URBACT Health&Greenspace network

Health-responsive planning and management of urban green infrastructure

Thematic report No. 3 | August 2021

Urban Heat Stress and Cooling with Green Infrastructure

Authors:

Birgit Georgi *(Strong cities in a changing climate, URBACT Ad-Hoc Expert)*

Tamás Kállay *(Lead Expert of the URBACT Health&Greenspace network)*

The authors of this report were Birgit Georgi (Strong cities in a changing climate, URBACT Ad-Hoc Expert) and Tamás Kállay (Lead Expert of the URBACT Health&Greenspace network).

Key contributors:

Sanda Lenzholzer (Wageningen University, Landscape Architecture and Spatial Planning)

Maria Sitzoglou (UIA Expert, OASIS)

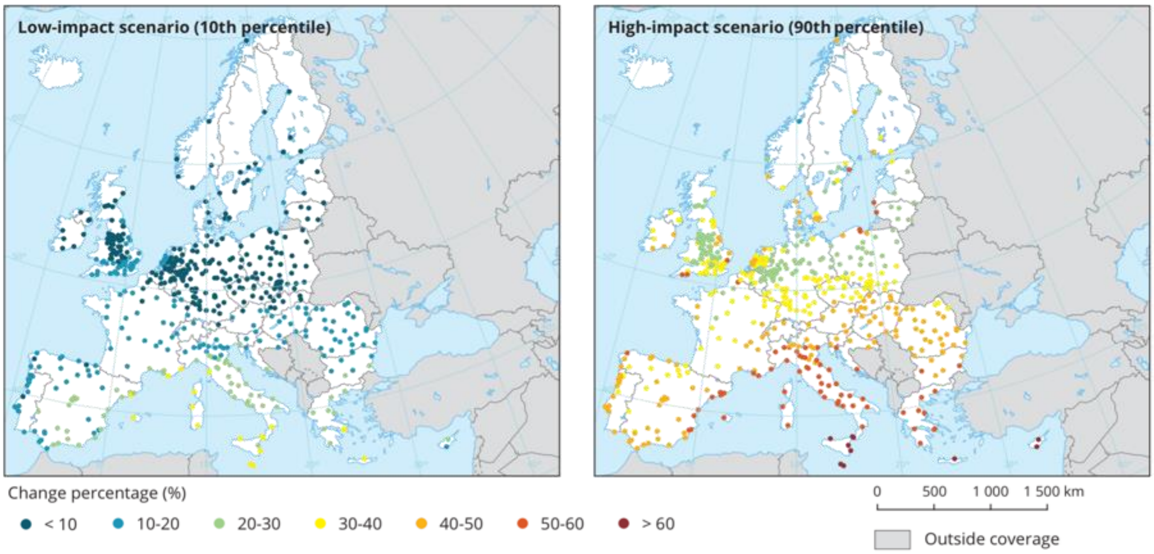
cover image: Jonas Weckschmied, Unsplash

Table of Contents

General context

Climate change and heatwaves

Our world and Europe are warming due to climate change. Apart from the general increase of the annual average temperature, there has also been an increase in the number and intensity of heat waves over the last decade, which is a trend that is projected to continue in the future[1]. The change in the number of heatwave days compared to the current situation will be moderate to high depending on the level of greenhouse gas reductions to be achieved and on the geographic position. While there is a strong north-south gradient in the number of heatwave days, the increase will not only happen in Southern Europe. Even Northern and North-Western Europe will partially face drastic increases (*Map 1*).

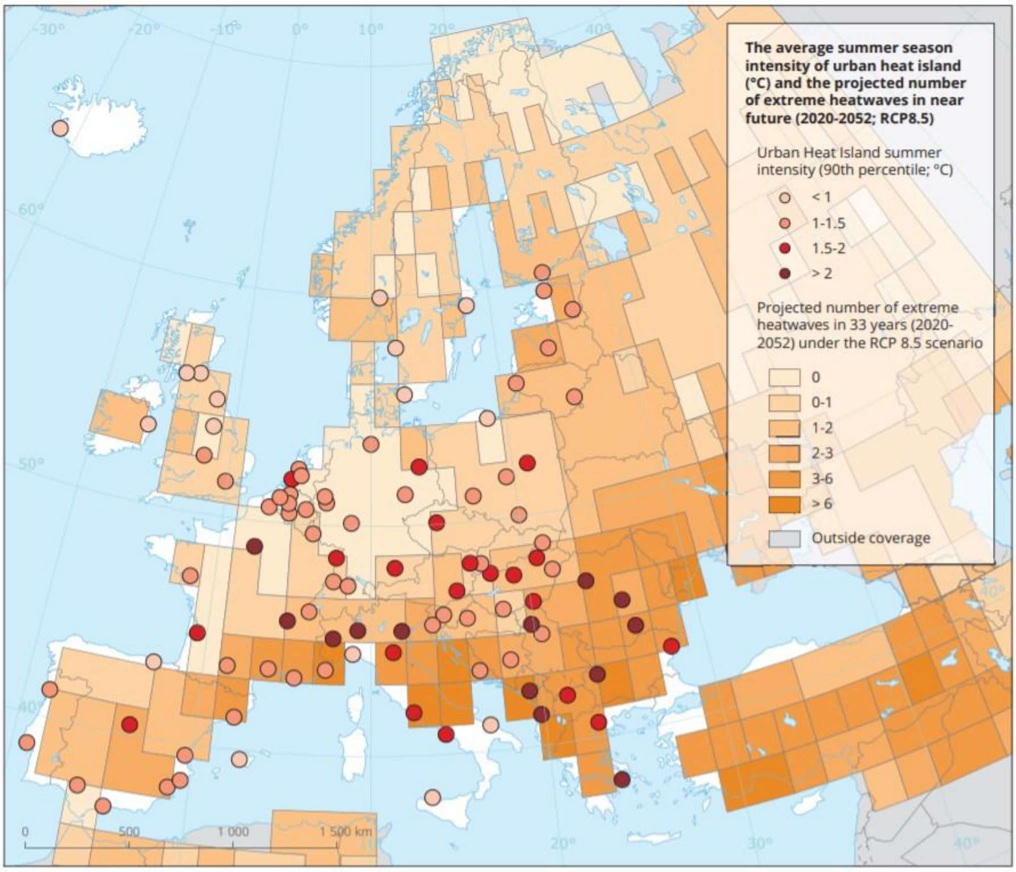


Map 1*. Change (%) of heatwave days between the periods 1951-2000 and 2051-2100 in European cities*

Source: EEA, 2020[2]

Urban heat island effect

The impacts of heat waves are more, sometimes much more pronounced in cities than in the rural hinterland (*Map 2*). Cities across Europe may already experience twice as many heatwave days as their rural surroundings[3, 4]. The reason for this is the so-called urban heat island effect (UHI). It is linked to climate conditions (the average wind speed and the number of sunny days) but caused by anthropogenic heat sources in cities such as cars, industrial processes, exhaust air from cooling processes etc. and the high imperviousness of many urban surfaces made of stone, concrete and asphalt, which absorb and store heat from the sun[5] (*Figure 1*). During the night, these artificial surfaces release the heat, thus, keeping cities warmer than the surrounding rural areas (*Figure 2*). The UHI effect can vary in cities and can reach as much as 9 °C in Europe, e.g., for night-time temperatures measured in central Paris under heatwave conditions[6].



Map 2. *Average summer season intensity of urban heat island and the projected number of extreme heatwaves in near future.*

Source: EEA, 2020[7]

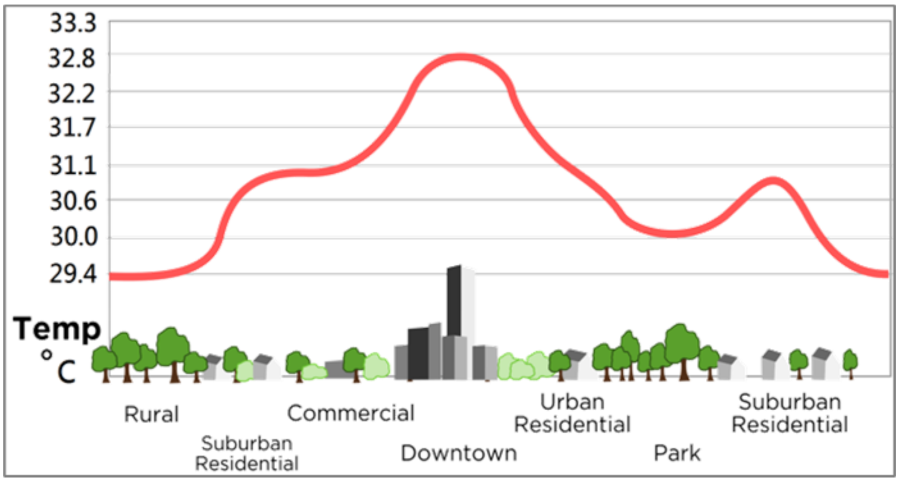


Figure 1: *Scheme of the urban heat island effect.*

Source: Pixabay

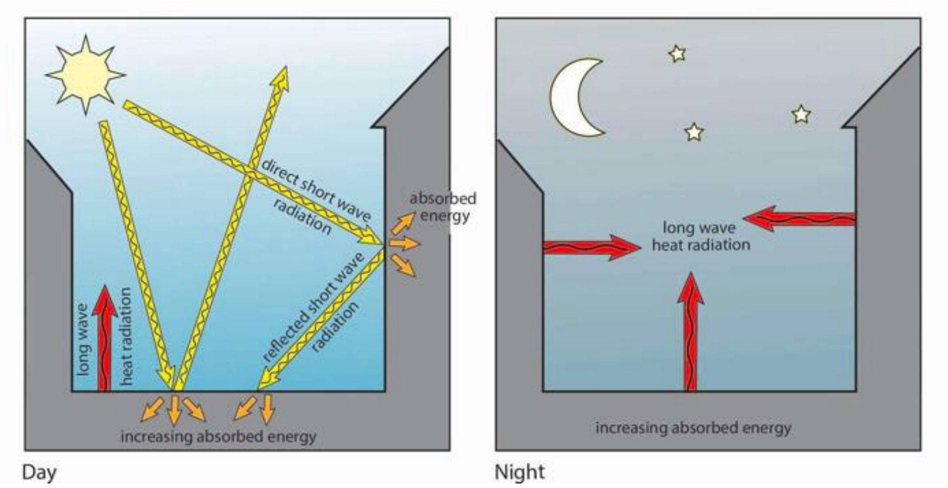


***Figure 2**: Radiation by the sun at day (short wave radiation) and the emission of heat back from the heated surfaces (long wave radiation) at night.*

Source: Sanda Lenzholzer (2015) Weather in the City: How Design Shapes the Urban Climate. nai010 publishers, Rotterdam, p.34.

The amount of impervious surfaces, their materials and urban forms significantly contribute to the differences in the extent of the UHI effect between cities as well as between areas inside cities. For example, concrete, red brick, and sand have a low reflection of sun radiation (albedo), store the energy and have a high emission of this heat load once the radiation from the sun stops (*Table 1*). White surfaces reflect the radiation from the sun and can mitigate the absorption of energy and thus protect building interiors from heating up. However, this reflected energy can – depending on the urban form - hit absorbing surfaces outdoors (as the ones mentioned above) and thus also contribute to the heat load.

Material	Albedo	Emissivity
Concrete	0.3	0.94
Red brick	0.3	0.90
Sand	0.24	0.76
White plaster	0.93	0.91

***Table 1**: Examples for albedo and emissivity for selected surfaces.*

Source: Littlefair, 2000[8]

As a natural effect, warmer air tends to rise, if not blocked, and cooler air will flow in. This effect can be very pronounced over densely built-up city centres, where at night heat released from the absorbing materials rises, while cool air from, e.g., open grasslands can flow in. This is the so-called the chimney effect. In loosely built-up areas and less open surroundings, like in suburban areas, the chimney effect is weaker (*Figure 3*).

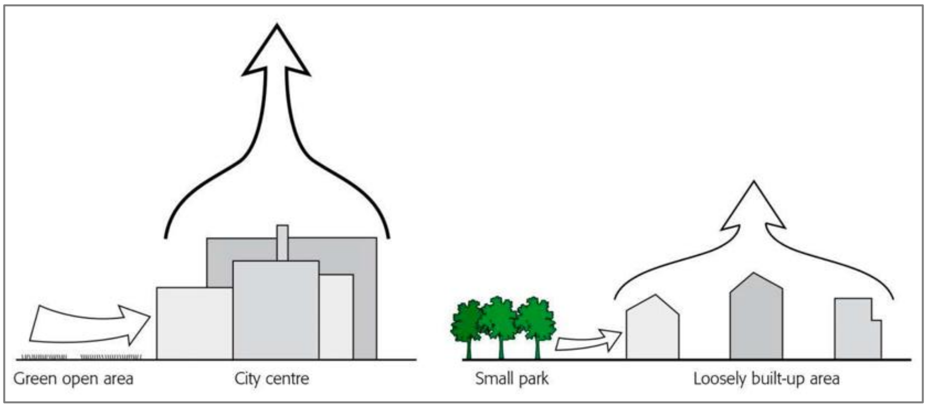


***Figure 3**: Ventilation, local wind systems, chimney effect.*

Source: Sanda Lenzholzer (2015) Weather in the City: How Design Shapes the Urban Climate. nai010 publishers, Rotterdam, p.41.

Heat stress for people

Outdoor heat stress for people is built up by direct or reflected shortwave radiation of the sun and longwave radiation by emitting surface. The load can be altered by the level of humidity and ventilation (*Figure 4*).

Heat stress can be deadly. The 2003 heatwave in Europe killed more than 70,000 people, when outdoor temperatures exceeded 40°C over a longer period. Heat stress for humans is, however, caused by more than just air temperature. If high temperatures appear together with high humidity, it makes it impossible for the human body to sweat and cool down the body temperature, thus, becoming deadly even if the same air temperatures are bearable under lower humidity conditions. Scientist developed the concept of wet bulb temperature that combines both parameters and indicates the lowest temperature to which air can be cooled via evaporation of water into the air. At wet bulb temperatures above 35°C researchers estimate that even fit people will overheat and potentially die within 6 hours. It equates with almost 45°C at 50% humidity. Scientists expect that, due to climate change, places in southwest Asia, India, and China are likely to experience these conditions, but also a couple of Southern European areas have come close to 30°C in past events[9].

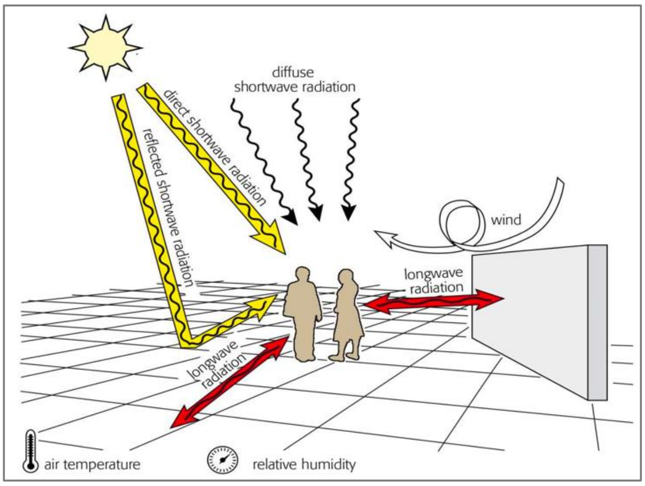


***Figure 4**: Physical thermal sensation.*

Source: Sanda Lenzholzer (2015) Weather in the City: How Design Shapes the Urban Climate. nai010 publishers, Rotterdam, p.22.

Apart from the potential of being deadly, heat stress can also cause other health problems. The impacts are usually stronger among vulnerable people, such as elderly people, younger, and sick people. Health impacts of heat stress include:

- feeling uncomfortable, fatigue or stress and aggressive behaviour
- feeling dehydration
- aggravating cardiovascular, respiratory diseases, kidney diseases or electrolyte disorders and other diseases.[10]

In addition, lower performance and work efficiency is common under heat stress, which has economic impacts. In a typical south-facing office building in Antwerp around 4% of working hours are currently lost due to heat during summer, and the number of hours lost may quadruple by 2100[11].

The potential of green infrastructure to reduce heat stress

Green infrastructure, such as parks and gardens, trees, green facades and roofs, can reduce the heat load in cities. In general, it reduces the heat storage capacity of urban surfaces, reduces air temperature through shading and evapotranspiration of water from the leaves and support the chimney effect and ventilation bringing cool air into the city. EEA, 2020 has analysed sources on the effectiveness of different types of nature-based solutions to reduce heat and found strong evidence that nature-based solutions are moderately and highly effective (*Figure 5*). The UIA project IGNITION[12] has analysed over 1000 sources and collected evidence for cooling for different types of nature-based solutions. Trees and greenspace appear to be in particular effective to cool outdoor air temperatures, but also green facades and green roofs are cooling and protecting materials and decreasing indoor air temperatures (*Table 2*).

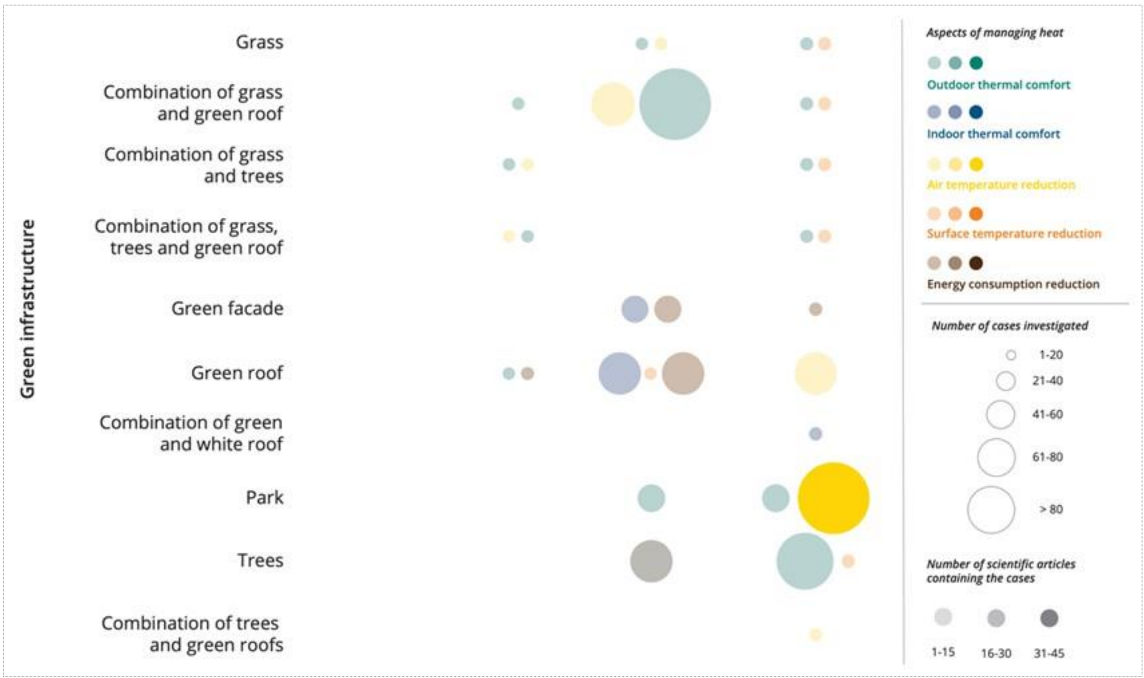


Figure 5*: Effectiveness of different NBS types to reduce heat.*

Source: EEA, 2020[13]

	Indoor air	Exterior wall/surface	Ambient outdoor air
Living wall	4.8	1.0 - 3.0	0.5 - 4.1
Green facade	1.7 - 4.0	0.4 - 7.1	1.0 - 3.0
Green roof extensive	2.0 - 4.0	2.0 - 20	0.5 - 1.5
Green roof intensive	0.3 - 4.0	7.0 - 22.0	average 1.0, max. 4.2
Trees		10.0 –12.0	0.9 - 5.2 (globe temperature: 3.8 - 15.0)
Urban green space			daytime: 0.5 – 7.0; nighttime: 1.2

Table 2: Reduction in Temperature in °C; IGNITION project's evidence base.

Source: IGNITION[14]

Box 1 - Salzburg's urban climate model helps combat overheating

The city of Salzburg developed an urban climate model under the ADAPT-UHI project that was funded from 2018 to 2020 by the Climate and Energy Fund of the Austrian Climate Research Programme (ACRP). The model served to identify potential urban heat islands in the future and to simulate the effects of different adaptation measures on reducing the number of summer days (with temperatures over 25 °C) and hot days (with temperatures exceeding 30 °C).

The average number of hot days per year has increased significantly in Salzburg over the last couple of decades, and with a changing climate this trend is expected to continue. The climate model helps the city to prepare for the future and to plan adequate combination of adaptation measures.

The impacts of three distinct scenarios were assessed under ADAPT-UHI. Measures under the White City scenario increase the reflectivity of artificial surfaces such as roofs, walls and streets and sidewalks. The Green City scenario was based on the application of measures that increase the evaporative cooling of the city through increasing urban vegetation and unsealing surfaces. The third, Combination scenario included all the measures from the White and Green City scenarios.

The key findings from the modelling for Salzburg has indicated that the application of the combined adaptation measures (Combination scenario) that include the doubling of the reflectivity of sealed surfaces such as roofs, walls and pavements; the reduction of sealed surfaces by 30%; greening 50% of rooftops; increasing the number of trees by 50%; and replacing bare soil with grass, will result in the same number of hot days in 2050 as in 1981-2010. The results suggest that massive greening measures that are smartly planned can effectively hinder or at least substantially moderate overheating of cities in the future. There is even a chance that the denser urban areas of the city could be even cooler than in the historical period.

Source: ADAPT-UHI. https://adapt-uhi.org/[15]

Cooling by vegetation happens in two ways - by **evapotranspiration** and shading. When the sun radiation hit the trees' canopy it causes water to evaporate from the surface of leaves. In addition, during transpiration, water moving through a plant is converted from liquid into gas as it passes through small openings on the undersides of leaves[16]. This process of direct evaporation at the ground and on plant surfaces combined with transpiration, called evapotranspiration, cools the plants down – just as sweating cools humans' skin. The leaves release water into the atmosphere which vaporizes and cools the surrounding air. Urban green can thus catch the radiation before it reaches the ground and use the energy for evapotranspiration. However, the extent of this cooling effect depends on the type of vegetation and on how well it is thriving. Evapotranspiration can be greatly reduced if the growing conditions are poor[17].

Trees provide cooling by **shading** and this is not just a physical effect. Peoples' perception may even play a bigger role. While the reduction in air temperature is found to be relatively small, a research team of the University of Applied Sciences Amsterdam[18], that analysed shaded and sunny locations in parks, streets, squares, and near water bodies in Amsterdam, found a reduction in the physiological equivalent temperature (PET) between 12 and 22 °C in spaces shaded by trees compared to sunlit areas. While shaded areas are perceived cooler and more comfortable, open grassy green spaces were not perceived as cooler. These results have been found consistent with other studies and lead to the conclusion that thermal comfort in parks on summer days could be improved by placing more trees and shade provisions.[19, 20]

It needs however to be noted that the actual heat reduction potential of green space and elements depends not only on the type of vegetation, but also their distribution and design. Open, vegetation-covered areas at the edges of cities will deliver fresh air during night time, if ventilation corridors are not blocked. Vegetation that shades in surplus of cooling by evapotranspiration, like trees, provide humans more relief in outdoor environments than grasslands. However, if standing densely or as a tunnel in streets, trees may block **ventilation** and hamper cooling.

Cities can generate a country breeze, a local low-level air flow directed towards the centre. Its driving force is temperature difference between the usually warmer urban areas and cooler rural areas. The warmer air over built-up areas rises and cooler air rushes in into its place from non-urban areas.[21]

Similarly to rural areas, parks, acting as small-scale 'non-urban areas', can create a smaller circulation, the 'park breeze'. The daytime cooling that is a result of evapotranspiration of park vegetation and the evening cooling that happens as vegetation does not retain as much heat as artificial surfaces, creates a 'park cool island' (PCI) effect. As a result, the cooler air over parks replaces warmer air in nearby neighbourhoods.[22] Larger parks are able to cool the surrounding urban fabric by creating stronger park-breezes[23].

Practical approaches to reduce urban heat stress with green infrastructure

Adaptation to the impacts of climate change with warming temperatures in cities requires re-thinking urban design, in particular the design of green urban spaces and green elements. In a design guideline titled 'Clever and cool - Generating design guidelines for climate responsive urban green infrastructure'[24] Klemm provides a range of recommendations on cooling with greenery on city, park and street level:

- On a city level a network of interconnected green spaces and green elements should be maintained and developed further.
- In dense neighbourhoods with minimal private outdoor spaces the presence and accessibility of public green spaces should be ensured.
- Detailed microclimatic analysis (i.e., the assessment of shadow or wind patterns) can help answer design questions, such as whether cooling is prioritized during day or night time, or whether cooling is desired within or outside buildings.
- In a park, green fraction should be preserved or increased on the wind side of the park (prevailing summer wind direction should be considered) and cold air corridors should be kept open, to improve thermal conditions within the park.
- In a park, gradients of open areas and shading elements should be developed, as edges between sun and shade are popular places for visitors in parks providing them opportunities to adapt to diverse thermal conditions. A ratio of 40% sun, 20% half-shade and 40% shade seems to be in line with the preferences of park visitors under various thermal conditions and on various times of the day.

- Flexible and multifunctional spaces should be created in parks to enable individual thermal adaptation.
- In streets with high solar radiation tree species with large canopies should be planted.
- In streets with heavy traffic, to avoid the 'tunnel effect', space should be created for wind circulation between tree canopies.
- In street canyons a diversity of microclimates should be created with sunny and shaded areas so that pedestrians might select their preferred route for walking.
- In street canyons the thermal perception of pedestrians can be improved when green elements are installed at various heights.
- Deciduous trees should be preferred for cooling as they can provide shade during summer and do not block radiation during winter.
- Species resistant against heat and drought should be used.

Box 2 - Cool City concept implemented in Stuttgart: Focus on green ventilation corridors

As Stuttgart is located in a valley basin with low wind speeds, heat is easily trapped in the city. Over time, development on the valley slopes has prevented cooling airflows from moving through the city. As a response, early on, since the 1970s the German city has embarked on a long-term and complex climate planning strategy to become a cool city.

Stuttgart has adopted a wide range of interventions to apply the cool city concept, exploiting natural wind patterns and the positive effects of dense vegetation. To hinder overheating through the preservation of cool air flows in the city, at strategic places, such as valleys and hillsides, construction bans have been used, and green ventilation corridors have been developed and kept wide. In densely built areas and around new developments increased vegetation has been recommended. The prevention of construction projects enhanced the ventilation effect of cold-air flows at night rushing down from the hills surrounding the city.

An environmental office with the task to evaluate the effect of planned buildings on the microclimate and to protect key areas was established in the city. In 2008 a Climate Atlas was developed for the Stuttgart region, indicating the distribution of temperature and cold air flows. With the help of these detailed climate plans the city has stopped planned construction over 60 hectares.

More than 60% of the city is covered by green area. Starting from the 70s, Stuttgart has integrated green areas into a massive U-shaped public park that has a substantial cooling effect on the city, and besides that the city boasts lots of other parks. Furthermore, Stuttgart is a global frontrunner in green roof infrastructure development.

As a result of a combination of economic incentives and regulatory instruments introduced from the mid-'80s, over 300,000 m^2 of rooftops have been greened by 2019.

Other adaptation measures implemented include the greening of 63 kilometres of tram tracks, using street trees for shading building facades, developing smaller public spaces into 'cool spots', and installation of water fountains, since dispersed water has a significant cooling effect.

Sources: Rehan, 2016[25], Climate ADAPT[26]
Image: City of Stuttgart, Office for Environmental Protection

A guide titled 'Planning for a Cooler Future: Green Infrastructure to Reduce Urban Heat'[27] that synthesises research funded by the Victorian Centre for Climate Change Adaptation (VCCCAR) in Australia, lists a number of relevant recommendations on how to use green infrastructure to mitigate urban heat:

- Areas with high exposure and vulnerability should be prioritized when designing green infrastructure interventions for cooling. Neighbourhoods with a high proportion of elderly and very young citizens, or with large numbers of aged care facilities can we considered particularly vulnerable.
- Wide street canyons and narrow canyons with low buildings can be considered priority streets for cooling with greenery. Green cover should be maximised on the west-facing (east) side of the street, that is likely to become the hottest, as it is exposed to the afternoon sun.
- In street canyons 'overhead' vegetation canopy cover should be maximized (optimally tree canopies, or vine-covered archways). Broad, wide and short trees are particularly effective at shading sideways.
- Trees can trap heat under their foliage at night, therefore street trees should not form a continuous canopy to allow hot air to escape through the spaces between the plants.
- Urban green open spaces with primarily grassed areas and a relatively sparse or absent tree canopy, can provide 'islands' of cool in hot urban areas and can also lower the temperature of the surrounding landscape. Larger urban green open spaces should be located upwind of priority areas as they can effectively cool down areas downwind.
- Adequate water supply is essential for maximizing the cooling services of vegetation. This can be achieved through storm water capture and storage, providing sufficient root space, and increasing the cover of permeable surfaces.

Box 3 - OASIS: Schoolyards converted into green cooling islands in Paris

By September 2019, nine new schoolyards were transformed in Paris into 'cool islands', by integrating nature-based solutions for shading and for storm-water management.
Over the last decades the frequency of heatwaves has increased in Paris. During a heatwave in June 2017, due to record-high temperatures the schools had to be closed down for 3 days. This event triggered the idea of converting the predominantly asphalt covered schoolyards into shared green spaces.
Under the UIA OASIS project, the city has selected pilot 10 schoolyards out of which nine was converted into 'cool islands'. These revitalized spaces will also be open on a regular basis to the local neighbourhood after school hours and weekends, providing a recreation area to the broader local community. During heatwaves the schoolyards offer a cool and shaded refuge for locals. The OASIS project is implemented under the broader frameworks of the Climate Adaptation Strategy and the Resilient Strategy of the City of Paris.
During the planning stage, the aim was to focus the renovation of schoolyards on the well-being of children, especially through nature, to design more natural spaces at low costs, and to strengthen the social bonds within neighbourhoods.
The new schoolyards offer increased vegetation, permeable grounds, inventive play areas, natural and artificial shaded areas, water points, quiet corners and an inclusive use of space. At least 20-30% of the total area of the schoolyards are dedicated to green spaces. These new shared spaces provide an opportunity for residents to come together and interact. The newly transformed schoolyards are places for physical activity and contact with nature, which offer comfortable microclimates. They support psychomotor learning, sensory learning and the development of imagination.
Building on the experience of the pilot projects, OASIS has produced a set of recommendations and plans for other schoolyards. So far, another 35 schoolyards have been transformed in Paris and the city is planning to have all 760 public schoolyards transformed into neighbourhood oases by 2050. As every Parisian resides within a radius of 250m from a public school, according to the plans eventually each neighbourhood in the city would acquire a cool and shaded green refuge for days of extreme heat.

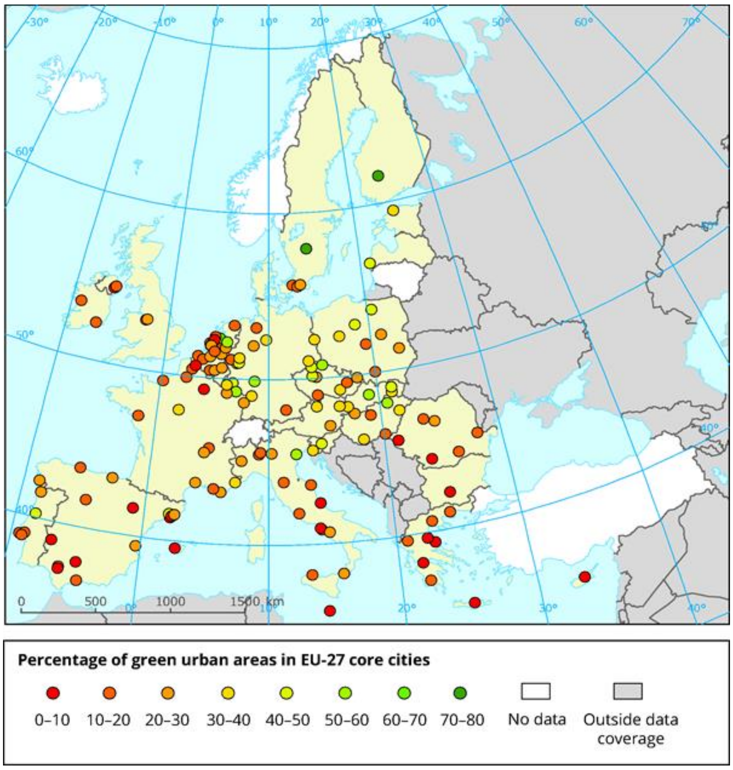
Sources:

Maria Sitzoglou, UIA Expert, OASIS, 4th Health & Greenspace Academy
https://www.uia-initiative.eu/fr/uia-cities/paris-call3[28]
https://ec.europa.eu/regional_policy/en/projects/France/oasis-in-paris-greening-the-city-and-reversing-climate-change-one-schoolyard-at-a-time[29]

Image: Forest School Ireland

Effective governance

Greenspace and nature-based solutions are an important part of strategies to adapt to heat stress and other climate change impacts to avoid negative health impacts. However, the initial situation is different across the European cities (*Map 3*). Often the ones most in need, like cities in Southern and South-Eastern European, where the heat load will be the highest, show lower degrees of greenspace coverage.



Map 3*: Percentage of green urban areas in EU-27 core cities*

Source: EEA, 2017 (https://www.eea.europa.eu/data-and-maps/figures/percentage-of-green-urban-areas-1)[30]

As apart from the pure amount of greenspace, the form and selected type of vegetation and its distribution across the city are also of importance for combating heat impacts, a strategy for providing relief from heat stress with the use of greenspace may have two major objectives:

- extending greenspace, trees, green roofs and facades and
- upgrading or redesigning existing greenspace

in the quantity and form needed. At the same time, it may contribute to multiple other benefits, which makes greenspace attractive to multiple users. Among these benefits are:

- flood prevention
- space for nature and biodiversity
- supporting health and wellbeing
- space for social interaction and outdoor activities
- nature education
- attractive and iconic places.

Multi-stakeholder collaboration

This complex situation calls for the collaboration of multiple stakeholders. Among these, the municipal departments responsible for greenspace and nature need to learn how greenspace can mitigate heat impacts, collaborate with the health services and integrate that knowledge and requirements in planning and management of public greenspace. To activate broader support, collaboration with further municipal departments and public services is necessary, considering in particular the ones responsible for urban planning, building regulations and transport.

Cities are a patchwork of public and private land. Investing in greenspace and green elements just on public land will not be sufficient. Private land and building owners will need to be encouraged by incentives or by regulations to boost green on their sites becoming thus a supplementary part of the green strategy of the city. Finally, the citizens as final beneficiaries should be involved in planning to ensure the proper consideration of their needs and wants. Citizen involvement can also be a valuable source to receive feedback on how well certain green space and elements work and what eventually need to be adjusted.

Awareness and knowledge

A pre-condition to design greenspace, which is also effective to reduce heat stress, is that public and private stakeholders – need to become aware of the multiple benefits that greenspace and its elements can provide, including prevention of heat stress. They then need knowledge on how green infrastructure needs to be designed to mitigate heat stress and to provide a multitude of other services. This includes targeted knowledge provided for different municipal services linked to nature, health, urban planning, transport etc., public and private investors, house and landowners, architects, landscape architects, gardening and landscaping companies on how to design greenspace that it provides relief from heat stress and a maximum of other services.

It requires also knowledge on how to make greenspace and green elements resilient to heat and drought as under a future climate, e.g., by selecting drought-resilient species, by adapting management and maintenance schemes, and by collecting and using rainwater and/or recycled greywater.

Financing

Financing the installation, upgrading and maintenance of greenspace and green elements can be a challenge. Generally, one could expect that, if there are so many beneficiaries of greenspace, there would be multiple stakeholders to finance them. In practice however, the co-financing approach is not always easy to establish, as the benefits are often not so easy to quantify in monetary terms to encourage investments and often there are no structures in place supporting collaboration among municipal departments or with other stakeholders to facilitate co-investment.

References

[1] EEA (2016) Climate change, impacts and vulnerability in Europe 2016. EEA Report No 1/2017. European Environment Agency.

[2] EEA (2020) Urban adaptation in Europe: how cities and towns respond to climate change. EEA Report No 12/2020. European Environment Agency.

[3] Hooyberghs, H. et al. (2017) Influence of climate change on summer cooling costs and heat stress in urban office buildings. Climatic Change, 144 (4). pp. 721-735. ISSN 0165-0009.

[4] Wouters, H. et al. (2017) Heat stress increase under climate change twice as large in cities as in rural areas: A study for a densely populated midlatitude maritime region. Geophysical Research Letters. Volume 44, Issue 17. 16 September 2017. pp. 8997-9007. https://doi.org/10.1002/2017GL074889.

[5] Lauwaet, D. et al. (2015) Detailed Urban Heat Island Projections for Cities Worldwide: Dynamical Downscaling CMIP5 Global Climate Models. Climate 2015, 3, 391-415. https://doi.org/10.3390/cli3020391.

[6] Tzavali, A. et al. (2015) Urban heat island intensity: A literature review. Fresen Environ. Bull. 2015, 24, 4537–4554.

[7] EEA (2020) Urban adaptation in Europe: how cities and towns respond to climate change. EEA Report No 12/2020. European Environment Agency.

[8] Littlefair, P. J. (2000) Environmental Site Layout Planning. Solar Access, Microclimate and Passive Cooling in Urban Areas (BR 380). April 6, 2000, IHS BRE Press, ISBN 9781860813399.

[9] AAAS. 'Lethal levels of heat and humidity are gripping global 'hot spots' sooner than expected'. Science, AAAS. Accessed 12 August 2021. https://www.sciencemag.org/news/2020/05/lethal-levels-heat-and-humidity-are-gripping-global-hot-spots-sooner-expected

[10] European Climate and Health Observatorium. 'Heat and Health'. Heat and health. Accessed 12 August 2021. https://climate-adapt.eea.europa.eu/observatory/evidence/health-effects/heat-and-health/heat-and-health

[11] Hooyberghs, H. et al. (2017) Influence of climate change on summer cooling costs and heat stress in urban office buildings. Climatic Change, 144 (4). pp. 721-735. ISSN 0165-0009.

[12] Greater Manchester CombinedAuthority. 'IGNITION'. Greater Manchester Combined Authority. Accessed 12 August 2021. https://www.greatermanchester-ca.gov.uk/what-we-do/environment/natural-environment/ignition/

[13] EEA (2020) Urban adaptation in Europe: how cities and towns respond to climate change. EEA Report No 12/2020. European Environment Agency.

[14] Greater Manchester CombinedAuthority. 'IGNITION'. Greater Manchester Combined Authority. Accessed 12 August 2021. https://www.greatermanchester-ca.gov.uk/what-we-do/environment/natural-environment/ignition/

[15] ADAPT-UHI. 'ADAPT-UHI'. Accessed 12 August 2021. https://www.adapt-uhi.org/

[16] Hillel, D. et al. (2005) Encyclopedia of Soils in the Environment. Elsevier/Academic Press. ISBN 978-0-12-348530-4

[17] Ennos, Roland. 'Can Trees Really Cool Our Cities Down?' The Conversation. Accessed 11 August 2021. http://theconversation.com/can-trees-really-cool-our-cities-down-44099

[18] Klok, L. et al (2019), Assessment of thermally comfortable urban spaces in Amsterdam during hot summer days. International Journal of Biometeorology 63, no. 2, 1 February 2019, 129–41, https://doi.org/10.1007/s00484-018-1644-x

[19] Klok, L. et al (2019), Assessment of thermally comfortable urban spaces in Amsterdam during hot summer days. International Journal of Biometeorology 63, no. 2, 1 February 2019, 129–41, https://doi.org/10.1007/s00484-018-1644-x.

[20] Klemm, W. et al (2015) Psychological and physical impact of urban green spaces on outdoor thermal comfort during summertime in The Netherlands. Building and Environment, Building and Environment, Vol. 83, 2015, 120-128, ISSN 0360-1323, https://doi.org/10.1016/j.buildenv.2014.05.013.

[21] Gál, T., Unger, J. (2009) Detection of ventilation paths using high-resolution roughness parameter mapping in a large urban area. Building and Environment, Vol. 44, Issue 1, 2009, 198-206, ISSN 0360-1323, https://doi.org/10.1016/j.buildenv.2008.02.008.

[22] American Planning Association. 'How cities use parks for climate change management' City Parks Forum Briefing Papers 11. Accessed 10 August 2021. https://www.planning.org/publications/document/9148693/

[23] K.R. Gunawardena, K.R. et al (2017) Utilising green and bluespace to mitigate urban heat island intensity. Science of The Total Environment, Volumes 584–585, 2017, 1040-1055, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2017.01.158.

[24] Klemm, W. (2018) Clever and cool. Generating design guidelines for climate responsive urban green infrastructure. 19 November 2018, ISBN 978-94-6343-305-1, DOI https://doi.org/10.18174/453958.

[25] Rehan, R. M. (2016) Cool city as a sustainable example of heat island management case study of the coolest city in the world. HBRC Journal, Vol. 12, Issue 2, 2016, 191-204, ISSN 1687-4048, https://doi.org/10.1016/j.hbrcj.2014.10.002.

[26] Climate ADAPT. 'Stuttgart: combating the heat island effect and poor air quality with ventilation corridors and green-blue infrastructure'. Accessed 24 August 2021. https://climate-adapt.eea.europa.eu/metadata/case-studies/stuttgart-combating-the-heat-island-effect-and-poor-air-quality-with-green-ventilation-corridors/#solutions_anchor

[27] Norton, B. et al. (2013). Planning for a Cooler Future: Green Infrastructure to Reduce Urban Heat. October 2013, ISBN: 978 0 7340 4905 6, DOI: 10.13140/2.1.2430.1764.

[28] UIA. ' OASIS - School yards: Openness, Adaptation, Sensitisation, Innovation and Social ties: Design and transformation of local urban areas adapted to climate change, working jointly with users'. Accessed 24 August 2021. https://www.uia-initiative.eu/fr/uia-cities/paris-call3

[29] EC. ' OASIS in Paris: greening the city and reversing climate change, one schoolyard at a time'. Accessed 24 August 2021. https://ec.europa.eu/regional_policy/en/projects/France/oasis-in-paris-greening-the-city-and-reversing-climate-change-one-schoolyard-at-a-time

[30] EEA. ' Percentage of green urban areas in EU-27 core cities'. Accessed 11 August 2021. https://www.eea.europa.eu/data-and-maps/figures/percentage-of-green-urban-areas-1