MISSIONE 4
ISTRUZIONE
RICERCA

CLIMATE RESILIENT STRATEGIES BY ARCHETYPE-BASED URBAN ENERGY MODELLING

Climate resilient UHI mitigation strategies and building technologies

DELIVERABLE 4.1

This study was carried out within the «Climate Resilient Strategies by Archetype-based Urban Energy Modelling (CRiStAll)» project – funded by European Union – Next Generation EU within the PRIN 2022 PNRR program (D.D.1409 del 14/09/2022 Ministero dell'Università e della Ricerca), M4C2, I 1.1. This manuscript reflects only the authors' views and opinions and the Ministry cannot be considered responsible for them.

www.cristall.polito.it

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
Politecnico di Torino

Index

1. INTRODUCTION

1.1 Purpose

Global climate change leads to increased ambient temperatures, causing buildings to overheat and demand more energy while worsening indoor environmental quality. Urban Heat Island (*UHI*) effects, caused by local warming in urban areas, further exacerbate these challenges. Existing Urban Building Energy Modelling (*UBEM*) struggles to address *UHI* due to limited data on microscale climatic conditions and detailed mapping of urban areas. The CRiStAll project aims to address these gaps by creating detailed climatic datasets and exploring different urban configurations at the microscale.

Under the CRiStAll project, three interconnected research lines are developed. These include:

(A) building an urban climate model that incorporates the impacts of the Urban Heat Island (*UHI*) at the microscale, as well as the short-, mid-, and long-term (future weather data) consequences of climate change;

(B) putting the archetype-based Urban Building Energy Model (*UBEM*) into practice using typical urban environment configurations (street canyons);

(C) evaluating the impact of climate resilience and *UHI* reducing methods in urban locations.

Within Work Package 4, “Resilient and Mitigating Strategies,” which addresses Research Line C, the effect of climate-resilient *UHI* mitigation strategies in urban context configurations will be evaluated across short, mid, and long-term scenarios. Task 4.1, “Definition of Climate-Resilient and Mitigating Strategies,” focuses on analysing and selecting the most effective climate-resilient cooling strategies to tackle the challenge of mitigating *UHI* effects both in the present and in a warming future. Furthermore, an evaluation of the benefits and limitations of the identified categories of cooling strategies is included.

1.2 Deliverable structure

This deliverable is structured into three sections, outlining the analysis and selection of climate-resilient cooling strategies to address Urban Heat Island (*UHI*) effects in both the present and a warming future. Section 1 serves as the introduction, detailing the purpose (1.1), deliverable structure (1.2), and partner contributions to Task 4.1 development (1.3). Section 2 focuses on the identification and description of climate-resilient and *UHI*-mitigating strategies, categorized into nature-based (2.1), grey (2.2), and soft solutions (2.3). Lastly, Section 3 presents a comparative analysis of these strategies, evaluating their effectiveness, benefits, and limitations for application in urban context configurations.

1.3 Contribution of partners

POLITO led the task and wrote the deliverable with contributions from the partners involved. It carried out the categorization and the state-of-the-art analysis of different climate-resilient cooling strategies.

UniTS participated in the analysis and categorization of climate resilient cooling strategies, focusing on the indoor environment and physiological aspects of residents, considering comfort and health issues, with a focus on fragile people. UniTS also contributed to drafting this deliverable.

2. CLIMATE RESILIENT AND UHI MITIGATING STRATEGIES

The challenges of global climate change and urbanization, particularly the Urban Heat Island (UHI) effect, demand innovative and integrated strategies to mitigate their impacts effectively. To accelerate the transition toward resilient built environments, it is essential to support and mainstream low-energy and low-carbon cooling systems. As outlined by IEA-EBC Annex 80, climate-resilient cooling solutions are those that mitigate the negative environmental impacts while also adapting to future scenarios to address and prevent emerging risks proactively.

This section introduces three main categories of climate-resilient strategies: nature-based solutions (leveraging natural systems), grey solutions (referring to design and interventions in the built environment), and soft solutions (operational and behavioural measures). These strategies collectively aim to combat urban overheating, improve energy efficiency, and enhance thermal comfort across diverse urban contexts.

2.1 Nature-based solutions

2.1.1 Green infrastructure

Green infrastructure (GI) has proved to be among the most effective solutions to alleviate the impacts of UHI caused by excessive urbanisation (Figure 1). Different factors can create variations in the effects of GI on reducing the UHI risk. A study by Gunawardena et al. (2017) shows that GI has an effective cooling effect on urban areas through evapotranspiration, shading, and increased surface roughness. Greenspaces that are dominated by trees are particularly beneficial in reducing heat stress during peak periods. The other determinant variables are the size, geometry, and spatial distribution of greenspaces, which can significantly influence the overall cooling impact. The study shows that although vegetated surfaces on buildings, such as green roofs and walls, provide localized cooling within the urban canyon scale, their broader impact on urban heat reduction remains limited as their cooling effects are confined to their immediate surroundings. The study suggests policymakers to prioritise urban greening initiatives and safeguard peripheral greenspaces to enhance climate resilience. Tiwari et al. (2021) examine the effects of existing and hypothetical GI on UHI formation, considering baseline GI coverage, a no-GI scenario, and hypothetical implementations of green roofs, grasslands, and tree cover. In line with the previous study, results reveal that trees are the most effective GI for UHI mitigation, reducing temperature by up to 2°C compared to grasslands. Green roofs, while limited in their impact at the city scale, demonstrate potential for localized temperature reductions. The study highlights that temperature variations are influenced by land use, anthropogenic heat emissions, and GI characteristics, emphasizing the importance of strategic GI planning for UHI risk mitigation.

Demuzere et al. (2014) emphasize the multiple benefits of green infrastructure, showing its ability to balance water flows, provide thermal comfort, and their effect on CO_2 capture. The study reveals that these benefits vary across cities and neighbourhoods. Sharma et al. (2016) conducted simulations in the city of Chicago to analyse the effect of green roofs on mitigating UHI risk, revealing that we can reduce daytime roof temperatures up to 3 °C by increasing the fraction of green roofs. However, the study also warns that green roofs might reduce air mixing, which could lead to poor air quality near the surface. The spatial configuration influenced by planning traditions of urban green infrastructure is another critical factor that affects the impact of green infrastructure. A study by Nastran et al. (2019) examines the relationship between green land use and UHI magnitude across 302 European cities, showing that the effectiveness of green infrastructure varies across different planning families, with northern and southern European cities showing contrasting outcomes due to variations in vegetation type and forest structure. Northern European cities see less cooling from coniferous forests, while southern cities benefit more from deciduous forests and aggregated green spaces. The study shows the importance of regional climate and the spatial distribution of green spaces in reducing urban temperatures and enhancing climate resilience. Larsen (2015) focuses on the broader societal benefits of green infrastructure, highlighting its role in reducing health risks during extreme heat events, particularly for vulnerable populations. This study stresses the importance of comprehensive planning to integrate green infrastructure effectively into urban spaces, guaranteeing improved air quality, enhanced stormwater management, and social equity.

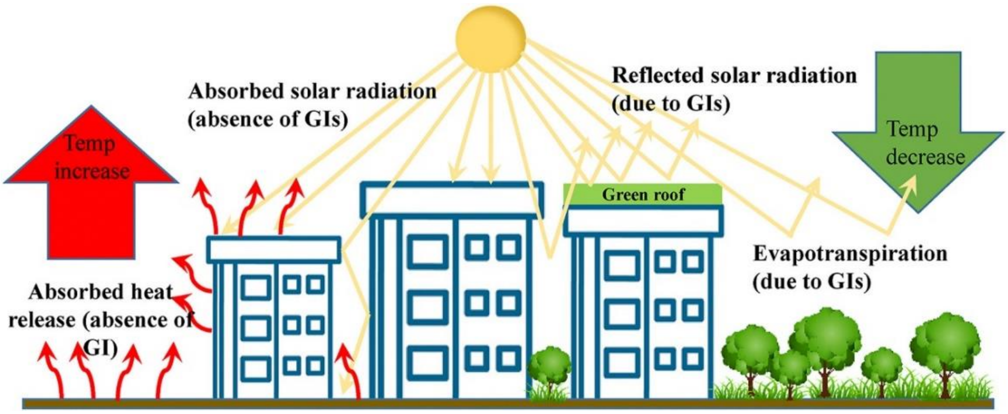

Figure 1: Mitigating Urban Heat Island Effects Through Green Infrastructure Strategies (source: Tiwari et al., 2021)

In summary, these studies emphasize the critical role of green infrastructure in mitigating UHI risk in urban areas, highlighting the importance of strategic implementation tailored to spatial scale to maximize its effectiveness.

2.1.2 Blue infrastructure

Blue infrastructure is effective in mitigating extreme heat in urban areas through evaporative processes and thermal inertia (Gunawardena et al., 2017). The size of water bodies significantly influences their cooling capacity, with larger ones providing stronger and more widespread effects, although they may contribute to nocturnal warming due to slower cooling rates. Wu et al. (2019) highlight a logarithmic relationship between water body size and land surface temperature reduction, emphasizing the critical roles of size and shape in cooling efficiency. Similarly, Antoszewski et al. (2020) analysed factors like water body geometry, location, and urban morphology, advocating for the integration of blue and green infrastructure to enhance cooling effects. Larsen (2015) extends this perspective, noting that blue infrastructure offers additional ecosystem services such as stormwater management, air quality improvement, and aesthetic benefits, making it a vital nature-based solution for mitigating UHI and climate change.

2.2 Grey solutions

2.2.1 Reflective cooling materials

Reflective cooling materials play a critical role in combatting the urban heat island (UHI) effect by minimizing heat absorption on surfaces. These materials are particularly effective on buildings and pavements, where they help lower surface temperatures, enhance thermal comfort, and reduce both cooling energy demand and peak electricity usage. In a study, Synnefa et al. (2007) highlight that solar reflective and infrared emissivity coatings not only improve building performance but also cool surrounding urban areas, reducing ambient air temperatures and heat stress. Similarly, Levinson et al. (2010) explore "cool-coloured" finishes, which use near-infrared reflective pigments and can lower surface temperatures by as much as 15 °C compared to traditional coatings (see Figure 2 for a comparison of black versus white roof performance).

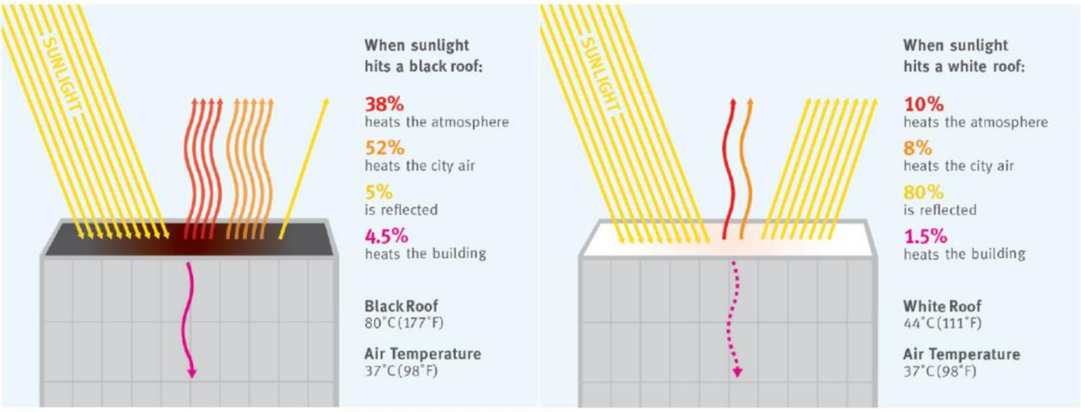

Figure 2: Impact of sunlight on black and white roofs: Distribution of heat absorption, reflection, and emission (source: Global Cool Cities Alliance Guide,2012)

Reflective materials also significantly contribute to increasing urban albedo. Santamouris et al. (2011) discuss their application on roofs and pavements, noting their ability to enhance thermal comfort and improve air quality by reducing smog production and energy consumption. However, they stress the need for thoughtful planning to avoid issues like glare or heat being reflected onto nearby spaces. Li et al. (2013) reinforce these findings, presenting field measurements showing that reflective pavements can reduce surface temperatures by up to 10 °C during peak solar radiation. Their adaptability to various climates and seasons underscores their broad applicability.

Despite these benefits, there are challenges. For example, Khan et al. (2022) warn that reflective materials may lead to overcooling during winter, increasing heating demands. To mitigate this, optically modulated materials with adjustable reflectance and emissivity have been proposed to balance seasonal performance. Furthermore, Yuan et al. (2016) emphasize the role of urban geometry, noting that interbuilding heat reflections can limit the effectiveness of reflective materials, making strategic design and placement crucial.

In summary, reflective cooling materials offer significant potential to mitigate UHI effects by reducing localized and city-scale temperatures. However, to maximize their effectiveness and avoid unintended consequences, careful implementation is required, considering material properties, urban geometry, and seasonal performance.

2.2.2 Solar shading technologies

Solar shading technologies reduce solar heat gain, enhance energy efficiency, and improve thermal comfort in built environments. Solar shading can be provided by urban greenery, building layouts, and facade design. Solar shading technologies can also be integrated with other types of cooling solutions, such as vegetation and photovoltaic systems. For example, solar shading technologies at the urban scale, such as photovoltaic integrated shading strategies (PVIS), provide a dual benefit of generating renewable energy and reducing building cooling loads, which makes them particularly effective in dense cities. By integrating these shading technologies into building facades and optimizing urban block layouts to reduce inter-building shading, cities can achieve significant energy savings and enhance the economic viability of renewable energy systems in urban contexts, especially in compact and high-density areas (Mendis et al., 2020).

Shading devices and facade self-shading strategies can diminish the amount of solar radiation absorbed by urban surfaces so that they help to reduce surface and air temperatures in cities. This mitigates the intensity of the UHI effect, especially in densely built environments (Valladares-Rendón et al., 2017). Another study by Garcia-Nevado et al. (2020) in Cordoba, Spain, demonstrates that urban canopy shadings can lower the ground temperatures of urban pavements by up to 16°C and facade temperatures by up to 6°C, significantly mitigating urban surface overheating. These devices reduce solar radiation absorption in urban canyons (Figure 3), enhancing pedestrian thermal comfort and decreasing cooling energy demands. This study highlights sun sails as a practical, adaptable, and efficient solution for heat mitigation in dense urban environments.

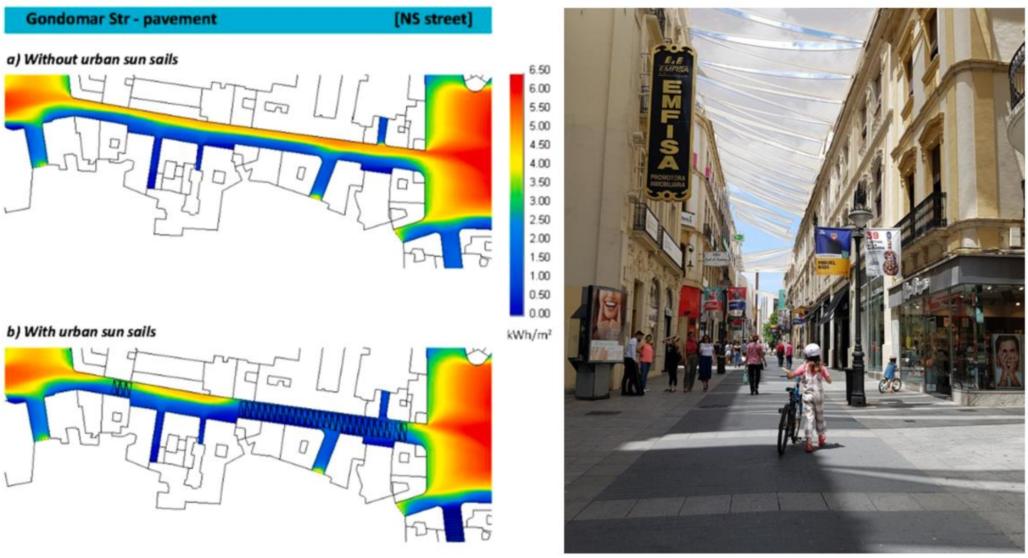

Figure 3: the effectiveness of urban solar shading devices on direct solar radiation impinging over the pavement in a street in Spain. Gondomar St between 15 May and 15 September, with and without urban canopy shading (source: Garcia-Nevado et al., 2020)

At the building level, solar shading systems can effectively mitigate the amount of solar radiation entering the building, reduce peak and average loads, and consequently decrease cooling energy use in actively cooled buildings, thereby helping to mitigate waste heat emissions into urban environments.

2.2.3 Ventilative cooling

Ventilative cooling can help combat the UHI risk by utilizing natural or mechanical airflow to reduce temperature. In urban environments, ventilative cooling reduces localized temperatures and improves pedestrian thermal comfort by enhancing airflow and dispersing heat and pollutants (Mirzaei et al., 2012; He et al., 2020; Hsieh et al., 2016). As Zhan et al. (2020) suggest, field studies and Computational Fluid Dynamics (CFD) simulations reveal that ventilation can reduce heat accumulation and enhance the cooling potential of natural breezes, particularly in coastal urban settings. Ventilative cooling in buildings reduces reliance on energy-intensive air conditioning by capitalizing outdoor air-cooling potential from the wind airflow, buoyancy forces, or fans to dissipate indoor heat effectively. Cross-ventilation systems and operable openings help the building to experience significant cooling even during peak summer conditions. This also reduces energy demands while maintaining thermal comfort (Zhang et al., 2021a; IEA EBC Annex 80 technology profiles, 2024). Naturally ventilated buildings do not emit waste heat into the urban environment and, in this way, have a smaller UHI footprint in comparison to air-conditioned ones. Ventilation corridors further support these buildings by stopping the re-circulation of heated air from surrounding areas (Duan et al., 2020). The integration of ventilative cooling technologies with green facades or green roofs enhances evaporative cooling effects, resulting in a reduction in internal and external temperatures and more thermal comfort. The other benefit of this integrated approach regards energy consumption reduction, offering a sustainable solution to urban heat risks.

In addition, air movement inside occupied areas could be a viable solution to reduce comfort or health problems due to high temperatures. Airflow can be created by windows opening, when external conditions are favourable, or by electrical ventilators. In the literature, the use of electrical ventilators has emerged as a viable alternative to air conditioning, or at least to reduce health problems due to high temperatures. Their use is characterized by low energy consumption and lack of impact on urban heat island, representing a more economical and viable alternative to mechanical cooling. World Health Organization (WHO), however, has expressed concerns about the effectiveness and safety of electric fans in high-temperature conditions, particularly when the temperatures surpass 35 °C; nevertheless, some research demonstrated that such temperatures are too low, therefore increasing the usability of such technique.

Several investigations have been conducted to analyse the effectiveness of various categories of fans. Tadepalli (2021) conducted experiments with ceiling mounted fans, demonstrating their capacity to mitigate thermal discomfort and reducing the dependence on air conditioning. To analyse the effect of ventilators on persons and to identify areas where the use of ventilators is beneficial, Morris (2021) devised a biophysical model to propose the optimal usage of fans for efficient cooling in various regions worldwide. Even if this research considered only external environments, neglecting the effect of buildings, its results showed that electrical ventilators could be effective in large areas of the globe. A similar approach, but using the Gagge (1971) biophysical model, was followed by Tartarini (2022) to corroborate the safety of electric fans in cooling individuals during heat waves. Jay (2015) further expanded on this issue by creating a model to evaluate the usability of fans during heatwaves, concluding that the protective advantages of fans may be underestimated by current guidelines.

2.2.4 Glazing technologies

Glazing technologies are effective because of their significant impact on cooling energy consumption, peak cooling loads, and occupant comfort. Above all, glazing technologies contribute to mitigating the waste heat emissions into urban environments since they reduce the reliance on energy-intensive air conditioning systems. In particular, designing advanced glazing technologies helps both optimize natural daylight and limit heat transfer into indoor spaces since they absorb, transmit and reflect certain portions of solar radiation based on the materials that are used for their construction. Fixed and dynamic advanced glazing technologies are the two general categories available. Fixed glazing technologies do not adapt to changing environmental conditions because of their static optical and thermal properties, while dynamic ones can shift and adjust their features as the environmental characteristics change. In addition, the properties of dynamic glazing technologies like smart windows can be transformed using active controls (Zhang et al., 2021a). Their operation is flexible and based on various factors, including independent modulation of visible and near-infrared transmittance. This adaptable design allows the system to reduce the heat gain but provide daylight in warmer climates, and, on the other side, improve performance in colder climates (Liu et al., 2021). In addition, glazing technologies can be integrated with advanced innovations such as photovoltaics. In this way, they encompass a dual benefit by both controlling solar heat gain and generating renewable energy (Lunt et al., 2021).

2.3 Soft solutions

Soft solutions for UHI risk mitigation include public behaviour advice, behavioural adaptations, and urban planning policy revisions, which are helpful and can complement infrastructural or hard solutions. As Zhang et al. (2021b) suggest, UHI education campaigns can play a crucial role in raising awareness about UHI impacts. They highlight the importance of utilizing accessible online and offline platforms to disseminate knowledge about the necessity of UHI risk reduction. More general, public awareness can drive pro-environmental behaviour and encourage participation in UHI adaptation and mitigation programs. In the same line, Parsaee et al. (2019) show the positive role of public engagement and education in the Urban Heat Island (UHI) mitigation strategies. Accordingly, urban climate governance is responsible for raising awareness regarding the adverse impacts of urban climate risks. Better public knowledge and awareness of the impacts of climate risks can improve community support for mitigation and adaptation strategies, align climate adaptation plans with local needs and preferences, and make governments more responsible. On the policy front, several solutions can be considered, including the adoption of integrated urban climate policies that align with broader city objectives, such as sustainability and public health, to ensure both widespread acceptance and successful implementation (Corburn, 2008). Furthermore, effectively transferring knowledge to policymakers and decision-makers is essential to bridging the gap between scientific advancements and the practical realities of urban planning.

3. COMPARATIVE ANALYSIS OF STRATEGIES

Section 3 presents a comparative analysis of the selected strategies, evaluating their benefits and limitations within the context of defined urban configurations in Task 3.1. The assessment incorporates insights from previous studies to emphasise their effectiveness and applicability.

3.1 Nature Based Solutions

The effectiveness of Blue and Green Infrastructures in decreasing the UHI effect depends heavily on the local environment and is usually dependent. Kumar et al. (2024) performed a thorough review of the literature about green and blue infrastructures for UHI mitigation, highlighting the different characteristics and usability. The analysis also suggested that implementing both strategies can bring co-benefits. However, some disadvantages, such as the increase in mosquitoes and pollen dispersion, should also be considered. Comparing different approaches, they pointed out that green walls and roofs, street trees and parks are more effective in reducing temperatures than attenuation ponds, pocket parks and shared open space since these solutions while giving rise to some degree of temperature reduction, are affected by great uncertainty. Similar results were indicated by Gunawardena et al. (2017), who noted that blue infrastructure can lead to temperature rise at night and towards the end of summer, suggesting that greenspace could give a greater benefit than blue infrastructures. But also, green infrastructure can behave in a different manner. Dealing with green infrastructure, Tiwari et al. (2021) suggested that the trees, thanks to the shading effect below the canopy, are a better solution compared to other green infrastructure solutions, such as grass cover.

3.2 Grey and green solutions

3.2.1 Cool roofs and green roofs

In literature, green roofs and cool roofs performance is often compared since they operate both on the same structural element. Wang et al. (2022) compared the two technologies and sentenced that, especially at night, cool roofs outperform green roofs in lowering urban temperatures. However, both strategies led to lower wind speed, lower mean radiant temperature, and higher relative humidity. The authors also stressed the requirement for cool roofs for periodic cleaning and green roofs and the importance of daily irrigation. Less definitive are the results of Jia et al. (2022), which consider cool roofs and green roofs both as energy-efficient strategies. However, they noticed that outdoor environmental conditions heavily affect green roofs since their effectiveness depends on the growth and health of plants. The efficiency of cool roofs in limiting the temperature is less affected by environmental parameters since it depends on the reflective characteristics of surfaces. In hot and sunny regions, both cool roofs and green roofs can reduce energy demands throughout the year. However, care should be taken in cold regions since cool roofs may increase heating consumption. From a practical point of view, the authors found that cold roofs are a cost-effective option, but green roofs are better suited to reduce UHI effects, with further improvement in air quality and possible stormwater management, with a positive effect on roof durability.

3.2.2 Solar shading and glazing technology technologies

Shading devices can be used at both city and building levels. Urban shading can be achieved by shading from buildings, trees and artificial shade. Shading from a building depends on the geometry and distribution of buildings. Shading devices such as sails and canopies are a strategy for urban cooling, and their use is similar to the use of nature-based green solutions, providing shade in localized areas but with greater flexibility (Nicholson et al. 2024). At the building level, fixed or movable shading devices can be compared to smart glazing technology as the main effect is to reduce incoming radiation to limit the energy consumption of air conditioning systems. However, when dealing with shading devices and glazing systems, daylighting issues should also be considered. The two technologies are merged together in some advanced windowing systems (Zhang et al., 2021a). Manzan (2014) performed an optimization to find the optimal geometry of external panel shading devices considering different glazing systems and daylighting issues. Moveable shading devices, external or internal, are also effective in reducing glare problems, as Manzan et al. (2017) considered the coupling of fixed and moveable shading devices to deal with energy consumption for air conditioning and artificial lighting while controlling glare. The same result was obtained by Lu (2024), who stated that a combination of electro-chromic glazing and blinds in particular conditions showed better performance considering visual, thermal, and energy factors.

3.2.3 Solar shading and ventilative cooling

Ventilative cooling is a solution that can be coupled with other strategies to limit the discomfort inside buildings, preventing the use of mechanical air conditioning. Typically, it can be used in combination with solar shading, which prevents or reduces the heating of internal walls and floors due to solar radiation. However, the efficiency in reducing internal temperatures relies on the efficient control of the activation of shading devices and window openings for natural ventilation. In this regard, van Moeseke et al. (2007) focus on the control system that must be carefully selected based on the building’s characteristics and weather data. The same approach holds when dealing with the use of electric fans that can be considered an integration for natural ventilation of buildings when the external wind conditions don’t allow a natural flux of air inside rooms.

3.3 Soft, natural and grey solutions

Nature-based and hard solutions cannot be effective without the implementation of soft solutions. These involve public administration and authorities that can implement the solutions and raise awareness of UHI risks for the population. Among public initiatives, the Covenant of Mayors Palermo (2000) is widespread, committing municipalities to develop plans to reduce the effect of climate change and implement natural solutions. Public administration is also important in providing information on the possible mitigation of high temperatures in UHI and in issuing alerts in case of dangerous situations affecting people's health.

4. REFERENCES

Antoszewski, P., Świerk, D., & Krzyżaniak, M. (2020). Statistical review of quality parameters of blue-green infrastructure elements important in mitigating the effect of the urban heat island in the temperate climate (C) zone. *International Journal of Environmental Research and Public Health*, 17(19), 7093.

Corburn, J. (2009). Cities, climate change and urban heat island mitigation: Localising global environmental science. *Urban studies*, 46(2), 413-427.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., ... & Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of environmental management*, 146, 107-115.

Duan, S., Luo, Z., Yang, X., & Li, Y. (2019). The impact of building operations on urban heat/cool islands under urban densification: A comparison between naturally ventilated and air-conditioned buildings. *Applied energy*, 235, 129-138.

Gagge, A. P. (1971). An effective temperature scale based on a simple model of human physiological regulatory response. ASHRAE Trans., 77, 247-262.

Garcia-Nevado, E., Beckers, B., & Coch, H. (2020). Assessing the cooling effect of urban textile shading devices through time-lapse thermography. *Sustainable cities and society*, 63, 102458.

Global Cool Cities Alliance. (2012, January). A practical guide to cool roofs and cool pavements. Retrieved from https://CoolRoofToolkit.org

Gunawardena, K. R., Wells, M. J., & Kershaw, T. (2017). Utilising green and bluespace to mitigate urban heat island intensity. *Science of the Total Environment*, 584, 1040-1055.

He, B. J., Ding, L., & Prasad, D. (2020). Urban ventilation and its potential for local warming mitigation: A field experiment in an open low-rise gridiron precinct. *Sustainable Cities and Society*, 55, 102028.

Hsieh, C. M., & Huang, H. C. (2016). Mitigating urban heat islands: A method to identify potential wind corridor for cooling and ventilation. Computers, *Environment and Urban Systems*, 57, 130-143.

IEA EBC Annex 80. (2018). IEA EBC Annex on resilient cooling for residential and small commercial buildings. Retrieved from https://annex80.iea-ebc.org/

Jay, O., Cramer, M. N., Ravanelli, N. M., & Hodder, S. G. (2015). Should electric fans be used during a heat wave? *Applied ergonomics*, 46, 137-143.

Jia, S., Weng, Q., Yoo, C., Xiao, H., & Zhong, Q. (2024). Building energy savings by green roofs and cool roofs in current and future climates. *Npj Urban Sustainability*, 4(1). https://doi.org/10.1038/s42949-024-00159-8

Khan, A., Carlosena, L., Feng, J., Khorat, S., Khatun, R., Doan, Q. V., & Santamouris, M. (2022). Optically modulated passive broadband daytime radiative cooling materials can cool cities in summer and heat cities in winter. *Sustainability*, 14(3), 1110.

Kumar, P., Debele, S. E., Khalili, S., Halios, C. H., Sahani, J., Aghamohammadi, N., Andrade, M. de F., Athanassiadou, M., Bhui, K., Calvillo, N., Cao, S. J., Coulon, F., Edmondson, J. L., Fletcher, D., Dias de Freitas, E., Guo, H., Hort, M. C., Katti, M., Kjeldsen, T. R., … Jones, L. (2024). Urban heat mitigation by green and blue infrastructure: Drivers, effectiveness, and future needs. *The Innovation* 5(2). Cell Press. https://doi.org/10.1016/j.xinn.2024.100588

Larsen, L. (2015). Urban climate and adaptation strategies. *Frontiers in Ecology and the Environment*, 13(9), 486-492.

Levinson, R., Akbari, H., & Berdahl, P. (2010). Measuring solar reflectance—Part I: Defining a metric that accurately predicts solar heat gain. *Solar Energy*, 84(9), 1717-1744.

Li, H., Harvey, J., & Kendall, A. (2013). Field measurement of albedo for different land cover materials and effects on thermal performance. *Building and Environment*, 59, 536-546.

Liu, X., & Wu, Y. (2022). A review of advanced architectural glazing technologies for solar energy conversion and intelligent daylighting control. *Architectural Intelligence*, 1(1), 10.

Lu, W. (2024). Dynamic Shading and Glazing Technologies: Improve Energy, Visual, and Thermal Performance. *Energy and Built Environment*, 5(2), 211–229. https://doi.org/10.1016/J.ENBENV.2022.09.004

Lunt, R. R., & Bulovic, V. (2011). Transparent, near-infrared organic photovoltaic solar cells for window and energy-scavenging applications. *Applied Physics Letters*, 98(11).

Manzan, M. (2014). Genetic optimization of external fixed shading devices. *Energy and Buildings*, 72, 431–440. https://doi.org/10.1016/j.enbuild.2014.01.007

Manzan, M., & Clarich, A. (2017). FAST energy and daylight optimization of an office with fixed and movable shading devices. *Building and Environment*, 113. https://doi.org/10.1016/j.buildenv.2016.09.035

Mendis, T., Huang, Z., Xu, S., & Zhang, W. (2020). Economic potential analysis of photovoltaic integrated shading strategies on commercial building facades in urban blocks: A case study of Colombo, Sri Lanka. *Energy*, 194, 116908.

Mirzaei, P. A., & Haghighat, F. (2012). A procedure to quantify the impact of mitigation techniques on the urban ventilation. *Building and environment*, 47, 410-420.

Morris, N. B., Chaseling, G. K., English, T., Gruss, F., Maideen, M. F. B., Capon, A., & Jay, O. (2021). Electric fan uses for cooling during hot weather: a biophysical modelling study. *The Lancet Planetary Health*, 5(6), e368-e377.

Nastran, M., Kobal, M., & Eler, K. (2019). Urban heat islands in relation to green land use in European cities. *Urban Forestry & Urban Greening*, 37, 33-41.

Nicholson, S., Nikolopoulou, M., Watkins, R., Löve, M., & Ratti, C. (2024). Data driven design for urban street shading: Validation and application of ladybug tools as a design tool for outdoor thermal comfort. *Urban Climate*, 56. https://doi.org/10.1016/j.uclim.2024.102041

Parsaee, M., Joybari, M. M., Mirzaei, P. A., & Haghighat, F. (2019). Urban heat island, urban climate maps and urban development policies and action plans. *Environmental technology & innovation*, 14, 100341.

Palermo, V., Bertoldi, P., Apostoulu, M., Kona, A., & Rivas, S. (2020). Assessment of climate change mitigation policies in 315 cities in the Covenant of Mayors initiative. *Sustainable Cities and Society*, 60, 102258. https://doi.org/10.1016/J.SCS.2020.102258

Psomas, T. (2024). International Energy Agency EBC Annex 80| Resilient Cooling of Buildings–Technology Profiles Report.

Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy*, 85(12), 3085-3102.

Sharma, A., Conry, P., Fernando, H. J. S., Hamlet, A. F., Hellmann, J. J., & Chen, F. (2016). Green and cool roofs to mitigate urban heat island effects in the Chicago metropolitan area: Evaluation with a regional climate model. *Environmental Research Letters*, 11(6), 064004.

Synnefa, A., Santamouris, M., & Apostolakis, K. (2007). On the development, optical properties and thermal performance of cool colored coatings for the urban environment. *Solar Energy*, 81(4), 488-497.

Tadepalli, S., Jayasree, T. K., Visakha, V. L., & Chelliah, S. (2021). Influence of ceiling fan induced non-uniform thermal environment on thermal comfort and spatial adaptation in living room seat layout. *Building and Environment*, 205, 108232.

Tartarini, F., Schiavon, S., Jay, O., Arens, E., & Huizenga, C. (2022). Application of Gagge's energy balance model to determine humidity-dependent temperature thresholds for healthy adults using electric fans during heatwaves. *Building and Environment*, 207, 108437.

Tiwari, A., Kumar, P., Kalaiarasan, G., & Ottosen, T. B. (2021). The impacts of existing and hypothetical green infrastructure scenarios on urban heat island formation. *Environmental Pollution*, 274. https://doi.org/10.1016/j.envpol.2020.115898

Valladares-Rendón, L. G., Schmid, G., & Lo, S. L. (2017). Review on energy savings by solar control techniques and optimal building orientation for the strategic placement of façade shading systems. *Energy and Buildings*, 140, 458-479.

van Moeseke, G., Bruyère, I., & De Herde, A. (2007). Impact of control rules on the efficiency of shading devices and free cooling for office buildings. *Building and Environment*, 42(2), 784–793. https://doi.org/10.1016/J.BUILDENV.2005.09.015

Wang, X., Li, H., & Sodoudi, S. (2022). The effectiveness of cool and green roofs in mitigating urban heat island and improving human thermal comfort. *Building and Environment*, 217. https://doi.org/10.1016/j.buildenv.2022.109082

Wu, C., Li, J., Wang, C., Song, C., Chen, Y., Finka, M., & La Rosa, D. (2019). Understanding the relationship between urban blue infrastructure and land surface temperature. *Science of the Total Environment*, 694, 133742.

Yuan, J., Emura, K., & Farnham, C. (2016). Potential for application of retroreflective materials instead of highly reflective materials for urban heat island mitigation. *Urban Studies Research*, 2016, 1-10.

Zhan, Q., Gao, S., Xiao, Y., Yang, C., Wu, Y., Fan, Z., ... & Zhan, M. (2020). Impact mechanism and improvement strategy on urban ventilation, urban heat island and urban pollution island: A case study in Xiangyang, China. *International Review for Spatial Planning and Sustainable Development*, 8(3), 68-86.

Zhang, C., Kazanci, O. B., Levinson, R., Heiselberg, P., Olesen, B. W., Chiesa, G., ... & Zhang, G. (2021a). Resilient cooling strategies–A critical review and qualitative assessment. *Energy and Buildings*, 251, 111312.

Zhang, L., Yang, X., Fan, Y., & Zhang, J. (2021b). Utilizing the theory of planned behavior to predict willingness to pay for urban heat island effect mitigation. *Building and Environment*, 204, 108136.