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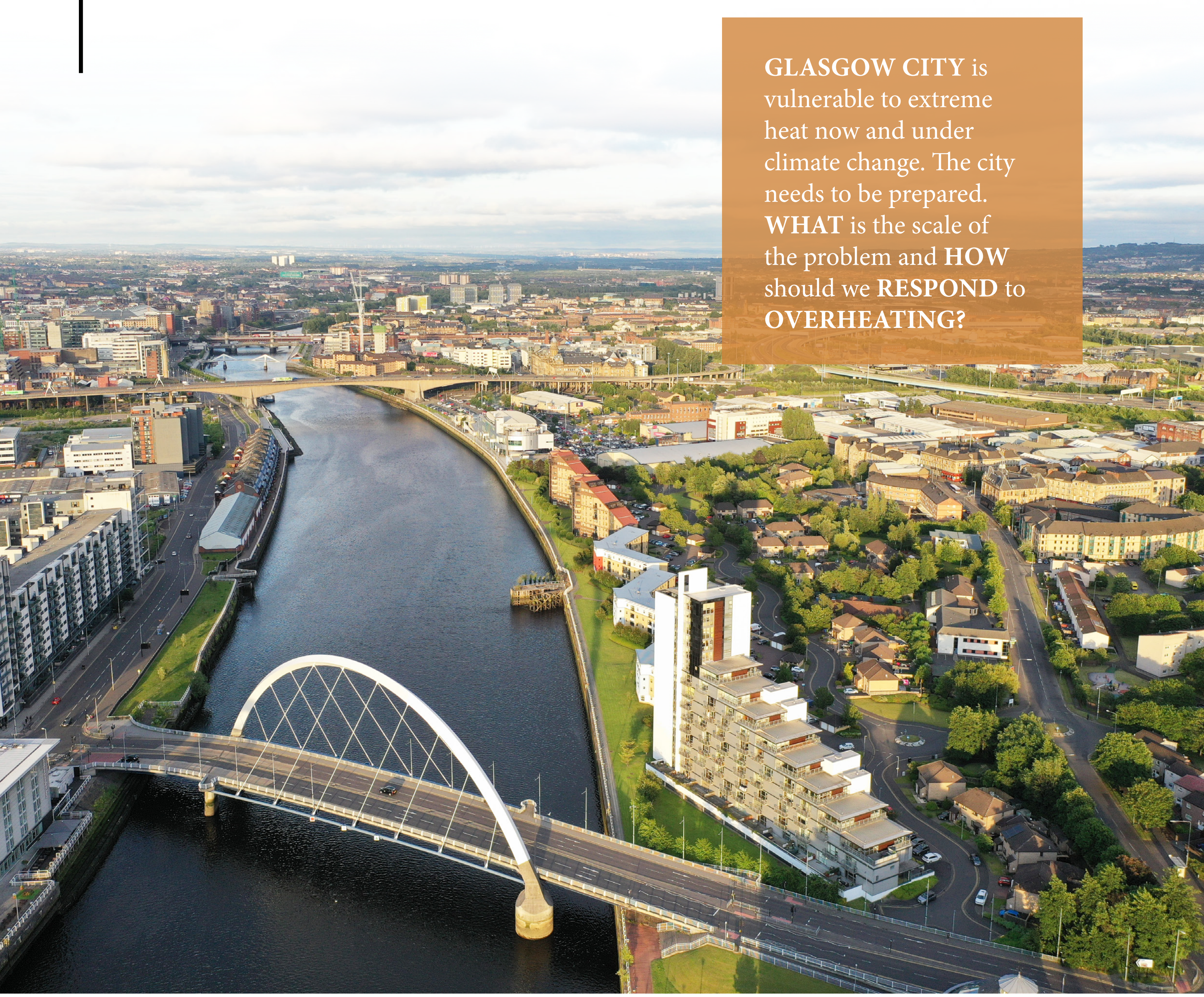
CLIMATE PROOFING GLASGOW

Adaptation Strategies for Urban Overheating

GLASGOW CITY is vulnerable to extreme heat now and under climate change. The city needs to be prepared. **WHAT** is the scale of the problem and **HOW** should we **RESPOND** to **OVERHEATING?**



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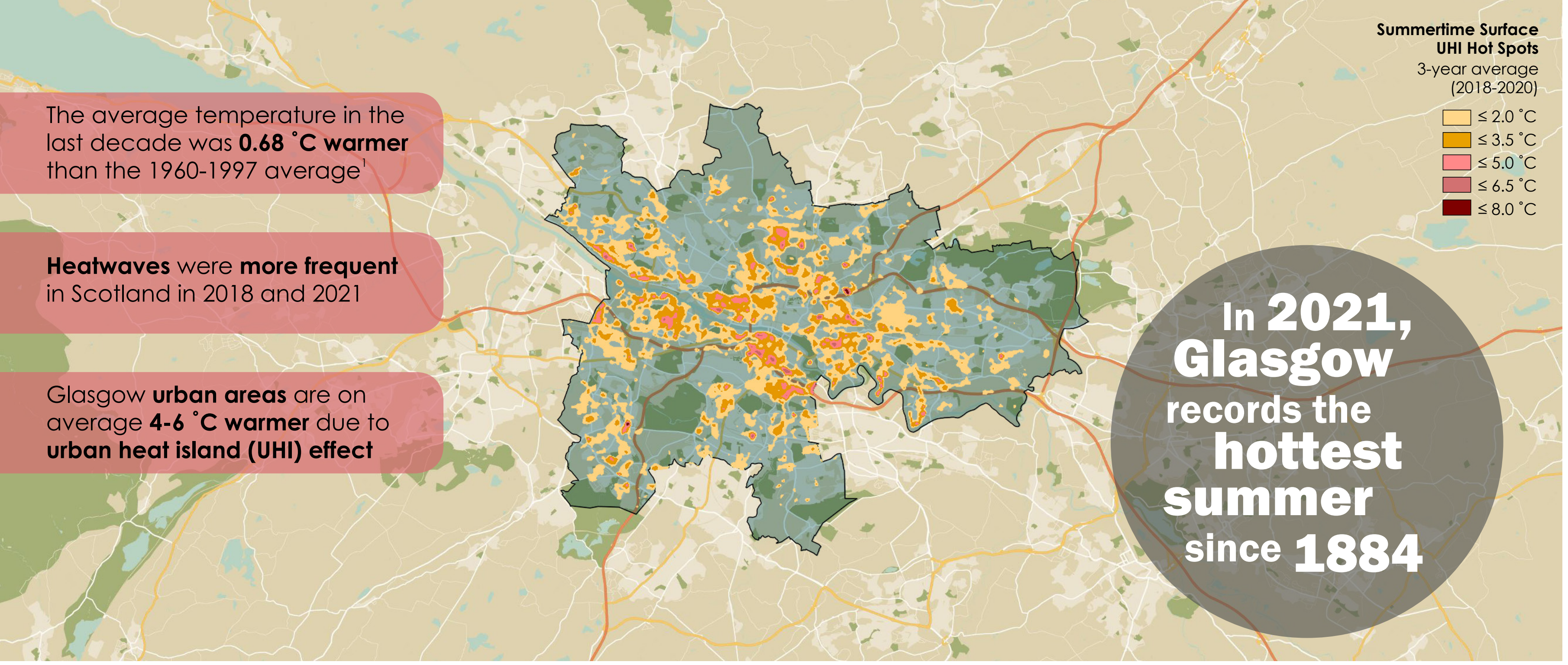


The **Approach**

This document brings together findings from four Glasgow-based urban climate studies conducted by MUrCS[4] students. The methodology for each is outlined on the next page in the form of flowcharts. The key utilised methods can be summarised as follows:

GIS-based Analysis urban heat risk mapping, analysis of UHI spatial patterns and interactions with UGI across different spatial scales, and mapping of ecosystems health and ecosystem services (ES)

Empirical Studies traverse air temperature measurements within the city centre to explore the intra-urban temperature variations, the relationship between UHI and vegetation cover, materials, and urban forms

Microclimate Simulations analysis of the performance of UGI types and quantities and surface materials modification in UHI mitigation (air temperature and thermal comfort effects) using ENVI-met[5] software

Glasgow City under Changing Climate

Scotland's climate is changing, and the consequences of climate change are affecting Glasgow. Record-breaking heatwave events of 2018/2021 and projected temperature increase of 1.2-1.5 ˚C by 2050 (Adaptation Scotland, 2021)[1] are alarming. Glasgow's urban core is already up to 4-6 ˚C warmer than rural surroundings due to the UHI[2] effect. The synergy of the warming produced by the UHI, coupled with the climate change-induced temperature rise, is likely to exacerbate heat stress affecting an increasing number of people and undermining the sustainability and climate adaptation capacity of the city.

While global effort is focused on cutting GHGs emissions to slow down the warming process, actions to cool the urban areas are needed now. Heat mapping is an effective technique for visualising heat vulnerability and identifying priority intervention areas. City planning has a vital role to play in designing thermally comfortable and healthy urban spaces. Since large-scale modifications of the built environment are less likely in mature cities, local urban regeneration projects, like the ongoing Glasgow city centre **Avenues programme**[3], can contribute to cooling the areas through the provision of urban green infrastructure (UGI), additional shading, and selection of high albedo surface materials.

The key objectives of this document are to:

» identify heat risk areas through **urban climate mapping** and highlight the **priority zones** for heat risk mitigation

» explore the **UHI mitigation** effect of the **Avenues programme**

» highlight the **cooling effect** of different **UGI** types and **streetscaping strategies**

» determine the role of **ecosystem health** in **climate adaptation** in Glasgow

» deliver **climate-sensitive** urban **planning recommendations**

Sources of **Data**

Data	Year	Source	Where it is Used
Scottish Index of Multiple Deprivation (SIMD)	2020	Scottish Govt	Heat Risk Map Pressure Indicator: Deprived Areas
Population Density	2017		Heat Risk Map
Sensitive Population	--	Scotland's Census	
Land Use	2017	HLAmap	
Wind Speed & Air Temperature	1980 to 2010	UK Met Office	
Local Climate Zone (LCZ)	2020	Zala[6]	
Landsat 8 - Land Surface Temperature (LST) - Normalized Difference Vegetation Index (NDVI)	2018 to 2021	USGS	Heat Risk Map Spatial Analysis: UHI Retrieval ES Adaptivity Sub-Indicator: Vegetation Health & Floodplain Area Pressure Indicator: Urban Temperature
LiDAR Digital Terrain Model (DTM)	2003, 2019	UBDC	Heat Risk Map and Spatial Analysis
LiDAR Digital Surface Model (DSM)	2019		Spatial Analysis of Green Infrastructure Distribution
PAN65	2000, 2008, 2019, 2020	Glasgow City Council (GCC)	Tree Canopy: ES Mismatch Analysis ES Adaptivity Sub-Indicator: Protected Area, Habitat Connectivity, & Extent of Habitats Pressure Indicator: Deprived Areas & Invasive Species Dominance

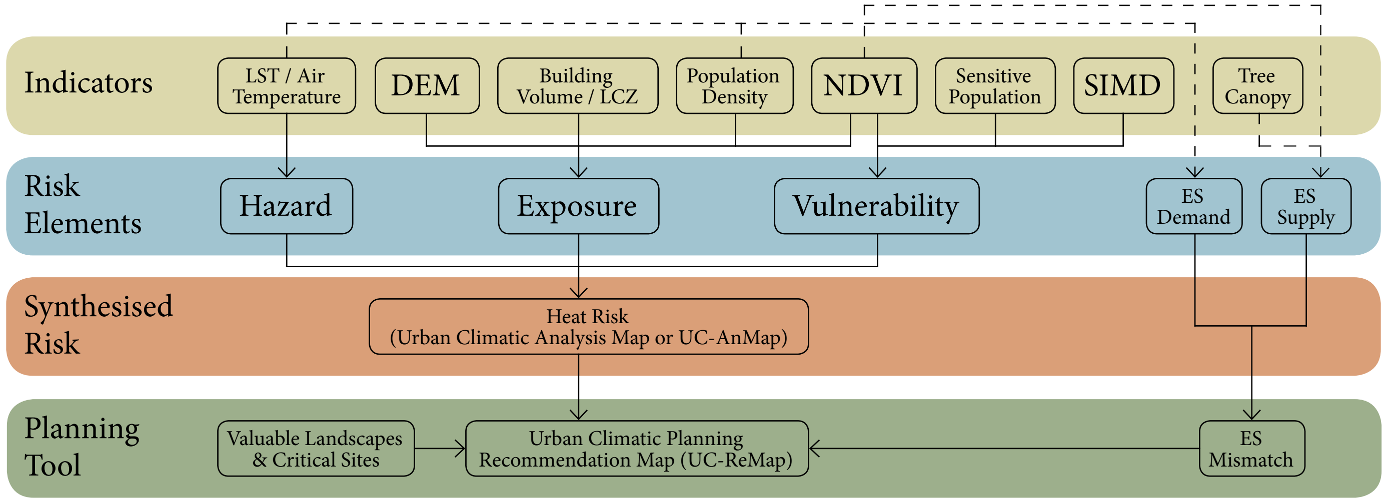
Data	Year	Source	Where it is Used
OS Greenspace Layer	2020	Digimap Ordnance Survey	Spatial Analysis of Green Infrastructure Distribution
OS Topography Layer			Microclimate Modeling
Buildings' Volume & Height Attribute	2019		
CSGN Integrated Habitat Networks	2012	NatureScot	ES Adaptivity Sub-Indicator: Natural Regeneration
Native Woodland Survey of Scotland	2000		ES Adaptivity Sub-Indicator: Protected Area
Water Environment Hub	2018	SEPA GCV	ES Adaptivity Sub-Indicator: Surface Water Quality
Flood Risk	2021	SEPA	Pressure Indicator
Potential of Policy CDP8	2019	GCC	ES Adaptivity Sub-Indicator: Floodplain Area
Delineation of Riparian Zones	2015	CGLS	
Urban Atlas Landcover Map	2018	CGLS	ES Adaptivity Sub-Indicator: Soil Sealing Pressure Indicator: Landscape Degradation
Species Records	2011 to 2021	NBN Atlas	ES Adaptivity Sub-Indicator: Pollinators & Key Species Pressure Indicator: Dominance of Invasive Species

*[1] Adaptation Scotland (2021). Climate Trends and Projections. Available **here**.*
[2] UHI is an urban area experiencing warmer temperatures than the surrounding rural areas due to the land use, surface/material properties, and human activities.
*[3] More information about the Avenues programme **here**.*
*[4] MUrCS, or Master in Urban Climate and Sustainability, is an Erasmus Mundus Joint Master Degree Programme. The curriculum is designed to inter-link the three thematic areas; Planning, Management, and Science. Click **here** for more information.*
*[5] ENVI-met is a modelling software that simulates microclimate in an urban area. More information about the software can be found **here**.*
*[6] Zala, M. (2020) 'Vulnerability and Glasgow Greendex : a framework to optimise the impact of green infrastructure in improving socio-environmental vulnerability', MUrCS Proceedings 2020, LAB University Press, Finland, pp. 98-112. Also available **here.***

Methods

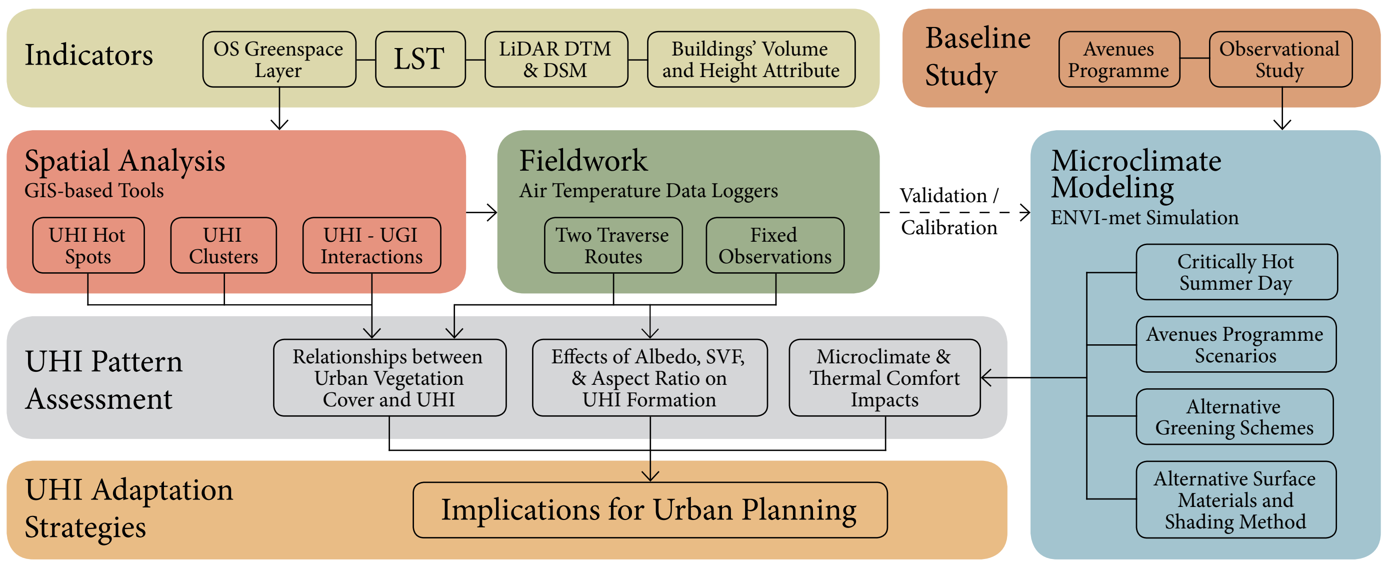
Urban Climate Mapping

GIS-based tools



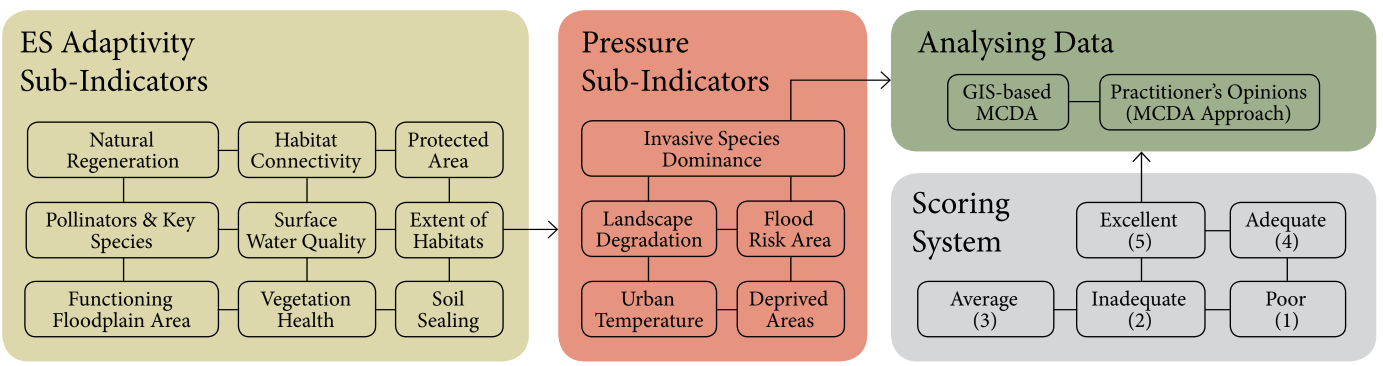
UHI Spatial Patterns and Mitigation Strategies

GIS-based tools | Air Temperature Data Loggers | ENVI-met



Ecosystem Health and Services

GIS-based Multi-Criteria Decision Analysis (MCDA) | Practitioners' Opinions

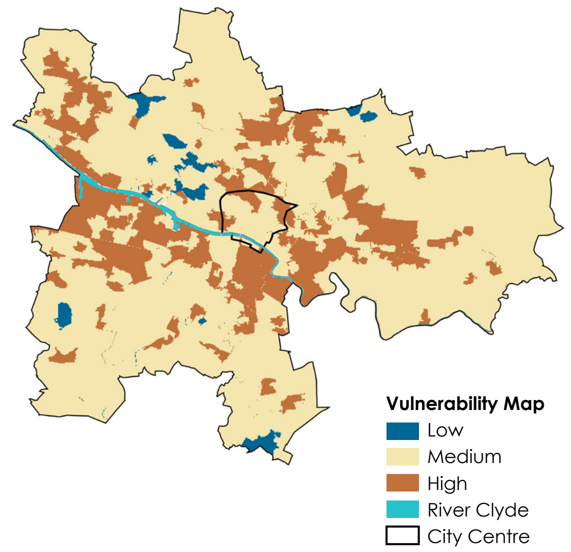


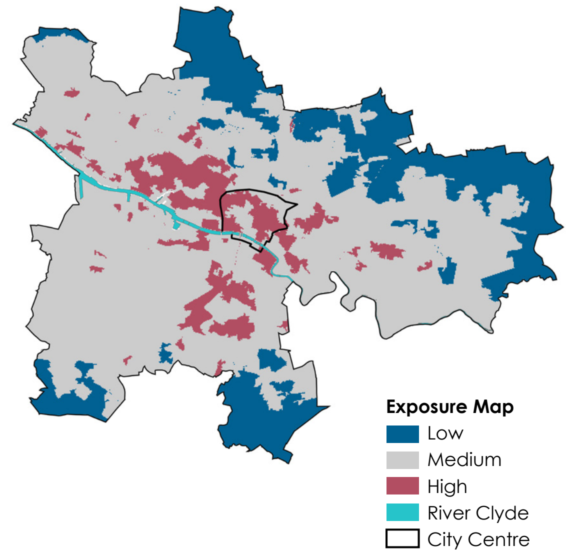
Urban Climate Risk Map

Urban climate risk, i.e., urban heat risk, is synthesised from the Hazard (LST), Vulnerability (socioeconomic and demographic conditions of the residents and vegetation index), and Exposure (topography, building information, and population density), following IPCC's risk definition.

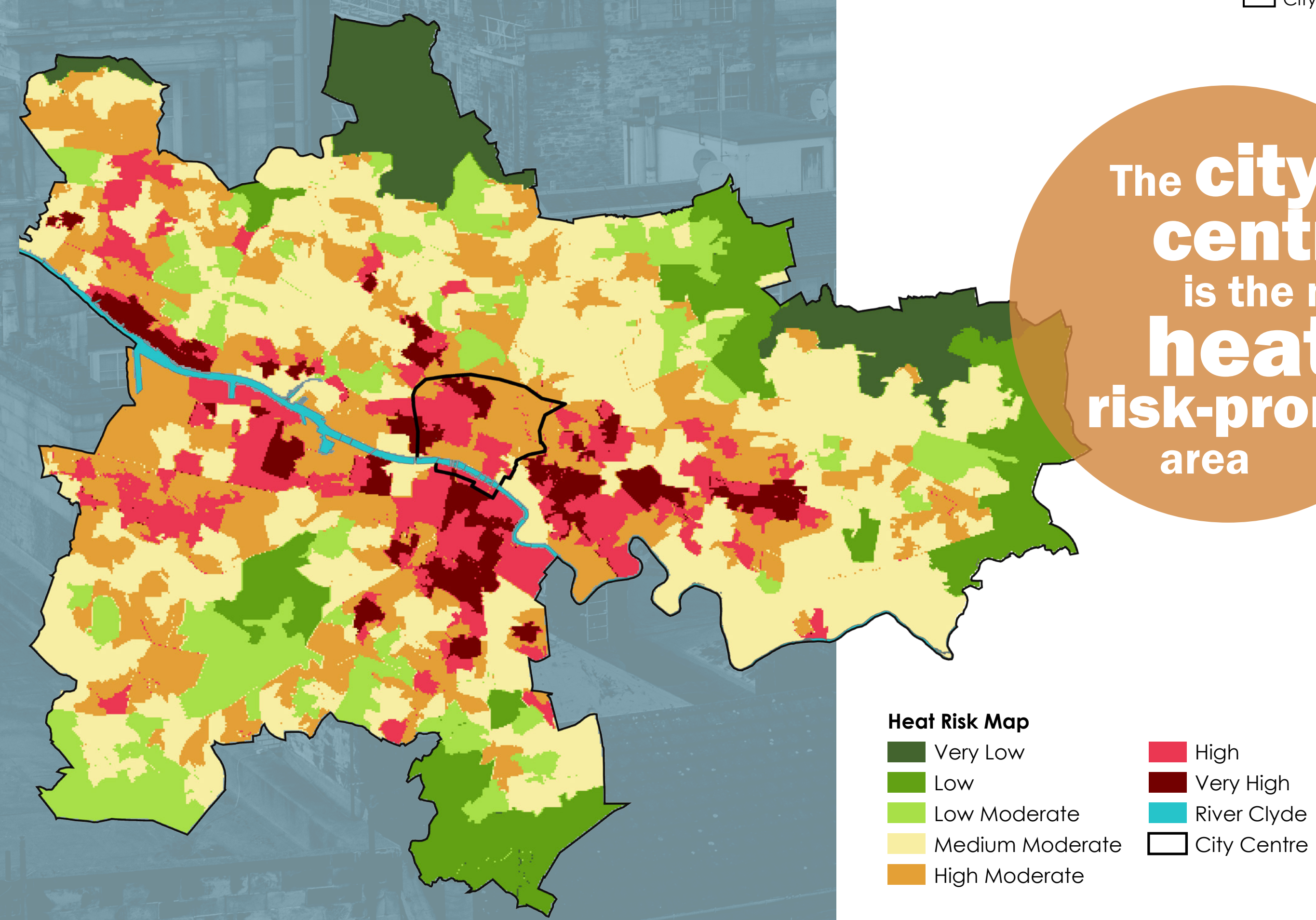
The urban heat risk map on the right highlights Glasgow **city centre** as the most **high heat risk** potential area, regardless of the climate mapping method used. It is largely due to high LST, dense building volume, low NDVI and topography, and high urban and commercial activities, combined with moderate socioeconomic conditions. Hence, the city centre is **highly exposed to heat hazards** but has low vulnerability to heat.

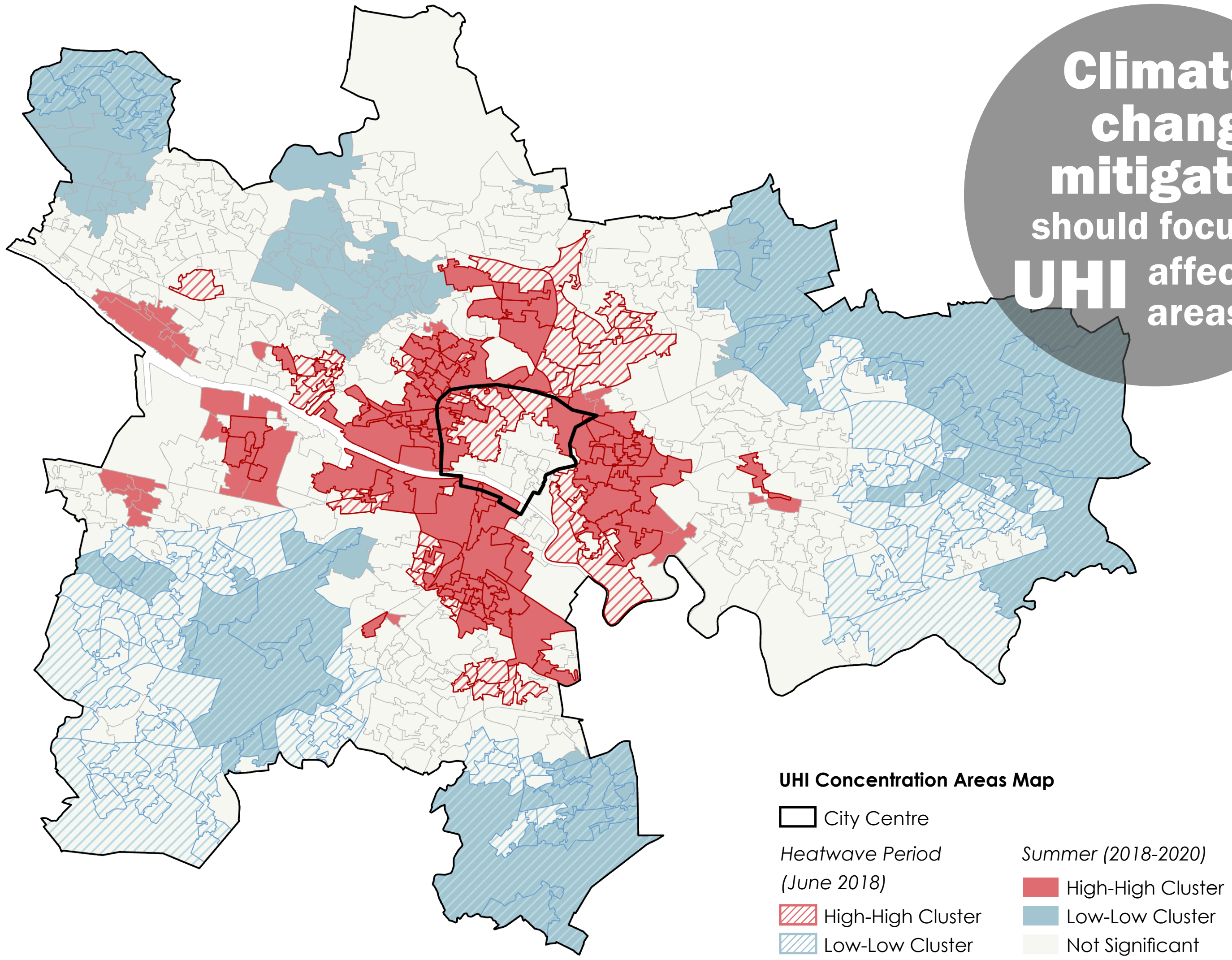
Other heat risk hotspots are observed within the River Clyde Development Corridor, although their intensity changes with the mapping method. In contrast, **low heat risk** areas are mostly found in the locality of large parks and green belt areas in the **north, northeast, and southern edges** of Glasgow city.





The city centre is the most heat risk-prone area





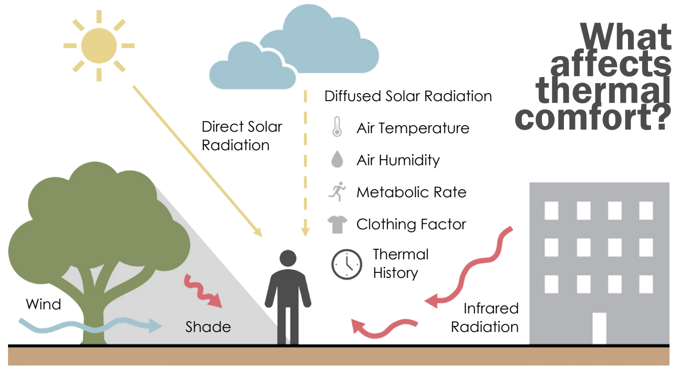
Climate change mitigation should focus on UHI affected areas

In summer,

urban core of Glasgow is **4-6 ˚C warmer** than the rest of the city, though temperature discrepancies can reach up to 10 ˚C in the regions with dense urban fabrics.

Identifying areas with higher-than-average heat stress within the UHI zone is essential for **targeting mitigation** measures. In Glasgow, due to imbalance in grey vs green infrastructure distribution, the **urban "hot" spots** show spatial dependence and clustering patterns in data zones along the River Clyde in the **central part** of the city. During **heatwaves**, the area affected by **excess heat is expected to increase**. To **counterbalance the clustering effect** of UHI, **UGI** (with priority to **trees and grass**) should also be incorporated in a **clustered manner** as isolated patches of grass or trees are not effective at cooling the clusters of overheated areas. Therefore, only **complex greening projects**, i.e., street trees cooling networks, would yield **effective temperature reduction**.

Could Avenues Programme improve the local climate?



Glasgow city centre is undergoing significant change with the Avenues programme – a project that will transform 21 streets through delivering pedestrian/cycle networks, UGI, and smart infrastructures.

While urban heat mitigation is not the primary aim of the Avenues programme, planned modifications might affect the thermal environment of the retrofitted streets and provide a valuable case study for the city planners and policy decision-makers.

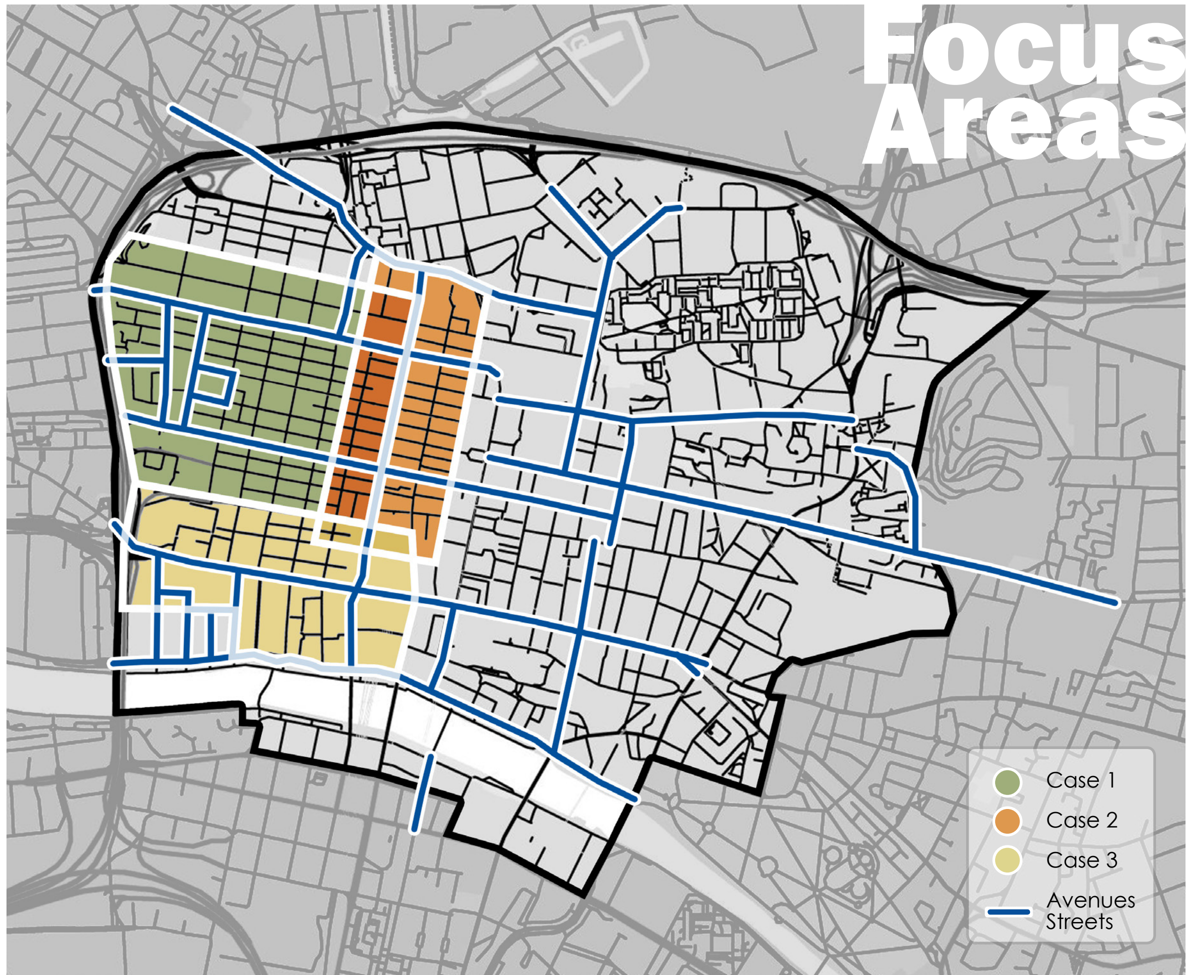
This document highlights the anticipated **urban climate implications of the Avenues programme** for six key streets with a focus on urban heat mitigation techniques such as **UGI, surface materials, and shading.**

Effects of Greening on Temperature

At present state, on a **hot summer day**, Glasgow city centre remains **thermally uncomfortable** for 7-9 hours. In the afternoon, pedestrians experience **strong to extreme heat stress** (PET[5] ≥ 40.0 ˚C).

Using ENVI-met, the cooling potential of the **greening scheme** proposed by the Avenues programme and **five alternative greening scenarios** were analysed (Case 1).

[5] PET, or physiologically equivalent temperature, is a thermal comfort index of perceived heat sensation of pedestrians.



Case 1

- Existing Situation
- Planned Avenues Scenario
- Five Alternative Green Infrastructure Scenarios

Case 2

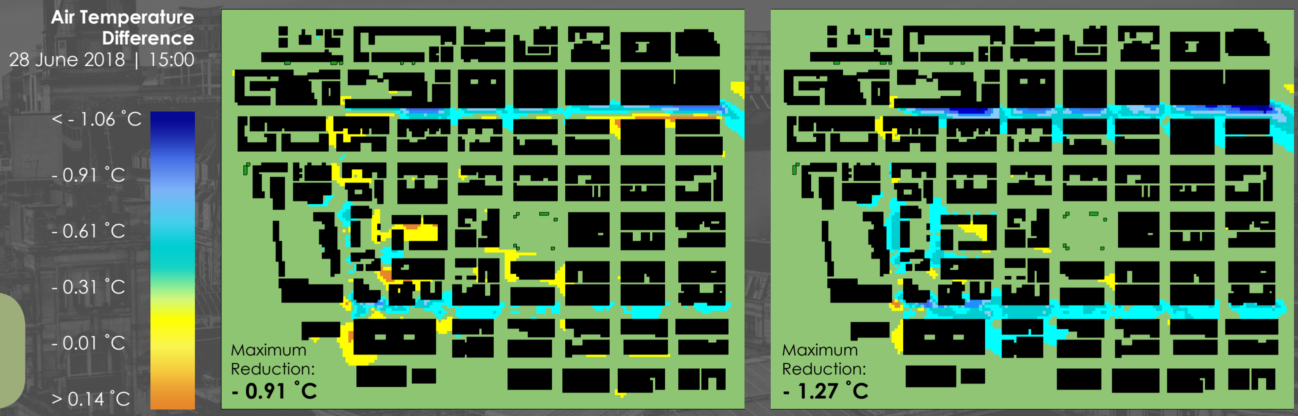
- Existing Situation
- Planned Avenues Scenario
- Alternative Surface Materials and Shading Scenario

Case 3

- Existing Situation
- Planned Avenues Scenario
- Alternative Surface Materials and Shading Scenario

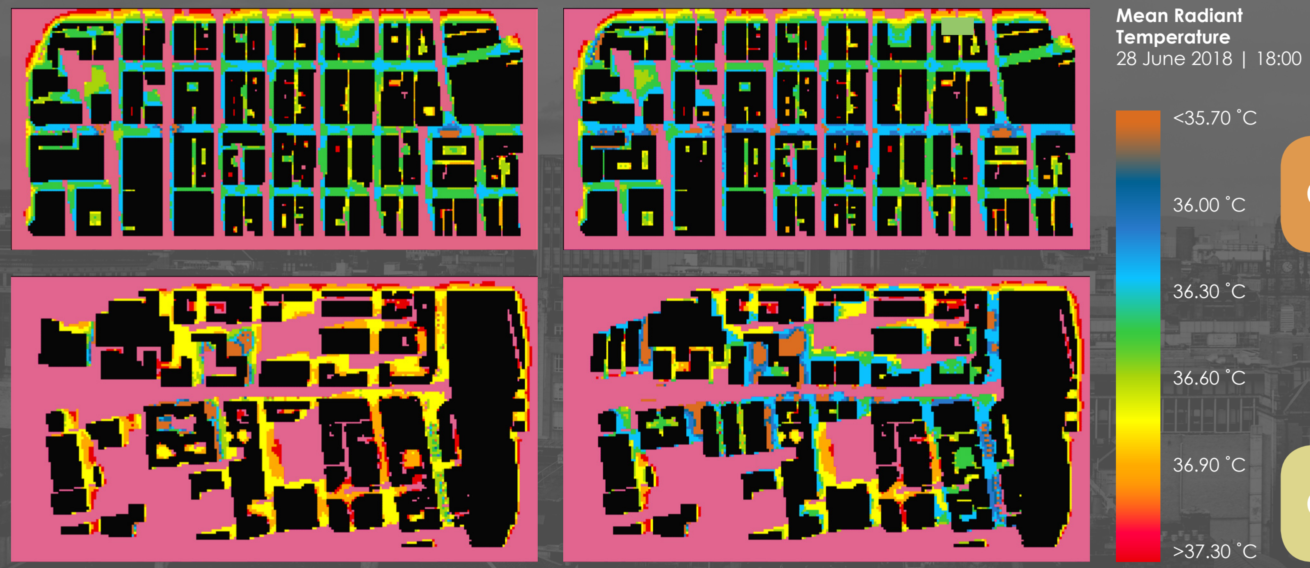
Simulation Outputs

Case 1



Avenues Programme
Planned Scenario

Avenues Programme
Alternative Trees Scenario



Case 2

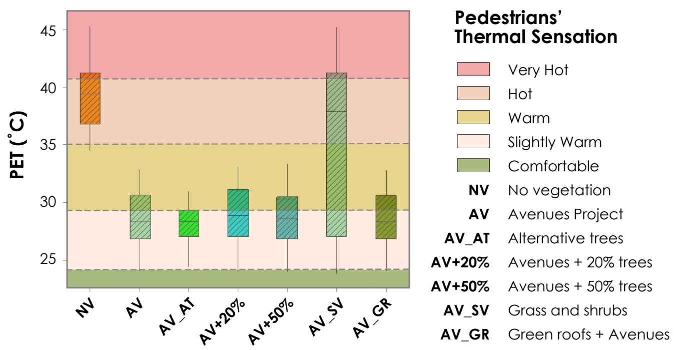
Case 3

Avenues Programme
Planned Scenario

Avenues Programme
Alternative Surface Materials and Shading Method

It is expected that:

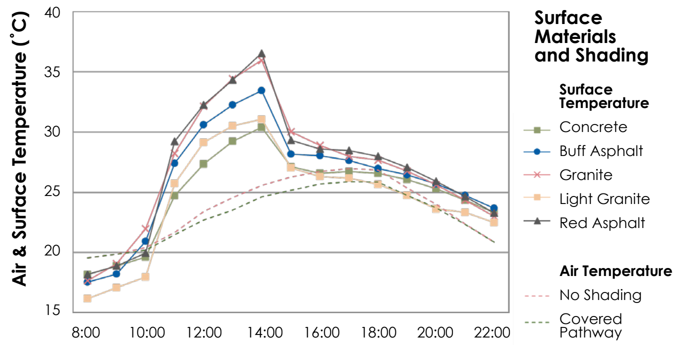
- Avenues programme could create local freshness effect by **maximum decreasing air temperatures by 0.91˚C** and improve pedestrian **thermal perception** from 'Very Hot' and 'Hot' levels to **'Warm'** and **'Slightly Warm'**;
- the **cooling effect** of the Avenues programme can be **further enhanced** by a selection of the tree species with **higher albedo**: e.g., *Tillia sp.*, which could lead to **1.27˚C** reduction in local air temperature. This, in turn, could counterbalance the warming expected due to climate change in 2050;
- further **increases in tree cover** may not be needed (increasing tree cover by **20% and 50%** from the Avenues baseline will only contribute to **0.92˚C and 0.93˚C** decreases in air temperatures);
- **grass and shrubs** may not have substantial reduction in air temperatures (less than 0.88˚C) and have **little effect on thermal comfort;**
- **green roofs,** may not lead to any additional cooling over the Avenues programme (less than **0.05˚C of additional cooling);**
- **trees** have the highest potential to **mitigate** heat and pedestrian's **thermal sensation** from **'Very Hot/Hot'** thermophysiological class (the present case) to **'Slightly Warm/Warm'**



What role materials have to play?

Studies show that reflective surfaces (high albedo values) could aid local-scale heating. In analysing the local urban climate consequences of the **existing situation vs the Avenues programme**, it was found that the latter led to modest net radiant heat loss (**8.31˚C**). Perhaps the **materials proposed** for the Avenues project, i.e., granite and red asphalt, could have affected the slight improvement due to their **low albedo values**.

The alternative scenarios in Cases 2 and 3 used **light granite and buff asphalt** to substitute **granite and red asphalt**. Likewise, urban form modification and enhanced shading were employed to explore the influence of SVF[6] and aspect ratio[7] in cooling the microclimate. The results show a



maximum net radiant heat loss of **30.64 ˚C**, mainly due to the **shading effect**. Hence, the use of high albedo materials is favoured if accompanied by covered pathways and canopies. Although the shading method effectively improves thermal comfort, staggering building facades is excellent in preventing overshadowing while establishing **higher SVF** and maintaining a **satisfactory aspect ratio.** In relation to the latter, it was found that an aspect ratio falling between **0.6 and 1** can significantly lessen the UHI in the city centre.

There is no set standard as to what values of albedo, SVF, and aspect ratio achieve a maximum cooling effect. However, this document proved that an **integrated approach** in UHI mitigation is **crucial** to maximising thermal comfort and pollution dispersion.

Linking Ecosystem Services to UHI Mitigation

Ecosystem health is key to understanding the ecosystem services (ES) supply. **Glasgow's Green Network** can deliver climate services, somewhat preserve the remaining biodiversity, and eventually **benefit the degraded landscapes.**

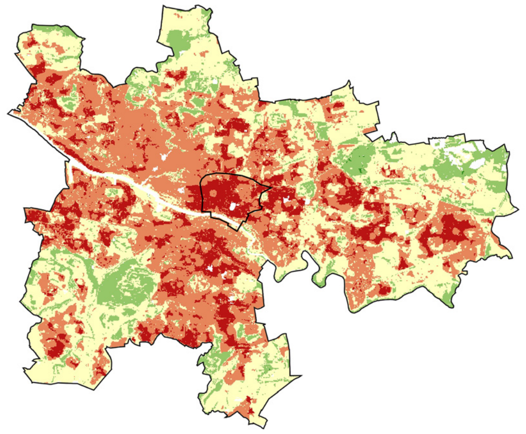
Even though multiple climate services are possible in *healthy* areas that have high levels of ecosystem health and integrity, ecosystem *dis-services* could emerge in an *unhealthy* environment created by poor planning decisions. Interestingly, all healthy areas do not fall within locally designated nature areas. In addition, **deprived areas have the least access to climate services.** For example, only 1 ha of *healthy ecosystem* exist in deprived areas.

[6] SVF, or sky view factor, determines the amount of sky seen from the ground in an urban area.
[7] Aspect Ratio is the proportion of height and width of a street canyon. Significantly high or low aspect ratios could contribute to thermal discomfort.

Besides, poor ecosystem health is evident in the city centre due to anthropogenic pressures and isolation from nature core. Likewise, a **slightly positive Temperature Regulating ES mismatch is obvious in the city centre**, which means there is a high ES demand for cooling effect but less ES supply.

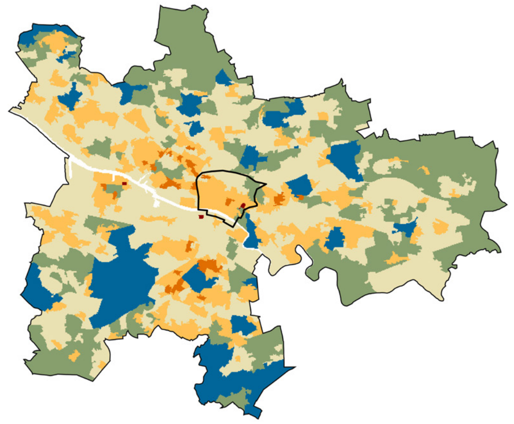
The Urban Climate planning recommendation map (UC-Remap) was generated with an overlay of Heat risk and ES mismatch map. The UC-ReMap has divided Glasgow city into **five planning zones**, where UPZ 1 and 2 should be protected and conserved. **UPZ 5** is the **most sensitive** zone, it includes the city centre, and it needs immediate intervention given its social, historical, planning, environmental, and economic value. As this zone has an exceedingly **high ES demand but little ES supply**, it is high time to focus on the temperature regulating ecosystem services and ecosystem health. Therefore, necessary climate change adaptation measures, including UGI, must be applied to reduce the UHI effect.

Ecosystem Health



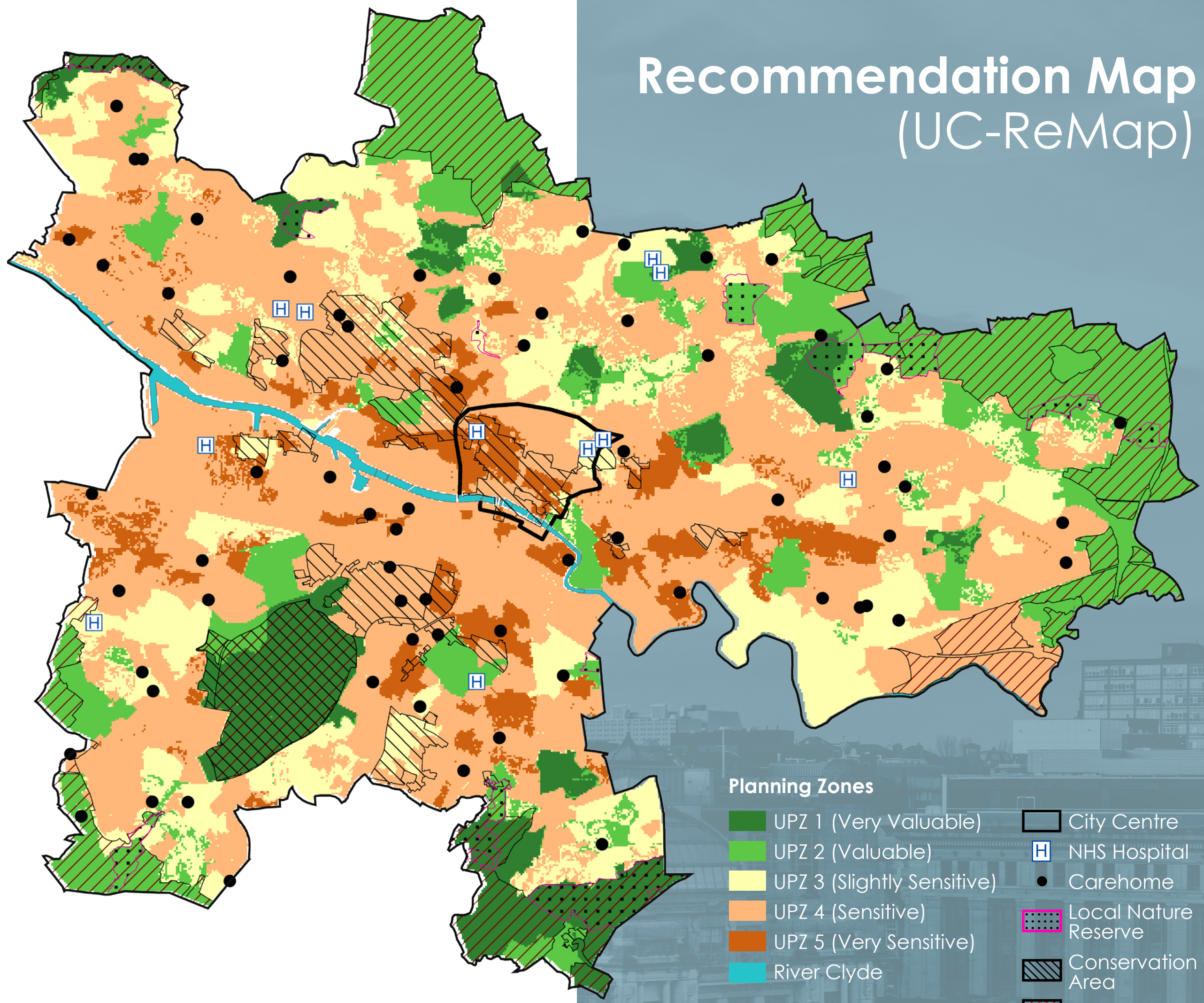
Ecosystem Health
- Poor (13%)
- Inadequate (38%)
- Average (39%)
- Adequate (11%)
- Excellent (0.05%)

ES Mismatch of Temperature Regulation



ES Demand - ES Supply
- Highly Negative
- Moderately Negative
- Slightly Negative
- Slightly Positive
- Moderately Positive
- Highly Positive

Recommendation Map (UC-ReMap)



Planning Zones
- UPZ 1 (Very Valuable)
- UPZ 2 (Valuable)
- UPZ 3 (Slightly Sensitive)
- UPZ 4 (Sensitive)
- UPZ 5 (Very Sensitive)
- River Clyde
- City Centre
- NHS Hospital
- Carehome
- Local Nature Reserve
- Conservation Area
- Greenbelt

Prospects for Implementation

Citywide Solutions

- Public participation in climate-sensitive community development can improve the microclimate
- Arranging for design competition brings in innovative solutions for urban retrofitting and open spaces
- Glasgow city central areas along the Clyde River, in particular Dennistoun, Anderston/City/Yorkhill, Southside Central, Calton Wards, should be the priority areas for urban heat mitigation
- City regeneration projects, like the Avenues programme, can contribute to climate resilience and provide the cooling needed to offset the warming related to climate change
- UHI mitigation effect of regeneration projects, such as the Avenues programme, can be enhanced by the strategical placement of trees, revision of the selected tree species, and careful consideration of surface materials
- Heatwave Forecasting System, designated local cooling centres, and Heatwave Management Guidelines should be developed

Urban Green Infrastructure

- Scale matters and cooling effect of trees is working better at the neighbourhood scale, therefore, complex greening schemes should be favoured
- Trees are more efficient at cooling urban spaces than other UGI types, though a combination of trees and grass is the best choice
- Strategic placement of UGI in the heat-affected areas and its quality is more important than quantity
- An aspect ratio of 0.4 could substantially improve the air temperature with the provision of street greening
- A Public-Private collaboration for developing accessible UGI should be embraced

Urban Form and Surface Materials

- Staggered building facades can demonstrate an enhanced temperature and allow solar access at the pedestrian level
- Pushing forward of walls in higher floor exhibits good shading technique, especially in south-facing facades
- Roof refurbishment with white paint or extensive green roof, i.e., a thin layer of substrate, pocket habitat, etc., should be implemented
- The use of light-coloured ground surfaces is favoured in narrow streets flanked by tall buildings to prevent indirect solar radiation, thus avoiding the increase in temperature
- Areas with narrow streets flanked by low-rise buildings could benefit from using covered pathways, canopies, or other shading devices, to improve thermal comfort, especially if there is no room for street greening
- A dense form, or an aspect ratio of 0.6 to 1.0, can maintain pollution dispersion and solar access within the streets

Team Contribution

Rabeya Begum
- Heat Risk Mapping
- Mismatch of ES
- Planning Recommendation Map

Oksana Ananyeva
- UHI Mapping
- Avenues Programme Analysis
- Green Infrastructure Effect

Aira Valdez
- Avenues Programme Analysis
- Surface Material Effect
- Shading Method Effect

Nichamon Rattanakijanant
- Ecosystem Health
- Ecosystem Services

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Valdez, A. (2021) 'Urban morphology and streetscaping as an approach to mitigate urban heat island in Glasgow city centre, in R. Emmanuel et al. *MUrCS Proceedings 2021*, LAB University Press, Finland (in press)

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