SOFTENING THE HABITATS
SUSTAINABLE INNOVATION IN MINIMAL MASS STRUCTURES AND LIGHTWEIGHT ARCHITECTURES

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# A lightweight textile device for urban microclimate control and thermal comfort improvement: concept project and design parameters.

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## Abstract

The proposed contribution presents the design process of a lightweight device for the mitigation of the microclimate in summer conditions in the public spaces of residential urban areas. In particular, the project is part of a wider and ongoing process of regeneration in the west urban periphery of Milan, Italy: throughout its implementation, several public areas with considerable social fragility and environmental outdoor discomfort are emerging. These areas are being studied for monitoring of the microclimatic and comfort conditions, in order to evaluate the installation potential of a lightweight device for mitigating thermal discomfort. Due to the specific context, the innovative aspect of the technological design and construction process of a lightweight structure is to respond to the twofold requirement of seasonal use of the device, namely its transportability and deployability, and of its applicability in public areas in terms of security, usability and comfort performances of the materials.

**Keywords**: shading systems, lightweight materials, thermal outdoor discomfort, microclimatic mitigation, deployability, portability.

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## 1. Introduction

The proposed contribution operates in the framework of environmental and technological mitigation strategies in the urban outdoor spaces which are characterized by a significant thermal discomfort.

Since the 80s, environmental research has studied the impact of the urban heat island by analyzing how urban morphology (Stewart et al., 2012), urban materials and microclimate conditions (Chatzidimitriou & Yannas, 2015; Chatzidimitriou & Yannas, 2016; Nikolopoulou & Lykoudis, 2006) influence the thermal comfort of users; on the other hand, environmental architecture (among others: Minati, 2004) analyses the link between built environment and users' behaviors. Environmental comfort is indeed essential to determine the use of spaces and thus it should be given as a design parameter in urban planning. The design approach to urban outdoor spaces can be addressed through performance analysis, which is used typically for the technological design; its extension to the design of urban spaces is recent and not yet consolidated (Dessì, 2007).

There is also room for further investigations in the matter of lightweight structures for mitigating outdoor discomfort in urban spaces. According to the state of the art, lightweight structures, combined with efficient materials under tension, are more frequently applied for covering wide span enclosures (Majowiecki, 1996). Nevertheless, in urban outdoor spaces, lightweight technologies and textiles are used mostly for their shading properties, while there is a lack of investigation on ephemerality and time-based technology as a design principle for microclimate mitigation in urban context. In this sense, there is a poor exploration of thermal micro-mitigation relying on the advantages of lightweight structures: namely minimal mass and thus transportability; adaptability in terms of modularity; retractability; structural efficiency; flexibility.

For the purpose of this project, lightweight temporariness is explored in terms of seasonal usability and transportability. In this contribution, a special emphasis is put on high–tech materials and their performances in relation to environmental comfort and, consequently, on the structural behaviors of tensioned fabric in combination of slender substructures.

### 1.1. The design context

The project is developed under the broader analytical work of the funded research entitled: *"West Road Project, a device for activating networks and public spaces through the diffused neglected areas"* that operates in the west urban periphery of the City of Milan, Italy. The main goal of this research-by-design programme is to provide the Municipality with an agile urban masterplan that highlights the crossovers between local resources, in terms of social and economic behavior, and governance resources, in terms of the definition of interests and design guidelines, in public and collective spaces of urban areas. Research shows, on one hand, that marginal areas are characterized by spatial deterioration, scarce mobility and high concentration of fragile populations. On the other hand, that experimental experiences around the common goods worldwide have been spreading out by local initiatives (Orsenigo, 2018).

## 2. Thermal mitigation strategies for summer outdoor comfort

In environmental studies (Chatzidimitriou et al. 2015; 2016; Gaitani et al., 2011; Nikolopoulou et al., 2006), several mitigation techniques have been analyzed to counterbalance the impacts of outdoor thermal discomfort. Along with cool materials and greenery, the use of solar control as well as the dissipation of the excess heat in low/high temperature heat sinks like the ground, the water and the ambient air, are also included. A summary of referenced main passive strategies and key technologies to reduce and/or mitigate the outdoor microclimate is shown in Table 1. Green roofs are not included because not significant in terms of pedestrian comfort (Chatzidimitriou et al., 2016).

| **Environmental strategies** | **Thermal processes** | **Design parameters** |
|---|---|---|
| Greening | Evapotranspiration<br>Regulation of the air movement<br>Solar radiation absorption | Soil humidity<br>Tree cover<br>Grass cover |
| Solar shading | Solar irradiance reduction<br>Surface temperatures decrease | Shading canopies |
| Water cooling (spraying/water lines) | Evaporation<br>Solar radiation absorption | Water cover<br>Water injection rate<br>Water collection [1] |
| Cool pavement | Solar reflection increase at the ground level<br>Surface temperature decrease<br>Temperature peaks mitigation | Pavements albedo<br>Pavements emissivity<br>Pavements thermal capacity |
| Green façades | Evapotranspiration<br>Solar radiation interception<br>Thermal insulation increase | Vegetation (low-medium size)<br>Grass cover |
| Night-time heat dissipation | Evapotranspiration<br>Radiative heat exchange increase | Tree cover<br>Grass cover<br>Roads Aspect Ratio (H/W ratio)<br>Sky view factor (SVF) |

Table 1: Main passive strategies and key technologies to reduce and/or mitigate outdoor air temperature. Elaboration by the authors.

Among them, the options that have been explored for the purposes of the project are: i) greening; ii) solar shading and iii) water cooling. In fact, the device aims to be deployed in different outdoor spaces that the masterplan would select as potential liveable spaces with an existing

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[1] No significant applications in urban areas of fog and drew harvesting (Morichi, 2017).

outdoor thermal discomfort. In the Mediterranean climate, liveable open public spaces offer environmental comfort conditions, especially the thermal one, that change according to seasonal and daily variations and to the activities taking place there. For this study, the Thermal Budget (TB) indicator used in the COMFA model (Brown and Gillespie, 1986) and in the extended COMFA+ model (Angelotti, Dessì & Scudo, 2007) has been adopted to measure outdoor comfort conditions. In the COMFA model the human being thermal balance is calculated by taking into account the various sensible and latent heat exchanges between the person and the surrounding environment.

The energy balance equation is:

$$TB = M + K_{abs} + L_{abs} - (Conv + Evap + TR_{emitted}) \qquad (1)$$

where:

- M is the net metabolic rate;
- $K_{abs}$ is the solar radiation absorbed;
- $L_{abs}$ is the thermal radiation absorbed;
- Conv is the heat lost by convection;
- Evap is the heat lost by evaporation;
- $TR_{emitted}$ is the emitted thermal radiation.

Therefore, a positive value of TB implies a thermal gain for the person; vice versa, a negative value indicates a net thermal dispersion. A net value around zero of TB indicates thermal neutrality and consequently thermal comfort. A comfort sensation is then assigned to the value of the Thermal Budget (TB) as shown in Table 2.

| **Thermal Budget TB (W/m$^2$)** | **Thermal sensations** |
|---|---|
| < - 150 | Very cold |
| - 150 ÷ - 50 | Cold |
| - 50 ÷ 50 | Comfort |
| 50 ÷ 150 | Hot |
| > 150 | Very hot |

Table 2: Comfort sensations and corresponding Thermal Budget ranges.

The original COMFA model was mainly intended for rural open spaces. In urban contexts, buildings are likely to interfere with the TB as they intercept, absorb and reflect solar radiation, they obstruct the sky view and they emit thermal radiation. The COMFA+ takes into account all these contributions to the thermal budget, allowing thus to evaluate comfort conditions also in open urban spaces.

## 3. Experimental Results

### 3.1. Microclimatic measurements

The TB data collection has been conducted on the 24th, September 2018 in the city of Milan and it was performed from 12 am to 5 pm in two urban sites: Cascina Case Nuove (CA) and via Zamagna (ZA). The two urban sites (Fig. 1) were selected due to their relevance stemming from the activities and insights achieved so far from the ongoing WRP project (see subsect. 1.1.) which has conducted a qualitative study preliminary to the measurements that suggested a thermal discomfort in the two areas.

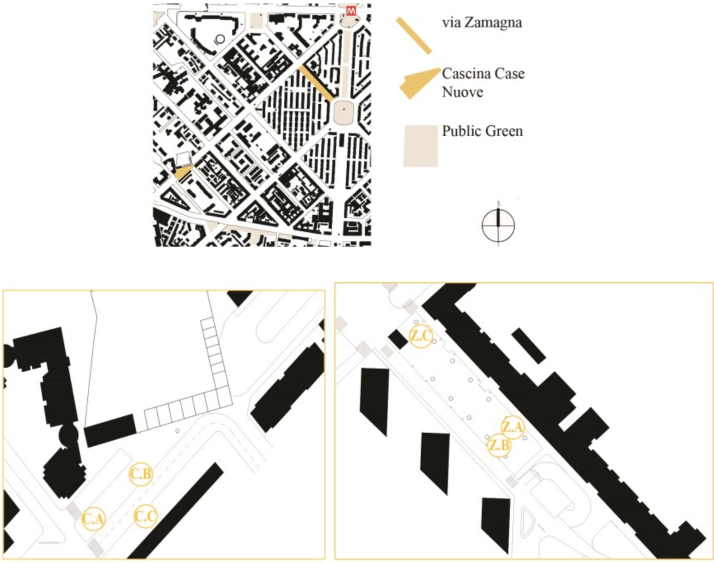

Figure 1: The monitored urban sites in Milan, Italy (latitude N45°):
on the left, Cascina Case Nuove (CA) and, on the right, via Zamagna (ZA).

The first site is Cascina Case Nuove (CA), namely it is a residual space in front of a semi-abandoned ancient farmhouse, now embodied in the urban perimeter. The urban environment is characterized by high-density residential buildings and the proximity of a high traffic density road; surfaces are made essentially by asphalt and vertical materials with a medium level of albedo. There are no urban canopies and trees, while an unofficial car parking occupies the grass area next to the minor road (Fig. 2). The second site is via Zamagna (ZA), a narrow rectangular square with a high H/W aspect ratio, a poor presence of vegetation, a large variety of surface materials, such as concrete tiles and asphalt, and vertical materials with medium levels of albedo (Fig. 2). Most of the square is accessible only to pedestrians.

Measurements were carried out through a mobile data logger equipped with a thermo-hygrometer, an anemometer, a globe-thermometer and a radiometer (Fig. 2). Measured quantities are then air temperature, relative humidity, wind speed, mean radiant temperature and global horizontal solar irradiance. Microclimatic variables were mapped in three different points for each site, one of them being always in shadow and providing thus a reference condition (Fig. 2). In each point, measurements were taken for about 20 minutes.

Figure 2: Above: the measurement equipment in Cascina Case Nuove.
Below: the measurement equipment in via Zamagna.

### 3.2. Experimental results

The experimental results are summarized in Table 3. For each quantity, the average of the collected data in the last 5 minutes, out of the 20 minutes long measurement period, is reported. Thermal Budgets calculated through COMFA+ are shown in Table 4, where the cases of a standing person (metabolic rate 90 W/m$^2$) and a walking person (at 4 km/h, corresponding to a metabolic rate of 190 W/m$^2$) are considered. The corresponding thermal sensations, according to the scale in Table 2, are also shown.

| **Site** | **Measurement Point** | **Start Time** | **End Time** | **Wind speed [m/s]** | **Air temp. [°C]** | **Rel. hum. [%]** | **Glob. hor. solar irrad. [W/m$^2$]** | **Globe temp. [°C]** |
|---|---|---|---|---|---|---|---|---|
| **CA** | C.A1 | 11:58 | 12:21 | 2,59 | 27,1 | 15 | 694 | 33 |
| | C.B1 | 12:30 | 12:52 | 1,17 | 28,2 | 15 | 743 | 36 |
| | C.C1 | 12:53 | 13:13 | 0,96 | 27,7 | 15 | 37 | 28 |
| **ZA** | Z.A1 | 13:33 | 13:53 | 1,50 | 28,6 | 15 | 750 | 38 |
| | Z.B1 | 13:53 | 14:13 | 1,08 | 27,7 | 16 | 51 | 28 |
| | Z.C1 | 14:14 | 14:35 | 1,62 | 28,6 | 15 | 728 | 37 |
| **CA** | C.A2 | 15:24 | 15:46 | 1,62 | 28,8 | 16 | 557 | 36 |
| | C.B2 | 15:48 | 16:09 | 1,53 | 28,9 | 16 | 466 | 35 |
| | C.C2 | 16:10 | 16:28 | 0,95 | 28,1 | 16 | 61 | 29 |
| **ZA** | Z.A2 | 16:43 | 16:59 | 1,48 | 28,0 | 16 | 82 | 29 |
| | Z.C2 | 17:01 | 17:21 | 1,04 | 27,9 | 36 | 331 | 35 |

Table 3: Environmental measurements on site. The input points for the measurements are named: C.A, C.B. and C.C for Cascina Case Nuove; Z.A., Z.B. and Z.C. for via Zamagna.

| | M [W/m$^2$] | **C.A 1** | **C.B 1** | **C.C 1** | **Z.A 1** | **Z.B 1** | **Z.C 1** | **C.A 2** | **C.B 2** | **C.C 2** | **Z.A 2** | **Z.C 2** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TB [W/m$^2$]** | 90 | 159 | 181 | -21 | 226 | -6 | 217 | 177 | 160 | -4 | -2 | 139 |
| | 180 | 195 | 220 | 19 | 265 | 34 | 256 | 216 | 199 | 36 | 36 | 179 |
| **Therm. sensat.** | | Very hot | Very hot | Comfort | Very hot | Comfort | Very hot | Very hot | Very hot | Comfort | Comfort | Hot/ Very hot |

Table 4: Thermal Budget (TB) calculated with a typical summer clothing thermal resistance: Rco = 0,042 m2K/W, for metabolic rate equal to 90 W/m2 and 180 W/m2.

It can be noticed that the thermal sensation in every point at a given time is generally the same for both metabolism levels considered. Experimental results show a significant outdoor thermal discomfort both in Cascina Case Nuove and in via Zamagna. Moreover, in both the sites thermal neutrality – and thus thermal comfort - is easily reached by providing solar shading (points: C.C, Z.B).

# 4. An integrated design concept for a lightweight textile device

## 4.1. Urban design typologies to mitigate outdoor microclimate

Environmental comfort has significant effects on the use of spaces and consequently it should be used as a design parameter in urban planning. Dealing with environmental comfort can be pursued through performance analysis which is used typically for technological design and that involves users' needs and environmental requirements in the definition of technological parameters. In literature, bioclimatic strategies for urban outdoor mitigation fall into two main architectural typologies: vertical elements (walling systems) and horizontal ones. The horizontal architectural components of the urban system that affect outdoor microclimate mitigation are roof structures (covering systems) and ground height differences. Covering systems normally reduce surface temperature on the ground by shading solar radiation. The best option in terms of roofing is a material with a high solar reflection, meaning a reduction of solar radiation that is transmitted and, at the same time, a low absorption of radiation and thus, a relatively low roof temperature. For thermal performances, opaque roofs with a high coefficient of solar absorption can be improved through the use of light materials, e.g. textiles and polymers, either by water irrigation of the outer side of the layer or by using double layers. Green roofs are typically a good solution if suitably designed to prevent the effects of the high coefficient of solar absorption of the vegetation. Membranes and textiles are particularly fitting the dual requirement, namely low solar absorption coefficients and low solar radiation transmission (see Table 5).

| **Materials** | **Solar absorption coefficient [%]** | **Solar transmissivity coefficient [%]** | **Solar radiation reflection [%]** |
|---|---|---|---|
| Vegetation and grass | 80-100 | 0-20 | 0 |
| Textile: light color | 10-20 | 25 | 55-65 |
| Rigid polymer | 10-15 | 13 | 72-77 |
| Textile: opaque material | 20-70 | 0 | 30-80 |
| Membrane | 19-11 | 4-17 | 72-77 |

Table 5: Solar radiation coefficients according to the different shading systems (Dessì, 2007).

While the use of membranes and textile materials in solar shading is widely common, the potential of lightweight structures is less exploited. Given the condition of the context of the site, indeed, several typical advantages of lightweight technologies could be beneficial, such as modularity, retractability, flexibility and transportability.

### 4.2. An integrated design concept of a lightweight textile device

Due to the specific context, the innovative aspect of the lightweight device is to explore seasonal operability and transportability in order to deploy it in different outdoor spaces that the masterplan would highlight. In the following diagram (Tab. 6) a preliminary analysis of the structural system of the device is investigated. Four main spatial configurations are introduced, according to the different structural behaviors of the components of the structure, and they are: i) open configuration: the device can be hanged to existing elements, i.e. surrounding buildings; ii) closed; iii) fix: the device is a self-standing lightweight structure, i.e. umbrellas, and vi) retractable configuration (a structural typology within the broader classification of mobile and rapidly assembled structures) if the device could be deployable thanks to the design of the structure and with a seasonal use. The greening and the water cooling are environmental strategies that can be explored either by using open and fixed covering systems, i.e. closed envelopes, or open and fix walling systems. As already mentioned, the green roofs are efficient but they need design strategies in order to induce the exchange of air in the area below. Shading canopy is the only design parameter to mitigate environmental discomfort that is supported by retractable structural covering systems.

| **Design Parameters (see tab. 1)** | **Technical requirem. (see tab. 5)** | **Building components** | **Structural systems** |
|---|---|---|---|
| Soil humidity | Solar absorption<br>Breathability | Green Roof<br>Green Façades<br>Mesh support layer | Open<br>Closed<br>Fix |
| Tree covering | Solar absorption<br>Breathability | Green Roof<br>Mesh support layer | Open<br>Fix |
| Grass covering | Solar absorption<br>Breathability | Green Roof<br>Green Façades | Open<br>Closed<br>Fix |
| Solar Shading | Solar reflection<br>Solar absorption<br>Breathability | Single membrane<br>Selective Roof<br>Green Roof<br>Green Façades | Open<br>Closed<br>Fix<br>Retractable |
| Water covering | Solar reflection<br>Solar absorption | - | - |
| Water collection | Solar absorption | Single membrane<br>Green Roof<br>Green Façades<br>Mesh support layer | Open<br>Closed<br>Fix |
| Cool pavement | Solar reflection<br>Solar absorption | Modular pavement | Open<br>Fix |

Table 6: Comparison of design parameters and preliminary structural systems.

In common construction practice, the main lightweight roofing to mitigate urban outdoor thermal discomfort are: i) single layer, ii) double layers, iii) multiple layers, iv) green roof and v) selective roof. The latter is particularly relevant because it combines the “dark tent” effect with high efficiency materials. The dark tent is the opposite of the greenhouse principle: the outer layer is highly reflective to the solar radiation while the inner one is permeable to infrared radiation supporting thus the heat exchange between the covered area and the area above. The best possibility to achieve good values of all the three environmental strategies coincides with the integrated design of a lightweight device in which the peculiar characteristics of high-tech materials can join the intrinsic properties of temperature decreasing of greening and water cooling design parameters.

## 5. Conclusion and further developments

In conclusion, the device has to perform as a temporary and transportable architecture, which can be implemented over time according to the context constraints in high density residential areas, and which assures a high efficiency cooling and solar shading performance through the use of textiles and greening. The methodology to define the technological criteria and the requirements of the thermal behavior of the device involved different levels of knowledge: 1) a field data analysis to measure real thermal outdoor discomfort in summer conditions and a field data report of the under-usage of specific spaces because of the thermal discomfort. 2) A state of the art in the matter of environmental strategies for mitigating which led to the definition of thermal performances of the device. 3) A state of the art concerning urban design parameters and architectural strategies that positively impact microclimate, which resulted in a set of best options in terms of technological performances of materials and a preliminary definition of structural sub-systems in the overall form by means of their general movement.

The presented study is to be seen as a conceptual method investigation, in which more detailed functions are to be integrated. Further and more detailed investigations are to be made upon the architectural proposal and the form finding-process of the membrane. Prototyping and model installation is going to be finalized within May, 2019.

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