Urban heat island, the missing links: smart monitoring & evaluation and citizens engagement

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Abstract
July 2023 and October 2023 have been the hottest than ever at global level. Last summer Southern Europe experienced extreme heat, breaking many local high temperature records. Climate warming and heat peaks are exacerbating the Urban Heat Island (UHI) effect, the relative warmth of a city compared to surrounding rural areas. Solutions able to mitigate urban overheating can prevent energy demand for cooling increase (there might be up to 14 billion items of cooling equipment in 2050!) and generate multiple effects on comfort and health, air and water quality and biodiversity, but also on urban regeneration and socio-economic development. So far main UHI measures in Sustainable Energy and Climate Action and/or Adaptation and Resiliency Plans seem to lack a suitable integrated and participated approach as well as monitoring and evaluation (M&E) strategies. Yet some exemplary plans do exist and can show the way to new approaches. Opportunities from digitalisation, smart city technologies and citizens availability to participate in planning and data collection remain underexploited. Mobile computing and mobile-based technologies allowing for participatory planning tools and co-creation, citizen science, volunteered geographic information (VGI) are integrating innovative concepts to increase UHI awareness, generate big-data and empower cities and communities to reduce the UHI effect. But only a few smart cities, – like Barcelona, currently combine bottom-up data, evidence-based planning and M&E. Reliability, privacy and interoperability constraint impede the spread of such applications. After recalling the state of the art of M&E and participation in climate adaptation plans, the paper provides some examples of urban overheating mitigation policies and actions encompassing these two aspects. Then, it briefly mentions what advancements smart cities applications can offer: for instance, greatly simplified UHI estimations through mobile transects for a widespread availability of ambient temperature data without the need for costly equipment and many hours of dedication by the researchers. Finally, the paper showcases a possible participatory M&E approach embedded in the new Rome adaptation strategy and inspired by the selected best practices. This second part is based on findings from a field study in municipal nursery schools, where an outdoor evaporative cooling system may locally reduce the outdoor air up to 5 °C and ensure the thermal comfort conditions for the majority of the interviewees who had before experienced overheating outside of the misted zone. The success of the initiative kicked off the idea of implementing a program for the real time monitoring and alerting of cool shelters in the city of Rome, by integrating an existing Smart City Platform (SCP).

Introduction
Due to climate change, around 200 million inhabitants in 350 cities already experience heat waves with summer temperatures above 35 °C. Heatwaves, the most lethal of climate risks, will affect a thousand cities by 2050 causing up to 14 % increased mortality, respiratory diseases, stress, mood swings and worsening of nervous system pathologies, as well as reduced productivity and damage to infrastructures such as roads and tracks. The categories at higher risk are the elderly, young chil-

dren, low-income populations who live in small, inadequate or uncooled spaces, the infirm, outdoors workers.

In 2023, heatwaves have been the most increasing hazard, as reported by the EEA members. In the same year, in Italy, record temperatures in all urban areas increased by +150 % compared to 2022 when the highest temperature ever registered in Europe occurred (49 °C in the city of Syracuse, Sicily). Average temperature and heatwaves, without proper policy implementation, are predicted to increase in all seasons.

Global warming exacerbates the Urban Heat Island (UHI) effect, the relative warmth of a city compared with surrounding rural areas; a phenomenon due to land use, to the configuration of the built environment and consequent reduced ventilation, the heat absorbing properties of urban materials, the lack of greenery and anthropogenic heat emissions from human domestic, and industrial and transport activities.

Policies to combat urban overheating are being developed and implemented through climate adaptation and resilience plans that interact, if they are not yet integrated, with health, energy, air and water quality, biodiversity and cultural heritage sector policies. UHI measures, in these plans, promote the use of high reflectance (cool) materials, nature-based solutions (NBS) such as vegetation on(green) roofs, walls and urban soil, tree lines and urban forests, permeable surfaces, shading systems (tents, shelters and special architectural structures), blue solutions based on water evaporation (nebulisers, fountains) beyond appropriate urban planning indices and, – to a minor extent – behaviour change.

Most of these solutions can simultaneously provide multiple, environmental but also socio-economic effects, contributing to sustainable development goals (SDGs) on poverty alleviation (SDG 1), health and well-being (SDG3), education (SDG4), water quality (SDG6), innovation and infrastructure (SDG9), responsible consumption and production (SDG12), preserving aquatic life (SDG14), as well as climate action (SDG13) and urban regeneration (SDG11). On the contrary some of them, i.e. lower urban density, could counteract sustainable mobility or dwelling availability or, even, adaptation costs could disfavour poorest or disadvantaged people (IPCC 2022). Citizens are directly affected, as for health, quality of life or job losses, e.g. in sectors such as tourism. That's why integrated planning approaches considering real citizens needs and acceptability should result in meaningful, effective and sustainable solutions solving society problems that should be reflected in M&E methodologies.

From a review of recent publications, main UHI measures in current national and local plans seem to lack a suitable integrated and participated approach as well as monitoring and evaluation (M&E)[1] strategies (Reckien et al, 2023). Challenges associated with UHI M&E are: cost of comprehensive M&E processes, lack of prioritization due to insufficient resources, data limitations including a lack of baseline data and standardised indicators, uncertainty associated with climate change and its inherent cross-sectoral, multi-stakeholder nature (UNDP, 2022).

1. M&E (for adaptation) is the process of monitoring whether adaptation measures are being implemented as planned and evaluating if they are being successful in meeting their intended goals (e.g., reducing vulnerability, increasing resilience, increasing adaptive capacity).

Identifying and implementing effective UHI solutions can be facilitated by engaging and mobilising stakeholders and citizens, who often have diverse values, beliefs and perceptions. From an extensive review of examples, public participation can lead to more ambitious and transformative local climate policy and decision making (Cattino & Reckien, 2021). In spite of time, politics, cost – constrains, community participation should occur in all steps of climate change adaptation planning (MIP4Adapt, 2023).

Digitalisation, smart city technologies and citizens availability to participate in planning, data collection and evaluation of climate policies are still underexploited. Participatory planning tools and co-creation, citizen science, volunteered geographic information (VGI) are integrating innovative concepts to generate big-data, increase UHI awareness, empower cities and communities to reduce the UHI effect and improve UHI M&E.

The paper describes some UHI exemplary participative policies and actions. By focusing on an ongoing UHI M&E campaign included in the framework of the new Rome Climate Adaptation Strategy,[2] it also highlights further opportunities for UHI mitigation through smart cities applications.

The Political framework

M&E AND CITIZENS ENGAGEMENT IN CLIMATE ADAPTATION PLANS

Urban overheating, hence UHI, is addressed through climate adaptation and resilience plans. Nevertheless M&E methodologies, data sources and indicators for assessing progress of their implementation still remain to be established. Countries voluntary elaborate systems to monitor and verify progress of Nationally Determined Contributions (NDCs) according to the Paris agreement and assess achievements of SDGs according to UN 2030 Agenda.EU MS have to track and report progress in the implementation of EU climate legislation within the EU Governance of the Energy Union and Climate Action Regulation. Nevertheless, there is no universally accepted measurement of overall climate change resilience, so impeding comparison of effectiveness between Countries (UNDP 2022).

In most of EU MS adaptation plans, monitoring and evaluation frameworks are under development or are recently implemented. Within the approaches used for monitoring, reporting and evaluating measures, moreover, the indicator types and how they contribute to evaluation purposes are not always clear. Existing indicators mainly support monitoring; experience of their use for evaluation is still limited. Evaluation of adaptation policies employ mixed methods, combining quantitative and qualitative information and evidence from multiple sources, such as indicator data and stakeholder views. (EEA, 2020).

In 2018 sixteen Member States were undertaking some monitoring and reporting of adaptation activities, although some NAS (National Adaptation strategies) or NAPs (Plans) were still to be adopted at that time. The extent differed to which activities: NAS and/or NAP implementation (BE); integration of climate adaptation in sectoral policies (HR, NL, SI); or regional,

2. https://www.comune.roma.it/web-resources/cms/documents/Strategia-adattamento-climatico.pdf

sub-national and local actions (es. DK). A few countries monitored two (FR, IE, PT) or the three of them (AT, DE, ES, FI, LT, SK, UK). A dozen EU countries were using or considering stakeholder engagement methods in M&E (EU Commission, 2018). Since then, according to the latest reports, participatory approaches and coproducing knowledge have become more common (EEA, 2023).

At city level, an analysis of urban adaptation planning instruments in 327 European cities between 2005 and 2020 shows only half of them are provided with one. If we exclude plans from a few cities like Dublin, Galway, Sophia, societal participation and M&E are particularly weak aspects. Nevertheless, after 2015, quality is significantly increasing over time, although involvement of citizens in M&E, particularly the most vulnerable ones, is still unusual as it amounts to 7 % of cases. (Reckien, D. et al., 2023).

To bridge this gap the 2021 Horizon Europe Mission "Adaptation to Climate Change, including Societal Transformation" tests integrated solutions that can achieve the vision of climate-resilience by 2050 with an emphasis on citizen engagement.EU funded Urban Innovation Actions (UIA) have already shown benefits of higher levels of participation.[3]Moreover, the European Climate Pact aims to empower individual citizens who will play a key role for local and regional contributions.[4]

Engaging stakeholders and citizens in the feedback and improvement process allows policy makers to review the plan and remain pertinent. In addition, it can be a powerful system to promote collective and individual climate action: from raising public knowledge and awareness to educating younger generations and ensuring ownership, commitment and engagement in its operationalisation. According to EU Mission Implementation Platform for Adaptation to Climate Change Manual (MIP4Adapt, 2023), based on tried and tested tools and methods, large public could also be engaged in M&E through Citizen Science methodologies, by means of open stakeholders fora and focus group, opinion polls, phone surveys, data crowding, etc.

A M&E participatory approach can be observed in the recently approved National Adaptation to Climate Change Plan (PNACC, 2023) for Italy, a country prone to natural hazards and one of the most vulnerable in Europe.[5]The plan promotes "monitoring ICT systems on extremes events" and "improving GIS, information and monitoring systems" specifically on UHI. The (long) preliminary stakeholder consultation co-designed processes to assess the public's perception of adaptation, to identify the criteria for evaluating the Plan actions and to build governance models. A Platform for Adaptation to Climate Change has been established that makes data from different sources available.[6] The PNACC provides guidelines for regional and local decision makers on how to identify a set of indicators for M&E in sub-national adaptation strategies that include mainstreaming and stakeholders' engagement. Currently, no regional adaptation plan is in force and only three Italian cities (Bologna the first) have pre-empted these guidelines experiencing UHI M&E as signatories of the Covenant of Mayors.

The 2021 national Italian experimental programme for urban adaptation to climate change in big cities[7] (>60k inhabitants) asked for tracking the UHI effect together with local economic development and socialisation. The programme funded green, blue, grey and soft measures. Regarding extreme heat, it suggested an integrated design of feasible mitigation solutions and success indicators such as: increase of UHI effect (T difference between urban and surrounding rural area), increase of mortality, increase of energy demand (for cooling) and of blackouts numbers during the summer period, presence of vulnerable people (% of elderly or chronically ill people, children, very low income, unemployed, NEET), proximity of hospitals, schools, protected housing and hospices, disadvantaged neighbourhoods.[8] It funded 35 soft measures to improve local knowledge, including enhanced monitoring systems. Almost 1000 hours of training courses with nearly 9000 attendees, 13 datasets/predictive ICT systems and platforms, 31 monitoring stations have been funded, beyond thousands of awareness raising and stakeholder engagement events. Projects will be completed this year; no specific requirement was established for citizens to participate in M&E of results.

UHI MITIGATION MEASURES: REFERENCE BEST PRACTICE IN M&E AND CITIZEN ENGAGEMENT

Some best practices (BP) showing the way towards participation and M&E in UHI mitigation policies are listed below. They have been selected as inspiring examples for a cool shelters programme proposal in Rome.

Amsterdam addressed urban heat together with floods, water supply, energy consumption and urban life quality by repurposing the rooftops of climate-vulnerable neighbourhoods. A Living laboratory, 10,000 m^2 area (8,000 m^2 on social housing) of smart-blue-green roofs will reduce the UHI together with drought and heavy rain effects, while improving building insulation, biodiversity and quality of life. The roofs are connected in a network, a smart grid of roofs, enabling real time data exchange and remote regulation of rooftop water levels based on weather forecasts and water management settings. A monitoring plan was established to track impacts, including social, fiscal, hydrological, climate adaptive and energy saving aspects. 1500 residents of all socioeconomic levels were engaged through bottom-up and co-creation approaches in this climate strategy and governance. Main outcomes were: technical innovation and product development, creating a water platform with intelligent data management, securing a viable and bankable business case, governance with the people (participation and community involvement).[9] Moreover 100 citizens participated in related citizen science campaigns (H2020 i-CHANGE): they agreed to install a small weather station in their homes to monitor indoor temperature, humidity and

3. https://www.uia-initiative.eu/en/ (see outcomes of the Amsterdam, Barcelona and Bologna Living labs in the Table).

4. https://climate-pact.europa.eu/index_en

5. https://www.mase.gov.it/notizie/clima-approvato-il-piano-nazionale-di-adattamento-ai-cambiamenti-climatici

6. http://climadat.isprambiente.it/

7. MASE decree n. 117, 15 April 2021, https://www.mase.gov.it/pagina/programma-sperimentale-di-interventi-ladattamento-ai-cambiamenti-climatici-ambito-urbano

8. https://www.isprambiente.gov.it/files2024/pubblicazioni/quaderni/quaderno_as_adattamento_finale.pdf

9. https://uia-initiative.eu/sites/default/files/2022-03/A%20roof%20journey%20-%20RESILIO%20final%20report.pdf

CO_2-concentrations, so helping researchers to explain the correlation between indoor and outdoor parameters. In exchange they got access to an App showing easy-to-read phenomena being measured (every 5 minutes) and to the Netatmo Weather Map where UHI around the world can be visualised.[10]

In 2100, **Barcelona** is expected to have 30 more days per year with temperatures above 30 ºC and an average 3.5 ºC increase in the summer. Since 2001, the municipality established a Citizen Council for Sustainability with more than 1,000 organizations (schools, companies, universities, etc.) that was instrumental to create citizen-initiated projects (85 % of the total) and to propose M&E indicators. Citizens were engaged (EU H20202 i-CHANGE) in order to identify the main problems related to the extreme heat cycle, particularly addressing aspects related to social behaviour. They also contributed to improve the early warning system, identify the best solutions, propose and prioritize nature-based solutions (NBS), develop new citizen cooperation networks to face extreme situations. School communities were engaged in the transformation of school game-fields into "climate green-blue -grey shelters" open to all inhabitants, with the 2030 goal of 100 % population within a 10-minute walking distance from a cool zone during the summer. These actions are part of an ambitious participated 2030 Climate Plan[11] integrating climate justice and citizen action and including perception indicators to measure how the public perceive (and value) the actions and their impact during M&E meetings. Among the plan short term actions: generate and make the most of thematic annual public events (e.g. exhibitions, art, photography, cinema festivals) to give practical examples; provide access to climate information through Smart Citizens and other applications; promote citizen science to obtain data on temperature, relative humidity, warnings, phenology, etc. and then share them; carry out more publicity, adapt information, ensuring vulnerable people's participation in climate change, for example to prevent gentrification effects of greening neighbourhoods.

Bologna adopted a participated approach that led to the shared drafting of the City adaptation to CC Plan. Based on the analysis of existing risks, the Plan included a monitoring system for all actions. Agreements between citizens and the administration for the care and regeneration of common green areas are established and monitored, including the ability to combat UHI and extreme weather events. Through the Life+ GAIA (Green Areas Inner City Agreement),[12] the municipality also developed a public-private-partnership (PPP) business model for green solutions: local enterprises can sign one of the 3 types of model contracts (paying between 200 and 4.200 Euros) to finance and entertain (for a 3 years' duration) new green areas to compensate their CO_2 emissions and contribute mitigating the UHI. In exchange the Municipality commits to provide a monitoring report every six months. An online calculator tracks the total CO_2 absorbed, showing areas in which co-funded interventions have been carried out, new trees number, species and photos. A special "stakeholder report" synthesises pilot participated actions implementing the city adaptation Plan.

New York City developed a comprehensive set of strategies, – policy instruments, incentives, training, job creation and awareness campaigns, and a specific governance for cool-roofs installation. Cool-roof installation is freely provided by partner organisations to social housing in selected higher vulnerable areas and is incentivised with grants and assistance for installation in private buildings. A Heat Vulnerability Index (HVI),[13] combines metrics proven to be strong indicators of heat risk through validation with health data. NY City and NY City College are installing a high-density hydro-meteorological weather network and collecting innovative data to deliver inclusive and health-focused climate policy. The data baseline is at neighbourhood-level and is used to more effectively target new initiatives. The resulting platform delivers real time meteorological and hydrological observations which can be used to assess response to extreme events, create an early warning system during heatwaves and flooding and assess the effectiveness of various mitigation strategies.[14]

Singapore, a city warmer than its surrounding by up to 7 °C due to UHI, has defined ambitious urban green targets, encouraging their integration into the Landscaping for Urban Spaces and High-Rises program (LUSH). The programme promotes green walls and roofs and urban farms to compensate green spaces sacrificed to land occupation by new buildings. The Singapore Digital Urban Climate Twin (DUCT) was created to map and monitor urban heat and deliver climate informed decisions and public awareness on UHI.[15] The digital twin includes not only geometry and textures for visualisation, but also dynamic behaviour of urban elements for the purpose of simulating causes and effects (e.g. traffic, air conditioning, microclimate). It is used to conduct what-if analyses and perform experiments that would otherwise not be possible in the real world.

Vienna UHI strategic plan[16] describes the different solutions and their effectiveness at the neighbourhood and urban scale. Among these solutions, BeRTA, a simple, inexpensive green façade module system for existing buildings, was developed to simplify the incentivising authorization by the municipality (50 % incentive). An initial free and non-binding assessment of the in-site performance (BeRTA Quick Check) is offered to the applicant: tenant, owner or property manager. The municipality evaluates the impact and cost-benefits before and after the system installation. Vienna UHI plan, under the city's Smart City Strategy and Climate Protection and Adaptation Programme (KliP II) benefitted from a preliminary survey on public perception and attitudes on heat (2013). As climate protection measures are profoundly shaped by individual behaviour changes and lifestyles, awareness raising and engagement campaigns are continuously carried out in Vienna: Geh-Café[17]

10. H2020 i-CHANGE project: https://ichange-project.eu/living-lab-amsterdam/

11. https://www.barcelona.cat/barcelona-pel-clima/sites/default/files/documents/climate_plan_maig.pdf

12. www.lifegaia.eu/IT/index.html

13. Heat vulnerability index is an indicator also applicable to the European* region. This indicator uses a composite index ranging from 0 to 100, which considers the proportion of the population over 65, the prevalence of chronic diseases (chronic respiratory diseases, cardiovascular diseases, and diabetes), and the proportion of urban population. Higher numbers represent higher vulnerability.

14. https://www.nyc.gov/assets/orr/pdf/Cool_Neighborhoods_NYC_Report.pdf

15. https://www.thegpsc.org/sites/gpsc/files/cooling_singapore_-_digital_urban_climate_twin.pdf

16. Vienna Urban Heat Island Strategic Plan (UHI STRAT, 2018), https://www.wien.gv.at/umweltschutz/raum/uhi-strategieplan.html

17. https://www.wienzufuss.at/

involves citizens in urban walks to measure how surfaces heat up differently in the city neighbourhoods during the summer and engages on climate and gender topics.

In **Rome**, ENEA and Roma Tre University have already developed a UHI GIS[18] that linked climate parameters (night temperatures increase at ground level from MODIS satellite, as an indicator of UHI) to others such as land use, urban density, rate of elderly people and children, green areas and infrastructure, soil permeability.

More recently the *MappaRoma* GIS[19] has included an UHI index that is calculated using outdoor temperatures from hourly data acquisition. The UHI index measures the differences between average, maximum or minimum temperatures coming from the 35 microclimatic stations in Rome central neighbourhoods, compared to the reference station in the surroundings (near Fiumicino airport). The index facilitates assessing UHI at yearly, seasonal and monthly level (average T values are taken into account). The GIS allows researchers to develop further analyses by integrating geo-references social indicators and is susceptible to be enriched through new bottom-up information.

The Technical framework

SMART CITIES TECHNOLOGIES AND IOT FOR UHI M&E AND ENGAGEMENT

IoT technologies in the current era is bringing opportunities to facilitate advances in urban microclimate study with finer spatiotemporal resolution beyond just satellite imagery analysis. New opportunities for trans-sectoral integrated M&E, participatory planning and co-creation are emerging from typical smart cities' technologies and IoT: big data and AI, augmented reality, geospatial models (GIS), blockchains and tokenisation, social digital innovation.

Urban computing can store, process, integrate, model, and analyze various big data and phenomena, such as real-time data generated by remote smart sensors and devices, urban geographical and building data, mobility and stationary meteorological monitoring data, social media data. These data have been integrated to assess UHI in more than 100 cities in the past 50 years.

Today low-cost technology sensors can be installed complementing traditional in-situ weather stations (as Swiss cities of Basel and Zurich did some years ago). Climate city monitoring systems can use these measurements, satellite images and artificial intelligence to precisely model air temperatures, precipitation and wind speed up to every 100 square metres, bringing the weather to each doorstep and letting citizens and enterprises visualize them for single points of interest (e.g., home address, working address, etc.), local areas, or for the entire city. Nevertheless, the integration of such measurements into indicators for climate and sustainability planning is not completely integrated yet (UNDP, 2022).

18. www.isprambiente.gov.it/files/eventi/eventi-2015/le-grandi-sfide-urbane-cambiamenti-climatici-e-qualita-ambientale/PresentazioneOmbuen_31_3_2015.pdf

19. https://www.mapparoma.info/mappe/mapparoma36-quanto-fa-caldo-nei-quartieri-di-roma/

Nevertheless, there is no single efficient computing architecture for large-scale or long-term UHI measurement yet. The three "computing, cloud, mobile and edge" paradigms can be combined according to different advantages. Cloud-computing techniques enable researchers to calculate geophysical parameters from large numbers of remote-sensing data with high and efficient performance: for example Google Earth Engine (GGE) was implemented by an algorithm using MODIS images to calculate the UHI intensity for over 9,500 urban clusters using over 15 years of data, resulting in one of the most comprehensive characterizations of the surface UHI to date. Mobile-based applications (i.e., iPad/smartphone application) can allow users to gather instantaneous energy performance feedback on their decisions and plans, such as deciding the building orientation. At the same time, portable mobile devices sensing provides volunteered geographic information (VGI) to enhance the near-real-time estimation of UHI thanks to the growing crowdsourcing capacity of the internet. Edge computing, finally, allows data produced by in-situ devices to be processed and analysed at the edge of the network, reducing the data traffic to the central repository and processing engine. (Qian Liu, Juan Gu, Jingchao Yang, et al., 2021).

Citizen science activities, – like the ones cited in Amsterdam and Barcelona examples –, allow for a participatory contribution in the collection of environmental data and can complement satellite images to detect areas of risk with higher spatial or temporal resolution and finer granularity. Distributed citizen-owned sensor network consisting of existing Smart Home and Internet of Things devices and mobile sensors that can be attached to publicly available infrastructure such as buses, rental bikes, or e-scooters help to gain temporary insights into areas which have not been covered yet. Machine learning algorithms can compensate gaps in such a combination, allowing for a fine-granular heat map and accurate localization of urban heat islands.

Low-cost measurement device consisting of a temperature logger and a custom-made, naturally ventilated radiation shield with available data from citizen weather stations are also beginning to be used by research studies. For instance open-access air temperature data from 1,452 privately-owned Netatmo weather stations within Oslo were used as reference data for satellite models of air temperature. Cheaper and faster UHI estimations through citizens' mobile transects is, for example, the results of a pilot project funded by ERDF in the neighbourhood of Los Remedios in Seville (Spain) in July 2022: a simple APP is capable of receiving the temperature data and capturing the GPS coordinates at the same time from personal smartphones. This allows to have spatial, temporal and temperature information for every timestep during any mobile transect, which may be viewed and exported in a fast and simple way. Combined to a web tool in order to obtain heat maps, this is a reproducible methodology for a more widespread availability of ambient temperature data anywhere in the world. The system makes it possible to quickly identify the warmer areas of the neighbourhood and suggest the location for UHI mitigation measures in a very efficient way (Romero Rodríguez L., 2023).

Intersection with perception, habits, health, consumption data which can be digitally analysed from the web, allows for a dramatic improvement of UHI knowledge base and for developing targeted services to citizens. Reliability, privacy and

Figure 1. Aerial 3D view of the Tesori di Gulliver school and its surroundings.

interoperability constraints impede the spread of such applications. With the spread of interoperable platforms and the advent of identification and certification systems that allow for decentralised control (blockchains), citizen will be in the position to contribute with a multitude of useful and more reliable data, to get access and to vote (e.g. through tokens) for a targeted development of climate resilience services.

UHI mitigation in Rome: defining a cool shelters programme

SCHOOL-USERS THERMAL RESPONSE TO A UHI MITIGATION SOLUTION

Rome metropolitan area has experienced the highest number of extreme events among Italian cities in 2023 and average temperature has increased by 1.7 °C compared to 1981–2010. Mortality due to extreme heat events has increased. Rome approved, in November 2023, the update of the Sustainable Energy and Climate Action Plan in the framework of the Covenant of Mayors agreement on Climate adaptation and mitigation, while the cited new Adaptation Strategy is in its consultation phase. Rome is among the 9 Italian cities selected within the Horizon Europe Mission 100 Climate Neutral and Smart Cities by 2030, that adopt an innovative participative governance (a Climate City Contract – CCC) to establish actions, responsibilities, necessary investments for Climate action. Community engagement is indicated as necessary to acquire local knowledge, induce collective learning and create non-discriminatory conditions.

ENEA Energy Technologies and Renewables Sources Department develops tools and solutions aimed at supporting smart cities and climate mitigation and adaptation. The impact of outdoor evaporative cooling systems on local microclimates has been widely studied in the past and recently applied to public kindergartens, in the framework of a voluntary collaboration agreement with Rome Municipality. In parallel, ENEA is developing a web-based tool to inform citizens about urban climate conditions and thermally mitigated spots to be used as cool shelters during the hot season and heat waves.

In order to monitor and evaluate the effectiveness of the misting cooling system installed in the *Tesori di Gulliver*, a nursery school located in the Northern outskirts of Rome, ENEA carried out a subjective thermal response from users. Rome city climate is Csa, Mediterranean climate according to the Köppen-Geiger classification.[20] The building density in this area is lower than the central districts' and the nursery is bordered by green areas. The school, one of the 5 pilots in the 2021 MASE Experimental Programme, was selected as teaching and technical staff rotated on a daily basis during the summer season so allowing to have a good number of potential interviewees during the period. On a daily basis, the nursery hosts about 40 two-three years-old pupils and around 8 employees, teachers and technical staff. Public nursery schools are generally open from September to June, but the Municipality supports low-income and full-time working households by keeping selected nurseries operating in July as well.

According to consolidated well-being protocols, it is important to ensure that pupils spend an adequate amount of time outdoors. Nevertheless, municipal regulations strongly limit this time because of the severe climate conditions usually registered during the summer. In central or high densely built city districts such conditions do not occur only in July and are more frequent because of the urban heat island (UHI) effect. Outdoor comfort solutions, like the one presented in our study, would benefit the everyday life of thousands of pupils for months each year.

Installing a misting system can mitigate the local outdoor climate thanks to the evaporative cooling effect of the nebulised water exiting the misting emission elements (nozzles) at high pressure. ENEA team evaluated the system effectiveness by both using instrumental analyses and subjective responses from pupils and adults. The misting system was installed in one of the gazebos of the school garden where the pupils use to play together. The gazebo is a simple wooden frame covered by a green plastic textile in order to provide solar protection. Sustainable architectural solutions for gazebos integrating the misting system with PV modules to provide the energy needed from the water pump and the nozzles and planters are at study.

During the survey adults were asked to: 1) move from indoor to the garden, 2) stay outdoor until the thermal sensation was well identified, 3) move under the misting zone and stay until the thermal sensation was well identified. Participants were

20. Köppen climate classification is the most widely used climate classification systems, which is based on mean temperatures and precipitation and their seasonality.

asked to rate their thermal sensation using ASHRAE classes (-3 cold, -2 cool, -1 slightly cool, 0 neutral, 1 slightly warm, 2 warm, 3 hot). Tests were carried out between July 21st and 28th involving 18 participants. The majority were women (16), 28 to 58 years old. The impact of the evaporative cooling on the thermal sensation and, as a consequence, on the thermal comfort conditions, is shown in Figure 3. During the tests the outdoor average temperature was 32.6 °C, that dropped to 27.6 °C under the gazebo, in the misted zone. The average score for outdoor conditions was 2.2 (warm) and was 0 (neutral) in the misted zone. Outdoor only 2 subjects expressed a slightly warm sensation, the vast majority expressed warm or hot sensation. The evaporative cooling solution strongly dropped the warm sensation, which caused a slightly overcooling in 5 cases; the results were well centered across the neutral sensation in this latter case. The disaggregation by gender and by age did not provide any insight: as the differences, compared to the general average values, were close negligible (lower than 0.25). The only identified trend was the increase of the warmness feeling in older-aged subjects when they stayed outdoor.

Due to the limited number of participants, the survey has no statistic relevance; however, the results clearly prove that water-based evaporative technologies could improve the thermal comfort conditions in the nursery outdoor spaces. One of the potential benefits, as an example, was the possibility of having lunch in the garden, despite the severe outdoor thermal conditions during the monitoring campaign, so affecting the lifestyle of pupils and staff. The Municipality of Rome expressed interest in the study and a new installation and campaign will be in fact carried out during summer 2024. Similar surveys will be systematically implemented in future installations and be part of the citizens engagement in M&E this specific UHI measure.

IMPLEMENTATION OF A WEB-BASED INFORMATION TOOL FOR COOL SPOTS IDENTIFICATION

Creating more comfortable outdoor spaces is crucial to make cities liveable even during hot days and heatwaves, which are continuously increasing in number and intensity. Many studies proved the heat mitigation potential of urban greenery and solar reflective materials (N. Nasrollahi et al. 2020). It is demonstrated that technologies based on water vaporizations have the highest mitigation potential per square meter of installation when compared to other solutions such as urban greenery and reflective materials (M. Santamouris, et al., 2017). Such systems, in fact, behave as punctual cooling shelters, unlike greenery and materials that require extensive applications, creating comfortable spaces to be used especially by those low-income citizens who cannot afford active cooling systems to get comfort at home. Misting systems use electricity and water which can be provided by integrated PV systems and water storage for

Figure 2. The gazebo with the misting system.

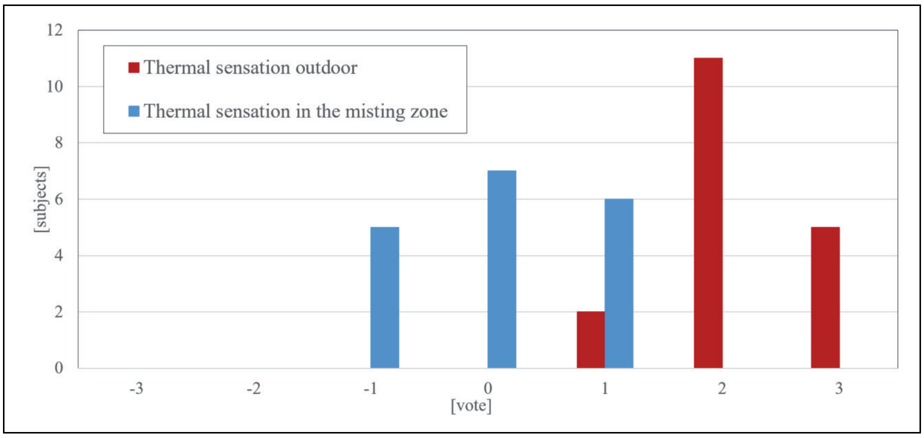

Figure 3. Distribution of thermal sensation votes outdoor (red bars) and under the misting zone.

self-sufficiency (G. Ulpiani, 2023). An additional advantage of this installation is that it can be easily mounted and removed depending on the season.

ENEA is developing a web-based tool able to provide information to citizens about the location and microclimate conditions, monitored in real time, of cool spots like the one described in the previous section. Two nursery schools in Rome city centre will be the first pilot applications of a series, where the evaporative system will be likely integrated to other solutions (soil de-waterproofing, shading, tree-lined barriers and NBS).

The monitoring system at *Tesori di Gulliver*, allows to measure air temperature, relative humidity, and wind speed both outdoor and under the misted zone; in addition, the globe temperature in the misted zone and the outdoor global horizontal solar irradiation are measured to calculate the mean radiant temperature. From measured and calculated parameters, it is possible to calculate the MOCI Mediterranean Outdoor Comfort Index, based on the ASHRAE 7 vote classes both outdoor and indoor. Each monitoring station is equipped with a data logger and manager, which also executes the calculation and stores data with 15 minutes time resolution.

The logger is web connected via APII to the ENEA Smart City Platform,[21] where a specific interface allows citizens to effectively visualize: the address of the cool spot, the time of the last acquisition, the specific strategy/technology (e.g. evaporative cooling, natural water source, greening, shaded zone, a combination of them) being used for heat mitigation, outdoor air temperature, cool spot air temperature, outdoor thermal comfort indicator (MOCI), cool spot thermal comfort indicator (MOCI). Advanced control systems are also crucial to monitor and activate the water vaporization only when the microclimatic conditions (high temperature, low wind, etc.) ask or when the cooling shelter is effectively occupied by the citizen.

In order to express the thermal quality of the outdoor environment and of the cool spot, the MOCI is displayed as an energy efficiency dashboard, using the usual colours red, yellow and green.

POSSIBLE DELIVERABLES, OUTPUT AND RESULTS INDICATORS OF THE PROGRAMME

Starting from the outcomes of the campaign, a Cool Shelters programme, that extends the use and integrates the technology for other schools and public/private open spaces is being drafted. The main result could be a GIS with associated services that can allow vulnerable citizens (not only pupils and school staff) to identify and be informed about the closest place where liveable and comfortable places are accessible during the extreme heat climatic events.

A programme to involve citizens in the preparation, implementation and evaluation of a Cool Shelters programme in Rome is at study that could aim at addressing several benefits.

The programme would maximise the use of existing interoperable smart cities infrastructures and IoT techniques and make use of ENEA Smart city platform that helps communication among heterogeneous platforms making different data collection and management systems interoperable. Possible deliverables, smart techniques and indicators that should be agreed by engaging local stakeholders,[22] are synthesised in Table 1.

Discussion and conclusions

From reviews of climate adaptation plans in recent publications, participation and M&E appeared particularly weak, that is applicable to UHI measures encompassed in there. Stakeholder engagement is crucial for acquiring relevant quantitative and qualitative data, for raising awareness and ownership and for interpreting the available data to monitor operation, evaluate results and drive further decisions. Participatory approaches in the whole planning cycle and, to a minor extent, in the final M&E phase, have become more common in the last decade although they are not regularly adopted.

Some exemplary cases of participated UHI measures and policies, mentioned in the first part of this paper, prove success and replicability on: mainstreaming of sectoral policies (health, welfare, urban design and housing, energy, transport and employment); enabling of real time data exchange including those collected via citizens engagement and crowdsourcing (e.g. temperature, humidity, radiation); integrated design of climate solutions and services (e.g. early extreme heat and UHI warning systems); share of UHI information including perception of heat risks, health and vulnerability; facilitating agreements on urban regeneration and management of NBS solutions, securing business cases, developing new citizens cooperation networks. These outputs were made possible by the early engagement of citizens and stakeholders in the evaluation of climate risks to inform main UHI measures and by creating opportunities and "platforms" for dialogue and data exchange. Main success of the participation practices seems to reside in preventing the uneven distribution of climate change impacts on people and places as well as the uneven capabilities (social, economic, political, health-related etc.) to partake in the benefits provided by the UHI mitigation measures. In some cases (Amsterdam, Barcelona, Bologna, Seville) citizens were also involved in the M&E phase, as it is also recommended by the EEA (MIP4Adapt) to assure the climate adaptation policy or action "pertinence".

Innovation and further opportunities to unleash citizen engagement and M&E practices in UHI mitigation come from digitalisation and IoT and are already practiced in some cities. Exemplary cases show that smart city datasets and interoperable platforms help overcome cost and data availability barriers for comprehensive participated M&E; that suggests us to make use of a City Platform that can integrate different smart techniques in a future programme for cool shelters in Rome.

It is demonstrated that blue technologies and misting systems, among solutions to combat UHI, have the highest mitigation potential and they can be quickly installed and removed depending on the season. Cooling shelters, that apply this technology, might be installed in the most heat hazardous areas of the city. Available GIS-based tools in Rome allow to identify vulnerable areas; they can be easily integrated (via a Smart City

21. https://smartcityplatform.enea.it/#/it/index.html

22. Those indicated in 2023 call EUI "Greening Cities" and from EU H2020 Connecting Nature project, that could be agreed with stakeholders by means of the related CO-IMPACT tool https://co-impact.app/TargetsEnvironmental.

Table 1. Possible deliverables, smart techniques and indicators that should be agreed by engaging local stakeholders.

Cool shelters deliverables	Smart technique	Output indicators*	Success indicators**
• Low-cost shelter business model for public/private spaces (municipal incentive? (ref. Vienna BP) • Contract and business models (for installation, maintenance, periodical management, de-construction) (ref. Bologna BP) • Alarm and booking systems for vulnerable people in the neighbourhood (ref. Barcelona BP)	• 3D simulation using google earth, • Cloud climate monitoring system • Mobile UHI Apps • Integrated GIS • Blockchain (facilitating management)	New products and services created	Users of new and upgraded digital services, products and processes (users/year)
• GIS showing shelters' location where UHI effect and social/health vulnerability are higher (ref. Amsterdam, Barcelona, Rome BP) • Climate data for denser micro-climate and well-being monitoring system integrating the existing stations in higher UHI areas (ref. Barcelona BP)	• Integrated GIS, • Climate database • Remote sensing • Remote users' engagement by online questionnaires • Portable sensing systems	• New equipment/Infrastructure created or supported (new, renovated) • Open (accessible) space created or rehabilitated in urban areas (m^2)	• Population benefiting from protection measures against extreme heat (% of the local population)
• Training on the installation/use of the model shelter • Training on use of the GIS, the booking and alarm system • Awareness raising on UHI from playful demonstration of the system and the GIS (ref, NY BP)	• Remote working systems • Citizen science apps	People supported (trained, upskilled, accompanied or assisted)	• Awareness creation (effectiveness tested through online questionnaires, surveys) • Jobs created (full Time Eq.)
• Simulation of mitigation impacts of energy use/CO_2 emissions of various UHI mitigation and nature based solutions (ref. Vienna BP) • What-if analyses by the means of Digital Twins of selected areas (rif. Singapore BP)	On-line simulation programmes (already encountered in Rome adaptation Strategy)	Public buildings with improved energy performance	• Annual final energy consumption reduced (% compared to previous year) • Estimated greenhouse emissions reduction
Citizens involved in the refining the initial idea, in goals setting, in the prioritization criteria for access to shelters and warning system, in the identification of possible co-benefits, and *evaluation indicators*. (ref. Barcelona BP)	Remote stakeholder engagement/voting Mobile app/gamification	Stakeholders involved in the preparation and co-implementation of the project Citizens involved in the preparation and co-implementation	Level of participation achieved in the engagement with local communities (information, consultation, co-creation, co-decision) (% of the local population engaged)

Platform) to localize new possible spots and document the climatic conditions in the cool shelters together with those registered in the reference urban conditions.

Starting from a pilot case in two nursery schools in the metropolitan roman region, a Cool shelter programme is being drafted within the framework of the new urban climate adaptation strategy; this will take advantage from an existing interoperable smart cities infrastructure and IoT and should deliver new integrated UHI mitigation services where users participate from design to evaluation (e.g. by mean of thermal subjective responses from the school staff). As a first result the action has already created awareness in the school community and helped ensure protection, health and wellbeing for the pupils population, children 0–3 years old as a vulnerable group.

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