Tackling Heat Stress: Adapting London's Public Spaces for Climate Resilience by 2050

VEDA BALIGA MSC(HONS)
Co-Founder, Virtual Climate Ltd.

RUGGIERO GUIDA MENG
Co-Founder, Virtual Climate Ltd.

Abstract

This opinion paper highlights the growing problem of urban heat even in temperate climates like the UK, drawing on public data and physics-based simulations to demonstrate the need for climate resilience focused on public spaces in cities. It uses quantitative metrics for human comfort to highlight how summer heat stress in London is projected to triple or quadruple by 2050 under a business-as-usual scenario and how basic adaptation measures can help reduce heat stress by more than 50%. This approach offers a workflow to measure and evaluate proposed adaptation solutions to future-proof public spaces and ensure they remain habitable in 2050.

Keywords Adaptation, Microclimate, Outdoor comfort, Annual CFD, Future weather files

1.0 Introduction

While the UK is known for its relatively temperate climate, the effects of climate change are projected to significantly increase the frequency and intensity of extreme heat events, particularly in urban centres like London.

Often framed as a future challenge, climate change is already impacting the country, with urban heat accounting for over 2,000 deaths each year in 2022 and 2023, primarily among people over 65 (1-2). These heat events were also responsible for increased stress on the NHS and transport delays, caused by damage to road and rail infrastructure.

In addition to the loss of human life and strain on public services, the economic impact of heat exposure is estimated by the London School of Economics to be in the range of £260–300 million per year (3).

UK climate projections data indicate that median summer temperatures in England could rise by 1.7 – 2.6°C, with the potential for extreme temperatures to reach or exceed 40°C. By 2050, projections suggest that heatwaves could become a regular event in southern England, even with the most optimistic emissions reduction targets. This is because the extent and pattern of regional changes in the UK until mid-century, will be caused by emissions that have already occurred (4).

This will have a profound impact on human health, particularly for vulnerable populations such as the elderly, young children, and people with pre-existing medical conditions.

While buildings are able be retrofitted with air conditioning or other cooling systems, public spaces cannot be similarly equipped. Instead, these areas require a combination of design and planning interventions to effectively mitigate heat stress. Since the specific interventions would change depending on the local context, one way to achieve consistent outcomes, would be to measure the results of these interventions. This would be similar in approach to setting targets for building performance, where specific measures are not prescribed, but the overall outcome can be quantified.

To ensure the long-term liveability of cities, it is essential that any public realm infrastructure provided is genuinely resilient – designed to remain functional and comfortable even with the changing climate over the coming decades.

2.0 Climate Resilience in the Public Realm

At present, most climate resilience strategies proposed for cities in the UK are, understandably centred on buildings. The public realm receives limited attention, and national approaches to incorporating green infrastructure focus on broad policies and lack specific targets. There is also little to no consideration given to addressing urban heat islands or the impact of thermal stress on the habitability of outdoor spaces.

Habitable public spaces – streets, squares, parks, and other communal areas – play a vital role in improving the quality of urban life. Access to urban green spaces can improve mental and physical health, enhance biodiversity, reduce air pollution, mitigate flooding, tackle urban heat islands and enable access to nature (5).

In addition to the benefits described above, improving external comfort in these types of spaces can also encourage a greater uptake of walking, cycling and increase the potential for multi-modal trips including public transport.

While the benefits of these types of spaces are universal, there isn’t a consistent approach to including green infrastructure. Guidance in the National Planning Policy Framework (6) and the Third National Adaptation Programme (7) mentions green infrastructure as a general net positive, but the decision to include such infrastructure is the remit of a range of local authorities. Any discussion of heat resilience is limited to new buildings, with no reference to the public realm in urban areas.

This lack of a broader strategy creates an uneven distribution in access to such spaces, with socially disadvantaged communities getting the least benefits. In the absence of clear national or regional requirements, frameworks at the local level, such as the London Plan, aim to address this by defining quantifiable targets.

The London plan includes a range of quantitative measures around access to green spaces, including providing residents with 5 sq.m. of open space per 1-2 residents and access to a public open space within 400m. It also sets clear requirements for the types of green spaces, and minimum distances, to be made available for urban residents.

There is also a qualitative discussion of including appropriate shade, shelter, seating and other microclimatic considerations to encourage people to spend time in a place, but no specific metrics are referenced (8).

This paper will try to show how some of these considerations can be quantified and evaluated in the context of climate adaptation over time.

While adaptation strategies can include a wide range of issues such as improving biodiversity, increasing permeability and including water-efficient vegetation, this paper will focus primarily on measures aimed at quantifying comfort and reducing thermal stress on occupants of the public realm.

This study intentionally refers to thermal comfort rather than air temperatures, because air temperature alone is not a meaningful indicator of thermal stress experienced by people. Heat exchange between the human body and the environment is influenced by a combination of factors, such as solar radiation, wind speed, humidity, clothing and activity levels.

For example, on a sunny day in London, with air temperature of 20°C and low wind, a person standing on a paved surface with no shade, can experience the thermal environment as being closer to 27°C. Air temperature or heat index – which accounts for temperature and humidity – are limited predictors of heat events since they do not allow for the impact of solar radiation or other environmental factors. This is borne out by the fact, that the heat deaths in 2023 were largely during several warm periods that did not qualify for an amber alert.

This is why metrics such as Universal Thermal Climate Index or UTCI (9), which consider the full thermal exchange between the human body and the environment, provide a better indication of the occurrence of heat stress.

3.0 Quantifying Comfort

3.1 Aim of Analysis

This opinion paper aims to highlight the growing impact of heat stress on public spaces in Southern England and the need for quantifiable metrics to evaluate the usability of these spaces now, and in the context of climate change.

To that end, the analysis described below outlines a workflow that allows us to quantify and benchmark current comfort conditions, predict thermal stress under future climate conditions in 2050 and review the efficacy of potential adaptation measures.

Just as building performance is evaluated on an annual basis, this study focused on annual hourly microclimate and comfort analysis to provide insights into when, and how often thermal stress occurs.

3.2 Site Description

Heat stress analysis was undertaken for a public park in central London; which under the London Plan would qualify as a small open space < 2ha. The geometry for the model shown in Figure 1 was obtained from an open-source database (10). The park has larger trees primarily around the periphery, with paved or gravelled pathways, and the rest of the ground is partially covered by grass.

3.2.1 Scenarios modelled

Baseline Scenario models the present-day geometry with present day weather to establish current levels of annual thermal comfort, summer heat stress and wind comfort

Future Scenario models business-as-usual in 2050, with no changes to the model

Future Scenario with Interventions models impact of basic adaptation measures in 2050; adding more trees, built-up shades and replacing grass with denser ground cover, shown in Figure 1.

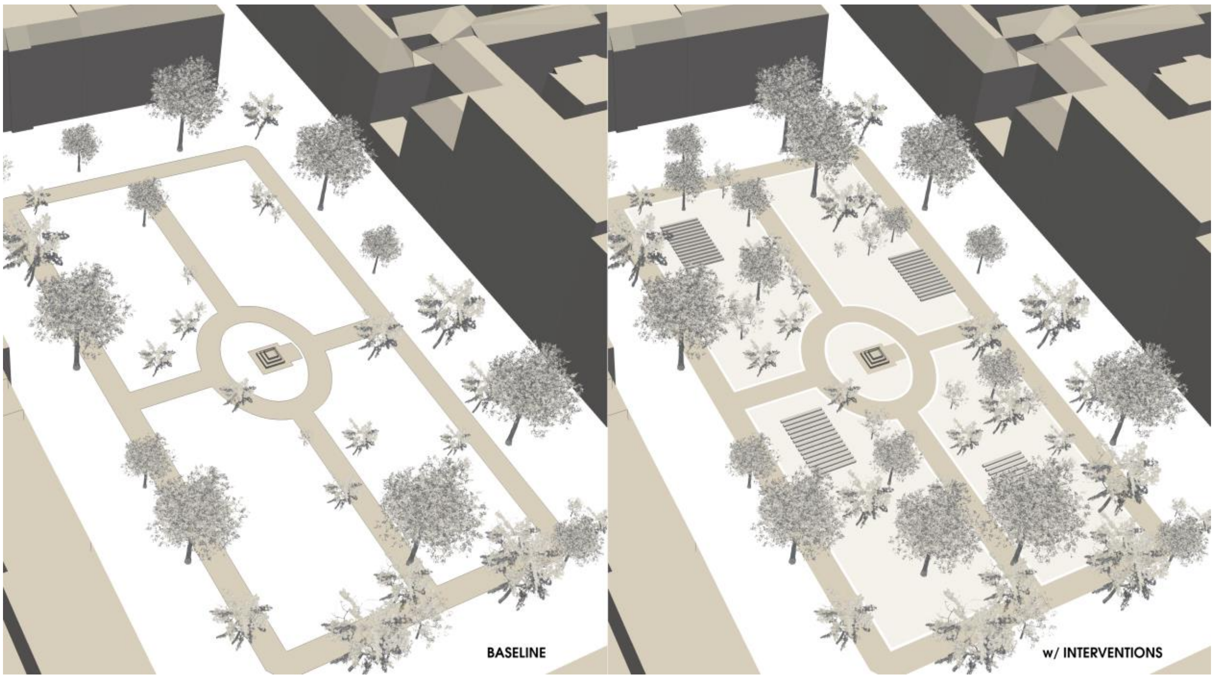


Figure 1 – Overview of geometry modelled for present day analysis (L) and with adaptation measures for 2050 (R)

3.3 Methodology

A description of the software used and approach to quantifying annual microclimate and comfort analysis have been documented in a previous paper (11). An overview of the methodology for this study is included below.

3.3.1 Analysis Grid and Weather Data

The analysis grid covered 10,000 sq.m. and comprised of 2700 individual points. This grid was modelled 1m above the ground to represent the space inhabited by people. The analysis period covered 365 days, between 8am – 8pm to focus on daytime impacts.

The model was simulated for the present day using a standard EPW file for a typical meteorological year (TMY15) for Heathrow, based on measured data between 2007 – 2021 (12). This is the same type of file used for building energy simulations, containing 8760 hours of weather data.

Future conditions for 2050 were modelled using a similar EPW file for a Design Summer Year (DSY) at Heathrow generated for a medium emissions scenario, 90th percentile, based on UK climate projections (UKCP09). This file was generated as part of PROMETHEUS; a multi-disciplinary project funded by the Engineering and Physical Sciences Research Council (EPSRC) and made available by the University of Exeter (13).

This analysis used meteorological start dates for all seasons; and the discussions around summer heat stress are focused on the period from June 1 to August 31.

3.3.2 Radiation Analysis

The annual radiation analysis used a ray-tracing approach based on Radiance (14) to evaluate the distribution of radiant gain across the site, accounting for the impact of massing, vegetative shade and material finishes. This analysis evaluated direct, diffuse, shortwave, long-wave, reflected radiation and impact of ground temperature. These calculations were undertaken for each point in the analysis mesh for every hour of the year between 8am and 8pm.

3.3.3 Wind Analysis

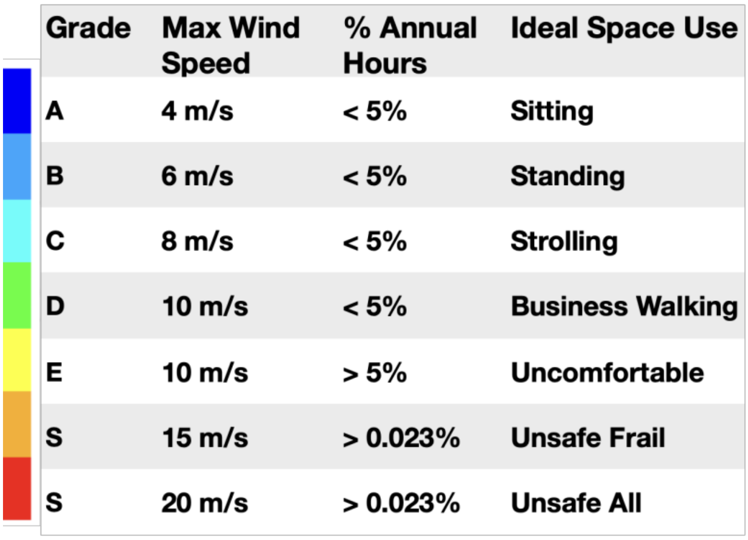
The CFD analysis used OpenFOAM (15). The domain size and refinement areas were programmatically generated based on the guidance outlined in EU COST 732 Best Practice Guidelines for the CFD Simulation of Flows in the Urban Environment (16). While simulations can be undertaken for up to 36 cardinal wind directions, this simulation used 8 cardinal wind directions, resulting in an octagonal domain. This approach has the advantage of needing to mesh the domain only once for all wind directions at the cost of slightly larger meshes. Since the CFD simulation was cloud-based, meshing was streamlined, and simulations for all wind directions were able to be run in parallel. Surface refinements were included for all objects in the model with an additional boundary layer refinement for the ground. The wind inlet boundary condition applied was the default Atmospheric Boundary Layer condition in OpenFOAM (D.M. Hargreaves and N.G. Wright). The solver used was SimpleFoam with a k-epsilon turbulence model. The results of these CFD simulations – wind speed, direction and pressure – were mapped via the OpenFOAM sampling feature to each point in the analysis mesh, based on the hourly wind speeds and directions in the EPW weather file. The closest cardinal direction was mapped for each hourly wind direction in the weather file and the velocity field was scaled proportionally to a reference wind speed of 5 m/s.

3.3.4 Comfort Analysis

Outputs from the preceding analyses for radiation and wind were used as inputs for the calculation of outdoor comfort metrics; which combine a range of environmental and physiological factors to provide a single value representative of the dynamic thermal 'load' on the human body. This analysis used UTCI to quantify heat stress; which represents an "equivalent temperature" that more accurately reflects the physiological response to the overall thermal environment. Typical ranges for UTCI values as they relate to thermal comfort and stress are shown in Figure 2.

Figure 2 – UTCI ranges for thermal stress

Wind comfort was quantified using the Lawson Comfort Criteria which evaluates the safety and usability of outdoor spaces based on how often a range of wind speeds are exceeded. An overview of the typical ranges as they relate to pedestrian comfort and usability of space are shown in Figure 3.



Grade	Max Wind Speed	% Annual Hours	Ideal Space Use
A	4 m/s	< 5%	Sitting
B	6 m/s	< 5%	Standing
C	8 m/s	< 5%	Strolling
D	10 m/s	< 5%	Business Walking
E	10 m/s	> 5%	Uncomfortable
S	15 m/s	> 0.023%	Unsafe Frail
S	20 m/s	> 0.023%	Unsafe All

Figure 3 – Lawson 2001 wind comfort criteria

Results for thermal and wind comfort were calculated for each point in the analysis mesh for each hour modelled.

4.0 Results Overview

Based on hourly simulations for current and future scenarios, Figure 4 shows the distribution and frequency of heat stress hours in summer; i.e. how often the UTCI exceeds 26. Currently, almost the entire park experiences heat stress for < 15% of summer hours. Since the central parts of the park are largely exposed to the sun, the incidence of heat stress is higher in these spaces.

By 2050, these areas experience heat stress for 45% – 60% of summer hours. While these hours don't necessarily occur concurrently, cumulatively, it equates to ~50 days each summer, when park visitors experience heat stress for the entire day.

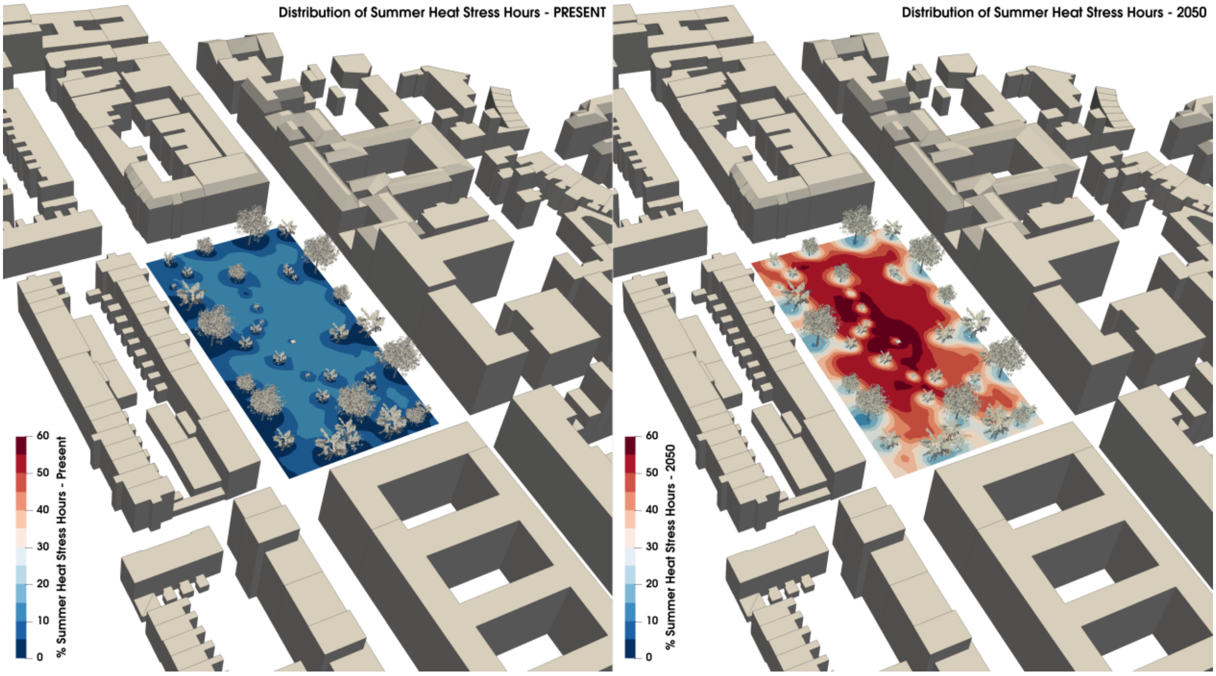


Figure 4 – Comparison between now and 2050: increase in summer heat stress

This pattern is even more pronounced in the occurrence of extreme heat stress (UTCI > 30), shown in Figure 5. At present, this occurs < 5% of the time, but by 2050, this will increase to between 15% - 25% of summer hours.

Aggregated over time, this translates to an increase from 2.4 cumulative days of extreme heat stress in the present, to 20 cumulative days by 2050

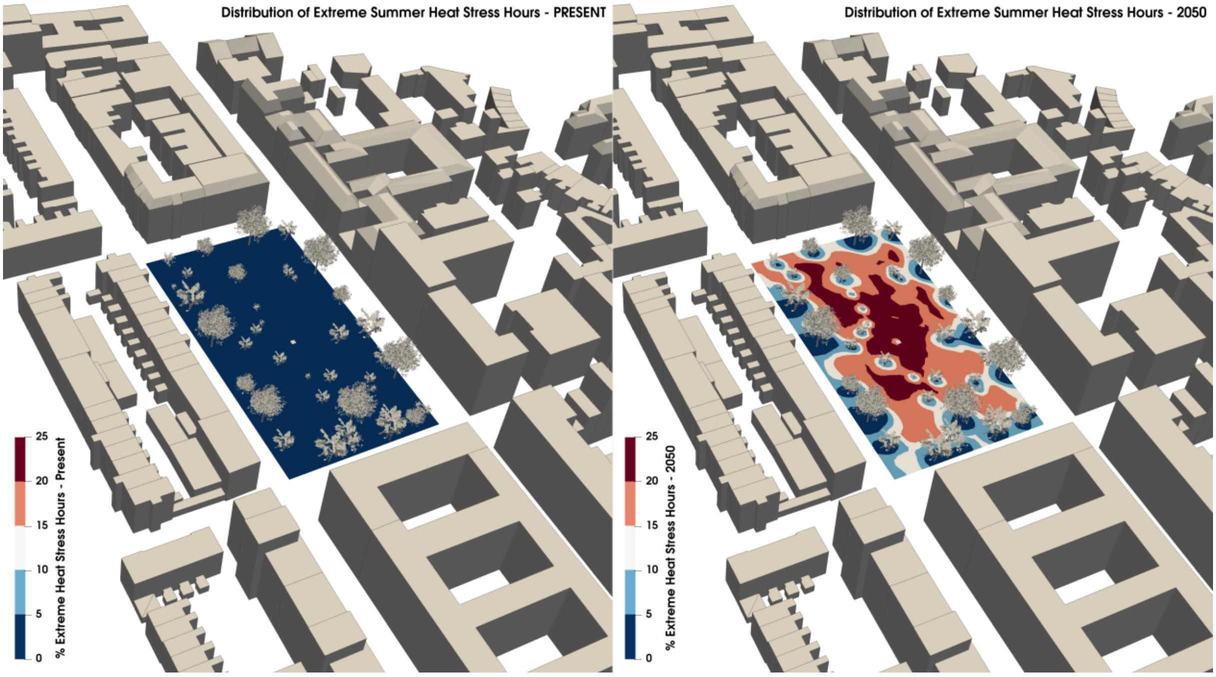


Figure 5 – Comparison between now and 2050: increase in extreme heat stress

The study also assessed annual wind comfort using the Lawson comfort criteria, shown in Figure 6. While increased wind speeds in future scenarios can highlight a need for wind breaks, in this instance, meaningful changes to wind safety and comfort were not observed.

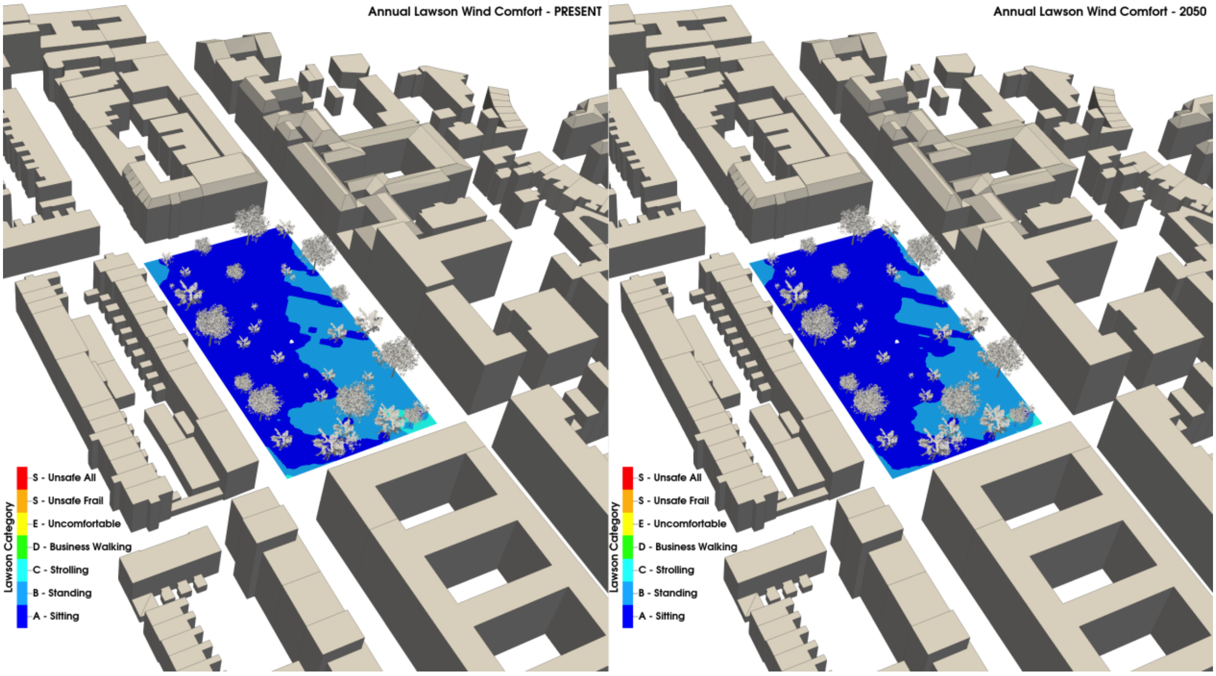


Figure 6 – Comparison between now and 2050: change in annual wind comfort

Since heat stress occurs in parts of the park with the most solar exposure, the adaptation measures shown in Figure 1 focused on reducing radiant gain. The simulation results with adaptation measures for 2050, shown in Figure 7 indicate a notable reduction in heat stress. Except for the central area that is still exposed, the occurrence of overall heat stress and extreme heat stress is reduced by more 50%. This equates to roughly 19 cumulative heat stress days, of which 7 days experience extreme heat stress; indicating that there is still room for improvement.

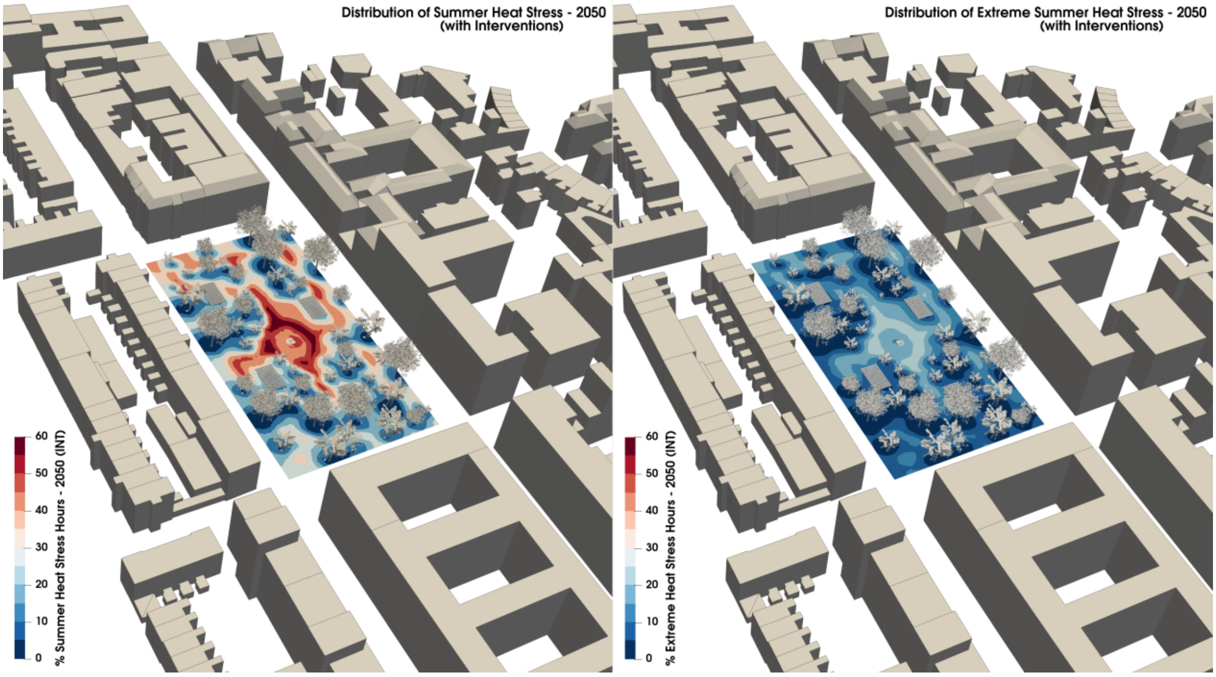


Figure 7 – Occurrence of total heat stress (L) and extreme heat stress (R) in 2050 with adaptation measures

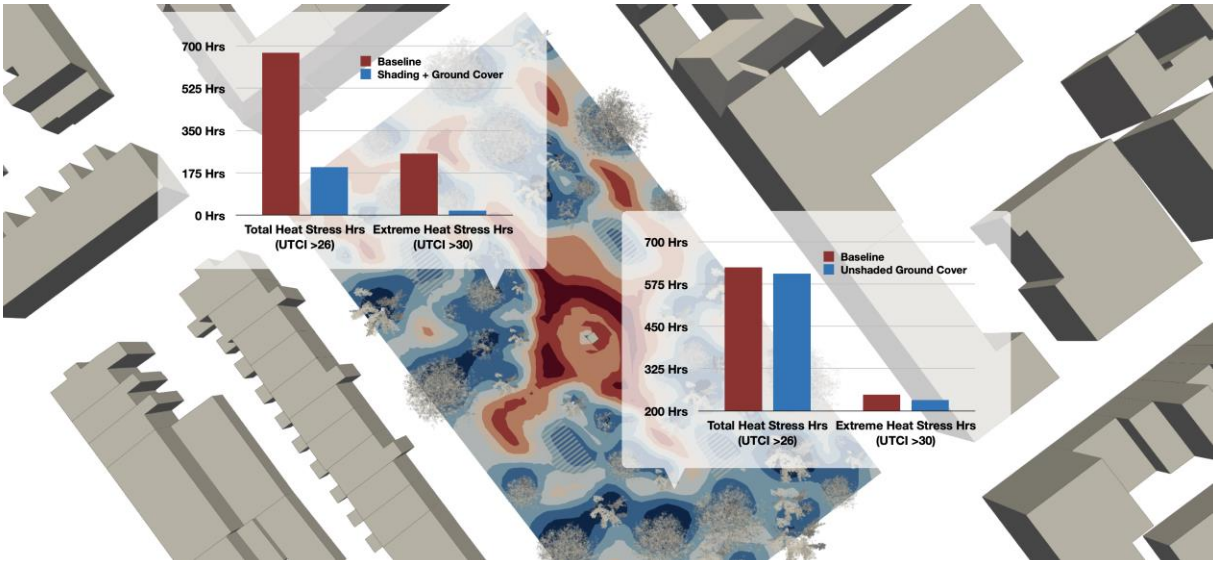


Figure 8 – Impact of interventions on heat stress in 2050: shading and ground cover (L) unshaded ground cover (R)

Figure 8 shows the relative impact of the two interventions tested on the cumulative occurrence of heat stress. Since the largest contributor to discomfort is radiant exposure, the change in ground cover provides limited benefits and the inclusion of shading provides a more noticeable improvement, particularly in the occurrence of extreme heat stress. This is supported by the hourly results in Figure 9 which show the reduction in radiant gain and resulting impact on ground temperature, mean radiant temperature and heat stress for two days in July 2050, with the inclusion of shading. These hourly results are for the same location highlighted in Figure 8.

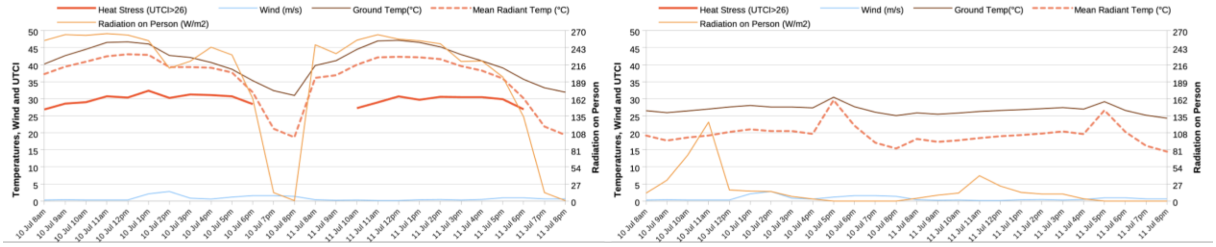


Figure 9 – Hourly overview of radiant gain and heat stress in 2050: baseline (L) and with shading and ground cover (R)

5.0 Conclusions

By simulating present-day conditions and projected future scenarios, this study illustrates how heat stress levels are expected to escalate three to four-fold by 2050, under a business-as-usual scenario.

The adaptation measures tested in this study were relatively simple but still showed a reduction in predicted heat stress hours of more than 50%; demonstrating how the impact of such interventions can be quantified to inform decision making.

This paper posits that the lack of definition of a ‘comfortable’ space, or guidance on how to improve heat resilience in the public realm limits the utility of climate adaptation plans. Providing clear requirements for minimum comfort levels in the public realm would help make such adaptation plans more specific and implementable.

In addition to specifying measurable comfort standards, climate adaptation plans could include requirements for the inclusion of adaptive species of vegetation better suited to the warmer climate and dryer summers expected by 2050. In addition to reducing the demand for water, including native and adaptive ground cover rather than grass, would also improve biodiversity and lower maintenance costs. Including requirements for permeability would allow run-off to percolate and help mitigate the increased rainfall expected in non-summer months.

In addition to public parks, this approach can also be extended to streetscapes to improve walkability and pedestrian access to public transport hubs.

As of 2022, cities like Seville are already looking to include design interventions such as underground aqueducts to address urban heat and keep public spaces usable during the summertime (17). Although the UK climate has not reached this level of severity, notable changes are expected over the coming decade. Even modest improvements made ahead of time will make a difference over the next few years.

One way to ensure a structured and coherent approach, is to establish minimum performance standards, so that even if individual approaches vary, comfort levels across all public spaces remain consistent.

A point of reference for this approach can be the thermal comfort guidelines for new developments in the City of London (18). A streamlined and more accessible version of these guidelines, with clear performance requirements for current and future scenarios, could be established for all boroughs in London.

These adaptation requirements would also need to focus on building resilience in existing public spaces rather than focus solely on new developments. This approach could be revised to leverage new data, such as the updated future weather files based on UKCP18, to ensure that all proposed strategies are based on the best available information.

This would allow local authorities to identify underserved areas and ensure that long-term resilience is built into the fabric of the city across all public spaces.

References

(1) Heat mortality monitoring report: 2022, 2024 Sep 15, Available from: https://www.gov.uk/government/publications/heat-mortality-monitoring-reports/heat-mortality-monitoring-report-2022
(2) Heat mortality monitoring report: 2023, 2024 Sep 15, Available from: https://www.gov.uk/government/publications/heat-mortality-monitoring-reports/heat-mortality-monitoring-report-2023

(3) Turning up the heat: learning from the summer 2022 heatwaves in England to inform UK policy on extreme heat. Grantham Research Institute on climate change and the environment, 2024 Sep 20, Available from: https://www.lse.ac.uk/granthaminstitute/publication/turning-up-the-heat/

(4) UKHSA's HECC report shows impacts on public health due to warming climate, 2024 Oct 01, Available from: https://www.gov.uk/government/news/ukhsas-hecc-report-shows-impacts-on-public-health-due-to-warming-climate

(5) Benefits of Green Infrastructure Report by Forest Research, 2024 Oct 31, Available from: https://cdn.forestresearch.gov.uk/2022/02/urgp_benefits_of_green_infrastructure.pdf

(6) Ministry of Housing, Communities & Local Government. National Planning Policy Framework 2023, 2024 Sep 15, Available from: https://assets.publishing.service.gov.uk/media/669a25e9a3c2a28abb50d2b4/NPPF_December_2023.pdf

(7) The Third National Adaptation Programme (NAP3) and the Fourth Strategy for Climate Adaptation Reporting, 2024 Sep 15, Available from: https://assets.publishing.service.gov.uk/media/64ba74102059dc00125d27a7/The_Third_National_Adaptation_Programme.pdf

(8) The London Plan: The Spatial Development Strategy for Greater London, 2024 Sep 20, Available from: https://www.london.gov.uk/sites/default/files/the_london_plan_2021.pdf

(9) Błażejczyk K, Jendritzky G, Bröde P, Fiala D, Havenith G, Epstein Y, et al, An introduction to the Universal Thermal Climate Index (UTCI), *Geographia Polonica,* 2013;86(1):5–10.

(10) OpenStreetMap, 2024 Oct 01, Available from: https://www.openstreetmap.org/#map=6/54.91/-3.43

(11) Baliga V, DeKay M, Guida R, *Dynamic Microclimate Modelling for Urban China,* Proceedings of the 34th International Conference on Passive and Low Energy Architecture, Hong Kong, PLEA, 2018.

(12) Climate Files | Repository of Building Simulation Climate Data from the Creators of the EPW, 2024 Oct 01, Available from: https://climate.onebuilding.org/WMO_Region_6_Europe/GBR_United_Kingdom/index.html

(13) Future weather files | Centre for Energy and the Environment | University of Exeter, 2024 Oct 01, Available from: https://www.exeter.ac.uk/research/centres/cee/research/prometheus/termsandconditions/futureweatherfiles/

(14) Radiance — Radsite, 2024 Dec 29, Available from: https://www.radiance-online.org/

(15) OpenFOAM ®, 2024 Dec 29, Available from: https://www.openfoam.com/

(16) Franke J, Baklanov A, *Best Practice Guideline for the CFD Simulation of Flows in the Urban Environment: COST Action 732 Quality Assurance and Improvement of Microscale Meteorological Models*, Meteorological Institute, 2007

(17) CartujaQanat – Recovering the street life in a climate changing world, 2024 Oct 31, Available from: https://uia-initiative.eu/en/uia-cities/sevilla

(18) Microclimate Guidelines, 2024 Oct 31, Available from: https://www.cityoflondon.gov.uk/assets/Services-Environment/thermal-comfort-guidelines-for-developments-in-the-city-of-london.pdf

Acknowledgements

The simulations and results discussed in this paper were undertaken using the Microclimate Tool developed by Virtual Climate.

Thanks to the University of Exeter for making future weather data publicly available.