Greening cities and buildings for climate resilience: lessons from Lambrate Park District in Milan (Italy)

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Abstract. The Lambrate Park District project, developed within the Reinventing Cities international design competition framework, became an opportunity to exemplify an original approach to urban regeneration that focuses on the need for green buildings and spaces. The main objective of the paper is to identify effective design strategies to mitigate the heat island effects and the improvement of air quality at the local scale. Hence, alongside the development of the individual buildings included in the comprehensive masterplan, characterized by high environmental standards, these strategies applied to the project also led to extensive efforts in enhancing the outdoor spaces to elevate environmental well-being at the neighbourhood level further. Additionally, the implementation of mesoscale optimization techniques contributed to enhance the performance of the buildings themselves. Through chrono-topic mitigation and urban cooling strategies, Lambrate Park District prioritizes green spaces and vegetation to enhance outdoor comfort naturally and improve the performance of buildings (energy efficiency and thermal comfort). Strategically selected trees mitigate air pollution and enhance resilience to climate change, contributing to microclimate regulation. Simulations using ecosystem, daylight, and thermal modelling (InVEST, LadyBug, and Honeybee) software demonstrate the area's performance in improving cooling capacity and thermal comfort, showcasing the project's adaptability to future climatic challenges. Architectural strategies ensure building resilience and flexibility, aligning with the competition's goal of sustainable urban development. By integrating vegetation and shading strategies, Lambrate Park District offers comfortable outdoor spaces year-round, fostering biodiversity and enhancing urban livability. The project highlights the potential of green infrastructure in creating healthier, more resilient buildings, districts and cities.

1 Introduction

The term resilience, when speaking about buildings and cities, refers to the capacity of urban systems to respond to various environmental pressures, mitigating any impacts and reducing both environmental vulnerability and the related social and economic consequences [1]. Improving resilience is an important need for urban communities, especially in where territories are most exposed to climate change risks. The case study, whose name is 'Lambrate Park District', provided an opportunity to study and propose strategies at the urban scale whose actual effectiveness, in terms of performance, can provide appropriate environmental responses, promoted through the application of design choices, oriented towards risk management, that could enable cities to better withstand the challenges they face in the long term. This approach proposes a new urban standard for "reinvented cities" (named from the international design competition that initiated the case study), as a socio-ecological system, capable of fostering urban sustainability.

As we will explain in the text, several Strategies could be included as part of the process:

- Implementation of nature-based solutions (NBS) such as green roofs, walls, and urban green spaces;
- Promotion of sustainable mobility and pedestrian areas;
- Energy efficiency measures and the integration of renewable energies;
- Water management and conservation;
- Developing educational programs, establishing community-based initiatives;
- Partnering with local government, businesses, and non-profits:
- Incorporating climate-resilient design principles;
- Policy development to incentivize climate-resilient development;
- Establishing monitoring systems to track effectiveness.

The Italian city of Milan, in which the case study is geographically located, specifically, exhibits a high degree of vulnerability to the impacts of climate change, whose consequences manifest locally in terms of intensified extreme events, affecting not only urban life but also increasing the risk of vulnerable groups such as children, the elderly, and the sick. The rise in average temperatures due to greenhouse gas emissions (projected at +1.5 to 2°C for the period 2010-2050, compared to the reference period 1961-1995) and the increase of impervious surfaces covered by concrete or

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asphalt, will result in both increased frequency and intensity of heatwaves, i.e., consecutive days where temperatures exceed the 90th percentile of historically recorded temperatures for the site during a specific period. Additionally, this temperature increase will also affect changes over time in building energy needs, leading to an increase in the proportion of energy required for conditioning. Lastly, climate change will increase hydrogeological risk due to increased precipitation.

Furthermore, the urban environment of Milan, in general, is affected by air pollution issues. Despite industrial decommissioning activities and traffic mitigation measures in Milan leading to a general reduction in traditional pollutants (CO_2, SO_2, total suspended particulates, NOx), there are still high concentrations of particulate matter and cyclical emergency conditions at the metropolitan and regional scales. These initial indications of the specificities of the city in which the case study is located strongly influenced the strategies experimented with and evaluated for their effectiveness.

1.1 The starting point, the C40 network and the international 'Reinventing Cities' competitions

The case study of the Lambrate Park District in Milan was developed within the urban design and redevelopment competitions called "Reinventing Cities", organised by the C40 network.

Founded in 2005, the C40: Cities Climate Leadership Group (C40) is a voluntary forum currently comprising ninety-six cities, which join through their municipal administration. The C40 states that 700 million people live in or near its member cities and they account for more than 20 per cent of the global economy.

One of the most prominent, replicable and impactful practical actions implemented by C40 are the 'Reinventing Cities' urban regeneration projects. They were first launched in November 2017 by fifteen of the C40 member cities.

1.2 Main features of reinventing cities projects

Reinventing Cities is, therefore, an international competition, which is designed to stimulate cities to build "ambitious" resilient and carbon-neutral developments in large urban areas for redevelopment. The main declared objectives are:

- to push the public sector to collaborate with the private sector to realise low-carbon and resilient urban projects;
- stimulate the implementation of design solutions that can be extended to other projects on a global scale;
- stimulate the development of public policies to support decarbonised, sustainable and resilient cities;
- push the construction sector to innovate.

To achieve the above-mentioned objectives, the Reinventing Cities calls explicitly encourage the formation of multidisciplinary teams from the outset, whose quality terms represent the many competencies required by such ambitious challenges. The call for proposal requires the appointment of three leading figures, representing the main and most important roles in the process:

- the architectural/urban designer;
- the environmental expert: resilience, sustainability and decarbonisation;
- the financial/real estate promoter.

An essential aspect of each of these calls for proposals is the "10 Climate Challenges," to which each submitted project must provide answers, also in numerical terms. The subject of this paper is to present the scientific results achieved in challenge 4: “climate resilience and adaptation” and challenge 8: “green space, urban nature and biodiversity”, which were inevitably linked, in synergy, within a typical complex system, with the other challenges.

1.3. Formation of the multidisciplinary team for the case study

Following the indications of Reinventing Cities, the Scalo Lambrate case study was realised by a multidisciplinary team. Overall, 170 people worked on it directly (including researchers, architects, engineers, investors, consultants, etc.), plus all the citizens and people consulted during this process.

The three main figures envisaged by Reinventing Cities in our case were: Benedetta Tagliabue-EMBT Architects as the leader for architecture, the Politecnico di Milano (through twenty-five professors and researchers belonging to different departments, each for their specific expertise) as the environmental scientific referent, and the Co-Inventing group as the investor.

The project site is one of the old 'Scali', formerly disused railway yards (there are seven of them on its territory), where the city of Milan has been working for years on regeneration with a view to sustainability.

The former railway yard that is the subject of our case study, the ‘Scalo Lambrate’, takes its name from the historical district of the same name in the city, and was characterised by being narrow and long, with a strong north-south trend. In addition, it was characterised by many constraints, including the observance of a distance of 30 metres from the embankment and from the first track in operation.

1.4 Main architectural characteristics of the case study

The Scalo Lambrate case study we proposed had set itself the goal of strongly reducing emissions, working synergistically not on individual Climate Challenges but through a horizontal approach in which the set of choices makes achieving the goal easier. The design intent was to mitigate the carbon footprint through the main design choices (layout and orientation of buildings, compactness of volumes), the passive properties of buildings and implementing urban-scale environmental strategies, the subject of this paper.

Overall, the team worked from January 2020 to March 2021.

The case study was created by focusing on the public space, predominantly located between the high railway embankment and the new buildings, to create four new semi-circular public squares and two buildings with a public inner courtyard and greenery, the features of which were designed thanks to the studies presented in this paper. The different names of the four squares, also linked to their function, were: "railway", " entertainment", "water", and "flowers". (Fig.1)

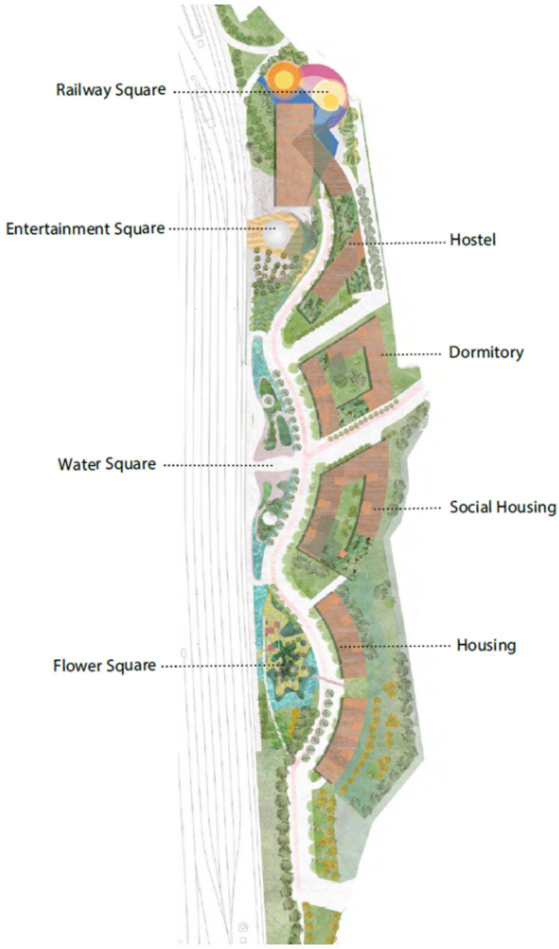


Fig. 1. Masterplan and project plot with the indication of functions and the four squares. The orientation of the plot is North-South.

The architecture of the new buildings and their layout aim to reconnect the fabric of the former industrial district of Lambrate. Overall, the case study includes four buildings with a half-moon layout, with different functions. Starting from the north, the first building is a hostel for young people, and the second building is a student dormitory with an internal courtyard organisation, which mitigates the climate and takes up a typical Milan building typology. The third building, also with a courtyard, is social housing. Finally, the fourth building, consisting of two separate single-storey volumes, are still apartment buildings.

All the buildings therefore overlook green spaces and the new four squares or courtyards.

The roofs are flat and are green or with photovoltaic panels. Other strategies to mitigate local variables to achieve an effect at the meso scale, like local vegetation and water surfaces can be easily recognized in Fig. 1.

2 Methods

In urban areas, a variety of microclimates emerge due to diverse morphologies, optical and radiative properties of surfaces, solar access, availability of green spaces and air circulation. Consequently, alongside city-scale strategies, mitigation efforts need to be addressed at the district or even urban canyon level, thereby influencing building design.

The research analysis steps and their connection with the project unfolded as follows:

1. Mapping ecosystem services to understand the area's mitigation potentials derived from different surfaces, including green, draining, and water features;
2. Harmonizing soil and vegetation types with architecture to maximize local mitigation potentials while also reducing building energy needs;
3. Subsequently selecting climate-proof and low-allergen species;
4. Deciding on their placement, considering potential future growth, to maximize shading impacts without interfering with the built environment and creating safe spaces for users in case of heat stress. This includes ensuring protected pathways during the hottest summer hours and maximizing solar access in winter months.

2.1 Ecosystem services mapping

Recently, the Ecosystem Services (ES) approach has gained attention in the scientific debate for its added value in integrating ecological consideration into decision-making processes and policy frameworks. ES-based approaches highlight the significant impact of natural environmental factors on the quality of life and public health within urban environments and beyond [2].

The urban cooling capacity of ecosystems to provide suitable conditions for human well-being is considered a fundamental ES able to identify the most appropriate use of land and define successful urban design parameters [3].

The cooling capacity in cities is strongly influenced by various factors among the many vegetation coverages (in terms of extent and density which depends on shading and evapotranspiration process), water bodies, urban morphology (i.e., density, built form, building orientation), surface materials.

The software InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) [4] was used for estimating the capacity of an ecosystem to contrast UHI effect and testing the efficacy of the project design.

The principal input data required by InVEST model is Land Use/Land Cover (LULC) with a high degree of resolution, for the case study, the Topographic database of the city of Milan combined with OpenStreetMaps and the LULC map of the Lombardy region of 2018 (DUSAF 6.0 database available at:) were used.

In addition to LULC information, other relevant data are necessary such as: i) Shade deriving by tree cover; ii) crop coefficient, i.e. a coefficient expressing the difference in evapotranspiration between the cropped and reference grass surface [5]; iii) albedo representing the proportion of solar radiation directly reflected by the LULC classes; iv) data on green areas (distance and territorial surface); v) evapotranspiration; vi) air temperature.

2.2 Outdoor comfort mitigation assessment

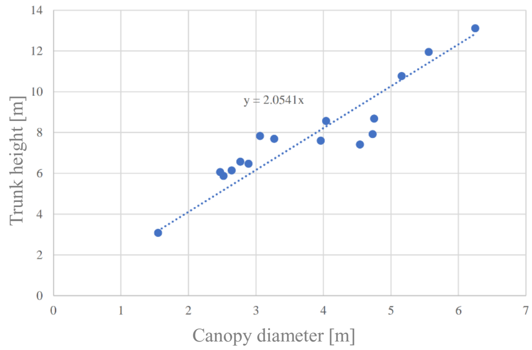
Outdoor thermal comfort for individuals is significantly influenced by considerable and abrupt variations in environmental conditions, particularly solar radiation. The Mean Radiant Temperature (MRT), adjusted to consider solar radiation effects, stands out as one of the crucial variables for assessing user comfort in outdoor environments. This calculation incorporates temperatures of surrounding surfaces and the impact of both direct and diffuse incident radiation on the user, as well as reflections from surrounding surfaces. Recent studies have highlighted that while reducing surface temperatures of high-albedo pavement materials can enhance comfort, the subsequent increase in reflected solar radiation affects users' thermal perception [6] stating that in an urban canyon, the best compromise happens when the albedo of the surfaces is reduced and the area shaded by trees is increased [7].

To address this topic, parametric studies were conducted to determine the optimal reflectance of plaza surfaces, ensuring compliance with SRI>29 values without compromising user comfort. Materials with an albedo between 0.3 and 0.5 were proposed, with a preference for natural surfaces possessing semi-permeable drainage capabilities, such as compacted earth, gravel, and stone pavers. Among various mitigation options, the use of green shading surfaces has been suggested in diverse urban contexts.

Our chosen mitigation strategy for users' outdoor comfort integrates greenery, intervening during summer months to reduce direct solar radiation exposure and enhance user comfort. This approach aims to design areas with alternating vegetation and open spaces, facilitating space utilization and meeting diverse user needs. Increased local green density will create varied environments for users.

In selecting plant species, chrono-topographic considerations were taken into account, with young and small-sized plants chosen initially, expected to mature over time and augment their positive impact on the area.

Considering the typical species and plants applicable to the Milanese context, we evaluated dimensional ratios from literature to understand how tree growth and size could influence the context [8], [9] (Fig. 2).



AVERAGE	0.15	0.68	3.76	7.86	1.63
MIN	0.09	0.50	1.55	3.08	1.63
MAX	0.22	0.85	6.25	13.11	2.56

Fig. 2. Relationship between the trunk height and the canopy diameter of the typical trees compatible with Milan weather conditions. The diagram illustrates an almost linear relationship in the growth rate of the trees, with a ratio of 1:2 between the average canopy diameter and the average height.

The Solar access and radiation analyses were conducted hourly, for characteristic reference periods of winter (December 21st) and summer (June 21st), throughout the daylight hours of the day. This involved identifying the cumulative periods of exposure to incident radiation on the project lot and the squares and streets present. The solar access and the comfort assessment analyses were carried out using the Honeybee and Ladybug plugin for Grasshopper [6] into McNeel Rhinoceros V6.

To comprehensively evaluate mitigation strategy effectiveness and for specific zone types, the hourly distribution of the Universal Thermal Climate Index (UTCI). UTCI is an equivalent temperature that helps discern the presence or absence of thermal stress conditions and is derived from air temperature, Mean Radiant Temperature, direct and reflected solar radiation, relative humidity, and wind speed, this index helps discern the presence or absence of thermal stress conditions. Absence of stress is considered between 9 and 26°C, with moderate stress between 26 and 32°C, and severe stress above 38°C.

The mean radiant temperature was adjusted to account for the effects of the incident and reflected solar radiation on the hypothetical user's body as proposed by several authors [10]. Adjusting the mean radiant temperature considering incident radiation emphasizes the benefit derived from localized shading. Additionally, the model includes the local change of the surface temperature per each surface surrounding the user, considering the incident solar radiation and, obtained through different iterations in EnergyPlus. The average ground surface albedo was established at 0.4 to align with the overarching design principle of minimizing highly reflective surfaces. Surrounding structures, including buildings, maintained an albedo of 0.3. In areas where trees were strategically placed to mitigate solar radiation, they were modeled as solid surfaces with a solar transmittance of 0.3.

3 Results and discussion

3.1 The average cooling capacity: ex-ante and ex-post comparative assessment

According to Ronchi et al., 2020 [11], the urban cooling modeling was run twice considering two different time thresholds. The first one is the T0 time, which corresponds to the current conditions of the project site (disused railway yard) and includes minimal vegetation cover and a high degree of impervious surfaces. The second is the T1 time as a projection of future conditions based on the completion of the Lambrate Park District project. This scenario envisages a complete area transformation including a design analysis of the built environment, materials and green spaces.

The results are expressed in a cooling capacity index, ranging from 0 (no cooling capacity) to 1 (maximum cooling capacity within the study area).

The comparative analysis (Fig. 3) shows a limited performance of the ecosystem in providing a cooling effect in Time T0 except for a spontaneous vegetated area in the southeast part. The cooling assessment based on the future realisation of the project demonstrates a considerable increase in the performance of the ecosystem to reduce UHI. This improvement derives mostly from the presence of permeable green areas (60%) of different types (forest trees, fruit trees, meadows, shrubs, flowering meadows, rows) and by water bodies integrated with the built environment and the system of squares, as well as by the use of semi-impermeable materials (draining asphalt present in 12% of the area) for the pedestrian paths and internal roads within the area which hypothesizes the future conditions of the area once the Lambrate Park District project has been completed.

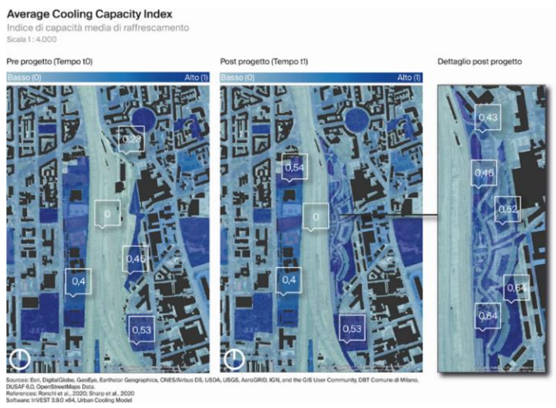


Fig. 3. Average Cooling Capacity Index in two different temporal thresholds: time T0 (on the left) and time T1 (on the right). Scale 1:4.000. The assessment expresses the ecosystem's performance in counteracting the rise in temperatures by reducing heat island effect and contributing to urban cooling.

The average urban cooling values highlight the excellent performance of the southeastern area in mitigating temperature rises due to a design of green spaces characterized by abundant, primary dense, and tall trees. Differently, the northern area of the project has lower cooling values (just under 0.5) than the southern one due to the greater use of waterproof pavements and smaller built spaces and green areas. Finally, it is evident that the built environment, often recognized as contributing to rising temperatures, effectively maintains favourable cooling conditions within the Lambrate Park District. This achievement is attributed to the adopted settlement morphology, which incorporates permeable surfaces in internal courtyards used for greenery. These features, combined with natural air movement, significantly enhance climatic comfort, offering important benefits for future residents.

3.2 The effects of trees on thermal comfort

The intensity of directly perceived solar radiation depends not only on the position of the sun but also on the user's position within the context. The orientation of the project lot is defined along the north-south axis, with buildings in Lambrate Park District having greater height in the eastern portion. These volumes shield direct solar radiation throughout the year and during the early hours of the day. On a typical summer day (June 21st), hours of direct radiation incidents on the surfaces of the lot were evaluated, identifying the surfaces most exposed to radiation. The contribution of radiation to the lot was then analyzed, identifying areas with a higher frequency of occurrence, namely greater exposure to solar radiation (Fig. 4).

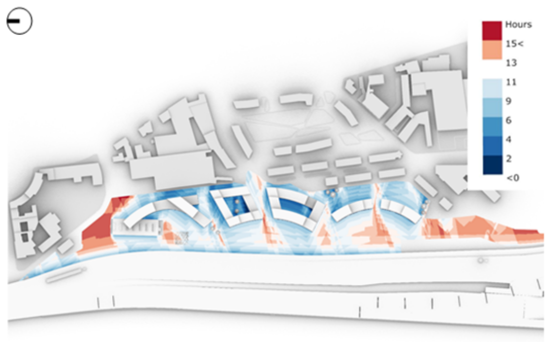


Fig. 4. June 21st - Cumulative hours of direct radiation on the lot - Scenario without vegetation. This scenario assumes zero reflectance from surfaces but evaluates solar access. The site area is divided into a 5x5 meter grid, with each grid cell accumulating the total hours of direct sunlight exposure on its surface.

Based on the preliminary analysis of the proposed plant species for the reference lot, considering their growth curve and dimensional ratios, an hourly preliminary analysis was conducted.

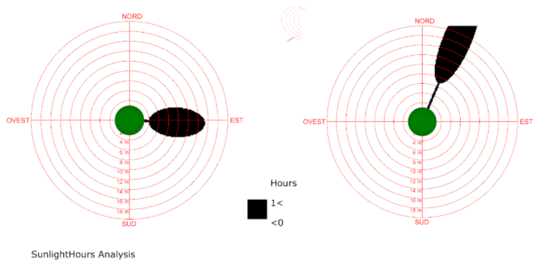


Fig. 5. Shading effect of the same tree in different seasons (21th June 17:00 on the left - 21th December 14:00 on the right). This is an example of the analysis repeated of all the

geometrical aspect ratios listed in Fig. 2. The purpose is to size the length and the effect of the shadow.

This aimed to understand, the various growth stages of the plants, the potential maximum shading on the square or pathways, and the distance from the trunk that could be relied upon to delineate a shaded area. (Fig.5)

Based on the preliminary analysis of the proposed plant species for the reference lot, considering their growth curve and dimensional ratios, an hourly preliminary analysis was conducted.

Consequently, the study results were integrated into the architectural design concepts of the four squares of the lot and the distribution of greenery, identifying relaxation areas and areas with different levels of activity and user engagement (Fig. 6).

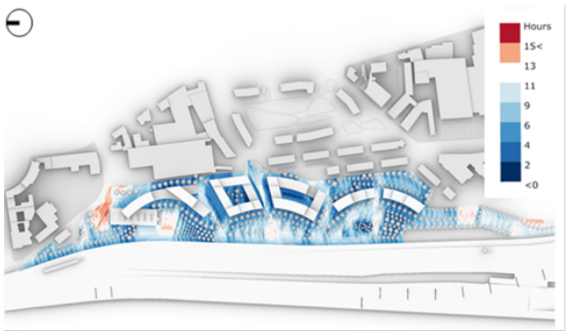


Fig. 6. June 21st - Cumulative hours of direct radiation on the lot - Scenario with vegetation.

All selected trees and their respective geometries have been incorporated into the model. Please refer to the caption of Figure 4 for descriptions of other figures. Along main communication routes and in urban forest areas, tall trees will provide both shade and adequate air circulation in the area. "Protected" paths will therefore connect, in a branched manner, the most social places within the project site, increasing the spatial and temporal usability of the city. This approach also mitigates the effects of the typical urban summer situation, allowing sensitive groups such as children and the elderly to enjoy outdoor areas not only in the early morning and evening hours, thus contributing to solving a clear social problem. During winter months, however, solar radiation availability will be renewed during the few daylight hours, thanks to radiation permeability resulting from the use of predominantly deciduous plants. The use of deciduous plants will also impact the energy needs of the lot's buildings, shading the peak radiation exposure from a westward orientation and certain building floors during the summer months. Losing leaves in winter, the plants will allow incident solar radiation to filter through, also favoring natural light availability.

In Figures 7 and 8, it is possible to understand on an hourly basis and over a period of days between May 1st and September 30th, the effect resulting from the absence (Fig. 7) or presence (Fig. 8) of greenery in the relaxation area of the Spectacle Square. For the analysis, we used validated historical climatic data, representative of the current climatic condition of temperature, humidity, radiation, and wind speed, but with a condition of vegetation in full development. The objective was indeed to show the variation in the profile given by the potential shading when the vegetation will be developed, and not to derive the absolute value of comfort temperature. For safety reasons, we did not consider the local mitigation of air temperature due to plant evapotranspiration. Another limitation is due to the lack of a detailed wind velocity analysis at the site.

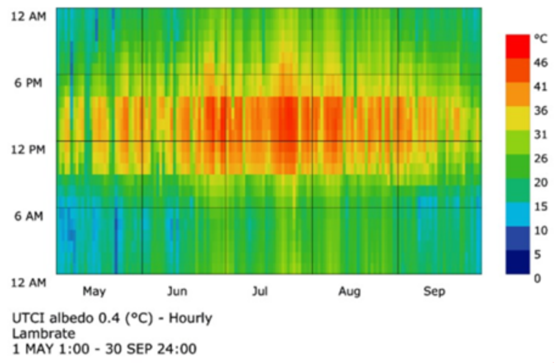


Fig. 7. From May to September: Hourly distribution of UTCI values for the relaxation area of Spectacle Square, in the absence of vegetation. During the summer months, there is a noticeable extension of the discomfort period, particularly during the central hours of the day.

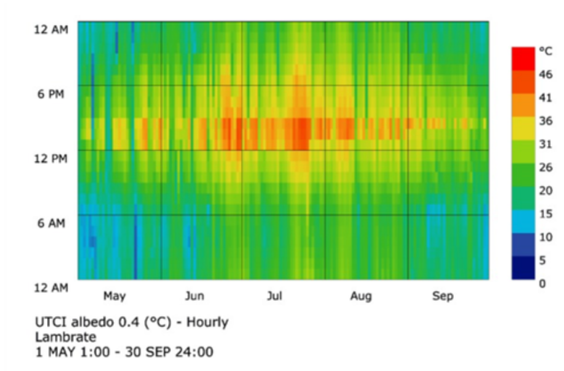


Fig. 8. From May to September: Hourly distribution of UTCI values for the relaxation area of Spectacle Square, in the presence of vegetation.

The presence of trees and their shading effectively decreased the number of hours of exposure and limited solar radiation access over the plaza.In this specific case, for the calculation, we chose the user's position at an urban furniture in the area, in order to have a faithful representation of a hypothetical characteristic situation. It is immediately noticeable that, in the presence of vegetation, the number of hours of discomfort decreases significantly, especially in the central hours of the day and for all months considered, thus increasing the hours of usability of spaces in comfortable conditions.

4 Conclusions

The greenery creates a natural environment where plant and animal species can find habitat, developing in harmony with the surroundings and fostering conditions of biodiversity. It represents an essential tool for environmental mitigation and compensation in a city where high building density and significant anthropogenic disturbance leave little space for natural dynamics. Green elements also serve as connectivity components within the city, making it permeable to the passage and residence of both animal and plant organisms.

Increasingly dense greenery in relaxation areas allows users to choose their preferred exposure, such as the presence of a forest and the adoption of interconnected water basins represents an additional mitigation strategy for highly exposed surfaces, leveraging the possibilities of evaporative cooling.

There is indeed significant interest in the role that urban forests and woodlands can play in modifying the urban microclimate. In fact, both the shade from trees and the evapotranspiration of plant organisms influence local energy flows and mitigate microclimatic conditions, with beneficial effects on human health and outdoor comfort. Future iterations should also consider the induced air movements and the induced wind velocity due to the weather location, local temperature changes, and building geometry.

5 Lessons learnt

Key insights gleaned from the preceding analysis can be succinctly summarized as follows:

- Identification of the direction of prevailing winds to shield in winter and promote circulation in summer.
- Reduction of surface sealing, favoring permeable surfaces with water accumulation to exploit evaporative cooling (latent). Caution should be exercised, as these surfaces have high solar absorption.
- If low albedo values are utilized for surfaces, increase local shading through large-canopy trees. The reduction of canopy can be compensated by improving local wind speed.
- Use of green pavements, reinforced lawns, and planning rows both along the perimeter (for walkways) and on internal surfaces, selecting autonomous species resistant to both climate and pollution.
- Arrangement of local areas for cooling/water elements for local mitigation, facilitating the creation of microclimates.
- It is important to plan for climate-proof vegetation depending on the location and with a low allergen content.
- The growth stages of plants and their long-term effects must be considered to avoid destructive interference between species.
- Seasonal mitigation of local temperatures could promote the activation and maintenance of passive building operation strategies.

Acknowledgements: The authors express their gratitude to Benedetta Tagliabue and her team at Benedetta Tagliabue - EMBT Architects for their invaluable support in developing the architectural and urban planning aspects. Special thanks are also due to Co-inventing Doria S.r.l., acting as the project's promoter, for enabling our research within the 'Lambrate Park District' initiative. Additionally, sincere appreciation is extended to the extensive working group that facilitated coordination among numerous engineering disciplines, with particular recognition to all colleagues at Politecnico di Milano and Tecneas Studio - Integrated Building Design.

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