characteristics (geometry, sky view factor, degree of enclosure, albedo).

2.1. Microscale mobile monitoring of urban climate

Microclimatic data was recorded with a mobile meteorological station at pedestrian level inspired by Middel and Krayenhoff [10] and mounted on a reconfigured bike trailer. This station was moved through the spatio-climatic devices while recording the variables of the observer's three-dimensional environment (Table 1). Four spatio-climatic devices were investigated every hour and a half from 11:20 a.m.

Table 1. Technical properties of sensors of the mobile meteorological station (campbellsci.fr)

Variables	Sensors	Accuracy (+/-)	Field	R/T
Wspeed	WindSonic1	2%	0.01 to 60 m.s-1	1 s
Wdir	WindSonic1	3°	0° to 360°	1 s
Tair	2 thermocouples T	0.5 °C	-185 °C to +400 °C	Inst.
	HMP155A	up to 0.5 °C dep. on temp.	-80 °C to +60 °C	< 20 s
RH	HMP155A	1% -2.8% dep. on temp.	0.8% to 100%	< 20 s
Solar Rad.	NR01	10 % on daily totals	-0.1 to +50 mV	18 s

2.2. Unobtrusive observation of urban activities

Activity-observation was carried out with the methods of 'mapping' for static groups and 'tracking' for moving groups [4]. Each group was coded with the socio-demographic information (number of people, gender and perceived age) and the activity information relevant for thermal comfort (activity, movement, posture, cooling technique, bodily engagement). Observations were conducted within hourly intervals. Each observation combined two points of view and lasted for 20 minutes to document static and dynamic activities. As a result, 339 static and 261 moving groups were recorded.

2.3. Observation of individual behaviours in public spaces

Behavioural observations focused on the specific interactions of individuals or small groups with the space. They were conducted every hour within 15 minutes-sequences and did not required informed consent of visitors according to French law, what helped to keep spontaneous behaviours. They were conducted in public spaces with punctual video recordings using a wide-angle lens (GoPro Hero6©) to

record panoramic views of groups of people. In total, 70 interaction scenes were observed. As a complement, citizens were shortly interviewed (not recorded) to describe their expectations.

2.4. Study area

The combined method was tested in the ‘Extraordinary Garden’ of Nantes (France). Designed by Phytolab landscape architects, it is situated in a former granite quarry surrounded by 25 m-high cliffs facing South and West. It offers a special microclimate with different spatio-climatic devices, among which four of them are significant in terms of urban cooling: (1) a metallic footbridge with misting nozzles surrounded by a landscape scenery with three programmed waterfalls; (2) a densely tree-shaded path including benches; (3) a metallic footbridge over a waterbody; (4) a bamboo-shaded path. Table 2 presents their climate relevant characterizations.

The experimental campaign was carried out under normal summer weather conditions during July 2020. The site was investigated for 7 days (July 16 to 17 and 20 to 24, 2020) between 11 a.m. and 6 p.m.

Table 2. Climate relevant characterization of each spatio-climatic device

		1	2	3	4
Geometry	Total area (m ²)	778.07	83.04	127.65	351.37
	Useful area (m ²)	78.25	19.44	39.2	117.05
	Perimeter (m)	113.01	36.06	44.93	134.93
Material	Mean albedo (-)	0.11	0.23	0.14	0.22
Space	Sky view factor (-)	0.594	0.173	0.771	0.511
	Degree of enclosure (-)	0.549	0.477	0.263	0.781

3. Data analysis approach

The data analysis was conducted in a two-step procedure. First, acquired data was treated separately according to adapted techniques for each method. This allowed for a comparison with other spatio-climatic devices and information of the design’s potential for cooling the local atmosphere as well as the main trends for activities (age, genre, type of activity) and behaviors (postures and engagement). Second, a visual approach presents cross-disciplinary data in a single representation allowing richer interpretations of their role in the experience of the space.

3.1 Separate data analysis

Microclimate data was analyzed in each spatio-climatic device by considering their prior- and post-spatiotemporal environment as reference gradients, contrasts and thresholds in the pedestrian experience. Based on the six-directional radiation method, the mean radiant temperature was calculated and wind speed was converted to a height of 10 m. Subsequently, different thermal comfort indices suitable for the outdoor environment were calculated based on an algorithm in Python 3. However, only the Physiologically Equivalent Temperature (PET) is presented hereafter.

The data acquired from both ethnographic methods was analyzed in R analytics with statistic techniques (Principal Components Analysis PCA, Exploratory Factors Analysis EFA, pairwise correlations, correlation matrix and Non-metric Multi-Dimensional Scaling NMDS), with the aim of understanding the links between independent variables, and through clustering techniques (K-means), with the aim of inducing an observational data typology. Both procedures contributed to selecting the more influential variables for conducting a spatial analysis through GIS techniques (QGIS and Kepler.gl), whose purpose was to clarify the spatial factors in the data distribution.

Given the focus of the paper on the interactive experience of space and climate created by spatio-climatic devices, not all results of these methods will be presented here. After a general description of the four spatio-climatic devices, we will discuss device 1 in more detail.

3.2 Visual analysis of cooling scenes

With the aim of defining the interactions between pedestrians and their environment, an ‘urban transect’ approach is proposed [11]. It consists of an exploratory protocol based on an urban section-drawing that superimposes layers of spatial, microclimate and social data throughout sequences of the studied space.

The section encourages a human-centered perspective related to urban forms and urban design devices. It can also express a diversity of immaterial phenomena related to local climate experiences.

Given the amount of data acquired, the “separate data analysis” contributes to a preliminary filtering of displayed information in order to characterize specific but representative cooling scenes in the transect. On the one hand, the individuals’ PCA analysis and the K-means clustering highlight the behavioural observations that represent the most frequent cooling scenes. On the other hand, the PCA dimension and correlation analysis reveal the most relevant observational variables characterizing the cooling scene. In this case, these variables were the number of people, the mean age, the % of women, the body posture and the type of activity. Lastly, the measured microclimate variables and the PET comfort index were represented. Figure 1 shows one observation of device 1 representing the footbridge in front of the waterfalls.

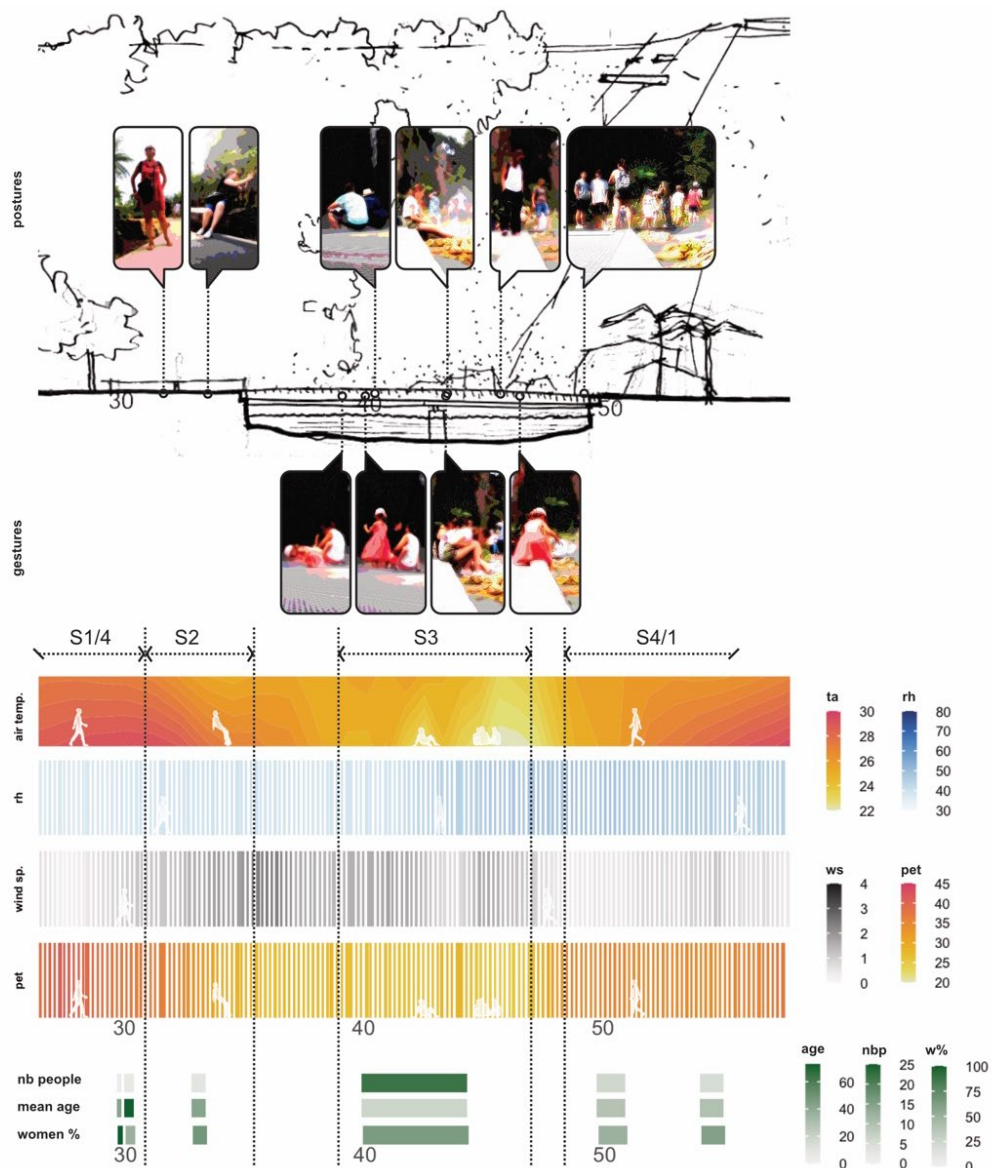


Figure 1. Example of an observation in the spatio-climatic device 1.

4. Analysing cooling related interactions

The four spatio-climatic devices, designed by the landscape architects, lead to contrasted ways of experiencing the urban atmosphere and different spatial distributions of activities and behaviors. Device

1 modifies the air temperature, relative humidity and received short- or long-wave radiation, which leads to a cooler thermal sensation (e.g. device 1 reduces PET by $-6\text{ }^{\circ}\text{C}$ and device 2 by $-7\text{ }^{\circ}\text{C}$). In parallel, the spatial settings of these two devices concentrate the majority of the garden visitors towards static activities and a broader range of postures while sojourning in these spaces. On the contrary, devices 3 and 4 have less influence on thermal sensations (e.g. device 3 reduces PET by $-1\text{ }^{\circ}\text{C}$ and device 4 by $-3,5\text{ }^{\circ}\text{C}$) and their main use is the functional circulation in the garden.

In the context of warm but not extreme heat weather conditions, different spatio-climatic devices lead to similar results in comfort indexes. However, the citizen experience of the space can be fundamentally different. The study of devices 1 and 2, with similar PET indices, supports this conclusion. Open to the surrounding landscape, device 1 has a bigger useful area including more interaction opportunities (e.g. sitting, touching). Hence, its spatial setting contributes to a larger variety of observed activities and postures, just like the diversity of cooling strategies contributes to a variety of individual cooling scenes. As the main attraction of the garden, device 1 is more crowded than device 2, leading to frequent short period staying ($< 10\text{ min}$). In contrast, device 2 is densely tree-shaded, smaller in surface, more intimate and offers fewer interaction opportunities. This leads to longer staying periods, often in groups, during the central hours of the day when solar radiation is higher.

As an example, Figure 1 helps in characterizing the spatio-climatic sequences of device 1:

- The approach sequence: once the space is identified by its visual or sonic presence, visitors follow a light grey concrete path exposed to solar radiation to reach the spatio-climatic device.
- The threshold sequence: located at the beginning of the device, this sequence allows an entire visual appreciation of the space and includes benches for formal sitting. The cooling effect is soft but noticeable, in particular depending on the wind direction. Older people often sit on the benches and thus stay longer in this warmer and less humid sequence.
- The inner sequence: located right after the centre of the footbridge, in front of the waterfall, this area allows for the total immersion of visitors in a cooler (air temperature drops by $-2\text{ }^{\circ}\text{C}$ on average) and more humid (the relative humidity rises up to 15%) atmosphere, whereas they remain exposed to solar radiation. The integrated misting nozzles in the floor structure intensify the air-cooling effect within the first 50 cm of the floor-level (the air temperature drops up to $-7\text{ }^{\circ}\text{C}$ compared to the approach zone). This localized cooling is accompanied by direct ground-level interactions, such as direct exposure of hands or feet, opening arms, strolling or playing around the nozzles. Similarly, it also contributes to postures closer to the floor, like informal sitting or kneeling. These are also favoured by the design of the footbridge borders, which are 30 cm lower than the central platform, creating an informal bench of 15-meters long. This sequence is often experienced by children, young and middle-aged adults (2–55 years).
- The exit threshold sequence: once the visitor decides to move out of the inner sequence, this sequence is crossed faster than the entry one. Same as the entry threshold, it involves a spatio-climatic transition towards the surrounding conditions following the light concrete path of the garden. Given the almost symmetric setting of the space, the exit threshold can be experienced as the entry one depending on the visitor's direction.

A general analysis of the interactions in device 1 reveals three types of interactions with the space through movements, gestures and postures. Movements involve displacements of visitors towards, away from or around the cooling sources once they are identified. They appear in the thresholds and inner device sequences. Gestures involve punctual actions with the physically body-space interactions, such as exposing the hand, moving the arms towards the mist or fanning through it. They only appear in areas closer to the nozzles or in front of the waterfall of the inner sequence. Postures involve the choice of the body's position in the space, such formal and informal sitting or standing. They appear in all the sequences of the device.

5. Conclusions

At a time when urban climate sciences examine urban heat islands and overall urban cooling effects, it becomes increasingly important to study how citizens actually experience the urban climate through in-situ methods. Microclimate measurements at pedestrian level combined with urban ethnography

contributes to a better understanding of the mechanisms of citizens to seek thermal pleasure in the urban environment.

The key findings of this study, show that i) combining urban ethnography to mobile microclimate measurements helps to target measuring points and patterns related to the space activity without avoiding it; ii) outdoor thermal comfort indices need to be discussed with more context-sensitive methods when analyzing cooling strategies at the pedestrian level; iii) almost equally comfortable areas in thermophysiology terms attract different people, depending on socio-demographic aspects, but also lead to different reactions according to individual culture, intentions or perceptions and iv) according to the framework of environmental affordances and adaptive thermal comfort, the spatio-climatic devices become interaction opportunities for visitors, which experience the space beyond its primary function.

Moreover, representing multiple data in a single graphic allows for comparing information, identifying sequences and relating them to the space. The climatic urban transect, explored in this paper, is a useful instrument to achieve this goal. However, keeping a global understanding of data interaction involves a reduction of data complexity and precision that has to be considered carefully.

Finally, the fine understanding of punctual situations presented here deserves to be discussed in comparison with a larger panel of sites and experiences. Thus, the outlined methodology is going to be applied to other spatio-climatic devices in Nantes and Paris. Their selection will depend on covering a wider variety of cooling techniques, while differentiating the usage of the accommodating urban spaces (transition, destination, etc.). Limitations are principally given by the devices accessibility with the mobile station and the refreshing potential extent with its close environment.

Acknowledgements

The authors acknowledge the support of the French National Agency of research (ANR) under reference ANR-18-CE22-0003 (COOLSCAPES project).

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