6th International Conference on Countermeasures to Urban Heat Islands

4 - 7 December 2023
Melbourne, Australia

Holistic approaches to address urban heat islands

CONFERENCE PROCEEDINGS

UHI2023
6th International Conference on
Countermeasures to Urban Heat Islands
4 - 7 December 2023 | Melbourne, Australia

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Foreword

The International Conference on Countermeasures to Urban Heat Islands (IC2UHI) is a series of conferences held every three years. The first conference was held in 2006 in Tokyo (Japan) and since then it has been hosted at various locations, in Berkeley (USA), Venice (Italy), Singapore (Singapore), and Hyderabad (India). Besides providing a platform for researchers and academics to share their latest research in UHI and its mitigations, this conference also aims to be a platform for policy makers and practitioners to share their efforts in mitigating the UHI effects in the cities.

The main conference theme for the 6th International Conference on Countermeasures to Urban Heat Islands is “Holistic approaches to address Urban Heat Islands”. The diverse range of sub themes in this conference will broaden the scope and knowledge on new approaches, findings and evidence around countermeasures to urban heat islands.

The Conference Proceedings are grouped into ten sections:

- Anthropogenic heat and urban pollution, social and economic dimensions - UHI, economy, health and well-being
- Cool material roof pavements and advanced material developments
- Cooling effect of natural resources (vegetation, lakes, rivers, ground)
- Machine learning and remote sensing of cities and urban climates
- Modelling and forecasting urban climate and weather
- Program development, policy and evaluation of UHI mitigation and adaptation
- Relationship between UHI and urban and city planning
- Resilient design of buildings in response to climate change
- Simulation and analysis of UHI and its effects across scale
- UHI and building performance-energy consumption and indoor comfort

Contributions to the above groupings of research-areas have been sought to cover relevant content relating to UHI from disciplines of energy, health, building, urban design, air quality and human studies. Scientists, academics, engineers, builders, architects, policy makers and government officials were invited to participate in 6th IC2UHI Conference to share their knowledge about activities that have been or will be undertaken to address urban heat islands.

This publication covers 115 accepted papers presented at the Conference, hosted by the School of Property, Construction and Project Management, RMIT University, Melbourne, Australia, 4 - 7 December 2023. Each paper in these proceedings has undergone a rigorous peer review process. Following the call for abstracts in July 2022, a total of 174 abstracts were submitted for review. Each abstract was blind peer reviewed by two members of our International Scientific Committee, made up of 72 experts. Of these, 167 abstracts were accepted for development into full papers. Following this, 134 full papers were submitted, each of which was again blind peer reviewed by two to three members of our International Scientific Committee. Based on the reviewers’ recommendations, 115 papers were accepted for presentation at the conference, which are all included in this publication.

Although the editors of these proceedings have made every effort to ensure that the work presented here is correct and absent of errors, the contents and opinions of the papers are the sole responsibility of the authors. The editors' role was to structure these proceedings into a meaningful and informative sequence.

On behalf of the Organising Committee, we would like to sincerely thank all the people who have contributed to realising this Conference. Thank you to all the authors for their interest and contribution to the success and the quality of papers and discussions of the Conference and its Proceedings. We are also very grateful to the members of the International Scientific Committee for their rigorous reviews, without which we would not have been able to maintain and improve the quality of the papers.

We would like to thank our Sponsors: Cool Roof Rating Council and Sustainable Building Innovation Laboratory (SBi Lab) at RMIT University. We thank those who have worked behind the scenes from the School of Property, Construction and Project Management (PCPM) at RMIT University.

Priyadarsini Rajagopalan

Melbourne 2023

Details of the Conference are currently at https://www.ic2uhi2023.com/, and papers in these proceedings are archived at the IC2UHI website: https://www.ic2uhi2023.com/

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An Urban Plug-in Evaporative Cooling Systems to Improve Urban Microclimatic Conditions in Rome

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ABSTRACT

The research project is about design solutions for the integration of evaporative cooling systems in urban public spaces for the mitigation of the urban heat island effect and the improvement of microclimatic conditions. The study focuses on the definition of an architectural prototype, on the integrability of technological devices - greenery, evaporative ceramic systems, shading devices and nebulization appliances - and on the development of multi-criteria matrixes and simulation procedures for the comparison of different scenarios in terms of microclimatic conditions, energy and water consumption and functional spatial needs. Besides the design aspects, the prototype's construction and installation was tested assuming a specific location within the city centre of Rome, Italy. From a methodological point of view, the research involved five phases: identification of design objectives and design strategies; definition of the meta-design concept of the design prototype; prototype development and fine-tuning of the different technological components; implementation of the prototype on pilot site; prototype assessment through the software simulations of the water and energy consumption of different configuration scenarios and microclimatic simulations. The simulations return a decrease of up to about 2°C in temperature and of about 1°C in UTCI, considering only the misting system, with a further decrease respectively by 2,7°C and 1,5°C, when nature based solution are added. Yet, the overall microclimate improvement occurs only at a punctual scale, involving mainly the exact area where the structure is placed.

Keywords: evaporative cooling, public space, urban heat island, design prototype.

Introduction

As urban microclimate conditions are significantly affected by local and climate change, they are expected to worsen in the coming years because of the synergistic effect of rising temperatures and the urbanisation rate. One of the major issues contributing to uncomfortable microclimate conditions, especially in Mediterranean historic city centers, is the Urban Heat Island (UHI) effect. For this reason, relevant research focuses on a combination of mitigation and adaptation strategies to improve the overall urban microclimate and thus increase the livability of public spaces (Santos Nouri 2018). Existing UHI mitigation strategies comprise cool materials, urban greenery, use of water, and shading to reduce temperatures and boost cities' adaptive capacity to climate change (Santamouris et al. 2019). The effectiveness of each UHI mitigation technique varies depending on location, urban

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context (density, scale), and climate zone (Osmond and Sharifi 2017). Inner city areas are generally associated with high density urban areas and a low-sky view factor. As a result, the inner city urban fabric is unable to provide acceptable microclimatic conditions for public spaces, which are thus underused by citizens. Since the quality of urban public spaces is determined, to a large extent, by its microclimatic conditions, the UHI effect reveals to be more than just an environmental issue, as it brings about social implications concerning the use of public space (Battisti 2022). Evaporative cooling strategies are highly effective within the urban environment since they can be easily implemented through passive and active systems based on the physical process of using water phase changes to remove heat from the atmosphere (Santamouris 2012, Gill et al. 2007). Surface water can use ambient heat for evaporation, cooling the air temperature. Passive direct evaporative cooling can be fostered by using natural wind flow, use of running water or water bodies. Active evaporative cooling includes evaporative sprays and nebulization systems that deliver a cool mist of very fine water droplets which absorb ambient heat from the environment (Ulpiani 2019). Acting on microclimate conditions activates public space, increasing its accessibility, livability, and daily use (Battisti et al. 2020). We asked ourselves whether it was possible to flexibly shade and cool inner city public spaces, while also providing a focal point for public interaction. Both in research and in the practice field, punctual and small scale implementation of cooling evaporative systems has been studied. Cold Spot is a project created by Harvard Graduate School of Design to regulate heat gain through the use of ceramics. A system of stackable terracotta bricks cools the surrounding air while providing a unique public space. For EXPO 2015, an transdisciplinary group supported by the Institute of Architecture and Landscape of Graz University of Technology and Transsolar Studio came up with the “Breathe. Austria” Pavilion, in which fog and fine water jets provide a unique microclimate within a forest of more than 190 different species. In this direction, the present study intends to develop a prototype of a temporary and movable plug-in urban cooling nearly-zero-energy structure. The research focuses on the design of an open modular structure that incorporates an evaporative cooling system, and other passive technologies (shading and greening) capable of ensuring optimal wellbeing conditions (psychophysical and thermal) even in the most extreme microclimatic conditions. With the term plug-in we refer to a structure that can be added to a system (urban public outdoor space) to provide extra functions, features and conditions.

Methodology

The plug-in structure is conceived as a temporary semi-open public space that can host different functions according to where it is placed in the city, allowing the use of public outdoor space also during summer overheating. The prototype is designed in line with objectives of flexibility, fast installation, cost-effectiveness, reversibility, replicability, sustainability and self-sufficiency in terms of energy and water. Since users' needs may vary over time, in different socio-cultural contexts, and according to site-specific microclimate, the aim of the study is to develop a toolbox of multiple feasible configurations that differ in terms of space, morphology, size, microclimate, function, operating and initial costs, laying the foundation for participatory design. The research approach is based on (Battisti 2018) methods applied in prior studies on similar topics. A first research phase focused on the identification of objectives and strategies for the definition of the meta-design concept of the urban plug-in structure, through the development of a space-functional matrix aimed at identifying and comparing different potential solutions generated from the basic model. This phase involved the creation of energy and water consumption matrixes that can be applied to every morphological-functional configuration (size, functions, quantity and type of devices and technologies installed). The prototype was defined using BIM (Building Information Modeling) software to better control and manage the model in all its aspects and parameters.

The use of BIM allows for the real-time evaluation of different morphological solutions also in terms of technical-economic, and management aspects. A wide range of plug-and-play devices and technologies that can be added to the structure were also identified and conceived as a toolbox from which the client can select the components that best meet his needs.

The prototype was applied on a pilot site in the context of an urban public space in the historic center of Rome. On-site analyses were carried out at different scales and from multiple perspectives. Climate data are collected for the period from January 1, 2014 to December 31, 2017 acquired from a climate station located about 350 m from the pilot site. A last assessment phase involved the evaluation of the prototype under two main aspects: The first one concerns the use of software ENVI-Met for estimating microclimatic parameters based on the data gathered in the previous phase. Different scenarios are defined to compare the variation of parameters like temperature, relative humidity, wind speed and thermal comfort indexes. The second one involves the computation of energy and water consumption using the matrix developed in phase 1. For the purpose of the analyses, 8 configurations (differing in number and type of integrated vertical closure panels) were defined.

The Plug-in Design

The urban plug-in is a prefabricated modular structure made up of elements that can be easily assembled/disassembled and that allows for the integration of different environmental-technological devices (Figure 1) according to the user's needs. The structural grid is based on multiples of a square of 2,50 x 2,50m (basic configuration). The juxtaposition of two or more basic configurations along their short side generates different solutions, which are summarized in the spatial-functional matrix. Different spatial layouts can be associated with different functions (educational, cultural, recreational use, etc.). In particular, the study focused on the 75 m² configuration made up of two basic modules, as it is the most suitable for easy insertion in medium-sized squares and public areas, which are more common within historic centers. In terms of construction, drywall systems with bolts and mechanical anchors were used to enable rapid integral disassembly. The structure is secured to the ground through telescopic devices capable of adapting to the site's uneven surface. The walking floor height is slightly raised above ground level to create a cavity at the base of the structure to host the plant system equipment: photovoltaic (PV), misting and lighting system equipment, and water collection tanks. The misting system consists of a grid of metal profiles with a pitch of 1,25 x 1,25 m positioned at a height of 3 m above the walking level. The hollow profiles host the misting nozzles as well as the water supply and distribution circuit. Along the perimeter of the structure, placement arrangements allow the application of modular facade components.

Plug-in Devices

The rainwater storage system is entirely contained within the hollow volume at the structure's base. The capturing surface (71 m²), is positioned at the base of the structure under the walking surface metal grid and above the plant system devices and water tanks. It consists of two metal plates anchored to the structure and slightly inclined towards the central axis where the collection channel is located. The polyethylene water tanks are arranged one beside the other through connectors that allow them to be filled in sequence. Each tank can store up to 187 l of water for a total of about 12.000 l (considering 62 tanks). Anti-limescale filtering devices and the anti-legionella system are used in order to avoid clogging of the nozzles and to sanitize the water for the misting system. The misting system devices (controller, circulation pump) are in a customized safety box at the structure's base. The controller allows to monitor and modify the performance of the misting system and to filter the water that is supplied into the circuit. The misting nozzles are spaced 1,25 m apart at 3 m height and have an output of roughly 4,8 l/h each. The rooftop is equipped with a PV system. To ensure optimal performance, the panels are supplied with an anchoring device that allows their tilt angle to be adjusted according to the latitude of the site (in this case 20° S-E). The configuration under study hosts 4 monocrystalline PV panels oriented towards S/SE of 400 Wp each, with a total output of 1,6 kWp.

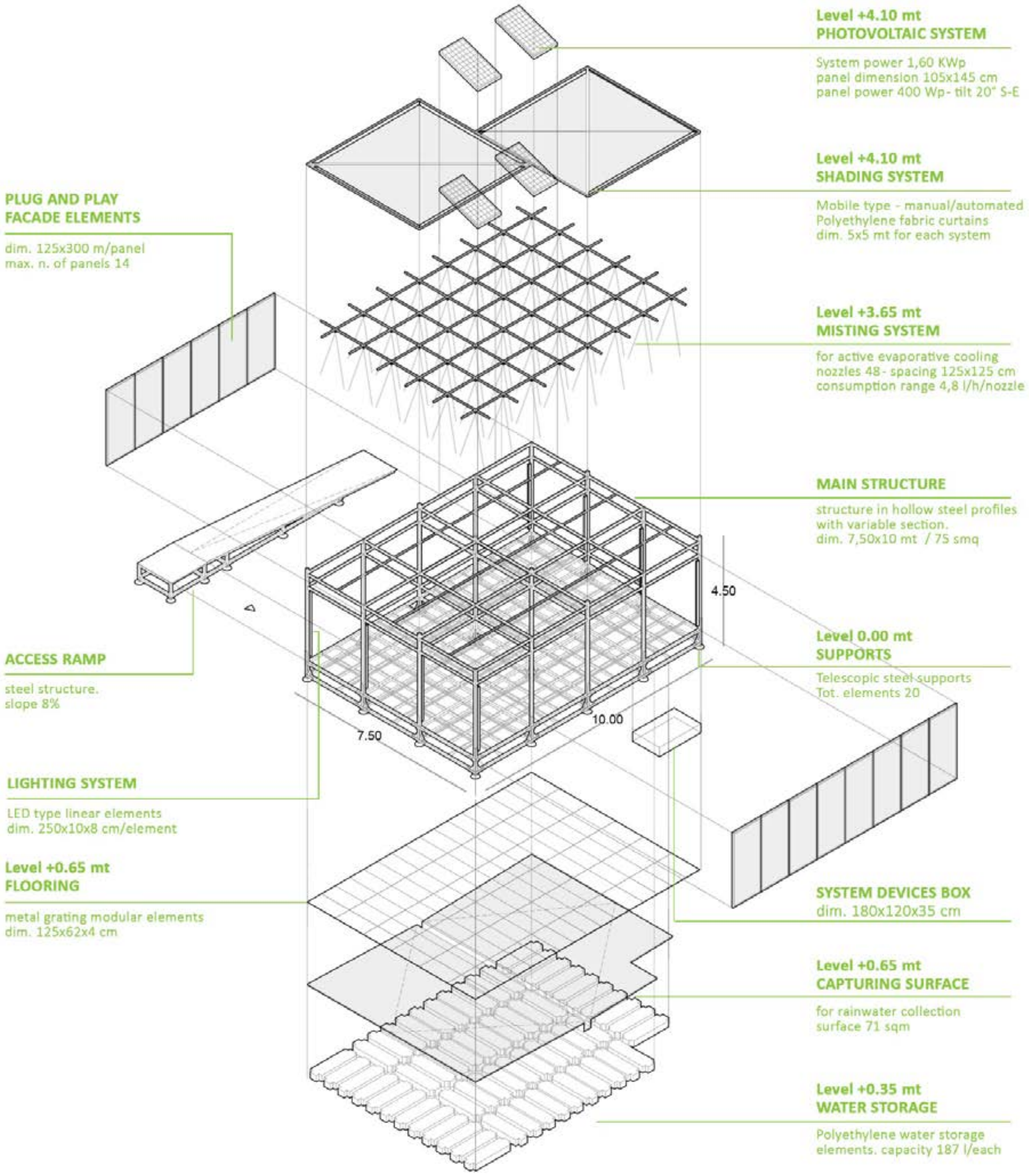


Figure 1. Axonometric view of the plug-in structure with the identification of the plug-and-play devices and technologies. *Source*: Alberto Calenzo, Livia Calcagni.

A LED-type linear lighting system is installed along the structure's external pillars to enable its eventual use also in the evening hours. The shading system (of 50 m²) consists of two shading permeable triangular-shaped fabric elements (UV radiation block factor of 96%) wrapped diagonally around a central stem. It is a mobile mechanized system that can adapt to different conditions and needs. The fabric in polypropylene has a moderate dense mesh (cover factor 94) capable of allowing an adequate degree of permeability to ensure the misting system efficiency. The prototype is equipped with plug-and-play façade devices with different bioclimatic, aesthetic and functional characteristics. The structural modularity of the grid and the plug-and-play mechanism allow rapid installation/removal of the devices as well as easy management and maintenance. Depending on the functional, microclimatic and spatial needs of the users and context, multiple configurations can be arranged. The façade devices include bioclimatic panels, panels with integrated LED screen for sharing multimedia and information content, and functional elements. The device basic module can be hosted 28 times within the vertical external structure for a total of 19.656 potential configurations. The bioclimatic panels are of two types: ceramic panels (CP) with passive evaporative cooling (C5 evaporative cooling system with terracotta tubes; C6 evaporative cooling system with ceramic wall tiles); green panels (GP) (C1 vertical hydroponic system; C2 horizontal hydroponic system; C3 vertical soil cultivation system; C4 vertical soil cultivation system on grid).

The Pilot Study

The prototype was applied on a pilot site in the historic center of Rome, San Silvestro square, a public space particularly prone to summer overheating, of great social and cultural importance and located in an extremely central position adjacent to some of the main historic central roads, the main tourist-commercial attractions, and various transport stops. According to the Koppen-Geigen classification, the climate of the site is dry-subtropical (Csa). The square of roughly 80x60 m is entirely pedestrian, paved in typical roman basalt blocks. The buildings surrounding the square have 4-5 floors and an average height of 30 m. At the time the study was carried out, the square was not equipped yet with shading arrangements or vegetation, hence it experienced critical summer microclimatic conditions. According to the sunlight analysis carried out on 2/09/2017, the square revealed to be almost entirely affected by intense solar radiation during the central day hours, causing excessive overheating.

Calculation and Microclimatic Simulations

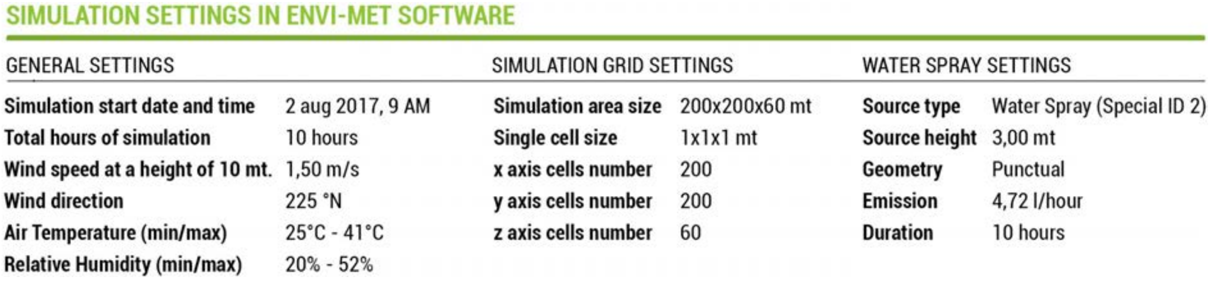
Considering that the final design of the plug-in structure is the result of a participatory process, we have looked into different potential layout choices. More specifically we have define 8 possible layouts (L.), differentiated according to the degree of closure of the structure (%), the typology and number of panels (Table 1), in order to carry out a comparative analysis of water and energy consumption and compare the effect on microclimatic conditions. For the microclimate simulations, three different scenarios have been compared: S0, current setting (absence of urban plug-in); S1, site with urban plug-in equipped with misting system; S2 (L.1.3), site with urban plug-in equipped with misting system and 14 green vertical panels.

Table 1. Plug-and-play panels configurations

	Config. 1 (50% façade coverage)				Config. 2 (20% façade coverage)			
Layout	L.1.1	L.1.2	L.1.3	L.1.4	L.2.1	L.2.2	L.2.3	L.2.4
Green panel C.1	2	0	0	0	1	0	0	0
Green panel C.2	2	0	0	0	1	0	0	0
Green panel C.3	2	6	7	0	1	2	3	0
Green panel C.4	2	0	7	0	1	1	3	0
Ceramic panel C.5	2	6	0	7	1	2	0	3
Ceramic panel C.6	2	0	0	7	1	1	0	3
Info panel C.7	2	2	0	0	0	0	0	0
Tot. n. of panels	14	14	14	14	6	6	6	6

A matrix of the energy and water consumption was developed to allow for the evaluation of the best integrated solution based on the site energy and water supply, available economic resources and effectiveness in improving microclimatic conditions. The matrix has a predefined structure with placeholders for variables (i.e. number and typology of the chosen plug-and-play devices, as well as the presence or absence of the misting. It allows users to change the number and type of closure panels and calculate their corresponding consumptions, to quickly determine the best configuration according to the location and site-specific conditions. Some parameters should be entered appropriately based on site-specific conditions: for water supply rainfall yield depends on precipitation values; for energy supply depends on the type, power, tilt and number of PV panels as well as on the site's latitude. In this paper we present the study related to the application of the matrix for scenario L.1.3.

The simulation settings are described in Figure 2. Green facade plug-and-play elements were discretized and modelled as vegetation elements (3.00 m high default hedge). The Universal Thermal Climate Index (UTCI) value was estimated with ENVI-Met using BIO-Met post-processing tool. The subject assumed for the UTCI computing purpose is a 35-year old male of 75 kg and of 1,75 m height. For the clothing insulation parameter, a default summer-clothing coefficient value of 0,5 was chosen. All the parameters extracted from the simulation output dataset - temperature, relative humidity, wind speed, UTCI - refer to the day August 2, 2017 for the time range of 9 am to 9 pm and were extracted at a height of 1.50 m above the ground level and in a specific point of the square where the plug-in was assumed to be placed (point A) in order to compare the microclimatic conditions before and after the installation of the plug-in (S0 – S1/S2).



SIMULATION SETTINGS IN ENVI-MET SOFTWARE

GENERAL SETTINGS		SIMULATION GRID SETTINGS		WATER SPRAY SETTINGS	
Simulation start date and time	2 aug 2017, 9 AM	**Simulation area size**	200x200x60 mt	**Source type**	Water Spray (Special ID 2)
Total hours of simulation	10 hours	**Single cell size**	1x1x1 mt	**Source height**	3,00 mt
Wind speed at a height of 10 mt.	1,50 m/s	**x axis cells number**	200	**Geometry**	Punctual
Wind direction	225 °N	**y axis cells number**	200	**Emission**	4,72 l/hour
Air Temperature (min/max)	25°C - 41°C	**z axis cells number**	60	**Duration**	10 hours
Relative Humidity (min/max)	20% - 52%				

Figure 2. Key input parameters to set the ENVI-met model and simulation.

Results

Water and Energy Uses

Regarding water demand, the misting system uses 226,6 l/hour. Considering an average operating time of 10 h/day for 53 days/year, the overall annual water consumption for active evaporative cooling would amount to 120.098 l. With a lower operating time of 4 h/day (hottest hours), water usage might be limited by 40%, for an annual total consumption of 48.030,8 l. A water consumption matrix has been drawn up for each layout. The matrix in Table 2 refers to L.2.3. Panel irrigation for L.1.3 requires of 114.975 l/year, which is much higher than L.2.3 (43% less) for instance. Overall, a comparative analysis of the different layouts reveals a trade-off between a variety of typological solutions, water autonomy and the degree of closure of the structure (n° of panels). Given the rain yield in Rome, the rainwater collection surface collects up to 60.000 l/year. Storage tanks ensure self-sufficiency up to 12.000 l and are filled by rainwater to supplement the volume of water progressively being used. Different locations correspond to different rain yield values. As a result, the configuration and quantity of vertical panels will have to take into account the available resources and the local rain yield. The energy requirements (Table 3) of the prototype are related to the operation of the misting system (circulation pump and controller), the panel irrigation system, which varies depending on C1 and C2, and the LED lighting system.

Table 2. Water consumption (WC) matrix for L2.3.

WC devices	N°	WC [l/h]	Tot. WC [l/h]	Daily WC [l/day]	Year WC [l/year]
Misting nozzles	48	4,72	226,6	2.265,6	48.030,8
Green panel (C1)	0	300	0	0	0
Green panel (C2)	0	60	0	0	0
Green panel (C3)	3	20	60	60	21.900
Green panel (C4)	3	25	75	75	27.375
Ceramic panel (C5)	0	0,19	0	0	0
Ceramic panel (C6)	0	1,8	0	0	0
Total water consumption					**97.305**
Water harvesting			Surface[mq]	Precipitation[mm]	Rain yield/y [l]
Total annual water harvested [l]			71	837	**59.427**
Water from the local supply system [l]					**37.878,8**

Table 3. Energy consumption (EC) matrix for L.1.3.

EC	Daily use (hours)	Annual use (days)	N° of devices	EC [kW]	Annual EC [kWh]
Circulation pump	10	53	1	1,10	583,00
Controller	4	53	1	0,05	10,60
Irrigation pump (CP)	4	53	0	0,03	0,00
Irrigation pump (GP)	4	365	2	0,03	87,60
LED lighting (20 devices)	5,5	365	20	0,04	1.429,34
LED lighting (20 devices)	5,5	365	10	0,02	367,37
Total energy produced					2.477,91
Energy production (EG)	Nominal Power [Wp]	N° of panels	Panel tilt	Peek power [KWp]	Annual EG [kWh]
PV system	450	4	20°	1,8	2.770,24
Total renewable energy produced					**2.770,24**
Total energy surplus produced					**292,23**

Since the temperature varies throughout the day, we considered a 10 h operating time for the misting system based on an average of the operational months. The overall use is 243,8 kWh/year. However, considering the irrigation of façade panels, while green panels require irrigation 365 days/year, ceramic ones only for the time they are in operation (53 days). L.1.3, for example, requires 87,60 kWh/year to run the irrigation circulation pump. Finally, the lighting system consumes 1.796,7 kWh/year, operating year-round with an average of 5,5 hours/day, based on an annual average of the hours of darkness until midnight. Overall, the total energy demand ranges from 2.396,67 kWh for the layout with the highest number of panels and lowest consumption (L.2.4) to 2.477,91 kWh for the one with the most panels and highest consumption (L.1.3). Given the energy demand, a PV system comprised of 4 panels (105 x 169 cm) of 450 Wp each would produce electricity not only to ensure the energy autonomy of the entire plug-in in all its configurations, but also for any other integrated devices (i.e. smartphone charging stations). In fact, in the highest energy-consuming scenario, a surplus of 292,23 kWh of energy is available.

Environmental Performances

Parameters such as potential air temperature (°C), relative humidity (%), wind speed (m/s), and UTCI (°C) were extracted from each scenario's output datasets (Figure 3) in order to compare the different scenarios and their associated microclimatic conditions (Figure 4).

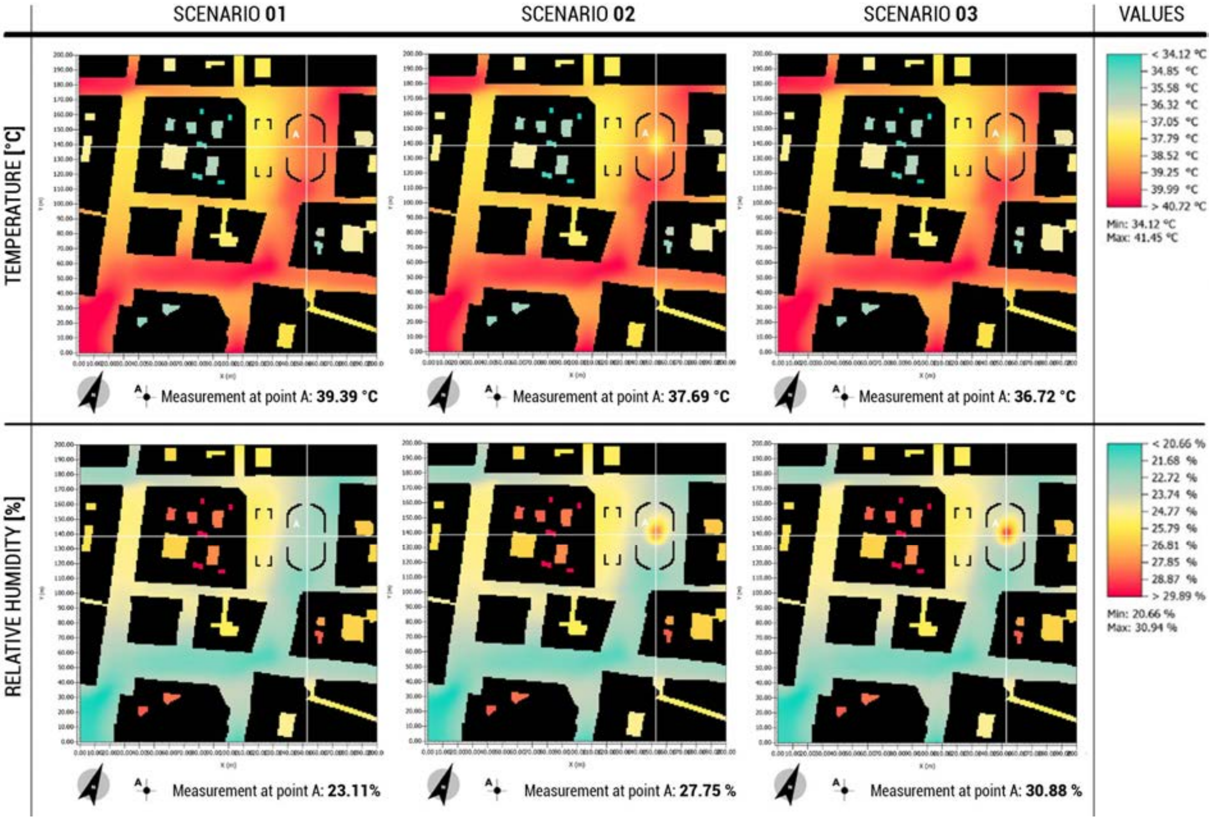


Figure 3. Temperature and relative humidity microclimatic simulation outputs distribution (from ENVI-met) for the three scenarios S0, S1, S2. *Source*: Alberto Calenzo, Livia Calcagni.

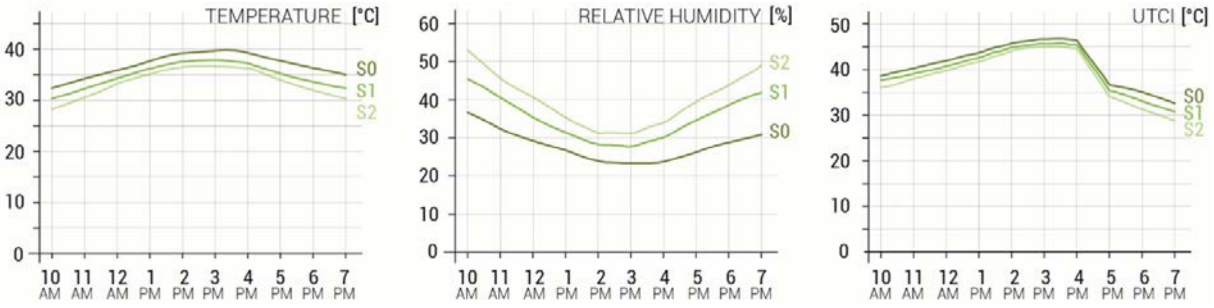


Figure 4. Comparison of temperature, relative humidity and UTCI (microclimatic simulation outputs) for the three scenarios S0, S1, S2. *Source*: Alberto Calenzo, Livia Calcagni.

Scenario S0. The trend of the specified parameters over the 10 hours of simulation were observed computing S0 climate profile at survey point "A." The temperature graph shows a daily parabolic distribution of the parameter with maximum values in the central hours and minimum values at the beginning and end of the day. Temperatures are mostly above 35 °C (8 out of 10 total hours monitored) and the maximum peak (39,4 °C) is at 3 pm. Relative humidity ranges between 25-35%, with lower values in the middle of the day and a minimum peak of 23% at 3 pm. In contrast, the UTCI graph for 5 pm shows a reduction in values of around 9,5 units (from 46,5 to 37,1°C) compared to the previous hour. This variation, which is not as visible in the temperature trend, is caused by the onset of the shadow cast by the building on the west front of the square, which affects the area in the "A" detection point from around 4:30 pm onwards. The maximum peak of the UTCI (46,9 °C) is at 3 pm. The climate maps show a uniform distribution of average temperatures (38-39°C) in the entire area. The maximum temperature (40 °C) is in the middle of the square as it receives the most sunlight.

Scenario S1. The climatic profile for S1 shows that the trends are the same as for S0 with lower absolute values for temperature and UTCI and higher values for relative humidity due to the introduction of the plug-in equipped with the misting system. Indeed, the variation of parameters near point A is clear on the climate maps. Moving away from the plug-in, the microclimatic conditions are identical to those in the S0. At 3 pm, the temperature at point A reaches its peak of 38°C. Concerning the UTCI, an identical trend is observed between 4 and 5 pm due to the shadow cast by the surrounding buildings. Temperatures in S1 are lower by about 1,5-1,8°C during the central hours, and by 2-2,5°C at the start and end of the day, with drops of about 3°C in the evening hours. Within the structure area, temperatures reach over 35°C in fewer hours than in the previous scenario (about 5h in S1 versus 8h in S0), with peaks of 38°C at 3 pm, (-1,7°C compared to 39,4°C in S0). A similar pattern emerges from the UTCI data analysis, with drops of approximately 0,9 to 1,2°C in the central hours and greater than 1,5 °C in the evening hours, recording the same trend as S0 between 4-5 pm. Relative humidity, instead, recorded increases of 5% in the central hours and between 8-12% at the start and end of the day due to the presence of the misting system.

Scenario S2. The layout used for the simulations is L.1.3 (panels along the two long sides of the building, facing SW and NE). The main differences compared to the previous scenarios concern a further decrease in absolute values related to temperature and UTCI and an increase in relative humidity due to the addition of vegetation components in addition to the effects of the misting system, wind speed values from previous scenarios remain unchanged. In S2, the temperature reaches its highest peak with 36,7°C, and registers a decrease of 1°C compared to S1, and of -2,7°C compared to S0. As in the previous scenarios, temperature values decrease moving away from the central hours, with the lowest values recorded in the evening hours. Compared to S1, the introduction of green elements resulted in an increase in relative humidity levels of roughly 3% during the central hours of the day and of 7% in evening and night hours. Compared to S0, this increase is on the order of 7-8% in the central hours, rising to 18-19% in the evening hours. For the UTCI values, S2 follows the same trend as the previous ones, with lower values compared to S1. The maximum value is at 3 pm with 45,4°C (0,6°C less than S1;1,5°C less than S0), whilst the minimum values occur during the evening.

Discussion and Conclusions

The prototype is adaptable to any given location within historical city centres due to the availability of multiple spatial-technological configurations that reflect different needs. Moreover, the speed and ease of comparison amongst different potential choices concerning consumption demands, spatial and aesthetics result, and costs, supports the end users in the decision making process. For instance, if connection to the local public water supply is not possible, and the reservoir is used exclusively to supply the water needs of the misting system, it will be necessary to refill the water storage several times depending on the rainfall yield of the site and on the operating time. Assuming that the misting system is fed directly from the local water supply, the reservoir could serve as a storage (constantly supplemented by onsite rainwater collection) and could meet the annual irrigation needs of several scenarios without the need for additional filling. The urban plug-in located in Piazza San Silvestro is water self-sufficient in terms of the usage of plug-and-play facade modules but not for the misting system, which requires enormous amounts of water to operate.

The microclimatic simulations performed on the pilot site show that site-specific factors, such as any shadows cast by surrounding buildings, the material and color of paving surfaces, the presence of vegetation, water or shading elements, all significantly contribute to the effectiveness of the plug-in on the site, and thus to the improvement of the overall microclimatic conditions. Based on the simulation output data, the whole area maintains the same microclimatic conditions in all scenarios, with the exception of the region affected by the presence of the plug-in, where changes in the microclimatic parameters occur with regard to the scenario S0. Assuming 3 pm as the critical time for overheating in the pilot site, activating the misting system (S1) reduces the temperature by about 2°C and the UTCI by about 1°C. Temperature and UTCI further decrease respectively by 2,7°C and 1,5°C, when nature based solution solutions are added (S2). Regarding the UTCI, there is a change to a lower class of thermal index discomfort in the middle hours, shifting from "extreme heat discomfort" to "very severe heat discomfort". As one moves away from the critical hours, these parameters keep decreasing. In the case of Piazza San Silvestro, the onset of shade brought by the building located to the west from about 4:30 pm onwards would significantly reduce the operating time of the misting system with consequent large water savings. Due to these conditions, the use of the misting system alone (S1) at 5 pm results in a reduction in UTCI values of roughly 9 units, making full usage of the misting system unnecessary.

The consolidated methodological process, the type of public space for the implementation of the prototype (medium-sized squares), and the spatial-functional matrixes, enable to reiterate elsewhere not only the study but also the prototype itself. The main challenges experienced during the research were related to the impossibility of building the prototype and carrying out Post Occupancy Evaluation studies due to the outbreak of SARS-CoV-2. Compared to previous studies, the integration of different types of passive devices to reduce UHI effect within an integrated organism, is crucial to optimize the performance of each distinct system. For instance, transpiring and mobile shading devices ensure the correct functioning of the misting system. The rainwater collection surface has a two-folded function: cool the air through surface water evaporation and provide water for irrigation of green and ceramic panels. Future studies intend to use simulation software that is more suitable for the analysis of complex structures that integrate diverse cooling devices and capable of discretizing elements like misting nozzles and evaporative ceramic components with greater accuracy.

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