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Environmental high performance urban open spaces paving: experimentations in Urban Barriera (Turin, Italy)

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Abstract

The aim of this paper is to describe the experimentation on environmental high performance urban paving for open space re-design in Urban Barriera program framework in Turin (Italy). Urban Barriera is a program designed to trigger a process of improvement of the “Barriera di Milano” area, the historical neighborhood in the northern part of the city. It was supported by the City of Turin, the Piedmont Region and the European Community, in order to operate on physical, economic, social aspects of the city by encouraging collaboration and proactive interaction between all actors and beneficiaries of urban redevelopment. Particular attention is given to the issue of re-design of urban open spaces, as an instrument for regeneration of the district also from the social point of view. The phase of competitive tender was preceded by a research on environmental high performance paving characterized by good properties related to solar absorption/reflection and permeability, selecting one of this materials for the redevelopment of public open space. In this work, the microclimate conditions of three urban areas were compared, with similar characteristics of morphological urban shape of buildings’ surround but different paving materials. The experimentation started with microclimate monitoring to evaluate outdoor thermal comfort; interviews on citizens and the calculation of thermal comfort indexes completed the analysis. Some of the thermal comfort indexes used are intended for outdoors spaces, but others were developed starting from indoor indexes. A first investigation on the correlation between outdoor thermal comfort indexes and subjective thermal perception have been conducted. The results of this paper analyse thermal comfort conditions during summertime with different paving materials and compare thermal comfort indexes with the subjects’ response. Some considerations on procedural aspects of an ordinary competitive tender concluded the study.

Keywords: paving materials, outdoor microclimate, outdoor thermal comfort, thermal comfort indexes, thermal sensation.

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1. Introduction

The relationship between microclimate and built environment has been explored since almost forty years, with reference not only to architecture but also to urban and landscape design as instruments for outdoor comfort in public spaces [1-2]. Recently, scientific studies on urban climate point the attention on Urban Heat Island (UHI) and related mitigation strategies as the main focus theme, also developing new sustainable urban design assessment methods [3] and multiscalar approaches [4]. Nowadays, an increase of the inhabitants of the cities is expected, then microclimates control through urban design is studied with more awareness evaluating public health [5]. More attention is given to the "hard" urban surfaces of public spaces, stressing the concept of impervious surface areas as one of the primary driver of the UHI increase [6], in order to characterize them as "cool" surfaces, i.e. instruments to create urban cool-island; this issue could be used to redesign the existing urban open spaces.

2. Geographical contextualization

The European context, due to its variety of climatic conditions, is a "territorial lab" for studying UHI with thermal comfort in outdoor urban open spaces [7] also with regard to the open space design methodologies as instrument for microclimate control in urbanized areas. In the Mediterranean area UHI phenomenon is particularly critic [8] and the hot summer of 2003 has the heat epicenter in the northern part of Italy.

Turin is the fourth most populous Italian town with 899,291 inhabitants and a population density of 6,917 inh/km². Moreover, Turin is the Italian city with more public green with about 21.1 m² of green per capita and about 160,000 trees along the streets and in the parks. The climate is temperate with cold-dry winters and hot-humid summers and, as the majority of urbanized centers, Turin is characterized by the UHI phenomenon with significantly higher temperatures than in the rural and hilly areas around the city. Regarding the outdoor air temperatures, UHI causes an increase of average monthly temperatures of about 2°C in winter and 1°C in summer respect to the '70-'90. Considering the climatic stations inside the town, there are differences of air temperature principally due to the urban contest, the presence of industrial plants and the proximity of the rivers; particularly, the hottest areas of the city were the suburban districts, including the neighborhood "Barriera di Milano". Urban Barriera is an urban regeneration program (2011-2015) designed to trigger a process of improvement of the district where green per capita is 1.64 m^2, lower than the 8% of the average value in Turin.

3. Selection of case studies

Paving materials used for the experiments were selected from next generation environmental high performance pavements products already on the market. In particular, two water-bound path surface has been chosen: Biostrasse and i.idro Drain. Biostrasse and i.idro Drain are two different polymer modified concrete surfaces, consisting of sand, gravel clean, water, pigments, cement and a binder, without oils and bitumen substances. In this work, thermal comfort in three urban areas were compared, with similar characteristics of morphological shape of the buildings' surround, but different characteristics of pavement (Fig. 1): the project area with new paving materials and two public spaces with grass and a mix of grass and concrete paving.

a b c

Fig. 1. (a) Area with **Biostrasse** paving (Bottesini square); (b) **Mix** area with grass and concrete paving; (c) **Green** area with grass.

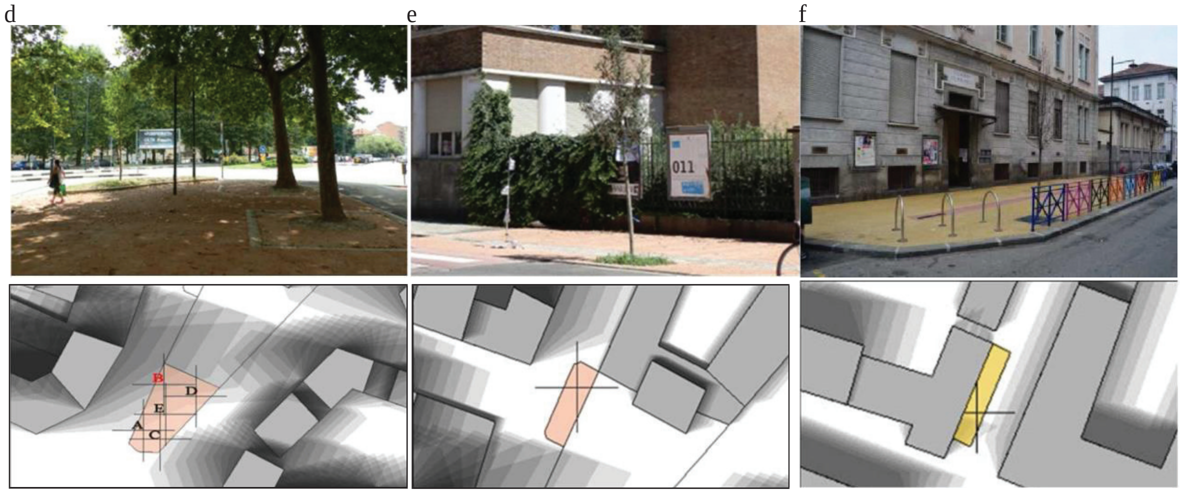


Fig. 2. (d) Area with Biostrasse paving: **Bottesini** square; (e) Area with Biostrasse paving: **Mercadante** street; (f) Area with i.idro Drain paving: **Santhià** street; the represented points have similar sunshine index and indicate the grid of measurements.

As shown in Fig. 1, the selected areas are characterized by the presence of trees and similar urban contest. The determination of a grid of points with similar obstructions and sunshine indexes (Fig. 2d) was conducted with Ecotect 2011®. The selected points have been used for the measurements campaign. Moreover to analyse the thermal behavior of paving materials under direct solar radiation conditions, two other zone were selected. In Fig. 2e the area with Biostrasse paving and in Fig. 2f the area with i.idro Drain paving are reported.

4. Instruments and methods

In recent years interesting studies detect and examine the design elements affecting comfort perception within an urban space [9, 10]. Studies on outdoor thermal comfort are more complex than those on interior spaces. In the outdoor the urban microclimate environment changes continuously, while inside the buildings thermal conditions are more stable. Another fundamental difference is related to the delaying time of people in the indoor or outdoor space, since people spend most of their time indoors. These differences suggest that different indexes should be used to evaluate indoor or outdoor thermal comfort. RUROS [7] showed the strongly correlation between the microclimate conditions and the thermal comfort of the external spaces. To design comfortable urban spaces the variety and variability of microclimates characterizing urban spaces must be taken into account, as they influence the behavior of people, the use of outdoor spaces and the resulting user feedback in terms of thermal comfort.

4.1. Thermal comfort indexes and thermal sensation response

In the evaluation of thermal comfort is important to consider that the microclimate of an environment cannot be assessed only in objective means. With objective data describing climate conditions, subjective aspect must be taken into account as the activity and clothing of people but even their thermal sensation. As the objective physical quantities about the climate could be measured, the subjective feeling about outdoor thermal comfort can outcome from interviews or questionnaires to users. The objective data obtained from measurements and subjective data collected from interviews are then used to calculate the indexes of thermal comfort.

The questionnaires were used to collect subjective information [11] as:

- people characteristics: age, gender, activity, clothing,
- thermal sensations vote (TSV), according to a scale of nine values ranging from -4 (very cold) to +4 (very hot),
- preferences on four microclimatic parameters: air temperature, relative humidity, wind speed, solar irradiation,
- level of acceptability of the thermal conditions: not comfortable, acceptable, comfortable.

There are three types of indexes for thermal comfort [12]:

- direct indices, based on direct measurement of environmental climatic variables;
- empirical indices, based on both objective data on climatic thermal sensation of individuals;
- rational indices, based on the equation of heat balance of the human body.

Most of the indices used to evaluate the outside thermal comfort, (PMV, ET, PT and SET*), are indicators originally developed for indoor use, and subsequently adapted and used for the outdoor environment [2]. In this work, thermal comfort indexes based on stationary models as Predicted Mean Vote PMV, Effective Temperature ET, Outdoor Standard Effective Temperature OUT-SET*, Perceived Temperature PT, Physiological Equivalent Temperature PET, Universal Thermal Climate Index UTCI have been considered. In addition, an index evaluating the thermal stress in warm environments has been compared: Wet Bulbe Globe Temperature WBGT [13].

In order to assess how these indexes of thermal comfort can evaluate thermal sensation expressed by the subjects in outdoor urban spaces, in Table 1 the indexes values are reported with the relative thermal sensation vote [14].

Table 1. Thermal comfort indexes and thermal sensation limits.

Thermal Sensation Vote TSV (-)		**Index** **PMV**(-)	**ET**(°C)	**OUT-SET***(°C) [15]	**PT**(°C) [16]	**PET**(°C) [17]	**UTCI**(°C) [18]	**WBGT**(°C) [13]
Frosty	**-4**	< -3.5			< -39		-27 ÷ -40	
Very cold	**-3**	-2.5 ÷ -3.5	< 1		-39 ÷ -26	< 4	-13 ÷ -27	
Cold	**-2**	-1.5÷ -2.5	1 ÷ 9		-26 ÷ -16	4 ÷ 8	0 ÷ -13	
Cool	**-1**	-0.5 ÷ -1.5	9 ÷ 17	< 17	-13 ÷ 0	8 ÷ 18	9 ÷ 0	
Comfortable	**0**	-0.5 ÷ 0.5	17 ÷ 21	17 ÷ 30	0 ÷ 20	18 ÷ 23	9 ÷ 26	< 18
Warm	**1**	0.5 ÷ 1.5	21 ÷ 23	30 ÷ 34	20 ÷ 26	23÷ 35	26 ÷ 32	18 ÷24
Hot	**2**	1.5 ÷ 2.5	23 ÷ 27	34 ÷ 37	26 ÷ 32	35 ÷ 41	32 ÷ 38	24÷ 28
Very hot	**3**	2.5 ÷ 3.5	> 27	> 37	32 ÷ 38	> 41	38 ÷ 46	28 ÷ 30
Sweltering	**4**	> 3.5			> 38		> 46	> 30

5. Experimental campaign

Currently there is no standard on outdoor thermal comfort field surveys. There are, however, several standards for indoor conditions and guidelines that can support outdoor analyses. Johansson et al. [2] reviewed instruments and methods used to measure outdoor thermal comfort conditions and to assess thermal perception. The standard EN ISO 7726:2001 [19] provides guidance on how to measure thermal comfort, the measurement range, accuracy and response time of the instruments. It also specifies the heights of the sensors, which were fixed in order to evaluate the thermal comfort of seated and standing people. In order to detect the microclimatic parameters useful to calculate the indexes of thermal comfort, two types of measurements have been carried out: continuous (measuring temperatures and relative humidity) and discontinuous (measuring all variables to evaluate thermal comfort indexes) measurements. Measurements have been carried out on three different summer days: 27, 28 and 31 July in 2014 as shown in Table 2 (warmer and no raining days). Data about the instruments used are reported in Table 3.

Table 2. Experimental campaign.

Date 2014	Direct solar irradiation	Period of measure (h)	Time lag (min)
July 27	no	09:00 - 18:00	1'
July 28	no	08:30 - 14:30	1'
July 31	yes	08:45 - 17:00	1'

Table 3. Characteristics about the instruments used.

	Probe	Data logger	Physical quantities	Range	Accuracy
Continuous measurements	T-RH probe	Testostor 171 Testo 175 -H2	Air temperature Relative Humidity	-20°C ÷ 70°C 0 ÷ 100%	±0.5°C ±3%
Discontinuous measurements (Babuc LSI-LASTEM)	Surface temperature	Testo 175 – T3	Paving temperature	-50 °C ÷ +400 °C	±0,5 °C
	Globe thermometer	Black d = 10 cm	Globe temperature	-40 ÷ +80 °C	±0,15°C
	Psychometric probe	2xPt100 DIN Pt100 1/3 DIN	Air temperature Relative Humidity	-5 ÷ 60 °C 0 ÷ 100%	±0,10°C ±2%
	Speed probe	Hot wire	Air speed	0÷45 m/s	±0,5 m/s

6. Results and discussion

Thanks to several recent studies on outdoor thermal comfort, there is a significant database suggesting that thermal comfort indexes should be adaptable to different climates and contexts [7, 20]. In this work, the average thermal sensation vote TSV has been correlated with the selected thermal comfort indexes grouping them in intervals of constant amplitude to consider an average value. In Table 4 the linear correlations between TSV and the thermal comfort indexes are represented. The indexes having the best correlation with the thermal sensation vote are: PT, UTCI, PMV and PET.

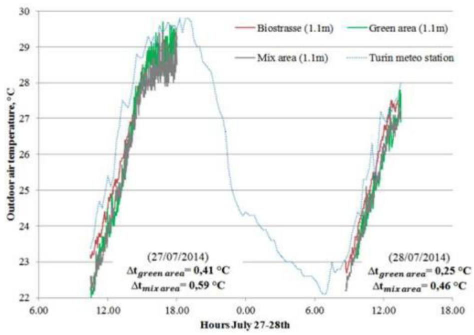
Table 4. Correlation of thermal sensation (resulting from 85 interviews) as function of thermal comfort indexes.

Index	Data					Linear correlation		
	n. values	Min value	Max value	Intervals	Int. Amplitude	Slope	Constant	R^2
PMV	84	-2.1	6.9	9	1.00	0.467	0.000	0.81
PT	70	15.6	59.5	8	5.48	0.101	-2.377	0.93
ET	84	22.3	27.1	7	0.68	0.752	-17. 595	0.65
OUT-SET*	84	24.6	59.4	10	3.47	0.102	-2.168	0.29
PET	84	18	52.8	9	3.86	0.125	-2.690	0.81
NET	84	19.2	26.7	9	0.84	0.494	-10.689	0.70
UTCI	84	20.6	40.1	9	2.16	0.229	- 5.697	0.91
WBGT	84	21.7	35.8	8	1.76	0.313	-6.457	0.39

In Table 5 the results of temperature measurements at height of 0.1, 0.6 and 1.1 m on the pavement are represented for the three selected areas: Biostrasse area, mix area with grass and concrete paving and green area with only grass. As it is possible to note, with Biostrasse paving material the temperature is always higher than in the green and mix areas, with higher differences in the mix area and for low heights. Considering standing people, at the height of 1.1 m, the differences are just of 0.3-0.6°C in areas with trees and without solar irradiation (Fig. 3a).

Table 5. Temperature gradient of Biostrasse area respect to green and mix areas.

Height from pavement	Δt_m 27/07 (°C)		Δt_m 28/07 (°C)		Δt_m 27-28/07 (°C)	
(m)	green area	mix area	green area	mix area	green area	mix area
0.1	-	2.78	-	1.79	-	2.28
0.6	0.63	0.80	0.52	1.03	0.58	0.92
1.1	0.41	0.59	0.25	0.46	0.33	0.53

a 

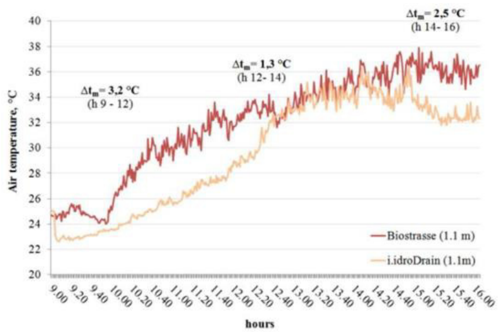
b 

Fig. 3 Air temperatures comparison at 1.1 m. (a) without solar irradiation; (b) with solar irradiation.

Using data obtained from continuous and discontinuous measurements carried out July 31st with incident solar irradiation, it was possible to make a comparison between air and surface temperatures of the two areas characterized by new paving materials: Biostrasse and i.idro Drain. The pavement with Biostrasse had a temperature always greater than that with i.idro Drain: ΔT>2.7 °C at 0.6 m and ΔT>1.3 °C at 1.1 m (Fig. 3b). Moreover, Biostrasse and i.idro Drain were also compared with typical pavements in concrete and asphalt; Biostrasse is characterized by a surface temperature less than about 5 °C if compared with asphalt and concrete.

Finally, the thermal indexes PT, UTCI, and PMV are compared for the three areas in Fig.1 considering an height of 1.1 m and varying air temperature from 20 to 41 °C. For the "mix" area and the "green" area, values are very similar and thermal comfort is reached in 38% of the data; with Biostrasse pavement thermal comfort is satisfied only for the 25% of data. Green is always the best solution, but very expensive to maintenance; the research should evaluate other alternative materials.

7. Conclusion

The aim of this study was to analyse the thermal comfort of urban spaces evaluating the performance of two new paving materials: Biostrasse and i-idro Drain. The new materials reach higher temperatures respect to the grass but much lower temperatures if compared with concrete and asphalt (materials requiring the same level of maintenance).

Respect to the thermal comfort of confined spaces, the indicators used for outdoor thermal conditions are still subject of study and experimentation. In this work, PT, UTCI, PMV and PET seem to have better results in term of thermal sensation during the warm season.

The experimentation has highlighted elements for future insights in relation to general aspects. The use of new paving materials, more expensive than typical ones, requires the introduction of specific procedures of contract. Then, the acceptance of the formal results of new pavements from the inhabitants is not obvious: the renovation should be associated by a process of accompaniment, also for highlighting to inhabitants aspects of performance.

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