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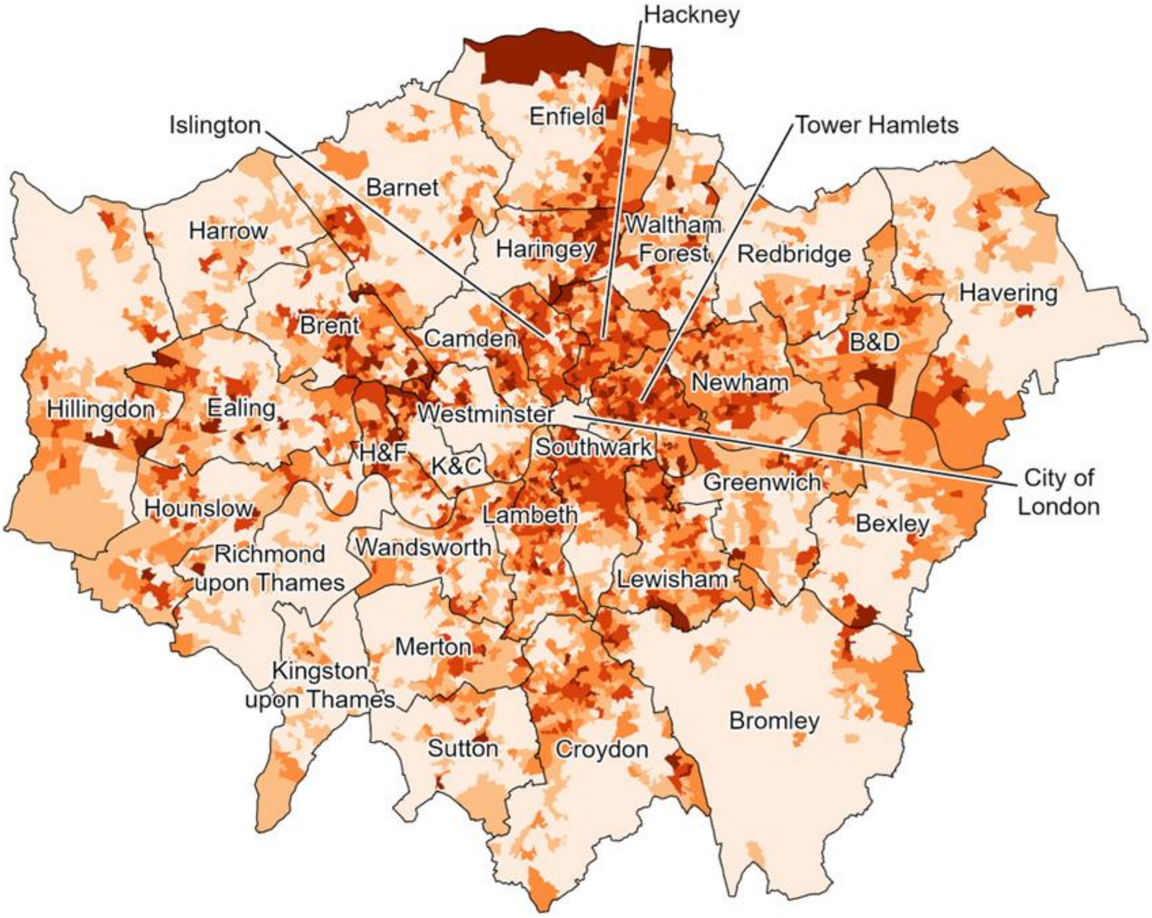
Properties Vulnerable to Heat Impacts in London

Prioritisation for adaptation interventions



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Greater London Authority
January 2024

Published by
Greater London Authority
City Hall
Kamal Chunchie Way
London E16 1ZE

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Copies of this report are available
from www.london.gov.uk

ACKNOWLEDGEMENTS & CONTRIBUTIONS

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CONTENTS

Introduction

Background

London is getting hotter. This is due to global climate change and London's Urban Heat Island (UHI) effect. Urban heat risk is an ever-growing pressure on London's physical environment and its people, with the most vulnerable people likely to be disproportionately impacted. In the summer of 2022, the UK saw its first ever 'UK Health Security Agency Level 4 heat alert', and its first 'Met Office Red extreme heat warning'. The heatwave was far more intense and widespread than previous comparable heatwaves, and marked the first time the UK had recorded a temperature of 40°C. This meant that impacts were expected beyond the health and social care system; and that even fit and healthy people were at risk. Heatwaves are projected to increase in both magnitude and frequency in the UK, and we may experience 40°C days more often in the future (Met Office, 2023).

The Greater London Authority (GLA) is already delivering a wide range of activities that will help to reduce the impact of rising temperatures and heatwaves in London. This includes targeted programmes for more vulnerable people, such as work done with schools and Early Years settings and care homes (*Climate Resilient Schools* and *Care Home Overheating Audit Pilot Project*) and the creation of a range of insightful and informative maps relating to heat such as Cool Spaces or the London Climate Risk Map. There is also research work carried out that looks at particular interventions such as green infrastructure's contribution to cooling the city and the integration work with the GLA's Energy Efficiency Programmes.

These programmes and approaches acknowledge that the impacts of climate on people can be exacerbated or mitigated by their built environment. London's existing properties have not been designed to accommodate more intense and prolonged high temperatures and may be exposed to heat during an extended period of the year, bringing greater risk to building occupants. However, there is limited data available to identify the neighbourhoods, building types, and sectors most at risk. Ageing infrastructure, inadequate maintenance and refurbishment, and demographic shifts emphasise the need to identify at-risk properties and people for better heat preparedness and prioritisation of adaptation investments.

The GLA has commissioned Arup to carry out this study in recognition of the need for better data to inform a long-term and sustained approach to locate and target interventions in London's built environment.

Objectives

The objective of the project was to identify and overlay:

- Neighbourhoods with a higher density of properties prone to overheating, due for example to their age, condition, or use type/activities.
- Neighbourhoods with higher ambient temperatures due to variability in the UHI effect.
- Residential settings with occupants that are vulnerable to adverse heat-related health outcomes due to their underlying characteristics.

The study focused on a distinct subset of properties in London considered essential settings, emphasising areas where occupants are especially vulnerable to heat-related hazards. This included **schools**, **hospitals**, **care homes,** and **residential** properties.

The work involved a systematic process of gathering, analysing and layering data, including factors that heighten the vulnerability of both properties and occupants, along with factors influencing the spatial extent of heat hazards throughout London. The result is a collection of heat risk maps and datasets tailored to each property type.

The resultant datasets and property heat risk maps were designed to equip the GLA with informed insights to drive targeted interventions, particularly addressing areas characterised by pronounced deprivation and inequality. Beyond the GLA's sphere, the project outcomes inform a diverse array of stakeholders across the public and private sectors, including the public, local authorities, building owners, developers, built environment experts, as well as decision-makers in education and healthcare.

The insights derived from this endeavour lay the foundation for cross-sector initiatives aimed at mitigating risks, tackling inequalities, protecting London's residents, and facilitating preparedness, response, and recovery from climate change impacts, especially extreme heat events.

The heat risk maps should be used in tandem with other GLA programmes and other related work carried out across London on heat risk to ensure mitigation initiatives are holistic and take on a whole systems approach.

Report Structure

The main insights from this project are drawn from the heat risk maps and the datasets that constitute them. The aggregated heat risk maps are presented in this report in the **Outputs** section. The main conclusions and suggested next steps are discussed in the **Conclusion**.

The **Methodology** section discusses the steps taken to produce the maps, which include research, data gathering and analysis, limitations, and assumptions. Further details are provided in the **Appendices**. This includes information on the datasets, detailed methodologies, and the full set of data maps.

Outputs

Approach

Heat risk is a combination of vulnerability to heat and exposure to heat hazards of a given magnitude or duration. Definitions have been used as per ISO 14091:2021 “Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment”.

Heat hazard

A “hazard” is a potential source of harm (ISO 14091:2021); in this case, extreme or prolonged heat. The indoor temperature and potential for overheating in a property are intrinsically linked to the outdoor temperature. Outdoor air temperature therefore serves as a key factor in gauging heat exposure throughout London. The concept of the UHI in London, and the resulting temperature disparities observed across different areas of the city, were employed to quantify the extent of the heat hazard.

Heat exposure

“Exposure” relates to the presence of (in this case) people or properties in places and settings that could be affected by heat hazards (adapted from ISO 14091:2021). Exposure can be determined by overlaying the locations of people and properties with data describing outdoor temperature variability across London. It is also important to note that exposure in a given location could change over time due, for example, to land use changes.

Vulnerability

“Vulnerability” refers to the propensity or predisposition to be adversely affected by the impacts of climate change (ISO 14091:2021). The propensity for a property to overheat is a result of the interplay between distinct factors that render it prone to overheating (e.g., the construction materials, orientation, glazing, shade, ventilation etc.). In addition, the predisposition of building occupants to be adversely affected by overheating relates to factors including their underlying health, age, and socioeconomic characteristics. Hence, this study considered both property and human vulnerability factors to understand properties at risk.

Mapping and Risk Scores

The property heat risk maps were created through combining datasets relating to property heat vulnerability, socioeconomic vulnerability,[1] and heat hazard across London with equal weighting given to each layer (further details in **Methodology** section).

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[1] Note that a socioeconomic vulnerability layer has not been included in the calculation of the heat risk map for care homes. This is discussed further in the Methodology.

Data mapping was carried out at Lower Layer Super Output Area (LSOA). This was considered an appropriate scale to represent the neighbourhood level assessment proposed for this project.

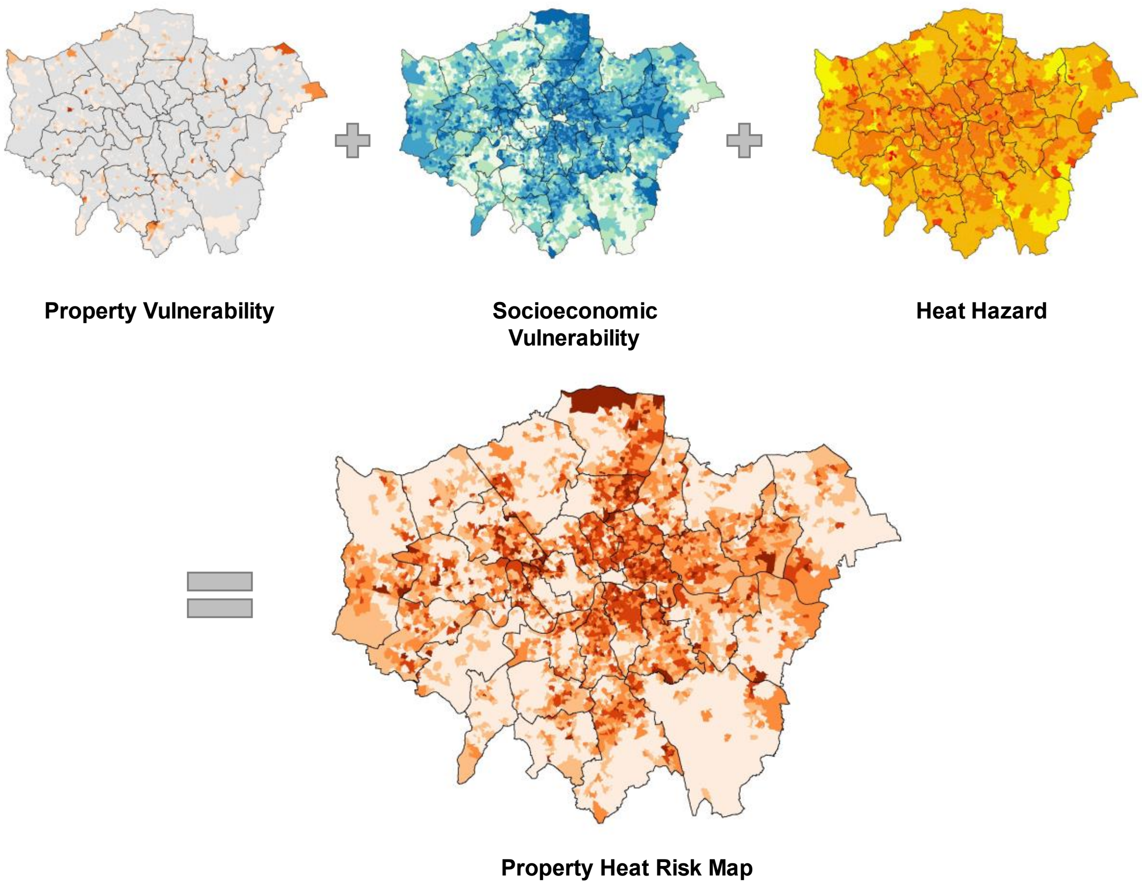

Figure 1: Calculation method for property heat risk map at neighbourhood (LSOA) level

Using the maps

Heat risk is presented at a scale of one to five, where one is the lowest heat risk and five is the highest heat risk. Maps have been aggregated to illustrate visually how heat risk varies for different property types across neighbourhoods in London.

Borough boundaries have been included to allow local authorities to determine how heat risk varies for different property types across their borough. Local authorities can use these insights to:

- Inform the development and implementation of adaptation solutions. The maps can help prioritise action in the areas and properties that need it the most.
- Further inspect properties in the most at-risk neighbourhoods to assess specific adaptation needs.

- Raise awareness in their borough through both stakeholder engagement and public awareness campaigns. This will also help gather further insights and can be used to promote short- and long-term actions.

Figure 2: London Boroughs

1	City of London	12	Hackney	23	Lewisham
2	Barking and Dagenham	13	Hammersmith and Fulham	24	Merton
3	Barnet	14	Haringey	25	Newham
4	Bexley	15	Harrow	26	Redbridge
5	Brent	16	Havering	27	Richmond upon Thames
6	Bromley	17	Hillingdon	28	Southwark
7	Camden	18	Hounslow	29	Sutton
8	Croydon	19	Islington	30	Tower Hamlets
9	Ealing	20	Kensington and Chelsea	31	Waltham Forest
10	Enfield	21	Kingston upon Thames	32	Wandsworth
11	Greenwich	22	Lambeth	33	Westminster

Outputs

Overview

The heat risk maps for all the property types considered show a higher heat risk towards the centre of London. This is associated with a higher heat hazard towards the centre of London due to the UHI effect. This makes the centre of London hotter on average compared to the outskirts meaning that properties and people located in these areas will be more exposed to heat.

There is a wider distribution of higher heat risk across London for care homes which is due to the assumption that care home residents tend to be more vulnerable to heat impacts. For hospitals, the heat risk is more concentrated in central, east, and a portion of west London. This is due to the combination of high heat hazard and concentrations of socioeconomic vulnerability in these areas. Both school and residential properties show higher heat risk towards central London but also have hot spots distributed across most boroughs.

Schools

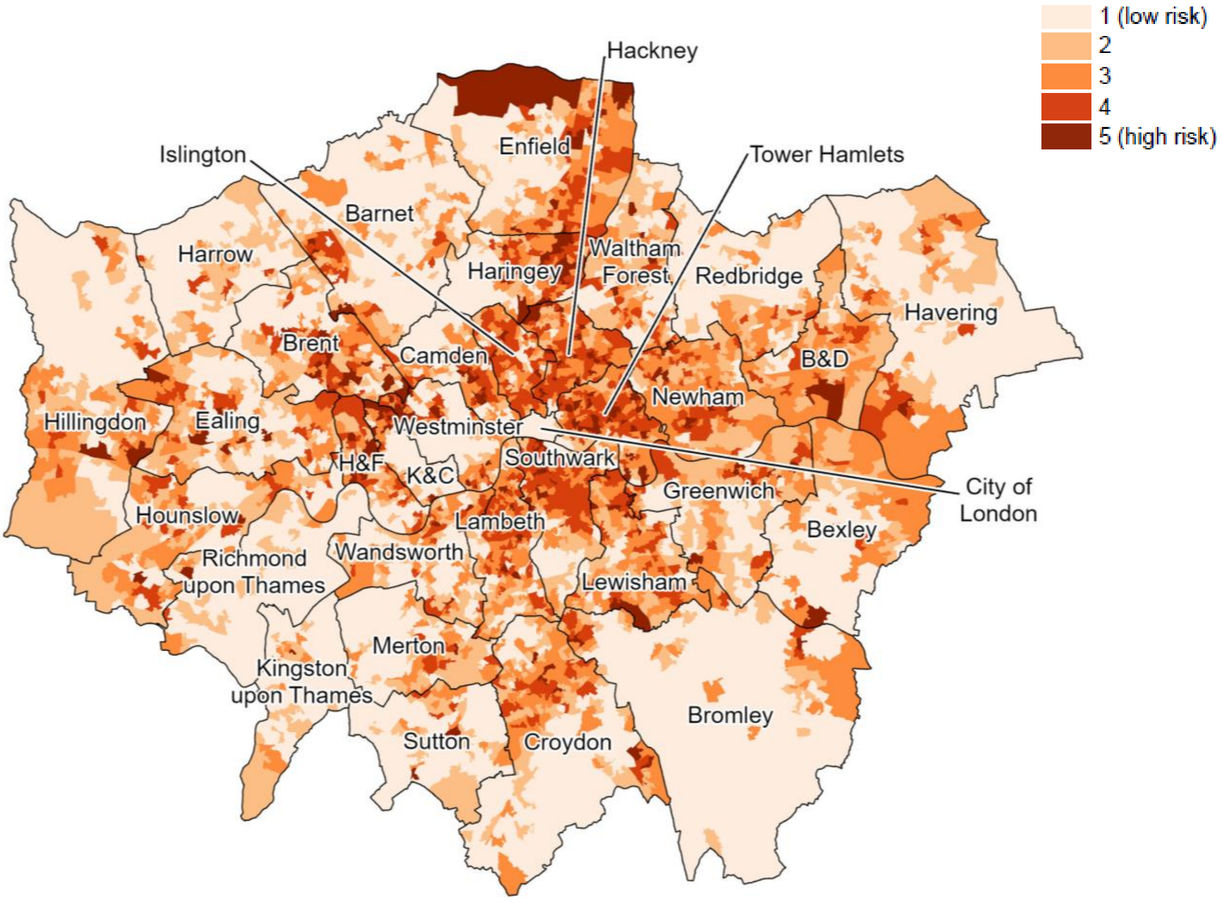

Figure 3: Heat Risk Map for schools aggregated to LSOA

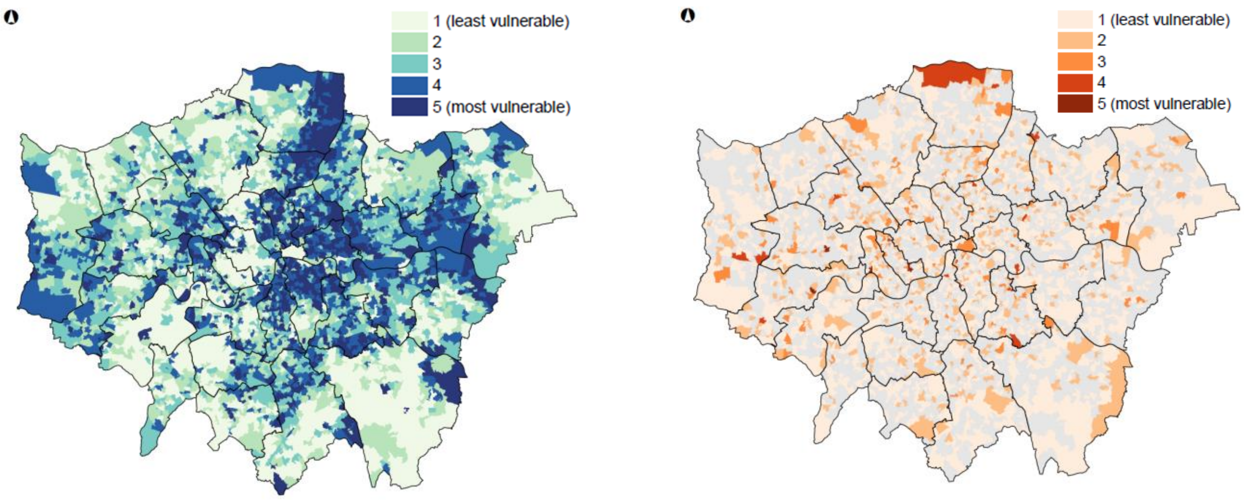

Figure 4: Socioeconomic Vulnerability Map (left) and Property Vulnerability Map (right) for schools

Key insights:

- The map indicates a higher heat risk for schools in areas closer to the centre of London.
- This coincides with a higher heat hazard in the centre of London (Figure 16) due to the UHI effect as well as higher socioeconomic vulnerability (Figure 4) towards the centre of London.
- Boroughs such as Islington, Hackney, and Tower Hamlets show the greatest heat risk for schools.
- Areas towards the outskirts such as Hillingdon, Kingston Upon Thames, Bromley, and Barnet show the least heat risk.
- The hotspot seen in the north of Enfield is attributed to high socioeconomic vulnerability and higher property vulnerability for schools in this area.

Hospitals

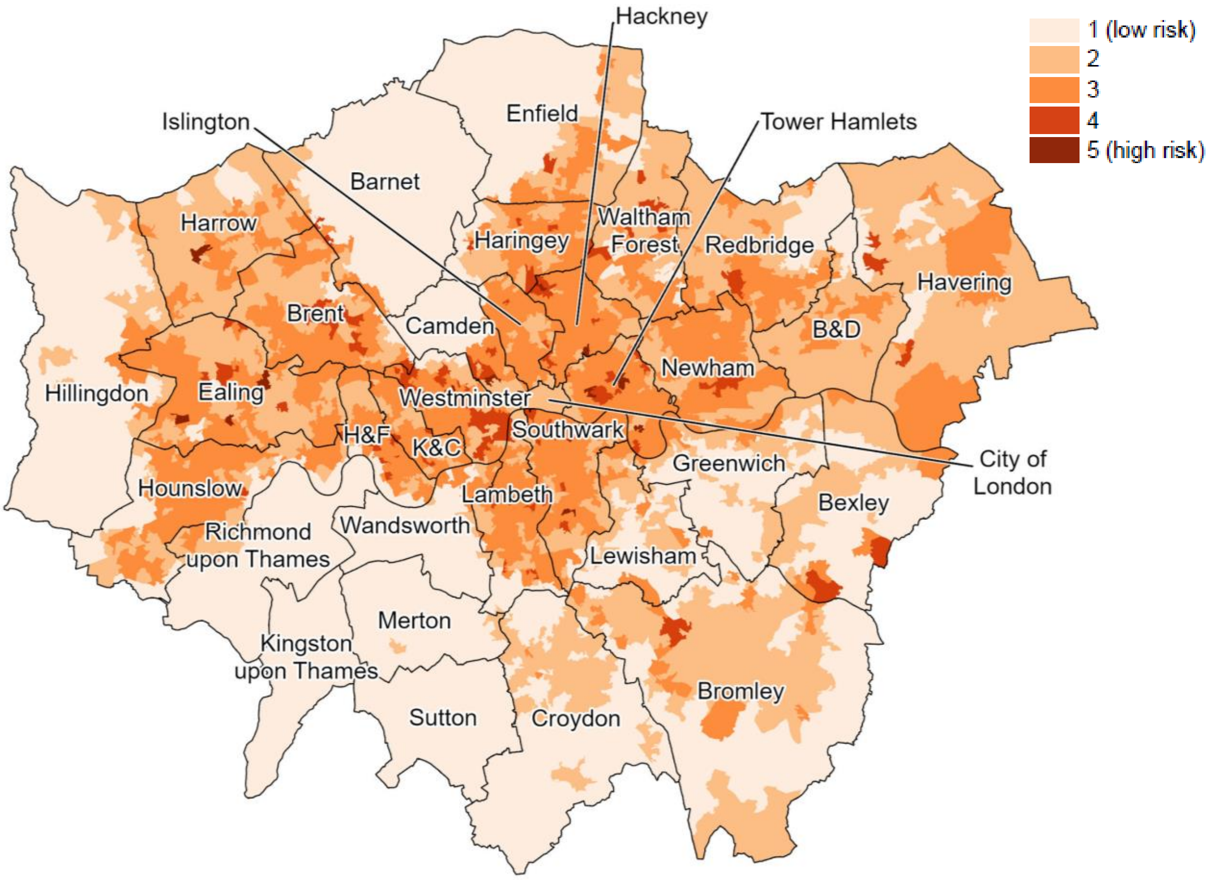

Figure 5: Heat Risk Map for hospitals aggregated to LSOA

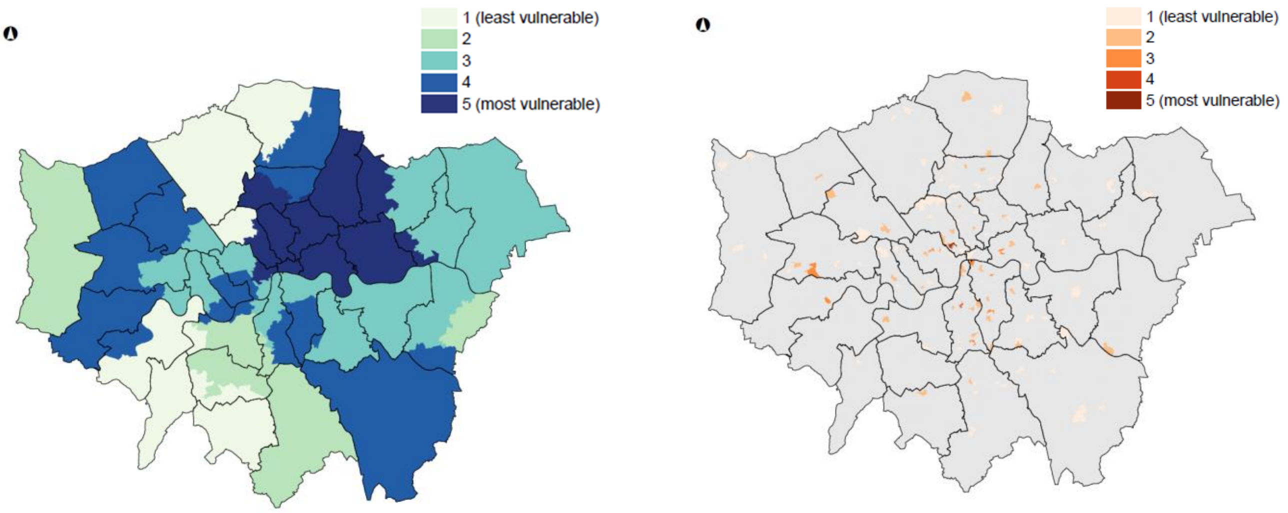

Figure 6: Socioeconomic Vulnerability Map (left) and Property Vulnerability Map (right) for hospitals

Key insights:

- The map indicates a higher heat risk for hospitals in areas towards the centre of London. This includes central boroughs such as Southwark, Tower Hamlets, Hackney, Islington, and Kensington and Chelsea. These areas have a higher heat hazard due to the UHI effect (Figure 16).
- Socioeconomic vulnerability is higher towards central and east London especially for the Barts Health NHS Trust, Barking, Havering and Redbridge University Hospitals NHS Trust, Homerton University Hospital NHS Foundation Trust, Whittington Health NHS Trust, and University College London Hospitals NHS Foundation Trust. These areas also show a higher heat risk for hospitals in these areas.
- Areas towards the outskirts such as Hillingdon, Barnet, Richmond, Kingston, Sutton, and Merton show the least heat risk. Note that the concentrations of hospitals in these areas are also lower.

Care Homes

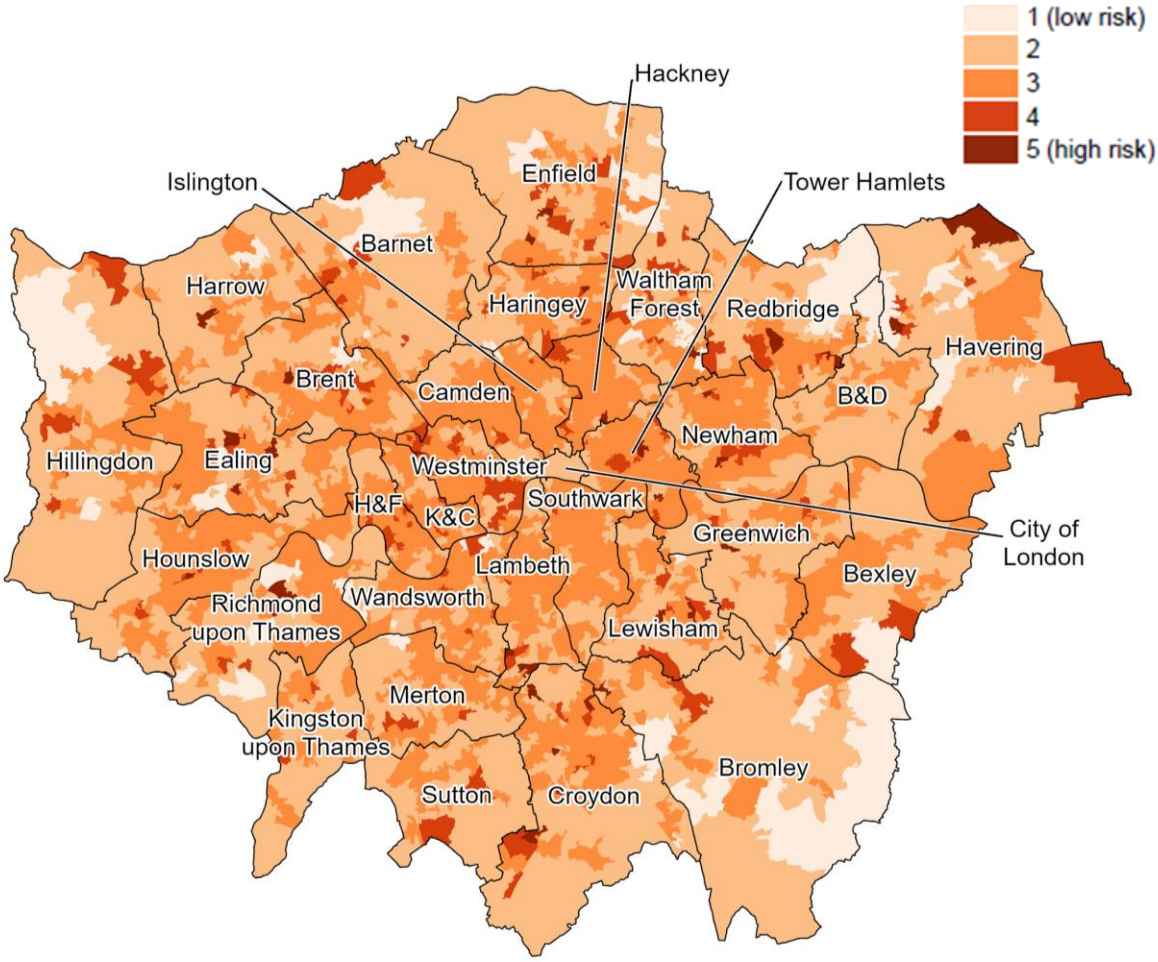

Figure 7: Heat Risk Map for Care Homes aggregated to LSOA

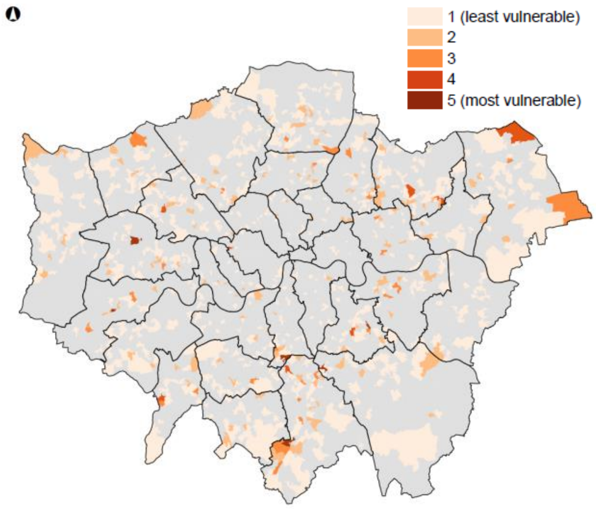

Figure 8: Property Vulnerability Map for Care Homes

Key insights:

- The care home heat risk map shows overall higher heat risk across London compared to other property types considered.
- Care home residents have been considered vulnerable to heat and a socioeconomic vulnerability layer has not been included to create the heat risk map (see Methodology section for further details). Therefore, the overall risk is considered to be higher.
- Boroughs towards central London are considered to have a higher heat risk which is related to the higher heat hazard in these areas.

Residential Properties

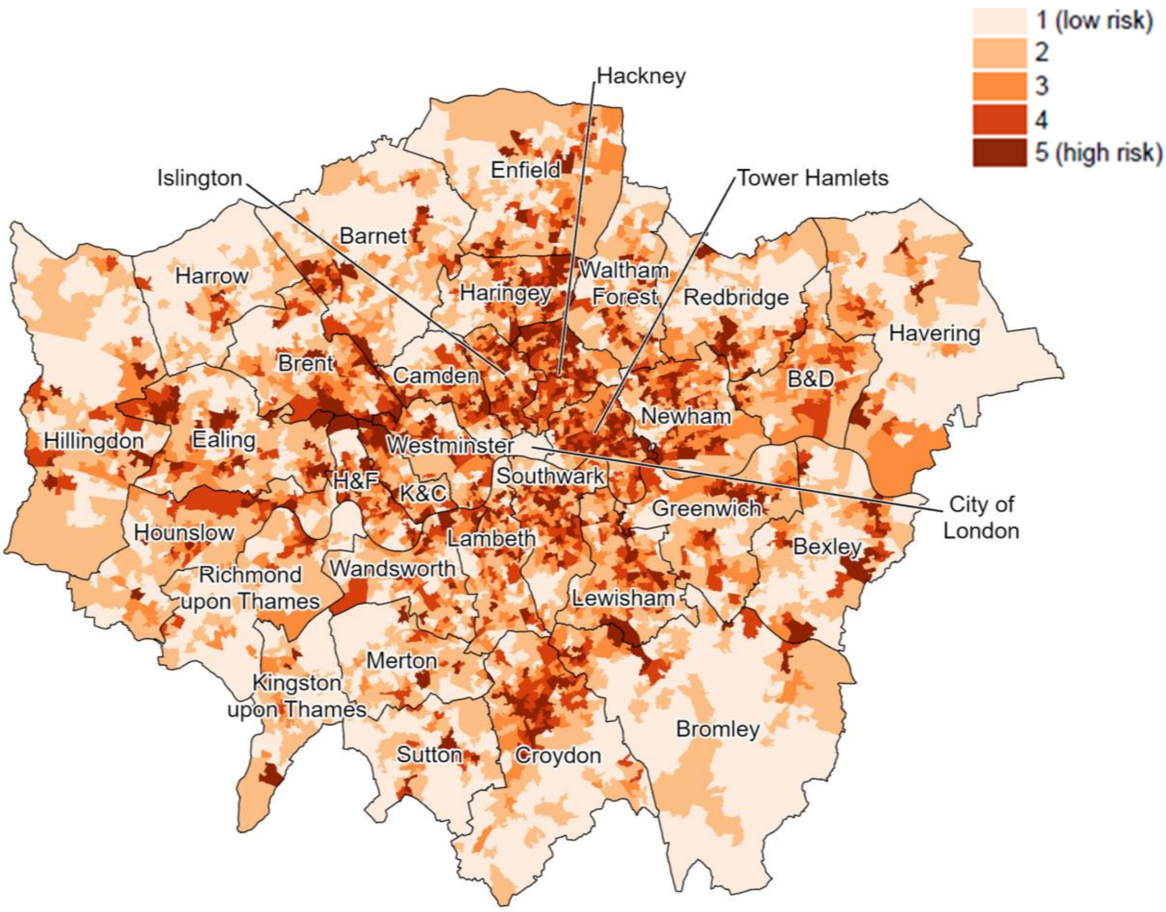

Figure 9: Heat Risk Map for residential properties aggregated to LSOA

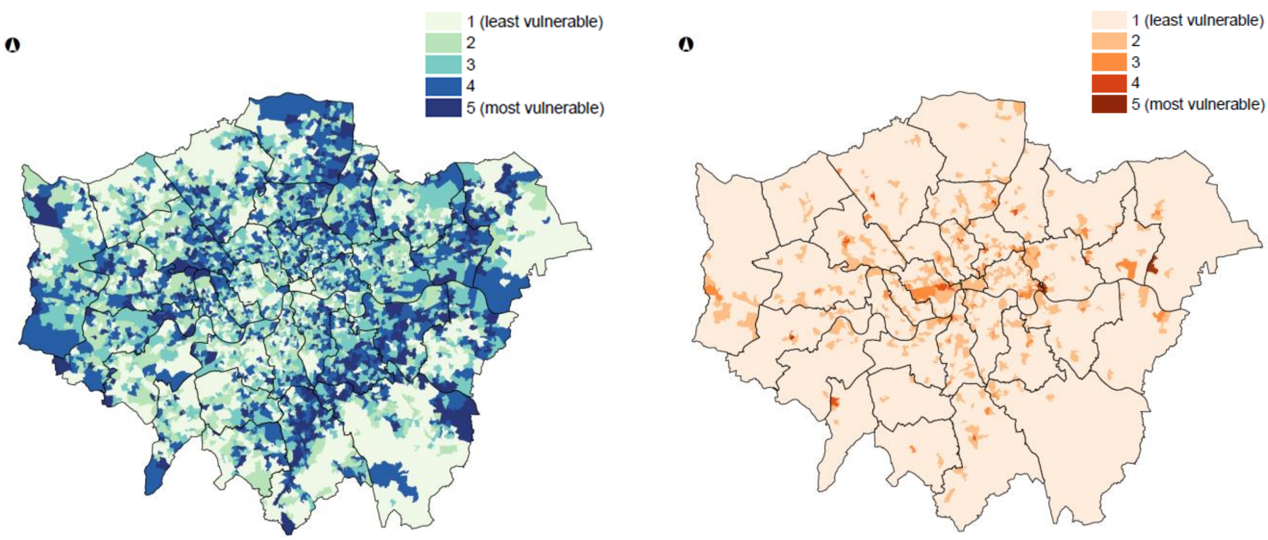

Figure 10: Socioeconomic Vulnerability Map (left) and Property Vulnerability Map (right) for residential properties

Key insights:

- The map indicates a higher heat risk for residential buildings in areas towards the centre of London. This includes central boroughs such as Hackney, Tower Hamlets, Islington, and Camden. These boroughs tend to have a higher proportion of flats, which are considered to be more vulnerable to overheating, compared to outer London broughs which have a higher proportion of houses.
- Areas towards the outskirts such as Bromley, Havering, and Hillingdon show the lowest heat risk.
- Within each borough there are hotspots where heat risk to residential properties is higher. These areas should be prioritised for heat intervention action.

Conclusion

This study identified neighbourhoods in London where properties are most vulnerable to overheating. By focusing on essential settings such as schools, hospitals, care homes, and residential properties, we have provided an understanding of the factors contributing to heat-related risks for various property types. The heat risk maps provide informed insights to drive targeted interventions, particularly addressing areas characterised by pronounced deprivation and inequality; one of the key objectives of the study.

This project provides a broad overview of heat risk, but there remains a need for more in-depth exploration of the intricate mechanisms that contribute to overheating in buildings. This will require a greater depth of data and insight which can be acquired through subsequent initiatives building upon this work as well as by establishing connections with other existing programmes that complement this work. As we move forward, it is also imperative that the insights gained from this study inform not only the GLA's initiatives but also broader policymaking and action plans. This should include other stakeholders such as the NHS, schools, private care home operators, social housing providers, and private homeowners. By aligning with other programmes and fostering a whole systems approach, we can ensure a holistic and effective response to the complex issue of heat vulnerability in urban environments.

Recommendations for catalysing further actions and potential follow-up steps include:

- **Comprehensive surveys and monitoring.** The property heat risk maps can help to prioritise the most at-risk locations in London, but further data would be needed to design mitigation measures. This can be obtained through undertaking in-depth surveys and continuous monitoring of selected properties to gather detailed data on heat vulnerability and occupant experiences. This could be carried out for a particular property setting across a portfolio of properties to gain more insight into the causation and impacts of overheating. The recent *Climate Adaptation for Schools* work through the *GLA Climate Resilient Schools* and the Care Home Overheating Audit Pilot Project programme provide good examples and an opportunity to build upon this research. In addition, the Good Homes Alliance's overheating Risk Tool (Good Homes Allliance, 2019) provides a framework for surveying individual properties in more detail for residential buildings.

- **Developing and implementing adaptation solutions**. Identifying risk is the first step but much work must be done to respond to the risk by identifying and implementing solutions to protect London and ensure the city's future resilience against heat related impacts. Solutions should include both operational and design solutions which address heat risk now and in the future. The work could integrate with tools such as the GLA's

Cool Spaces map (available annually from 1st June to 15th September in line with the UK summer). There could be a thorough investigation into mitigation measures and retrofit strategies to address overheating at scale. For instance, this could include building on work such as Roofs Designed to Cool to develop pilot schemes and retrofit at scale programmes in high-risk areas. This work may also feed back into wider policy changes, for instance through Building Regulations which could be updated to consider factors such as property location and magnitude of the heat hazard.

- **Stakeholder engagement.** To successfully design and implement solutions, cross-sector collaboration across a range of stakeholders is needed. This would entail working with decision-makers across the public and private sectors to disseminate findings, gather feedback, and discuss next steps. This could include engagement with local authorities, housing developers, the education and healthcare sectors, as well as local communities. Gathering local insights and perceptions will aid in the development of context-specific strategies. Engaging with the education, housing, and healthcare sectors is essential to contextualise heat risk. This collaborative approach ensures a comprehensive understanding of how heat risk interacts with other challenges and priorities within these sectors and how successful solutions can be developed.

- **Public awareness campaigns.** Raising awareness amongst Londoners can help with driving change and implementing programmes. This can include launching campaigns to raise public awareness about heat risks and promoting both low-cost, short-term actions, such as behavioural changes, as well as longer term interventions that contribute to increased heat resilience.

- **Overlaying maps with other climate hazards.** The GLA possesses an extensive dataset spanning various programmes. A valuable opportunity lies in overlaying these datasets with other ongoing climate adaptation programmes, such as flood and drought assessments. One opportunity would be to consolidate this work with the GLA’s existing Climate Risk Maps, perhaps adding air temperature data as a more accurate way to assess the heat hazard across London. This integration could yield comprehensive insights into multi-faceted climate risks. This will drive the development of solutions that can have co-benefits and will ensure that solutions designed to protect against one risk factor do not inadvertently cause issues with another.

- **Considering future trends**. There could also be a consideration of climate change projections and other future trends, such as projected changes in demographics and potential future urban development. For instance, consideration of where populations are expected to be ageing or where development density is expected to increase. This will help with understanding future risk and to further prioritise interventions. Risk may escalate faster in some locations than others.

- **Developing the dataset further**. More data on the key factors that drive overheating are needed to fill the gaps in what is currently available. This dataset should continue to be developed as more and more data becomes available. There is a potential to explore datasets that were not available for this study, such as data from the Valuation Office or data created through upcoming programmes by the Bartlett Centre for Advanced Spatial Analysis at University College London. Focused work on a particular setting could be carried out through modelling and surveys to produce a more informed and comprehensive set of property vulnerability factors and weightings. More data on the occupants of properties would also be beneficial in providing a better insight on where the most vulnerable people are located. For instance, for hospitals this was only available at NHS Trust level but occupant information for individual hospitals would allow a more detailed assessment of heat risk. In addition, further research and data to prove the extent to which individual socioeconomic factors are linked to heat vulnerability would provide a guide for weighting factors more precisely.

- **Expanding out to other property types and settings.** It was not possible to include the entire spectrum of London's building stock within this study. However, with climate change and the impact of the UHI, it is crucial to acknowledge that many other properties in London have the potential to experience overheating. Consequently, a subsequent programme could extend the scope to encompass a broader range of property types, thereby comprehensively addressing heat vulnerability across a wider spectrum of London's built environment.

In the dynamic context of climate change, this study serves as a stepping stone towards fostering a more robust and just future for London's residents, by directing action to people and places that are most vulnerable.

The effort to understand and reduce heat risk is an ongoing journey. Data is a pivotal element that allows us to gain deeper insights and examine the challenge from fresh perspectives. Ultimately, this will strengthen our efforts in developing a response that protects our communities and enhances our urban resilience.

Methodology

Property Types

The scope of the project was to focus on a specific subset of London's properties, prioritising settings where occupants may be particularly vulnerable to heat impacts. It's important to note that the effects of heat are not uniformly distributed, with certain people in the population such as older individuals, young children, and those with pre-existing health conditions bearing a greater burden (Taylor, 2023). Therefore, this investigation specifically focuses on institutions such as schools (including nurseries), care homes, and hospitals. In addition, the work also included residential properties including both flats and houses. Residential settings are where people spend a substantial portion of their time, including nighttime hours, during which health implications from heat can have a particularly negative impact (Taylor, 2023). Under current climate conditions, half of UK homes suffer from overheating risk, with a particularly high risk in London which is considered the hottest area of the country (Arup - commissioned by Climate Change Committee, 2022).

While it was impracticable to include the entirety of London's building stock within this study, it is crucial to acknowledge that many properties in London have the potential to both experience overheating and accommodate vulnerable occupants. The strategies for alleviating overheating risks emerging from this study could serve as a foundation for broader implementation, extending to various other property settings in the future.

Data Gathering and Analysis

Datasets were compiled from a diverse range of sources (e.g., the GLA, Office of National Statistics and the London Datastore), encompassing tabular and Geographic Information System (GIS) data in both vector and raster format[2], to create comprehensive data layers for the mapping exercise. Full details of the relevant datasets that were applied in this study and their sources are presented in Addendum I: Data Register.

A data gap assessment was carried out across each data layer category to determine the availability of either a direct or indirect source. A direct source is one which provides data on a factor or category that can be directly used in the mapping, whereas an indirect source is one where further data processing may be required to calculate the factor value. Further details on the gap analysis carried out for each data layer can be found in Appendices II to IV.

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[2] Raster data is a type of geospatial data that represents geographic information as a grid or matrix of cells. Vector data is a type of geospatial data that represents geographic features using points, lines, and polygons.

Preparation and Analysis

Geospatial data and related tabular data were initially downloaded, cleaned, and processed for application to the GLA study area. The data was downloaded from a range of sources which included London Data Store, Office for National Statistics and Ordnance Survey. All acquired geospatial data was managed in accordance with Arup geospatial standards and quality assurance procedures. The tabular data was then joined spatially to the appropriate spatial datasets, which include the LSOA census boundaries and Hospital Trust Catchment boundaries. Figure 14, in the next section, presents a good example, where specific data sources (in tabular format) are relevant to understand the socioeconomic factors associated with certain property types, and then joined to spatial boundaries. The colour schemes applied to the maps were chosen to ensure that they are colour-blind-friendly.

The spatial analysis and related mapping for this project was undertaken through the application of both GIS software (ArcGIS Pro 2.9.5) and FME 2022.2.5 (Feature Manipulation Engine) geospatial software.

Property Vulnerability Map

Research

The objective of this study was to provide a high-level view of vulnerability to overheating across all building stock for a given setting. The mapping is comparative and highlights properties that have the potential to overheat more compared with others.

The susceptibility of a building to overheating hinges on a variety of elements, encompassing the construction attributes of the building itself, such as building fabric, design, orientation, shading, massing, glazing, systems, and internal heat sources. External factors related to the building's surroundings, such as hindrances to window opening (like noise levels) and proximity to green spaces, also contribute to this vulnerability.

Research was carried out to define a set of factors which influence how vulnerable a property is to overheating. Heating and cooling mechanisms in a building are complex, with an interplay between different factors. For instance, windows enable natural ventilation and can help cool spaces down, but at the same time window glazing allows solar radiation into the space causing it to heat up. To assess the net impact of all the interlinked factors that contribute to heat flow in buildings and assess its potential for overheating, detailed information and assessments would be required.

Table 1: Summary of factors which influence heat in properties.

Category	Factor(s)	Impact on overheating
Building Form	Property type (e.g. for residential properties – house, flat etc.)	The form or design of a property can significantly contribute to overheating. The overall size, shape,

Category	Factor(s)	Impact on overheating
	Volume (height and area) Storey	volume, and orientation of a property will impact the level of heat gains and losses.
Ventilation	Openable areas Cross ventilation potential Barriers to opening windows (e.g., noise, air pollution, or crime)	Ventilation is a key means by which a property can mitigate overheating (BEIS, 2021). Windows can help regulate the internal temperature as well as provide air movement which can help with thermal comfort during hot conditions.
Solar Gains	Glazing properties Window sizing and location Shading feature (internal and external)	Solar gain through glazing is one of the biggest causes of overheating to living spaces in residential buildings (BEIS, 2021). The proportion and the type of glazing (single, double) will have an impact on the amount of solar radiation entering a property.
Building Fabric	Wall construction Roof construction Thermal mass Air tightness	Heat can transfer through the fabric of a building, so factors such as the level of insulation of the walls and roof will impact overheating. Thermal mass in a building has the ability to store and release heat. An airtight building will retain heat more effectively compared with a leaky building, increasing the risk of overheating.
Building Systems	Heating systems Mechanical system Air conditioning	Air conditioning will help cool a property down but will be energy intensive. Heating systems such as communal heating may add additional heat to a property.
Internal Heat Gains	Occupants Lights and small power	People, electrical equipment, and lights will add internal heat to a property. For instance, overcrowded buildings may be more likely to overheat due to larger internal heat gains.
Building Site	Onsite greening Proximity to green and blue space Surrounding buildings (i.e., overshadowing)	Nearby blue and green infrastructure, such as parks, extensive landscaped grounds, rivers, or sizable water features, contribute to the reduction of ambient air temperatures and provide a local area of respite (Good Homes Allliance, 2019). The size and quality (i.e., the health and amount of planting and trees) of green spaces has an impact on their ability to cool. The surrounding urban environment, including neighbouring buildings, can impact the amount of shade and airflow a building receives, affecting its susceptibility to overheating.

Detailed discussion of the factors and their influence on overheating is presented in Appendix II Property Vulnerability.

Data sources and gap analysis

The gap analysis illustrated that the availability of data about individual buildings is limited, meaning that not all factors that influence overheating are accounted for (Appendix II Property Vulnerability provides further details on the gap analysis). Table 4 to Table 7 present the datasets and attributes used to assess potential for overheating for buildings for each property setting considered. The data was gathered at property level where available, otherwise aggregated data was used (indicated with an * in the tables below). Further details in Appendix II Property Vulnerability.

Much of the data has been collated through the building Energy Performance Certificate (EPC) rating, which provided information on a number of the factors shown in Table 1 at individual property level. The EPC rating was not included holistically as not all the factors that make up the final rating are informative for overheating. Therefore, a linear relationship cannot be drawn directly between EPC rating as a whole and vulnerability to overheating. There was generally more data available for residential properties than schools, hospitals, and care home settings. However, there are still significant data gaps. A full assessment of vulnerability to overheating could not be made due to the lack of data at individual property level. This assessment is therefore indicative and provides a means to organise neighbourhoods across London to help prioritise action.

Data analysis

Individual properties were scored against the range of factors for which data was available. Each factor used in the assessment was assigned a weighting to describe the potential influence it would have on increasing or decreasing heat vulnerability. For a given property, a contribution score was given for each factor which showed if the factor contributed to heating or cooling the property. The contribution for each factor was multiplied by the factor weighting to give a final factor score. All scores were tallied for each property to give a final property vulnerability score. The method is presented in Figure 11 and the definitions for the factor contribution and weightings are shown in Figure 16.

This final score represents the potential heat vulnerability a property could have and should be seen as a comparative score against all other properties measured against the same set of criteria.

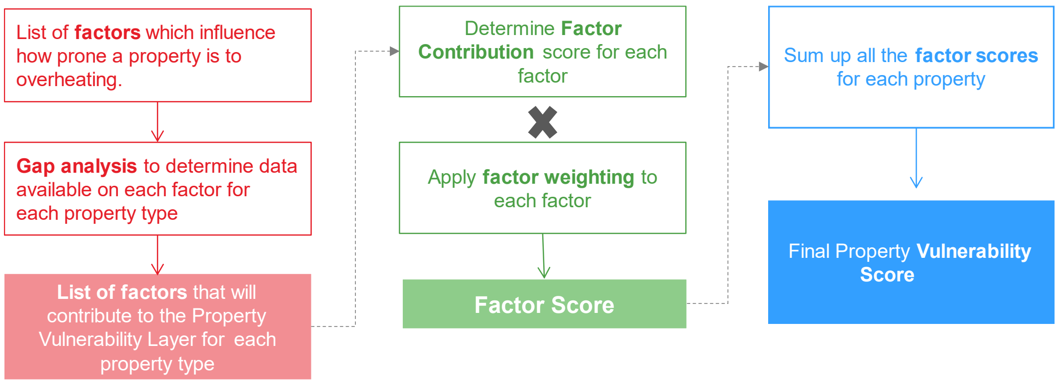

Figure 11: Method for creating the Property Vulnerability Layer for each property type

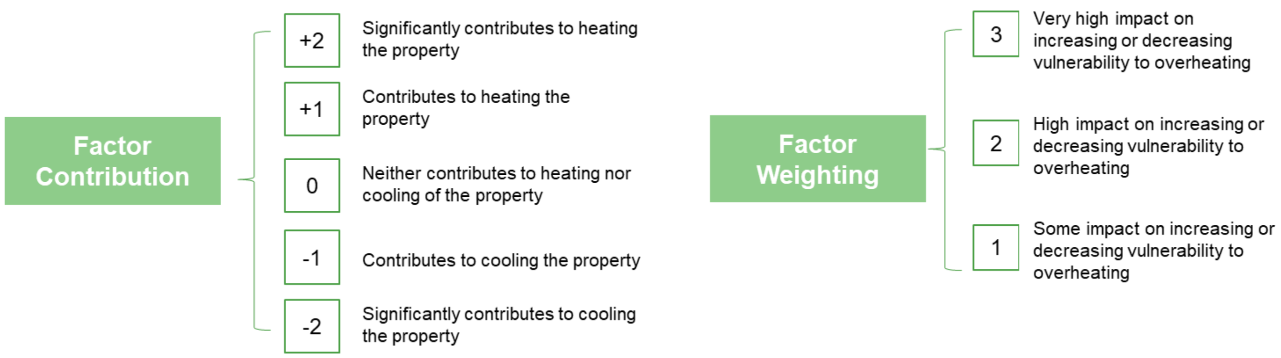

Figure 12: Definitions for *factor contribution* and *factor weightings*

Table 2 provides a list of sources and number of properties considered for each setting.

Table 3 to Table 6 also present the factor weightings for each property type.

Details on how factors have been scored and weighted are provided in Appendix II Property Vulnerability.

Table 2: Data sources for property types and number of properties assessed

Property Type	Data Source	Number of Properties Identified
Schools	London School Atlas (GLA)	3,372
Hospitals	Medical Site Data (NHS)	134
Care Homes	Care Quality Commission	1,271
Residential	EPC (DLUHC[3])	3.6 million

[3] Department for Levelling Up, Housing and Communities

Table 3: Dataset used for School Property Vulnerability Layer

Category	Factor	Data Source
Property Type	School Education Level [4]	EPC (DLUHC)
Barriers to openable windows	Noise Level *	London Data Source Noise pollution in London (GLA and Department for Transport (DfT)[5])
	Crime*	IMD[6]: Crime (GLA)
	Pollution level*	London Atmospheric Emissions Inventory (LAEI) (GLA)
Internal heat gain	Overcrowding	Percentage of pupils over school capacity obtained from DfE[7]
Location	Proximity to green space	Calculated from data in Ordnance Survey (OS)
	Proximity to blue space	Calculated from data in OS

Table 4: Dataset used for Hospital Property Vulnerability Layer

Category	Factor	Data Source
Property Type	Inpatient or outpatient	NHS
Barriers to openable windows	Noise Level *	London Data Source Noise pollution in London (GLA and DFT)
	Crime*	IMD: Crime (GLA)
	Pollution level*	London Atmospheric Emissions Inventory (LAEI) (GLA)
Location	Proximity to green space	Calculated from data in OS
	Proximity to blue space	Calculated from data in OS

Table 5: Dataset used for Care Home Property Vulnerability Layer

Category	Factor	Data Source
Property Type	Type of care home	Care Quality Commission
Barriers to openable windows	Noise Level *	London Data Source Noise pollution in London (GLA and DFT)

[4] Education level has been included as it indicates the age of the majority of occupants in the school setting. Although age is a socioeconomic factor, it was included in the property layer as data was available at individual property level via the EPC.

[5] Department for Transport

[6] Indices of deprivation

[7] Department for Education

Category	Factor	Data Source
	Crime*	IMD: Crime (GLA)
	Pollution level*	London Atmospheric Emissions Inventory (LAEI) (GLA)
Location	Proximity to green space	Calculated from data in OS
	Proximity to blue space	Calculated from data in OS

Table 6: **Dataset used for Residential Property Vulnerability Layer**

Category	Factor	Data Source
Property Type	Type of home	EPC (DLUHC)
Barriers to openable windows	Noise Level *	London Data Source Noise pollution in London (GLA and DFT)
	Crime*	IMD: Crime (GLA)
	Pollution level*	London Atmospheric Emissions Inventory (LAEI) (GLA)
Glazing	Average glazing window to floor ratio	EPC (calculated from Glazed Area, Floor Area)
	Glazing Type (e.g., double glazing)	EPC (Glazed Type)
Fabric	Wall insulation	EPC (inferred from Wall Efficiency)
	Roof insulation	EPC (inferred from Roof efficiency)
	Air tightness	EPC (calculated from Building Age)
Systems	Community Heating	EPC (Mainheat Description)
Location	Proximity to green space	Calculated from data in OS
	Proximity to blue space	Calculated from data in OS

*Where aggregated data is used. Further explanation and details on resolution are provided in Appendix II.

Producing the property vulnerability maps

A total property vulnerability score was obtained by summing all the factor scores. The summed scores were then banded into five equal intervals, with one corresponding to the lowest vulnerability, and five corresponding to the highest vulnerability.

Socioeconomic Vulnerability Map

Research

The people occupying a building are a key consideration when thinking about heat risk. Certain attributes will make some people in society more vulnerable to adverse heat impacts and more likely to suffer from heat-related health issues. These include age (for instance older individuals over 65 and young children under four are more vulnerable to heat), physiology, pre-existing health conditions, social isolation and living alone, deprivation, and occupation. Relevant socioeconomic factors were considered for the various property types under consideration to provide insights into the likely occupants. Accurate data regarding the specific occupants of individual buildings is generally unavailable. As a suitable alternative, the socioeconomic attributes of the area surrounding properties were utilised. For schools and residential buildings, the data is aggregated to LSOA level and for hospitals data is aggregated to NHS Trust Level. Table 1 presents further details. Note that socioeconomic factors were omitted for care homes, as analysing the demographics of the population surrounding a care home is unlikely to yield significant insights into the specific vulnerabilities of care home residents.

Data sources and gap analysis

The datasets on a number of socioeconomic factors which may increase vulnerability to heat were collated for each building type. Appendix III Socioeconomic Data provides a comprehensive discussion on the process of selecting socioeconomic factors for each building type. Appendix III also provides details on the assessment carried out to evaluate the relationship between different socioeconomic factors, namely the covariance assessment. This was carried out to identify inter-related factors and prevent data duplication or overcounting.

Table 7 presents the final datasets employed for each building type. Appendix I Data Sets provides further information.

Table 7: Datasets on socioeconomic vulnerability by property type

Property Type	Socioeconomic Vulnerability Layer Resolution for Property type	Socioeconomic Factor	Data Attribute
Schools	**LSOA**	Deprivation	Income Deprivation Affecting Children Index (IDACI)
Hospitals	**NHS Trust level**	Deprivation	Index of Multiple Deprivation (IMD)

Property Type	Socioeconomic Vulnerability Layer Resolution for Property type	Socioeconomic Factor	Data Attribute
		Age[8]	Admissions over 65
			Admissions under four
Care Homes	**N/A**	N/A	N/A
Residential	**LSOA**	Deprivation	Index of Multiple Deprivation (IMD)
		Age	Over 65
			Under four
		Social isolation	Under 65 and Living Alone

Data analysis and mapping

The socioeconomic factors for each building type were summed together with equal weighting given to each factor[9]. The summed scores were then banded into quintiles to give a score from one to five, with one representing the lowest fifth (0-20%) of values and corresponding to the lowest vulnerability, and five representing the highest fifth (80-100%) and corresponding to the highest vulnerability.

School, care home, and residential property socioeconomic vulnerability maps are presented at LSOA level. The hospital socioeconomic vulnerability map is limited to NHS Trust level due to the resolution of data available.

The data maps showing socioeconomic vulnerability are presented in Appendix V Data Maps.

For the property risk assessment, the socioeconomic vulnerability score for each property type was applied to the properties within the given spatial boundary.

[8] For hospital settings *Age* data was available by admissions to particular trust. All other data is based on the population surrounding the different property settings e.g. Deprivation is known for the whole population at Trust level for Hospitals not just admissions/patients.

[9] There was a lack of conclusive evidence to inform weighting of factors according to the strength of their relationship with heat vulnerability, so the decision was taken to assign equal weighting to all factors.

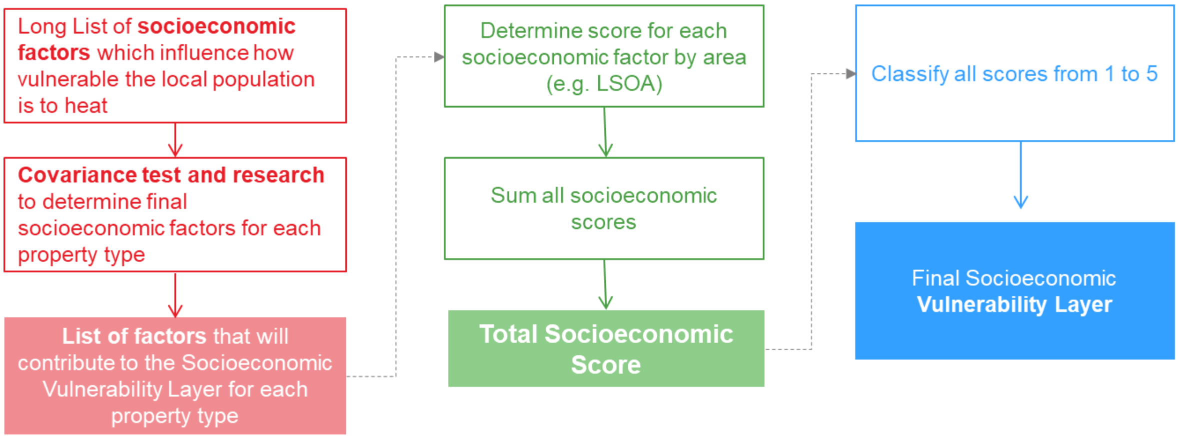

Figure 13: Method for creating the Socioeconomic Vulnerability Layer for each property type

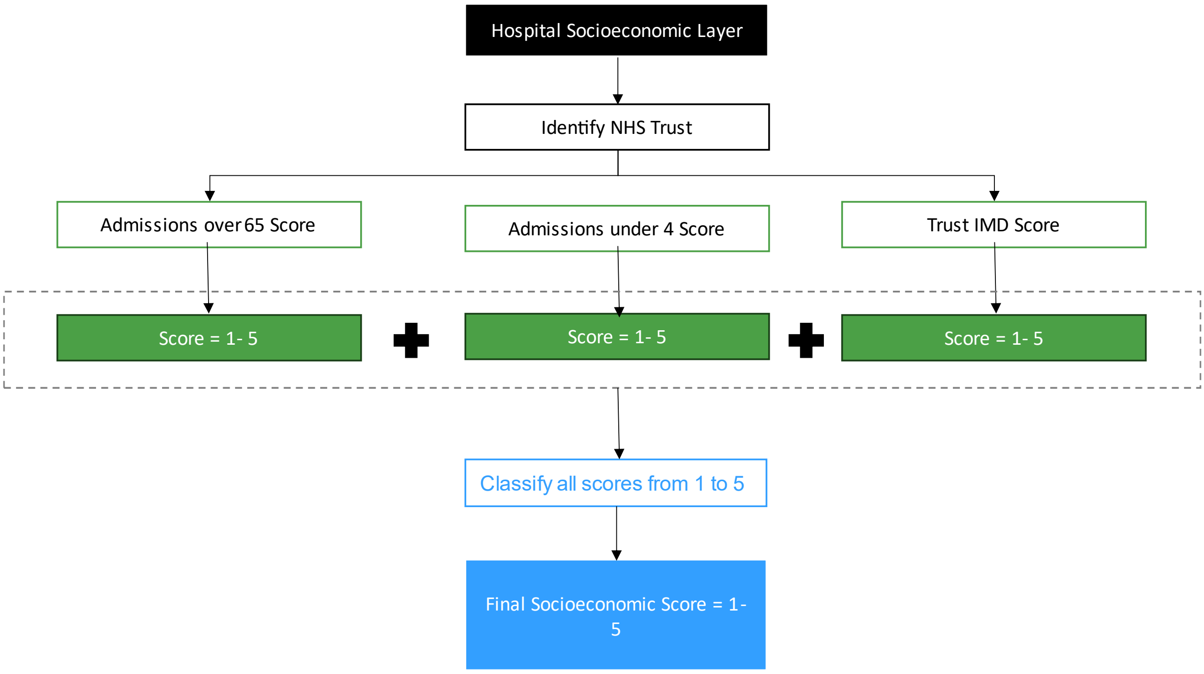

Figure 14: Example showing the calculation of socioeconomic score for hospital setting

Heat Hazard Map

Air temperature data for London was modelled using Arup's UHeat tool which utilises SUEWS (Surface Urban Energy and Water Balance Scheme). SUEWS is a neighbourhood/local-scale urban land surface model which simulates the urban radiation, energy, and water balances for an area using measured meteorological variables and information about the surface cover (SUEWS, 2023).

To obtain data on heat intensity across London, the model was run for the summer period (June to August) for five years (2018 to 2022). Input data for the model is described in Table 8. Detailed information on the datasets can be found in Appendix I Datasets. The output was obtained as hourly air temperatures for each LSOA for the analysis period. This data was then averaged temporally and classified to obtain the heat hazard map (see Figure 15).

The map is presented on a scale of one to five, where one represents the lowest average summer temperatures (the lowest fifth (0-20%) and five the highest average summer temperatures (the highest fifth (80-100%). The average summer temperatures by LSOA are predicted to vary between 17.0°C and 19.5°C. Further details on the modelling methodology, including the assumptions and limitations, can be found in Appendix IV Heat Hazard.

Table 8: Datasets used to produce heat hazard map

Data	Data Source
Land cover classification	Urban Atlas — Copernicus Land Monitoring Service
Tree canopy cover	London Data Store
Building heights	Joint Research Centre Data Catalogue
Surface albedo	Sentinel 2 (via Copernicus.eu)
Lower Layer Super Output Areas (2021) Boundaries EW BFC	Office for National Statistics
Population distribution	GHSL - Global Human Settlement Layer, European Commission (europa.eu)
Altitude	EarthExplorer (usgs.gov)
Climate Data	ERA5- Land hourly data from 1950 to present (copernicus.eu)

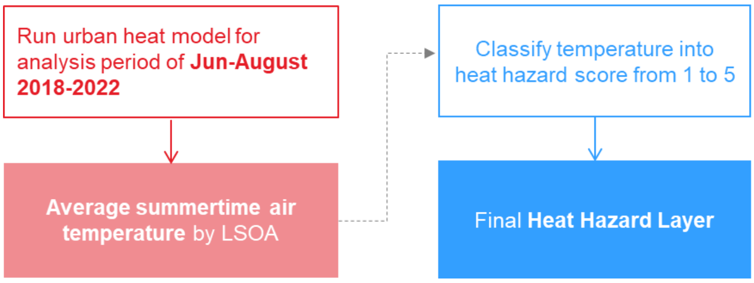

Figure 15: Method for obtaining the heat hazard layer

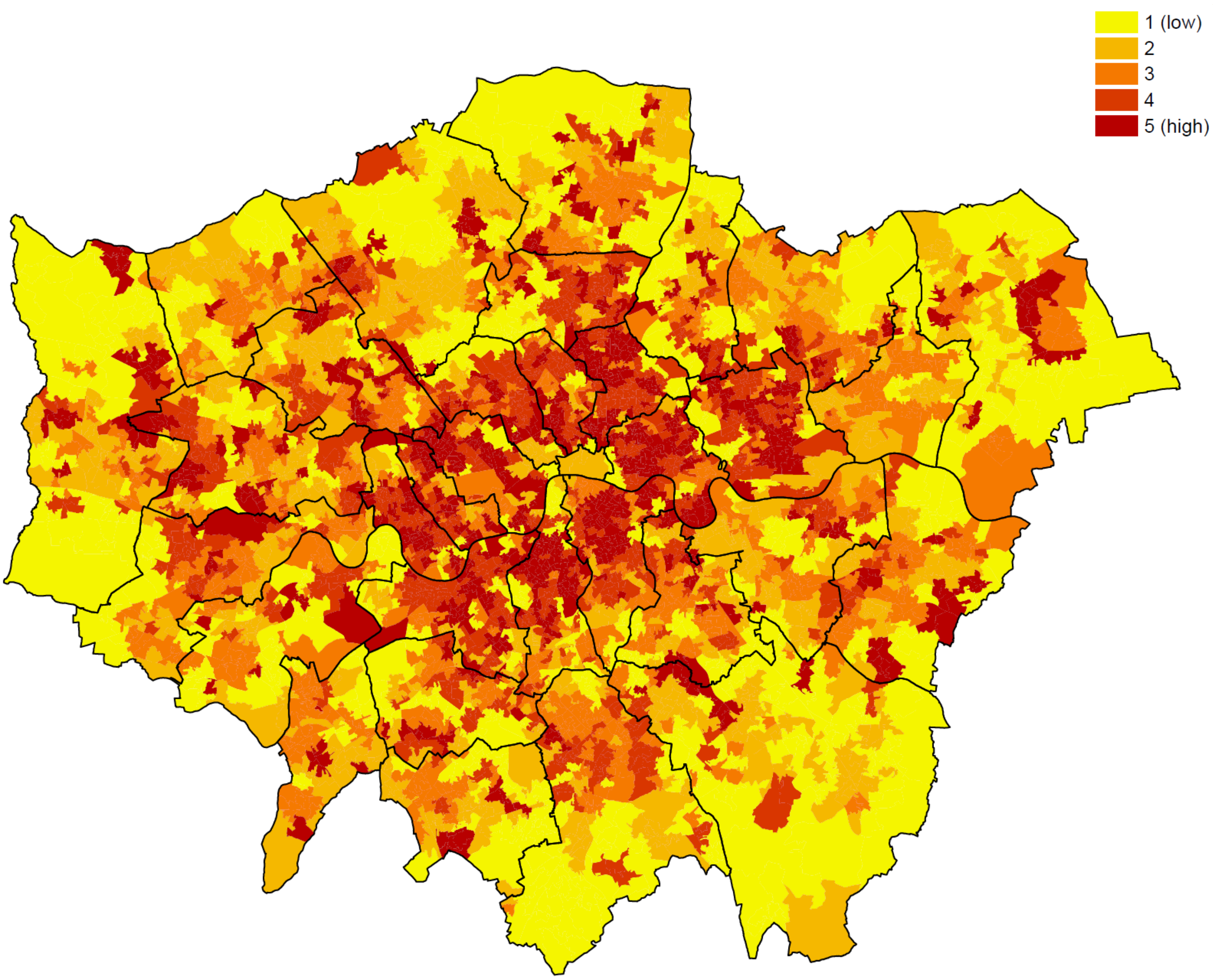

Figure 16: Heat Hazard Map (Averaged temperature predictions June to August 2018-2022)

Limitations and Constraints

The limitations, constraints, and assumptions are all provided in detail in the appendices. Some of the main limitations and constraints are discussed here:

- **Data Availability**. The limited availability of data, especially on London's building stock, made it challenging to carry out a comprehensive analysis of heat risk in properties. For instance, data on key factors such as ventilation (e.g., window opening area, size, and aspect) and internal heat gains (e.g., solar gains) was not available for any of the property types (detailed gap analysis is presented in the appendices). Despite limitations on data, the property heat risk maps can still provide valuable guidance on how heat risk is likely to vary across London and what factors influence this. The Conclusion provides suggestions on how this work can be used and further steps to build upon it.

- **Data on occupants and behaviours**. The actual occupants of buildings and their behaviours (with respect to controlling their own environments) will vary considerably and cannot be accounted for in this study. Stakeholder and community engagement would be a valuable next step to obtain insight on these considerations.

- **Mismatch of datasets and dates**. The property heat hazard maps used the most appropriate datasets available. However, due to differences in when data has been compiled between different datasets, it is not always possible to obtain a full comprehensive list of all buildings within a given property type. London and its properties are ever changing so it would be advisable to update the risk maps at appropriate intervals to ensure information is as current as possible.

- **Complexity of heat hazard**. The map displays average summer temperatures (day/night) but does not include other periods of the year. Vulnerable individuals might experience heat stress at lower temperatures, and different properties may overheat earlier. UHI effects could vary during heat waves, which were included in the time period studies but not examined explicitly. Similarly, night-time minima, which may also be important when assessing comfort, are not included separately. In addition, microclimate elements like solar radiation and humidity, crucial for understanding thermal comfort and heat stress, aren't included in the heat hazard map. These factors should all be considered when developing detailed strategies.

- **Air conditioning and active cooling systems**. This study does not account for the use of air conditioning and cooling systems in buildings. There was limited data on the systems including the location and extent of installation which is important for complex buildings such as schools and hospitals. However, it is important to consider the increasing prevalence of cooling especially in residential buildings. Although properties with cooling will be less vulnerable to overheating, there is still a need to include them when considering heat interventions to reduce energy use and costs for individuals and organisations.

- **Complexities of heat mechanisms**. Thermodynamics of properties and buildings are a complex interplay between different factors such as external heat gains (through glazing, building fabric etc.), internal heat gains, ventilation, thermal efficiency, and materiality. Properties such as schools and hospitals are particularly complex and often include a number of different buildings across a campus. The property heat risk maps evaluated the relative potential of overheating for properties at scale using the most appropriate available information. To truly understand the heat vulnerability of a property, further investigation through surveying, monitoring, or modelling would be required. This is something that could be carried out at later stages when developing mitigation initiatives.

- **Informed decision-making**. The property heat risk maps and their components are rooted in research-based evidence. However, when data gaps exist, decisions on data sources and weightings rely on professional judgment and experience of the project team. This approach was essential for advancing the project despite uncertainties.

Appendices

Appendix I Data Sets

Property Vulnerability Data

No.	Data overview			Geospatial Information		Metadata				
	Dataset	**Description**	**Theme**	**Data Type**	**Spatial Scale (e.g., ward, neighbourhood, point data)**	**Temporal Resolution**	**Date of Acquisition**	**Source**	**Source (location)**	**Accessibility of data**
1	**OS MasterMap Topography Layer**	Provides a map and dataset of the topography of Greater London which shows the geographic features across the area.	Infrastructure	Vector GIS data	Dataset of Great Britain - not specific to Greater London but will provide details of geographical features including building, road outlines and environmental features. Scale: 1:1250 to 1:10,000. Stated Accuracy Urban +/-1m.	2023	14/06/2023	Ordnance Survey Accessed through GLA PSGA licence.	OS Data Hub	Licensed
2	**AddressBase Premium**	Provides an enhanced dataset for address across England, Wales and Scotland - uses VOA data, OS MasterMap topography layer and Highways network data. Contains information on all stages of the	Infrastructure	Tabular	Dataset of Great Britain - not specific to Greater London but will provide details of geographical features including building, road outlines and environmental features. Scale: 1:1250 to 1:10,000. Stated Accuracy Urban +/-1m.	2023	13/06/2023	Ordnance Survey Accessed through GLA PSGA licence.	OS Data Hub	Licensed

No.	Data overview			Geospatial Information		Metadata				
	Dataset	Description	Theme	Data Type	Spatial Scale (e.g., ward, neighbourhood, point data)	Temporal Resolution	Date of Acquisition	Source	Source (location)	Accessibility of data
		property lifecycle.								
3	**Display Energy Certificates (DEC) - Non-domestic**	Display Energy Certificates (DEC) register for public buildings.	Property (Housing)	Tabular	Data is available per borough for buildings. Buildings are identified by UPRN.	2023	31/05/2023	Department for Levelling Up, Housing & Communities	Energy Performance of Buildings Data England and Wales (opendatacommunities.org)	Open Government Licence v3.0
4	**Energy Performance Certificates - Domestic**	Includes data on energy rating, property type, built form, energy consumption, CO2 emission, CO2 emission per floor area, lighting cost, heating cost, floor area,	Property (Housing)	Tabular	Data is available per borough for buildings. Buildings are identified by UPRN.	2023	31/05/2023	Department for Levelling Up, Housing & Communities	Energy Performance of Buildings Data England and Wales (opendatacommunities.org)	Open Government Licence v3.0

No.	Data overview			Geospatial Information		Metadata				
	Dataset	**Description**	**Theme**	**Data Type**	**Spatial Scale (e.g., ward, neighbourhood, point data)**	**Temporal Resolution**	**Date of Acquisition**	**Source**	**Source (location)**	**Accessibility of data**
		energy tariff, glazed type, windows description, walls description, roof description.								
5	**Energy Performance Certificates - Non-domestic**	Includes data on main heating fuel, floor area, aircon, building environment.	Property (Housing)	Tabular	Data is available per borough for buildings. Buildings are identified by UPRN.	2023	31/05/2023	Department for Levelling Up, Housing & Communities	Energy Performance of Buildings Data England and Wales (opendatacommunities.org)	Open Government Licence v3.0
6	**Statistical GIS Boundary Files for London**	Statistical boundaries covering Greater London.	Census	Vector GIS data	Available for - Output Area (OA) 2011, Lower Super Output Area (LSOA) 2004 and 2011, Middle Super Output Area (MSOA) 2004 and 2011, London Wards (two files: City of London merged into single	2011	30/05/2023	Greater London Authority Accessed through GLA.	Statistical GIS Boundary Files for London - London Datastore	Open Government Licence

No.	Data overview			Geospatial Information		Metadata				
	Dataset	**Description**	**Theme**	**Data Type**	**Spatial Scale (e.g., ward, neighbourhood, point data)**	**Temporal Resolution**	**Date of Acquisition**	**Source**	**Source (location)**	**Accessibility of data**
					area and split into separate wards). There is separate download file for 2014 & 2018 boundaries. London Boroughs					
7	**Medical Site Data (UK)**	Results from the 2021/22 Estates Return Information Collection (ERIC), a mandatory collection for all NHS trusts including Ambulance trusts. It comprises information relating to the costs of providing and maintaining the NHS Estate including buildings, maintaining and equipping hospitals, the	Infrastr ucture	Tabul ar	Available for NHS Hospitals in England maintained by a NHS trust including Ambulance trusts.	2021/22	30/05/2023	NHS	Estates Returns Informatio n Collection , Summary page and dataset for ERIC 2021/22 - NDRS (digital.nh s.uk)	Open

No.	Data overview			Geospatial Information		Metadata				
	Dataset	**Description**	**Theme**	**Data Type**	**Spatial Scale (e.g., ward, neighbourhood, point data)**	**Temporal Resolution**	**Date of Acquisition**	**Source**	**Source (location)**	**Accessibility of data**
		provision of services e.g., laundry and food, and the costs and consumption of utilities.								
8	**London Schools Atlas**	The London Schools Atlas is an innovative interactive online map of London providing a uniquely detailed and comprehensive picture of London schools, current patterns of attendance and potential future demand for school places across the capital. The Atlas is part of the Mayor's programme of initiatives aimed at driving up	Schools	Tabular	Individual asset for schools. LSOA level data about free school meals.	2023	04/07/2023	Greater London Authority Accessed through GLA.	London Schools Atlas - London Datastore	Open Government Licence

No.	Data overview			Geospatial Information		Metadata				
	Dataset	**Description**	**Theme**	**Data Type**	**Spatial Scale (e.g., ward, neighbourhood, point data)**	**Temporal Resolution**	**Date of Acquisition**	**Source**	**Source (location)**	**Accessibility of data**
		standards in education and ensuring there are enough good places for all children in the city. Covering primary and secondary provision, including academies and free schools, the London Schools Atlas for the first time uses data to illustrate current patterns of demand for school places at a pan-London level, rather than within boroughs alone.								

No.	Data overview			Geospatial Information		Metadata				
	Dataset	**Description**	**Theme**	**Data Type**	**Spatial Scale (e.g., ward, neighbourhood, point data)**	**Temporal Resolution**	**Date of Acquisition**	**Source**	**Source (location)**	**Accessibility of data**
9	**School capacity**	School places, which includes sixth form places and excludes nursery places, reported by local authorities. File also includes number of pupils on roll from the May School Census; the number of pupils in places that exceed their school's capacity and the number of unfilled places.	Schools	Tabular	Data is available for schools across the UK. Schools are identified by URN.	2009/10 to 2021/22	21/07/2023	Department for Education	Create your own tables, Table Tool – Explore education statistics – GOV.UK (explore-education-statistics.service.gov.uk)	Open Government Licence v3.0
10	**Care Homes**	Dataset about the location and specialisation of care homes.	Care homes	Tabular	Data is available for care homes across the UK. Care homes are identified by UPRN.	2023	07/08/2023	Care Quality Commission	Search Results - Care Quality Commission (cqc.org.uk)	Open Government Licence for Public Sector Information

No.	Data overview			Geospatial Information		Metadata				
	Dataset	Description	Theme	Data Type	Spatial Scale (e.g., ward, neighbourhood, point data)	Temporal Resolution	Date of Acquisition	Source	Source (location)	Accessibility of data
11	**Lower Layer Super Output Areas 2021**	The boundaries available are: (BFE) Full resolution - extent of the realm (usually this is the Mean Low Water mark but, in some cases, boundaries extend beyond this to include off shore islands).	Infrastructure	Vector GIS data	Lower Layer Super Output Areas in England and Wales.	2021	19/07/2023	Office for National Statistics	Lower Layer Super Output Areas (2021) Boundaries EW BFE | Open Geography Portal (statistics.gov.uk)	Open Government Licence
12	**OS Open Greenspace**	Location of public parks, playing fields, sports facilities, play areas, allotments and more with OS Open Greenspace.	Infrastructure	Vector GIS data	All of Great Britain or customisable area (100km2 tiles); 1:1250 to 1:10,000	2023	30/05/2023	Ordnance Survey	OS Open Greenspace | Data Products | Ordnance Survey	Open

Socioeconomic Vulnerability Data

No.	Data overview		Geospatial Information			Metadata			
	Dataset	Description	Data Type	Spatial Scale (e.g., ward, neighbourhood, point data)	Temporal Resolution	Date of Acquisition	Source	Source (location)	Accessibility of data
1	2021 Census: Topic Summary Table: Ethnic Group, National ID, Language and Religion	Age by 5-year age groups	Age	Tabular	Available for GLA wards and LSOAs	2023	09/06/2023	The data is from 2021 and therefore, is not entirely up-to-date. However, it is one of the most useful sources of accessible vulnerability data in the UK. It was recorded that 97% of households responded to the 2021 census.	Office for National Statistics Freely accessible to Arup via GLA.
2	2021 Census: Topic Summary Table: Ethnic Group, National ID, Language and Religion	Household composition (households)	Household compositio n	Tabular	Available for GLA wards and LSOAs	2023	09/06/2023	The data is from 2021 and therefore, is not entirely up-to-date. However, it is one of the most useful sources of accessible vulnerability data in the UK. It was recorded that 97% of households responded to the 2021 census.	Office for National Statistics Freely accessible to Arup via GLA.

No.	Data overview		Geospatial Information			Metadata			
	Dataset	Description	Data Type	Spatial Scale (e.g., ward, neighbourhood, point data)	Temporal Resolution	Date of Acquisition	Source	Source (location)	Accessibility of data
3	Indices of Multiple Deprivation 2019	Income deprivation, employee deprivation, education, skills and training deprivation, health deprivation and disability, crime, barriers to housing and services and living environment deprivation	Deprivation	Tabular	Lower-layer Super Output Area (2011)	2019	12/06/2023	The data is from 2019 and therefore the deprivation indices might have changed.	Department for Levelling Up, Housing and Communities Freely accessible to Arup via GLA.
4	Noise Pollution	This dataset maps noise pollution in London. Data is available for noise pollution from road and rail sources.	Noise Pollution	Vector GIS data	Available for GLA along roads and rail.	2019	27/06/2023	Dataset provides summary maps for major road and rail sources.	Department for Levelling Up, Housing and Communities Freely accessible to Arup via GLA.

No.	Data overview		Geospatial Information			Metadata			
	Dataset	Description	Data Type	Spatial Scale (e.g., ward, neighbourhood, point data)	Temporal Resolution	Date of Acquisition	Source	Source (location)	Accessibility of data
5	London Atmospheric Emissions Inventory (LAEI) 2019	The LAEI 2019 is the latest version of the London Atmospheric Emissions Inventory and replaces previous versions of the inventory. Estimated ground level concentrations of key pollutants NOx, NO2, PM10 and PM2.5 across Greater London for years 2019, 2025 and 2030 using an atmospheric dispersion model.	Air Pollution	Raster GIS data	Available for Greater London.	2023	27/06/2023	Due to the size of the LAEI database, datasets are provided in several parts and provided as ZIP files.	Greater London Authority Freely accessible to Arup via GLA.

No.	Data overview		Geospatial Information			Metadata			
	Dataset	Description	Data Type	Spatial Scale (e.g., ward, neighbourhood, point data)	Temporal Resolution	Date of Acquisition	Source	Source (location)	Accessibility of data
7	Noise exposure contours around London airports	Reports outlining average summer day and night noise exposure contours for Heathrow, Gatwick and Stansted airports.	Noise Pollution	Vector GIS data	Area around Heathrow, Gatwick and Stanstead airports.	2015	04/07/2023	Environmental Research and Consultancy Department (ERCD) produce annual reports on noise exposure contours at Heathrow, Gatwick and Stansted airports. These are detailed reports and essential reading to understand both how noise exposure contours are produced and how they should be interpreted. Contours from 2016 onwards are commissioned and published by the designated airports.	Department for Transport
8	NHS Acute (Hospital) Trust Catchment Populations Dataset	Information about hospital admissions per NHS Trust Catchment areas.	Hospital Admissions	Vector GIS data	Trust Catchment Areas for UK	2022	06/07/2023	This data is produced by the Local Knowledge and Intelligence Service within the Office of Health Improvement and Disparities (DHSC).	Office for Health Improvement and Disparities

No.	Data overview		Geospatial Information			Metadata			
	Dataset	Description	Data Type	Spatial Scale (e.g., ward, neighbourhood, point data)	Temporal Resolution	Date of Acquisition	Source	Source (location)	Accessibility of data
9	Income Deprivation Affecting Children Index (IDACI)	The Income Deprivation Affecting Children Index (IDACI) measures the proportion of all children aged 0 to 15 living in income deprived families. It is a subset of the Income Deprivation Domain which measures the proportion of the population in an area experiencing deprivation relating to low income.	Deprivation	Tabular	Lower-layer Super Output Area (2011)	2019	21/07/2023	The data is from 2019 and therefore the deprivation indices might have changed.	Department for Levelling Up, Housing and Communities Freely accessible to Arup via GLA.

Heat Hazard Datasets

No.	Data overview		Geospatial Information			Metadata			
	Dataset	Description	Data Type	Spatial Scale (e.g., ward, neighbourhood, point data)	Temporal Resolution	Date of Acquisition	Source	Source (location)	Accessibility of data
1	Curio Canopy - London Tree Canopy Cover	A pan-London high resolution canopy layer aggregated to LSOAs. (Also available in a hexagon grid, Ward (2014) and London Borough geographies. Detailed high resolution vector Curio canopy layer for Greater London area.)	Vector GIS data	Greater London - LSOA, hexagon grid, ward (2014) and London Boroughs	2020	30/05/2023	London Datastore	Curio Canopy - London Tree Canopy Cover - London Datastore	Open
2	Sentinel 2 Albedo	Albedo can be calculated for an area with no cloud cover from Sentinel 2 satellite imagery.	Raster GIS data	Global coverage	2023	14/06/2023	Copernicus Open Access Hub	Open Access Hub (copernicus.eu)	Open. See Legal Notice.

No.	Data overview		Geospatial Information			Metadata			
	Dataset	Description	Data Type	Spatial Scale (e.g., ward, neighbourhood, point data)	Temporal Resolution	Date of Acquisition	Source	Source (location)	Accessibility of data
3	Land Cover Classification (Urban Atlas 2018)	Contains the Land Cover Land Use product in 788 FUA's designed to cover cities with more than 50,000 inhabitants, covering EEA39 (EU28 + EFTA countries + West Balkans + Turkey).	Vector GIS data	Greater London	2018	14/06/2023	Copernicus Land Monitoring Service	Urban Atlas — Copernicus Land Monitoring Service	Open
4	Building Heights	Building height, derived from AW3D30, SRTM30, and Sentinel2 composite	Raster GIS data	Global coverage. 30m resolution raster.	2018	14/06/2023	European Commission	Joint Research Centre Data Catalogue - GHS-BUILT-H R2022A - GHS building height, derived ... - European Commission (europa.eu)	Open
5	GHSL - Global Human Settlement Layer	The spatial raster dataset depicts the distribution of residential population, expressed as the number of people per cell.	Raster GIS data	Global coverage. 100m resolution raster.	2023	14/06/2023	European Commission	Global Human Settlement - GHS-POP_GLOBE_R2023A - European Commission (europa.eu)	Open

No.	Data overview		Geospatial Information			Metadata			
	Dataset	Description	Data Type	Spatial Scale (e.g., ward, neighbourhood, point data)	Temporal Resolution	Date of Acquisition	Source	Source (location)	Accessibility of data
6	Altitude	Digital Elevation Model (DEM) to calculate altitude.	Raster GIS data	Global coverage. 30m resolution raster.	2023	14/06/2023	US Geological Survey	EarthExplorer (usgs.gov)	Open
7	ERA5	ERA5-Land is a reanalysis dataset providing a consistent view of the evolution of land variables over several decades at an enhanced resolution compared to ERA5.	GRIB	Global coverage	2023	14/06/2023	Climate Data Store	ERA5-Land hourly data from 1950 to present (copernicus.eu)	Open

Appendix II Property Vulnerability

Gap analysis

The vulnerability of a building to overheating is contingent upon a number of factors. These encompass intrinsic construction factors like building material, structure, windows, ventilation systems, and internal heat sources. Also influential are extrinsic factors linked to the building's surroundings, including impediments to window opening (e.g., noise pollution) and a building's proximity to green spaces.

Factors which influence how vulnerable a property is to overheating were collated through research and mapped to available data to determine gaps. In general, there was limited data available at property level across London's building stock. Table 9 shows a list of influencing factors and data availability (please refer to Appendix I Data Sets for details on the datasets). For some factors a direct source of data was available, for instance data on residential property type is available through Energy Performance Certificate (EPC) rating. In some cases, the data could be calculated, for instance the air tightness of residential properties was determined through considering the age bracket of the property which is available through the EPC rating. Some factors were not considered in this project for a number of reasons including complexity of obtaining data or the need for more information. These are summarised in the table.

Due to inadequate data availability, conducting a comprehensive evaluation of each property's potential for overheating was unfeasible. Instead, the existing data for each property type was gathered and organised through a scoring mechanism, resulting in the creation of a heat vulnerability scale.

Table 9: summary of factors which influence heat in properties (including data gap analysis)

Category	Factor(s)	School	Hospital	Care Home	Residential
Property Type	**Type**	Available through London School Atlas	Available through Medical Site Data (UK)	Available through Care Quality Commission	EPC used to identify residential properties (DLUHC)
	Function	Available through London School Atlas	Available through Medical Site Data (UK) Hospital type is available but not used due to complexities with differentiating between different vulnerabilities	Available through Care Quality Commission	Available through EPC (Property Type) (DLUHC)
	Age	Not available	Not available	Not available	Available through EPC (categories limited)
Building Form	**Volume (height and area)**	Available but with limited detail. Building footprints and heights are available but not for individual rooms. It is difficult to include this factor in a meaningful way without more complex modelling.			
	Storey	Not available	Not available	Not available	Available through EPC
Ventilation	**Openable areas**	Not available	Not available	Not available	Not available
	Cross ventilation potential	Not available	Not available	Not available	Not available
	Barriers to opening windows (e.g., noise, air pollution or crime)	Indirectly available. Determined from data on noise, crime and air pollution in London at a spatial scale. Noise Level: Noise pollution in London (GLA and DFT) Crime: IMD - Crime (GLA) Pollution level: London Atmospheric Emissions Inventory (LAEI) (GLA)			

Category	Factor(s)	School	Hospital	Care Home	Residential
Solar Gains	**Glazing properties**	Not available	Not available	Not available	Available but with limited detail
	Window sizing and location	Not available	Not available	Not available	Window area and type available through EPC. Not data on location available
	Shading feature (internal and external)	Not available	Not available	Not available	Not available
Building Fabric	**Wall construction**	Not available	Not available	Not available	Available through EPC but with limited detail.
	Roof construction	Not available	Not available	Not available	Available through EPC but with limited detail
	Thermal mass	Not available	Not available	Not available	Not available
	Air tightness	Not available	Not available	Not available	Indirectly available. Calculated using EPC Property Age (see next section)
Building Systems	**Heating systems**	Some information available through EPC but not informative for study	Some information available through EPC but not informative for study	Some information available through EPC but not informative for study	Available through EPC but only presence of centralised system considers for flats

Category	Factor(s)	School	Hospital	Care Home	Residential
	Air conditioning[10]	Available through EPC but without enough detail to include	Available through EPC but without enough detail to include.	Available through EPC but without enough detail to include.	Available through EPC but without enough detail to include.
	Mechanical system	Available through EPC but not informative for study	Available through EPC but not informative for study	Available through EPC but not informative for study	Available through EPC but not informative for study
Internal heat gains	**Occupants**	Available indirectly through data on school overcrowding through gov.uk	Not available	Not available	Not available
	Lights and small power	Not available	Not available	Not available	Not available
Building Location	**Onsite greening**	Not available	Not available	Not available	Not available
	Proximity to green and blue space	Calculated from OS open Greenspace	Calculated from OS open Greenspace	Calculated from OS open Greenspace	Calculated from OS open Greenspace
	Surrounding buildings (i.e., overshadowing)	Not considered as analysis would be required to determine factors such as overshadowing and airflow. Not feasible for this study	Not considered as analysis would be required to determine factors such as overshadowing and airflow. Not feasible for this study	Not considered as analysis would be required to determine factors such as overshadowing and airflow. Not feasible for this study	Not considered as analysis would be required to determine factors such as overshadowing and airflow. Not feasible for this study

[10] Many buildings will be air conditioned, and this is an important factor to consider. However, there was a lack of data to inform on the size and location of air conditioning systems especially for larger, more complex properties such as schools and hospitals making it difficult to make an informative assessment. In addition, measures to mitigate overheating can help to reduce reliance on energy consuming air conditioning systems.

Approach To Scoring

Each factor used in the assessment was assigned a weighting to describe the potential influence it would have on increasing or decreasing heat vulnerability. This includes whether it is a cause of overheating (or cooling) of the property itself or if the factor has an influence on occupant behaviour (for instance limiting their ability to cool). For example, glazing was considered to have a very high influence on overheating (through solar heat gains increasing heat) so was assigned a weighting of 3. In comparison, although proximity to green or blue space can have a beneficial influence on occupants, it was considered less influential compared to other factors and was assigned a weighting of 1.

For a given property, a contribution was given for each factor which represented the impact the factor has on heating or cooling the property. Scores were given from -2 to +2, where -2 corresponds to the factor contributing to cooling the property and +2 contributes to heating the property. Where a 0 was given the factor was deemed to neither contribute to heating nor cooling of the property. For instance, for barriers to openable windows, if a property has significant acoustic, crime or air quality barriers which prevent occupants from opening windows (and cooling down the property through ventilation) then it was given +2. If no barriers exist for a property then it was given a 0 as this has no impact on cooling or heating.

The contribution for each factor was also multiplied by the factor weighting to give a final factor score. All scores were tallied for each property to give a final property vulnerability score. Note final property vulnerability scores that are zero or negative were reset to one. Since all properties are vulnerable to adverse heat impacts, this was done to avoid misleading conclusions. In reality, it is important to consider that the relationship between the different factors is nuanced and further data and more detailed assessments would be needed to make a thorough evaluation of property vulnerability to overheating. This score represents the potential heat vulnerability a property could have and should be seen as a comparative score against all other properties measured against the same set of criteria.

The final property vulnerability data set was categorised from a scale of one to five, with one corresponding to the lowest vulnerability, and five corresponding to the highest vulnerability. Due to the distribution of data, the banding was done as equal intervals (rather than equal count).

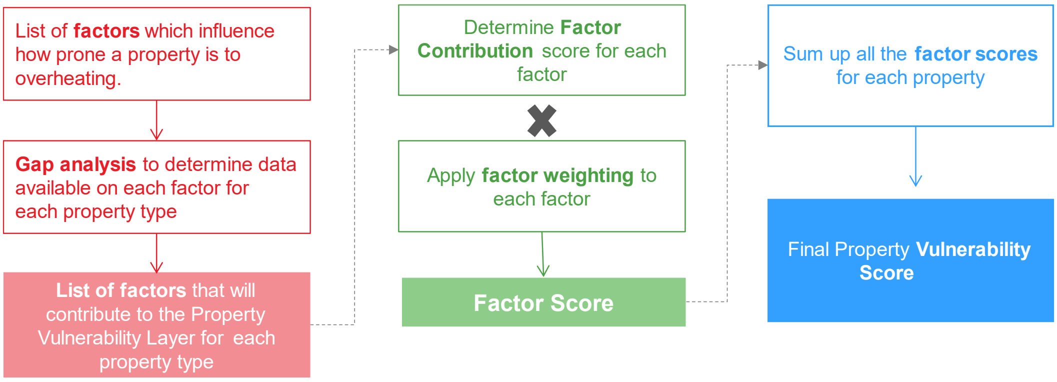

Figure 17: Method for creating the Property Vulnerability Layer for each property type

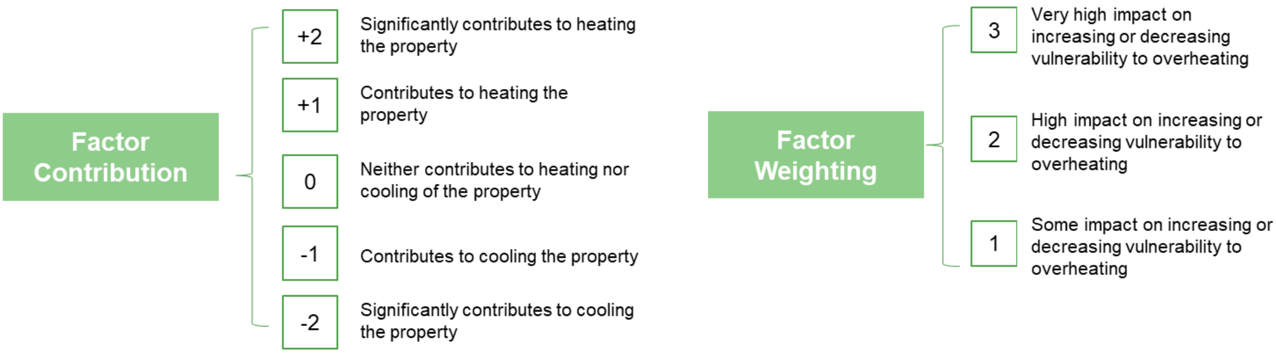

Figure 18: Definitions for factor contribution and factor weightings

Factors Included in the Assessment

Details and research on the factors used as part of the Property Map scoring are discussed below.

Property type

Applied to property types as below:

Schools

Nurseries and primary schools which will have younger occupants, are more vulnerable to heat, have been distinguished from other types of schools.

Scoring applied as follows:

Factor weighting: 3

- 1 point for other school properties
- 2 points for nurseries and primary schools

Hospitals

A distinction was not made for different types of hospitals, and it was assumed that a large portion of occupants could be considered vulnerable to heat risk. Many hospitals are large and complex with a number of different buildings providing a range of services. A distinction was made between inpatient and outpatient facilities, whereby inpatient facilities were given a higher vulnerability as there will be occupants that will spend longer periods of time in these properties including spending the night there.

Scoring applied as follows:

Factor weighting: 2

- 1 point for outpatient hospitals
- 2 points for inpatient hospitals

Care homes

Information was accessible via the Care Quality Commission (CQC) regarding care home categorisation, wherein a differentiation is made between a residential care home and a nursing home. Nursing homes provide a higher level of medical care and skilled nursing services for individuals with more complex healthcare needs. Consequently, the residents of nursing homes were considered as having a higher vulnerability to heat compared to those in residential care homes.

Scoring applied as follows:

Factor weighting: 2

- 1 point for residential care homes
- 2 points for nursing homes

Residential Properties

Research showed that flats are more likely to overheat compared to houses (BEIS, 2021). This is due to reasons such as smaller size, denser occupation, and fewer opportunities for cross ventilation (Good Homes Allliance, 2019). Houses in multiple occupation (HMOs) were also considered to be at a higher risk to overheating due to density. Upper storey flats are at even more risk due to higher solar exposure and heat rising (Good Homes Allliance, 2019). Note that these assumptions are general and there may be cases that deviate e.g., some houses may have a bigger vulnerability to overheating compared to some flats.

Scoring applied as follows:

Factor weighting: 2

- 0 points for houses (detached, semi-detached, terraces)

- 1 point for flats and HMOs
- 2 points for top story flats

Ventilation

Ventilation is a key means by which a property can mitigate overheating risk (BEIS, 2021). Windows can help regulate the internal temperature as well as provide air movement which can help with thermal comfort during hot conditions. Further details on a property's ventilation mechanism such as size and type of openings would be required to assess its overeating risk potential. Since this information was not available at scale it was not included in the assessment. It should be noted that this is a big limitation as ventilation is considered an important factor in overheating.

This assessment, however, did consider potential barriers to openable windows such as noise, air pollution, and crime. Data from the GLA and Department for Transport (DfT) was used to determine if a property is located within an area that suffers from an undesirable noise source, high crime, or bad air pollution. Further details on the data sources are available in Appendix I Data Sets.

Scoring applied as follows (all property types):

Factor weighting: 3

- 0 point for property not in high noise, crime, or pollution area
- 1 point for properties that exceed one UK pollution limit.
- 2 points properties that exceed two UK pollution limits or are located in a high noise area or high crime area.

Solar Gains

Solar gains through glazing is one of the biggest causes of overheating to living spaces in residential buildings (BEIS, 2021). The proportion and the type of glazing (single, double) will have an impact on the amount of solar radiation entering a property.

For residential properties EPC data was available on the total glazing areas (EPC: glazed area) and the floor area of properties (EPC: floor area), so these attributes were used to calculate the average window to floor ratio for a property. Since information on the glazing orientation and individual room areas was not possible to obtain, the total property glazing was assessed against "The Building Regulations - Overheating: Approved Document O" for a south facing façade (for buildings without cross ventilation) as a conservative estimate (HM Goverment, 2010).

In addition, EPC also gives information on type of glazing (EPC: glazed type). This was used as a proxy for the G value of glazing, with single glazing considered to have a higher G value (and therefore more solar gains) compared to double or triple glazing.

Data on glazing was not available for non- residential properties so this factor could not be included in their assessment.

Scoring applied as follows (only residential):

Factor weighting: 3

- 0 points for properties that do not exceed Part O regulation (for south façade, non-dual aspect)
- 1 point for properties that do exceed Part O regulation (for south façade, non-dual aspect)

- 0 points for properties with double or triple glazing
- 1 point for properties with single glazing

Building Fabric: Roofs and Walls

Wall insulation is a complex factor when it comes to overheating risk. Research showed that a highly insulated but poorly designed building (e.g., poorly ventilated) has an increased likelihood of overheating. Conversely a well-insulated but well-designed building will have a lower likelihood of overheating (Fosas, 2018).

On the other hand, research found that roof insulation could reduce overheating risk in homes (Arup - commissioned by Climate Change Committee, 2022).

Data on building fabric was only available through EPC rating for residential buildings. An energy efficiency factor is provided for walls and roofs in the EPC which was used as a proxy for the insulation level.

Building Fabric: Air Tightness

Air tightness or the leakiness of a building will have an impact on heat flow from a building. An airtight building will retain heat more effectively compared to a leaky building increasing the risk of overheating. This is made worse If the property has no effective means of ventilation, especially at nighttime (NHBC Foundation, 2012).

Direct data on the airtightness of buildings was not available. Instead, for residential buildings the age of the property provided on EPC Ratings was used to discern the airtightness based on guidance from Chartered Institution of Building Services Engineers (CIBSE) Guide A guidance on changes to Part L of the Building Regulations (CIBSE, 2021).

The EPC: Construction Age Band data is banded into categories which did not match the Part L update dates. Therefore, the dates were matched as closely as possible as shown in Table 10.

Table 10: Air tightness definitions used for data mapping

Part L Updates	**Air tightness definition**	**Corresponding EPC age band used**
Pre 2002	Leaky	Pre 1995
2002 Part L	Moderately leaky (not explicitly given in CIBSE Guide A)	2003-2006
2007 Part L	Moderately tight	2007-2011, 2007 onwards
2013	Tight	2012 onwards
Post 2013	Very Tight	

Scoring applied as follows (only residential):

Factor weighting: 3

- 0 points for properties that are leaky (Pre 2002) or moderately leaky (2003-2006)
- 1 point for properties that are moderately tight (2007-2011, 2007 onwards)
- 2 points for properties that are tight or very tight (2012 onwards)

Building systems: Community/Centralised/Network Heating

Properties with a centralised heating system are at a higher risk of experiencing overheating. This vulnerability stems from various factors, notably the lack of precise temperature control and the heat accumulation stemming from the building's pipework (Good Homes Allliance, 2019).

Scoring applied as follows (only residential):

Factor weighting: 2

- 0 points for properties without centralised system
- 2 points for properties with a centralised system

Internal Heat Gain: Overcrowding

Overcrowding in a property will increase the internal heat gains and can lead to a higher risk of overheating. In addition, occupants in crowded properties could also be considered as more vulnerable.

For residential properties, data on occupancy was only available as aggregate so this factor has not been included in the mapping.

Data on overcrowding in schools was available as a percentage of pupils over capacity. This was considered for the school's property vulnerability map.

Scoring applied as follows (only schools):

Factor weighting: 3

- 0 points for properties with 0-20% overcrowding
- 1 point for properties with 20-60% overcrowding
- 2 points for properties with 80% or more overcrowding

Building Location: Proximity to Green and Blue Space
Nearby blue and green infrastructure, such as parks, extensive landscaped grounds, rivers, or sizable water features, contributes to the reduction of ambient air temperatures and provide a local area of respite (Good Homes Allliance, 2019).

The guidance on proximity to green and blue spaces was obtained from the Heat Risk in London report and Guidance produced by WSP and commissioned by the GLA (WSP Supported by GLA, 2020).

Scoring applied as follows (all property types):

Factor weighting: 1

- -2 points for properties within 200m of a green space (minimum 0.5 hectares areas)
- -1 point for properties within 200-400m of a green space (minimum 0.5 hectares areas)
- 0 points for properties more than 400m away from a green space (minimum 0.5 hectares areas)

- -1 points for properties within 30m of a water body
- 0 points for properties more than 30m away from a body of water[11]

[11] Note that the thresholds have been simplified for proximity to water bodies compared to those recommended in the WSP Heat Risk report. This is due to the resolution of the mapping which may not allow for short distances to be assessed meaningfully especially for large buildings such as schools and hospitals.

Limitations and Constraints

- The limited availability of data especially on London’s building stock made it challenging to carry out a comprehensive analysis on heat risk in properties. For instance, data on key factors such as ventilation and internal heat gains was not available for any of the property types (detailed gap analysis is presented in the appendices). The non-residential buildings in particular were sparse on data availability and much more information would be needed to build a full picture of heat vulnerability for these types of buildings.

- The actual occupants of buildings and their behaviours (with respect to controlling their own environments) will vary considerably and cannot be accounted for in this study.

- The most appropriate datasets available were used. However, due to differences in when data has been compiled between different datasets, it was not always possible to obtain a full comprehensive list of all buildings within a given type. For instance, there was a mismatch between the London Schools Atlas data and EPC data which both provide information on what buildings are schools. We used the most appropriate source of data when this occurred.

- Thermodynamics and heat mechanisms of buildings are a complex interplay between different factors such as external heat gains, internal heat gains, ventilation, and materiality. Properties such as schools and hospitals are particularly complex and often include a number of different buildings across a campus. The property vulnerability maps evaluate the relative potential of overheating for properties at scale using the most appropriate available information. To truly understand the heat vulnerability of a property, further investigation through surveying, monitoring, or modelling would be required. This is something that could be carried out at later stages when developing mitigation initiatives.

Appendix III Socioeconomic Data

Overview

Since data about the occupants of properties are not easily available, the socioeconomic vulnerability layer provides some insight into the likely occupants of different building types.

Appropriate socioeconomic factors that contribute to heat vulnerability for the different property types had to be identified. The decision-making process for this was based upon research, literature review, and expert knowledge and judgment within the core team, as well as discussion with the GLA. In addition, gap analysis was carried out to assess the availability of recent datasets at a suitable spatial scale to facilitate mapping.

Due to the diversity of the property types selected, a different set of socioeconomic factors was selected for each property type. A multi-step, iterative process was undertaken to select the final socioeconomic factors. These steps and the results are as follows, and described in full in the subsequent sections:

- Step 1: Production of a long list of socioeconomic factors using literature review, data search, and analysis relevant to each property type.
- Step 2: Covariance tests and final factor selection.

Step 1: Production of a long list of socioeconomic factors

The first step was to create a long list of socioeconomic factors which affect heat vulnerability. A literature review was undertaken to analyse the methodologies employed in recent studies that have created maps of heat vulnerability. The review considered the socioeconomic factors included in each study and the justification for their inclusion as it related to heat vulnerability. The findings from the literature are summarised below. A gap analysis was carried out to identify the data available for each socioeconomic factor. Where there was appropriate data available, the factors were carried through to the long list of socioeconomic factors. The review informed the selection of the most appropriate factors for each property type.

Age-related vulnerability (Older individuals)

Older residents, such as those over the age of 65, are identified as being more vulnerable to heat health risks than younger people. Higher mortality and higher hospitalisation rates for this age group were found during heatwaves or periods of hot weather in many countries across the world by multiple studies. For example, in the USA (Knowlton et al., 2009) and in various European countries including Italy (Stafoggia et al., 2008), Austria (Hutter et al., 2007) and England (Thompson et al., 2022), among others. The vulnerability found among older members of the population is likely to be linked to the higher proportions of older individuals living with illness and disability, as well as physiological factors meaning that older people have a lower tolerance to extreme temperatures. Decreased mobility can also contribute to their vulnerability. This may impact their ability to open windows or get to a cooler place (for example, Tan, 2008; Klein Rosenthal, Kinney and Metzger, 2014). Many spatial studies of heat vulnerability have included over 65s or those over 75 as vulnerability factors (for example, Liu et al., 2020; Song et al., 2020; Zheng et al., 2020; Conlon et al., 2020; Estoque et al., 2020).

In this project, the factor used was over 65s. Recent Census data was available and so the percentage of the population who are older than 65 was considered in the long list of factors.

Age related vulnerability (Younger individuals)

Similar to the older population, young individuals are highlighted as vulnerable to high temperatures (Xu et al., 2017; Malmquist et al., 2021). This is a result of physiology, with infants having underdeveloped thermoregulation and immune systems. Additionally, they have a very low level of understanding and self-care ability (Xu et al., 2017). The most common factor used in previous mapping studies is children under six or five years of age (RInostroza, Palme and Barrera, 2016; Estoque et al., 2020; Zheng et al., 2020).

For this work, children under four years of age were considered. This choice was influenced by the data availability, as information was drawn from the 2021 Census, which categorises ages into bands. The initial band covers ages ranging from 0 to 4 years old.

Ethnicity

There is some evidence that ethnicity can play a role in vulnerability to heat risks, although the relationship is complex and context-specific, with ethnicity likely to interact with a range of other vulnerability indicators. Studies in the USA which have analysed heat-related mortality by ethnicity have found various results. By analysing correlations between temperature and mortality in extreme heat events, several studies have identified higher heat-related mortality in Black residents (Madrigano et al., 2015). However, it has also been found that Hispanic people living in the United States are less at risk of heat-related mortality (Basu and Ostro, 2008). Others have highlighted that there may be variations in the prevalence of air conditioning, education levels, and types of jobs (outdoor vs. indoor) among ethnic groups, which may contribute to observations about heat vulnerability (Hansen et al., 2013). Also linked with ethnicity are language and communication barriers, which may cause exclusion from certain media or health warnings (Uejio et al., 2011; Hansen et al., 2013), as well as higher levels of mistrust of local officials among some groups. It is notable that many of these findings are based on research in the United States, which may not be generalisable to the UK.

Ethnicity was considered in the long list of socioeconomic factors, with the potential to draw on Census data.

Pre-existing health conditions/ health deprivation

Pre-existing health conditions have been identified widely as risk factors for heat-related illness and mortality (Buoite Stella et al., 2020; Layton et al., 2020; Ebi et al., 2021). Relevant pre-existing illnesses include diabetes (Konkel, 2020), cardiovascular conditions (Yin and Wang, 2017), renal disease, nervous disorders, emphysema, and epilepsy (e.g. Semenza et al., 1999). Those suffering from mental health conditions have also been identified as vulnerable (Stafoggia et al., 2008).

No comprehensive data on individual illnesses was available at a spatial resolution that could be informative to this project. However, two related data sets were considered and taken forward into the long list:

- Census data on health, where participants could self-select their level of health.
- Index of Multiple Deprivation (IMD) data on health deprivation, which is one of the sub-indexes of the IMD[12].

Both were considered in the long list of socioeconomic factors.

Social isolation and living alone.

Individuals who are alone or socially isolated are a further group identified to be vulnerable during times of extreme heat (Poumadère et al., 2005). Single person households were used as a proxy for social isolation and included as a risk factor in multiple studies (Bradford et al., 2015; Hu et al., 2017; Conlon et al., 2020; Song et al., 2020).

Using household composition from Census data (at LSOA), the percentage of those living alone both under and over 65 could be calculated. Both were taken forward as part of the long list of socioeconomic factors to be considered.

Financial deprivation

Increased mortality during warm or extreme heat has been related to various measures of increased deprivation or lower income (Madrigano et al., 2015). This association could be explained by people on lower incomes being less able to afford air conditioning, hospital trips, information resources, or other preventative measures (Bradford et al., 2015). Deprivation among older people has been found to increase vulnerability even more. There are many different factors relating to financial status, income, or poverty being used to describe deprivation among populations (for example, Song et al., 2020; Zheng et al., 2020; Conlon et al., 2020; Estoque et al., 2020). Number of people receiving social benefits and number of unemployed have also been used as proxies (Kim and Joh, 2006).

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[12] The Health Deprivation and Disability Domain of the IMD measures the risk of premature death and the impairment of quality of life through poor physical or mental health. The domain measures morbidity, disability and premature mortality, but not aspects of behaviour or environment that may be predictive of future health deprivation. The indicators include: years of potential life lost (an age and sex standardised measure of premature death); comparative illness and disability ratio (an age and sex standardised morbidity/disability ratio); acute morbidity (an age and sex standardised rate of emergency admission to hospital); mood and anxiety disorders (a composite based on the rate of adults suffering from mood and anxiety disorders, derived from hospital episodes data, prescribing data and suicide mortality data).

The overall IMD and the IMD’s sub-index relating to income deprivation[13] were both taken forward to the long list of socioeconomic factors.

Free school meals (schools only)

Free school meals have also been analysed as a proxy for financial deprivation specific to children. The data is available from the Department for Education and provides statistics on number of pupils in England eligible for free school meals for all state-funded schools by local authority level (Department for Education, 2020).

Education deprivation

Lack of education has also been linked to higher vulnerability to heat risks. Several studies have shown a relationship between heat-related vulnerability and a lack of high school level education (Yin et al., 2018). IMD’s sub-index for education deprivation was considered in the long list of socioeconomic factors[14].

Occupation

Occupations experiencing higher exposure to heat – e.g., due to spending a long time working outdoors or in physically exerting tasks - are linked to vulnerability (Wong et al., 2016).

Spatial occupation data is available from the Census, but it was not included in this study due to the primary focus being on buildings rather than outdoor occupations. Additionally, challenges arose with respect to the categorisation of occupations in the Census data, making it problematic to distinguish which categories carried greater vulnerability.

Overcrowding

Overcrowding could be considered as a factor that increases vulnerability to heat as it can cause higher internal heat gains in properties. In addition, there is a link between overcrowding and deprivation.

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[13] The Income Deprivation Domain measures the proportion of the population in an area experiencing deprivation relating to low income. The definition of low income used includes both those people that are out-of-work, and those that are in work but who have low earnings (and who satisfy the respective means tests). The indicators include: adults and children in Income Support families; adults and children in income-based Jobseeker’s Allowance families; adults and children in income-based Employment and Support Allowance families; adults and children in Pension Credit (Guarantee) families; adults and children in Universal Credit families where no adult is classed within the 'Working - no requirements' conditionality group; adults and children in Working Tax Credit and Child Tax Credit families not already counted; asylum seekers in England in receipt of subsistence support, accommodation support, or both.

[14] The Education, Skills and Training Domain measures the lack of attainment and skills in the local population. The indicators fall into two sub-domains: one relating to children and young people and one relating to adult skills. It is likely that the ’adult skills’ sub-domain will be more relevant here, with indicators including: adult skills (the proportion of working-age adults with no or low qualifications, women aged 25 to 59 and men aged 25 to 64); English language proficiency (the proportion of working-age adults who cannot speak English or cannot speak English well, women aged 25 to 59 and men aged 25 to 64.

Census data on overcrowding is available and considered in the long list of socioeconomic factors, and specific overcrowding data was found. However, after some discussion these factors were transferred to the property layer due to their influence on internal gains and indoor temperature.

Another group of factors reviewed for the study were socioeconomic *neighbourhood factors,* which can influence the likelihood that people will act to cool their indoor spaces, for example:

Crime, noise and air pollution

Crime can contribute to heat vulnerability by influencing the behaviour of occupants in buildings. For instance, the fear of crime can prevent people from opening windows when they are away from their home or during the night (Hatvani-Kovacs and Boland, 2015; Baborska-Narożny, Stevenson and Grudzińska, 2017; Mavrogianni et al., 2017).

Evidence has been found that noise can also stop people from opening windows, meaning adequate cooling is not achieved (Barclay, Kang and Sharples, 2012; Baborska-Narożny, Stevenson and Grudzińska, 2017; Mavrogianni et al., 2017).

Furthermore, air pollution and poor air quality can create a barrier to window opening and is linked with increased noise (e.g., from road traffic). There are also links between heatwaves and elevated levels of air pollution (Li et al., 2019; Fang and Gu, 2022), which may compound this as a factor affecting behaviour. Higher exposure to pollution is also linked with negative health outcomes (Hankey and Marshall, 2017).

All three factors (crime, noise and air pollution) were included in the property layer as “barriers to openable windows”, as they relate directly to the ventilation of a property.

Table 11 summarises the long list of socioeconomic factors and the corresponding datasets (and variables selected), and indicates whether they have been incorporated into the socioeconomic vulnerability layer for each property type. The next section elaborates on the reasoning behind the selection of the final socioeconomic factors for each property type.

Table 11: Long list of socioeconomic factors, the corresponding datasets and final selection for each property type[15]

Vulnerability factor	Specific variable selected	Data source	Residential	Hospitals	Schools
Age related vulnerability (Older individuals)	% of population aged 65 and over	Census 2021	Yes	Yes	No
Age related vulnerability (Younger individuals)	% of population aged 4 and under	Census 2021	Yes	Yes	Yes *(younger primary school / nursery aged children more vulnerable than older children)*
Ethnicity	% of the population identifies as non-white	Census 2021	Yes	Yes	Yes
Pre-existing health conditions / health deprivation	% categorising themselves as in “bad health” or “very bad health”	Census 2021	Yes	No	No
	IMD sub-index health deprivation	IMD	Yes	Yes	No
Social isolation and living alone	% of the population living alone aged 65 and over	Census 2021	Yes	No	No
	% of the population living alone aged under 65	Census 2021	Yes	No	No
Financial deprivation	IMD sub-index - Financial deprivation	IMD	Yes	Yes	Yes

[15] As previously mentioned, socioeconomic indicators were not applied to Care Homes, since indicators from the surrounding area could not be used describe the occupants of a care home with any accuracy.

Vulnerability factor	Specific variable selected	Data source	Residential	Hospitals	Schools
Education deprivation	IMD sub-index - Education deprivation	IMD	Yes	Yes	No
General deprivation	Overall IMD *summarised by LSOA*	IMD	Yes	No	No
	Income Deprivation Affecting Children Index (IDACI)	IMD	No	No	Yes
	% of pupils on free school meals	Department for Education data	No	No	Yes
	Overall IMD *summarised by NHS Trust*	IMD	No	Yes	No

Step 2: Covariance tests and final factor selection

A combination of research, co-variance tests, and professional judgement has been used to select the final set of factors from the long list of factors compiled.

Co-variance tests were conducted as there is often multi-collinearity between factors, particularly within socioeconomic and demographic factors. This has been considered in many previous studies which map vulnerability (for example, Macnee and Tokai, 2016; Conlon et al., 2020; Song et al., 2020; Zheng et al., 2020).

To prevent overcounting, co-variance assessments were carried out employing Pearson's correlation coefficient calculation, which is used to measure the strength of the correlation between two variables. In cases where a substantial correlation was identified between two factors, only one of the factors was retained for further consideration. Note that the covariance tests were carried out specifically for each property type due to different data sets used for each setting (see Table 7). The results are presented with discussion in the following sections.

In addition, as discussed above, noise, crime, and air pollution have also been included at property level for all property types due to their impact on ventilation.

General observations

Deprivation

Financial, health, and education deprivation are all included in the Index of Multiple Deprivation (IMD). It is a widely used metric which measures relative levels of deprivation at neighbourhood level for England, Wales, Scotland, and Northern Ireland. The seven domains of deprivation, which combine to create the Index of Multiple Deprivation, are detailed in Figure 19. Research has shown that all of these indices are related to heat vulnerability. Co-variance tests also showed that these individual sub-indices of deprivation were highly correlated and therefore could not be disaggregated. As a result, when considering inclusion of deprivation factors, the IMD was used holistically and is assumed to cover the health, financial, and educational indicators linked to heat vulnerability.

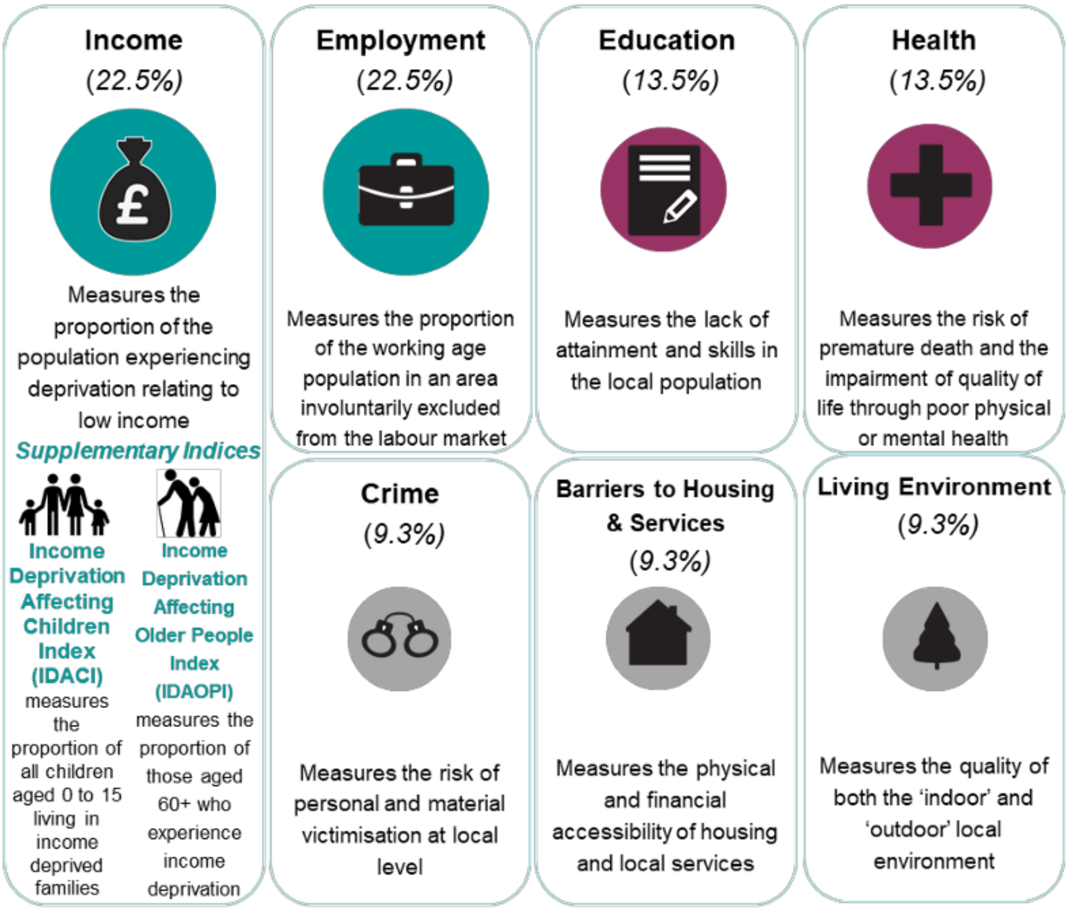


Figure 19: Deprivation factors included in the IMD (Ministry of Housing, Communities & Local Government, 2019)

Table 12: Co-variance test between individual indices of deprivation relating to heat vulnerability.

	Health IMD	Income IMD	Education IMD
IMD	0.85*	0.95*	0.73*
Health IMD		0.80*	0.59*
Income IMD			0.80*

Ethnicity

A number of references have identified ethnicity as a key factor representing vulnerability to heat. However, many of the studies which analyse mortality data in association with ethnicity are based in the USA and are not generalisable to the UK. The relationship between ethnicity and other socioeconomic variables is highly complex. Given the lack of evidence to clearly link ethnicity with heat vulnerability, it was not considered appropriate to include this indicator in the analysis.

Summary of socioeconomic indicators applied per building type.

A summary of the final factors used in the socioeconomic vulnerability maps is presented in Table 13.

Table 13: Summary of socioeconomic factors included for different property types

Property Type	Socioeconomic Vulnerability Layer Resolution for Property type	Socioeconomic Factor	Data Attribute
Schools	**LSOA**	Deprivation	Income Deprivation Affecting Children Index (IDACI)
Hospitals	**NHS Trust level**	Deprivation	Index of Multiple Deprivation (IMD)
		Age[16]	Admissions over 65
			Admissions under four
Care Homes	**N/A**	N/A	N/A
Residential	**LSOA**	Deprivation	Index of Multiple Deprivation (IMD)

[16] For hospital settings *Age* data was available by admissions to particular trust. All other data is based on the population surrounding the different property settings e.g. Deprivation is known for the whole population at Trust level for Hospitals not just admissions/patients.

Property Type	Socioeconomic Vulnerability Layer Resolution for Property type	Socioeconomic Factor	Data Attribute
		Age	Over 65
			Under four
		Social isolation	Under 65 and Living Alone

Schools

For schools, the only socioeconomic factor integrated into the socioeconomic map was deprivation, specifically employing the Income Deprivation Affecting Children Index (IDACI). The “Free School Meals” dataset was also considered and analysed for co-variance. As expected, it was highly correlated with the IDACI and was therefore not included.

Age was also considered for the school setting. It is widely accepted that younger children are more vulnerable, and therefore, children going to nursery and primary school are likely to be more vulnerable to heat than secondary school pupils. Since data on age (by way of school type) is available at individual property level, it was included in the property vulnerability layer instead.

Hospitals

Data relating to hospitals was available at NHS Trust level. Deprivation, ethnicity, and age were all considered for the socioeconomic layer for hospitals. As discussed earlier, IMD was used holistically as all the sub-indices within it would relate to heat vulnerability.

Table 14 shows the results of the Pearson’s correlation tests for the socioeconomic factors considered for hospitals.

Age data was available as the number of admissions at NHS Trust level, with the age brackets broken down such that data could be obtained for admissions of adults over 65 years and children under four years of age. The co-variance tests did not show correlation between admissions under four and the other factors. There is a correlation between over 65s and IMD. However, since research has shown that older individuals are at greater health risk from heat, it was concluded that this factor should be retained.

The final socioeconomic factors for hospitals included in the maps were deprivation (IMD at NHS Trust level) and age (admissions over 65 and under four).

Table 14: Co-variance test results for factors considered for hospital setting

	IMD	4 and under	65 and over
Ethnicity	0.53*	0.29	-0.39
IMD		0.35	-0.61*
4 and under			-0.47
*Signifies that the test was significant to a 95% confidence level. Red text signifies a possibly problematic level of correlation which needs to be addressed by the removal of one factor so that double counting does not occur (which was 0.5 or greater).			

Care homes

Data on the residents of care homes was obtained from the Care Quality Commission. The range of specialisms and services offered in care homes shown in Table 15 gave insight into the occupants residing in these properties. Research showed that all of these groups are more vulnerable to heat risk either through a higher physiological risk (e.g., older adults) or as a result of a lack of means to control their environment (e.g. individuals with learning disabilities).

Table 15: Specialisms and Services in UK Care Homes (Care Quality Commission, 2023)

Specialisms and Services in UK Care Homes
Caring for adults under 65 yrs.
Sensory impairments
Dementia
Mental health conditions
Caring for adults over 65 yrs.
Caring for children (0 - 18yrs)
Learning disabilities
Physical disabilities
Substance misuse problems
Services for everyone
Caring for people whose rights are restricted under the Mental Health Act
Eating disorders

The location of care homes and the socioeconomic and demographic characteristics of the surrounding area does not provide further insight into the occupants of care homes, especially since the people within a care home are unlikely to be from the surrounding neighbourhood. As such, it was considered inappropriate to include external socioeconomic factors when considering care homes.

Residential

All socioeconomic factors relating to heat vulnerability are relevant to residential properties. As discussed previously, there is a high level of correlation between IMD, and the individual sub-indices of deprivation related to heat vulnerability. Further co-variance tests presented in Table 16, were carried out to assess the correlation between IMD, individuals over 65, individuals under 65 and living alone, individuals over 65 and living alone, children under four, and ethnicity.

Research findings associating age with heat vulnerability led to the retention of age as a factor (encompassing both individuals over 65 and children under four), notwithstanding the correlation observed between older individuals and the IMD.

A correlation exists between the category of individuals over 65 and the subset of individuals over 65 who live alone. As a result of this correlation, the decision was made to retain the entire category of individuals over 65, instead of including both metrics. Furthermore, the analysis of co-variance did not reveal a significant correlation between individuals under 65 living alone and the IMD, thereby further substantiating the decision to retain this factor.

IMD was also found to be correlated to population over 65. However, both factors were kept because areas with higher proportions of older people and areas of higher deprivation are both important to this work.

The final factors included in the socioeconomic maps for residential properties are age (over 65 and under four), social isolation (under 65 and living alone) and deprivation (the IMD).

Table 16: Results of the co-variance tests between socioeconomic factors considered for residential properties.

	Alone and under 65	Ethnicity	Aged over 65	Under four	IMD	Health IMD	Health IMD	Health IMD
Alone and over 65	-0.30*	-0.40*	0.78*	-0.21*	0.31*	0.251	0.244	0.148
Alone and under 65		0.00*	-0.59*	-0.13*	-0.36	-0.282	-0.282	0.044
Ethnicity			-0.38*	0.20*	-0.57*	-0.365	-0.584	-0.451
Aged over 65				-0.01	0.55*	0.509	0.479	0.243
Under four					-0.19*	-0.122	-0.223	-0.294
IMD						0.848	0.950	0.732
Health IMD							0.803	0.591

	Alone and under 65	Ethnicity	Aged over 65	Under four	IMD	Health IMD	Health IMD	Health IMD
Income IMD								0.803
Education IMD								

Weighting of factors for the socioeconomic maps

When creating the final socioeconomic layer for each property type, the chosen factors were allocated equal weight. There was a possibility of adjusting weightings to emphasise certain factors which may be linked to higher vulnerability to heat. However, there was a lack of conclusive evidence to allow a comparative analysis or to guide specific weightings. Factors like age and health boast substantial research linking them to heat vulnerability, unlike factors such as social isolation which are less well studied. This may give rise to research bias. No comprehensive study was available to establish a hierarchy across all socioeconomic factors in relation to heat vulnerability.

Limitations and constraints

Some of the key constraints within the methodology and data include:

- Hospital socioeconomic data was only available by NHS Trusts, which is a large area comprising a number of LSOAs. This low resolution of data makes it difficult to distinguish between different neighbourhoods. The data available at LSOA level, such as IMD and age, could have been used instead but hospitals serve people over a wider area then their immediate neighbourhoods, so this approach was not considered suitable. Hospital catchment data was not accessible because patients are not necessarily constrained to attending their nearest hospital, particularly in the context of specialist medical facilities. Specialist hospitals, in particular, tend to serve patients from a broader geographic region, which could render catchment data less applicable.
- The Income Deprivation Affecting Children Index (IDACI), which was used for schools, is at LSOA scale. This was assigned to the individual school based on location of the school; however school catchments tend to cover a wider geographic area. This data was unavailable for inclusion.
- Data on the breakdown of health conditions in an area is not available. As a result, health was only considered as part of the IMD.
- The majority of the studies examined employed factors involving children under six or under five years old to assess heat vulnerability. However, due to the organisation of available data, this study utilised the category of under four years old, consequently excluding the vulnerable age group of five and six years old.

- Most socioeconomic factors are based on a proportion of the population with specific characteristics. However, adopting this approach results in the identification of regions with the highest proportion of vulnerable individuals. It is important to note that this approach doesn't imply the absence of vulnerable individuals in areas categorised as having low levels of vulnerability on average.
- Covariance tests provide valuable information for decision-making by helping determine which factors should be included in the socioeconomic maps while preventing the issue of double counting. However, it should be noted that the extent of correlation between two factors can vary. Correlation between two factors above 0.7 (70% correlation) is considered a strong correlation and correlation above 0.5 (50%) is considered moderate correlation. In the cases of moderate correlation, some professional judgment was exercised to decide if factors will be kept in the final socioeconomic map. As such, it is not possible to prevent all instances of double counting. In addition, there may be data that is missed, for instance, although *Health IMD* and *aged over 65* are moderately correlated, only *aged over 65* was included along with the total *IMD*. There may be instances of people with low Health IMD who do not suffer from other types of deprivation and are also under 65 who will be missed. However, it would not be possible to account for all of these instances of missing data without looking at all the data at an individual level. It is important to bear this limitation in mind and ensure that further work is done to understand specific demographics when considering implementation of heat mitigation interventions.

Appendix IV Heat Hazard

Background

The heat hazard map was produced using Arup's UHeat tool which utilises SUEWS (Surface Urban Energy and Water Balance Scheme). SUEWS is a neighbourhood/local-scale urban land surface model which simulates the urban radiation, energy, and water balances for an area using measured meteorological variables and information about the surface cover (SUEWS, 2023). The current Climate Heat Risk Map used by the GLA provides surface temperatures across London neighbourhoods. Although this is useful, air temperature is more intrinsically linked to overheating risk in properties.

UHeat and the underlying SUEWS model were selected to produce the heat hazard map for this project for a number of reasons:

- Predictions of air temperature could be obtained across London to understand how temperature is likely to vary across the city over the summer period. Air temperature is a better factor of the temperature that people will experience and can be more directly linked to health impacts compared to other metrics like surface temperature.
- Input data for London for the SUEWS model was openly available making it possible to use this methodology.
- The model allowed flexibility in terms of temporal resolution of the analysis. This included accounting for nighttime temperatures which are important to account for when considering adverse health impacts.
- The model can be carried out at LSOA spatial resolution which intersects with other data sources and allows property risk to be considered at neighbourhood level.

Method

To obtain heat intensity across London, the model was run hourly for the summer period (June to August) for five years (2018 to 2022) using meteorological data obtained for that period. A period of five years was selected to capture variations in summer temperatures which may occur from one year to the next. Input data for the model was obtained by LSOA with as described in Appendix I Data Sets. The output was hourly air temperatures for each LSOA for the analysis period which was then averaged temporally over that period and classified to obtain the heat hazard map. The map is presented on a scale of one to five where five represents the highest heat intensity and one the lowest heat intensity.

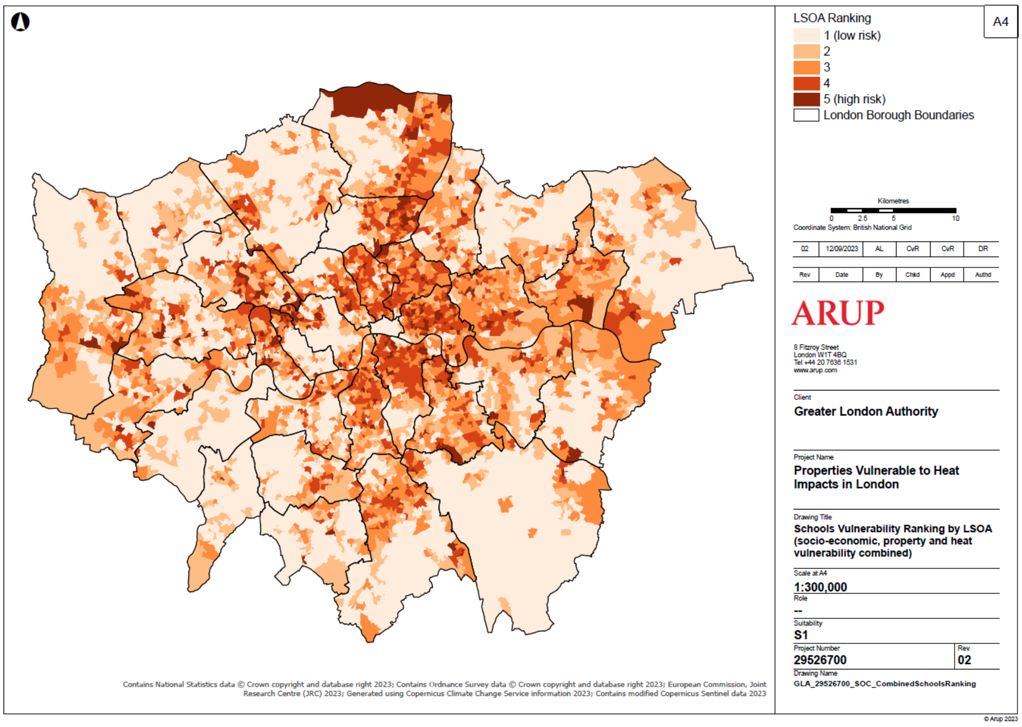
Limitations and Constraints

The heat hazard map provides a means to assess the average temperature variation across London and can be used to assess heat risk to properties. However, there are a number of limitations and constraints that should be considered:

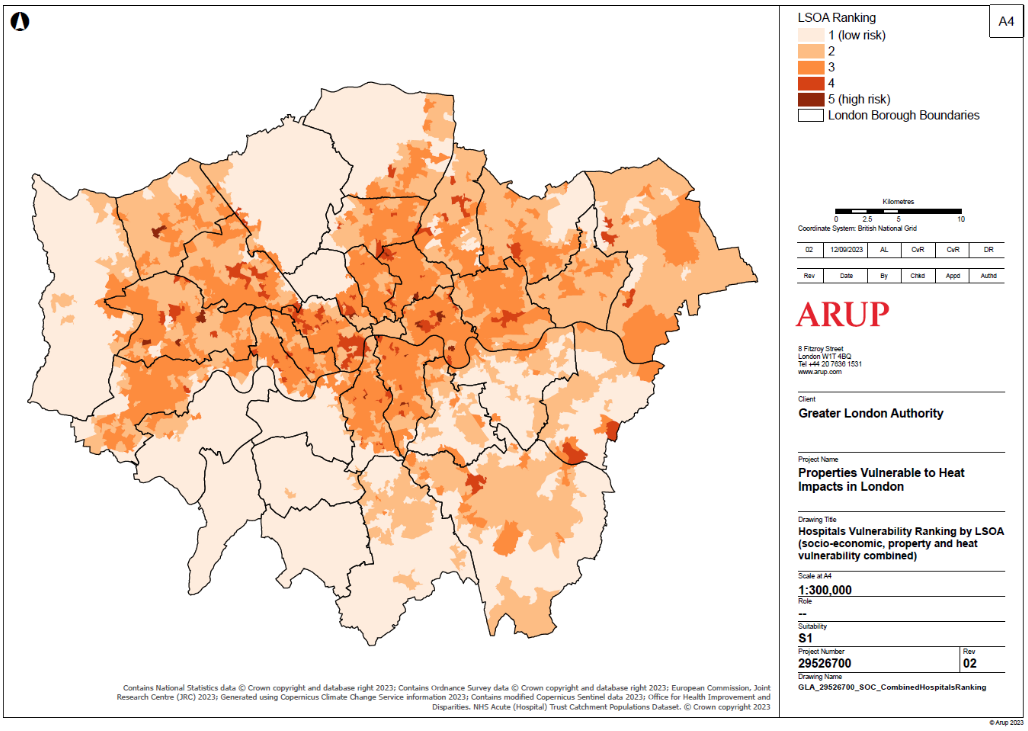
- The accuracy of the model is dependent on the accuracy and resolution of the input data on variable such as land surface classification, land surface cover etc. There may be small features and updates that may not be captured in the model.
- Data on anthropogenic heat emissions i.e., heat from buildings, transport, and people was not readily available. Population density was used in the model to make predictions for these variables.
- SUEWS is a surface model and limited to the resolution of the data available. It does not account for detailed 3D features.
- SUEWS is not a computational fluid dynamics model and does not account for advection across the city. In reality this would have an impact on the UHI effect of London but would require more complex modelling to be carried out which is outside the scope of this work.
- Other climate variables such as solar radiation and humidity will have an impact on thermal comfort and heat stress. These were not accounted for in the heat hazard map. These are microclimate features and should be considered when surveying a property in more detail.
- The heat hazard map presents the average temperature across the summer period (including day and night). There may be times outside this period where people may experience heat stress in buildings. For instance, vulnerable people may experience heat stress at a lower temperature threshold or some poor performance properties may get hot at lower ambient temperatures. In addition, there may be heat wave periods where the temperature variation across London could look different and more extremes of UHI effect may occur.

Appendix V Data Maps

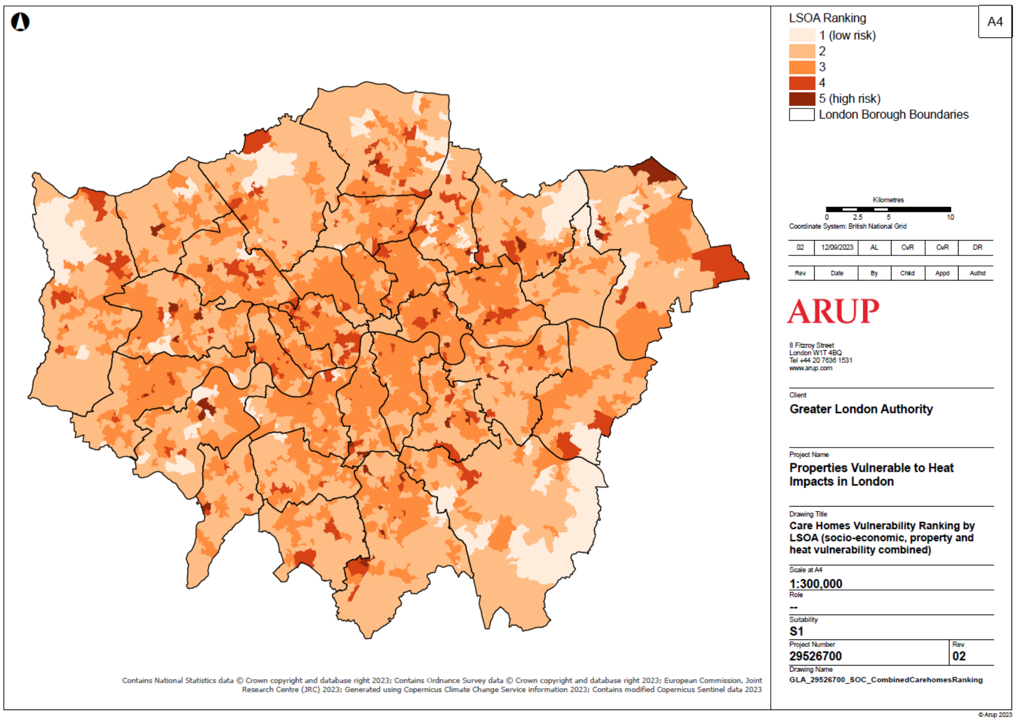
Property Heat Risk Maps



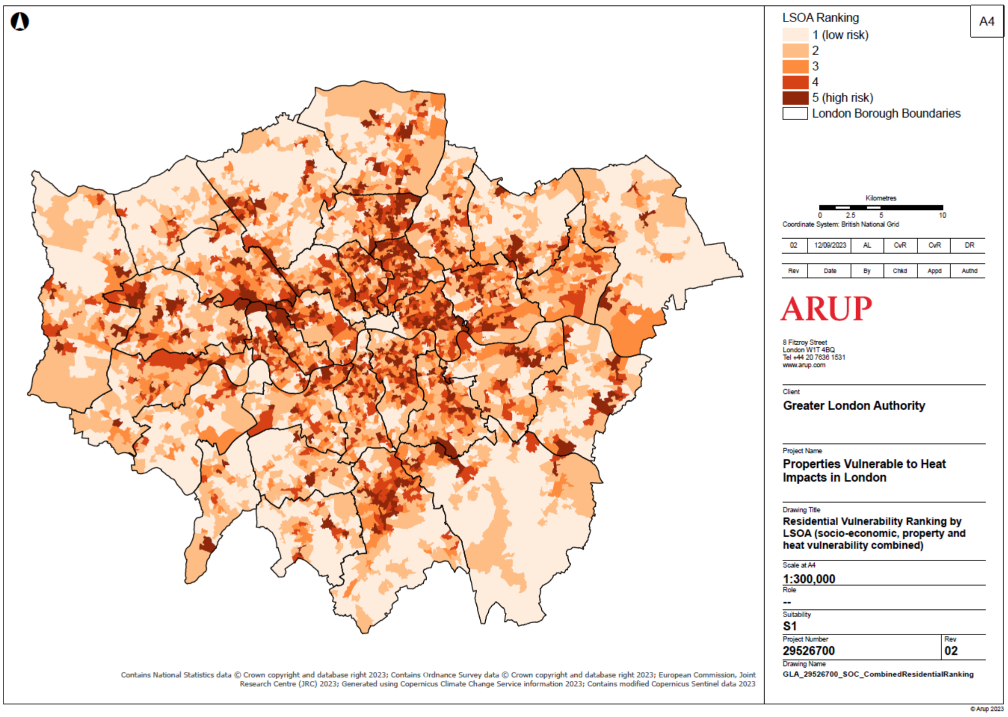
Schools Property Heat Risk Ranking by LSOA



Hospitals Property Heat Risk Ranking by LSOA

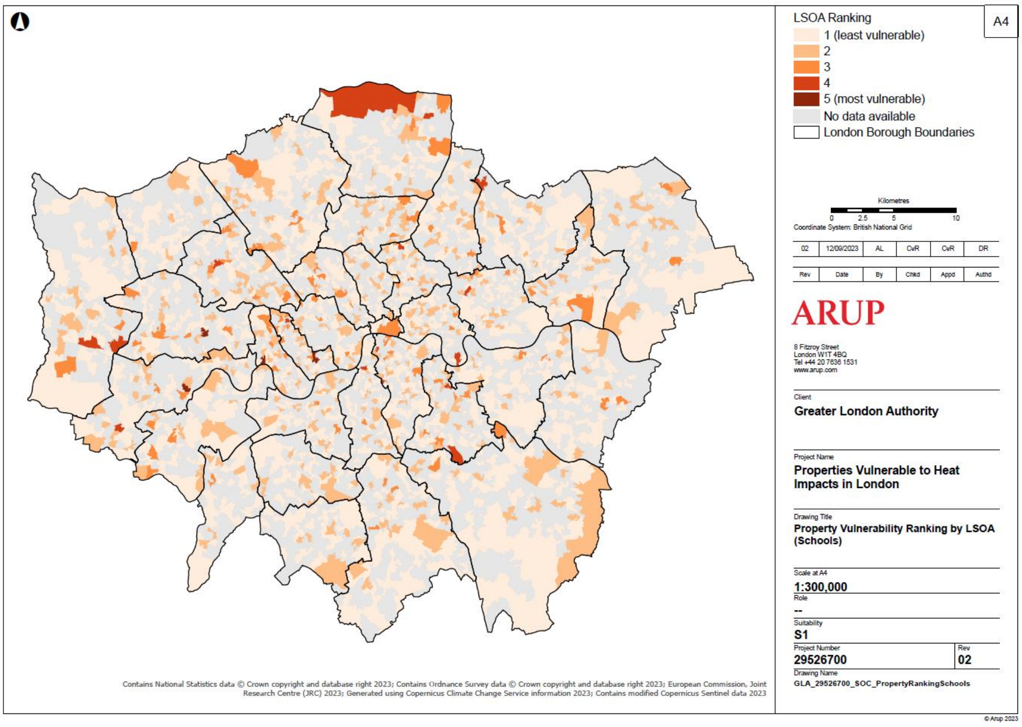


Care Homes Property Heat Risk Ranking by LSOA

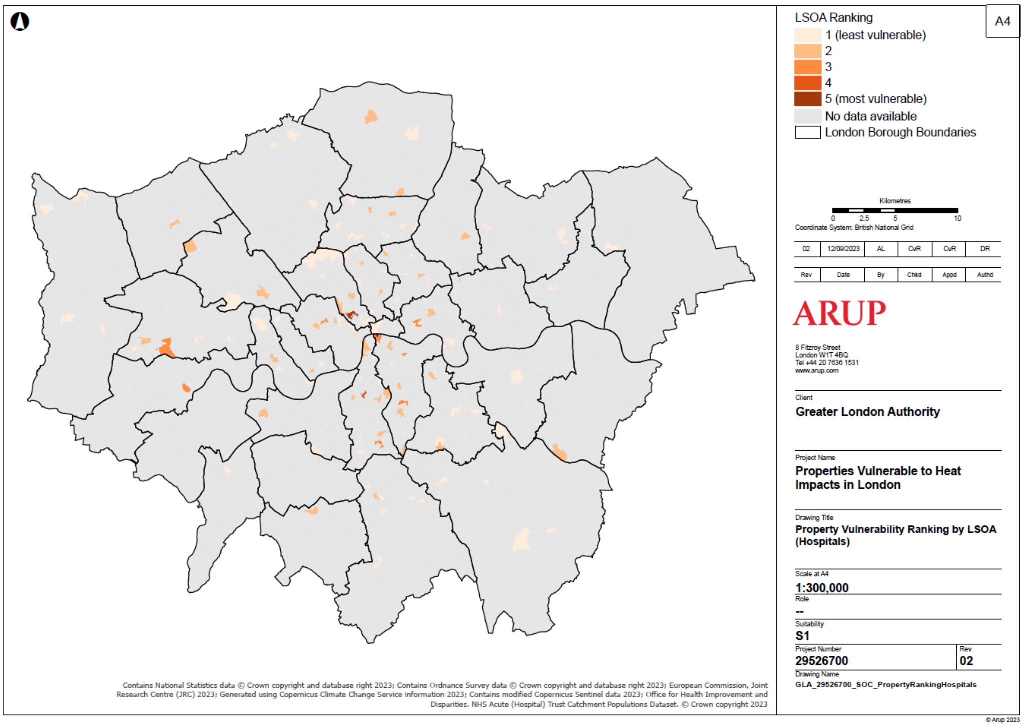


Residential Property Heat Risk Ranking by LSOA

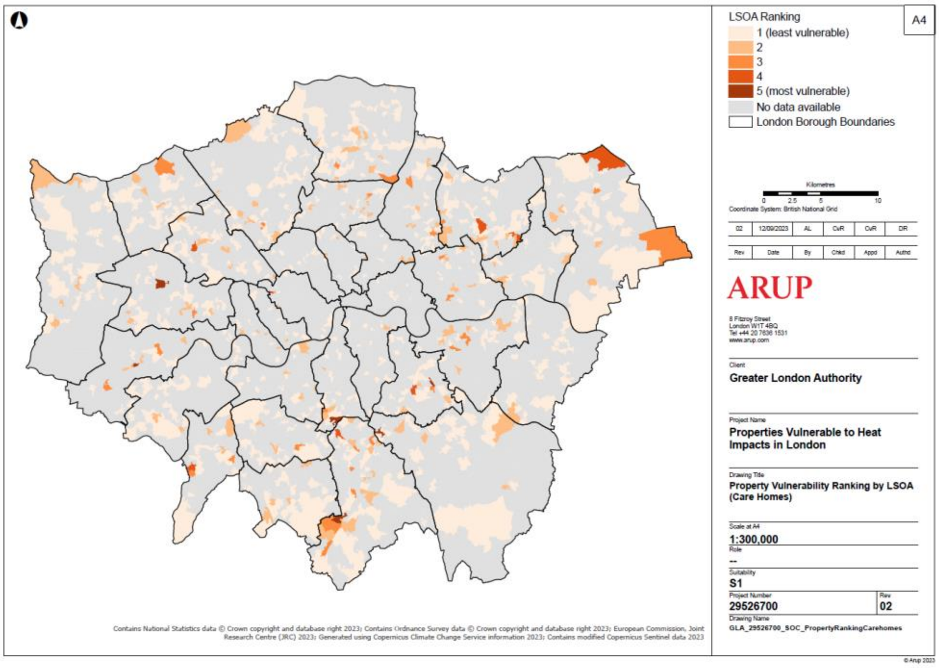
Property Vulnerability Maps



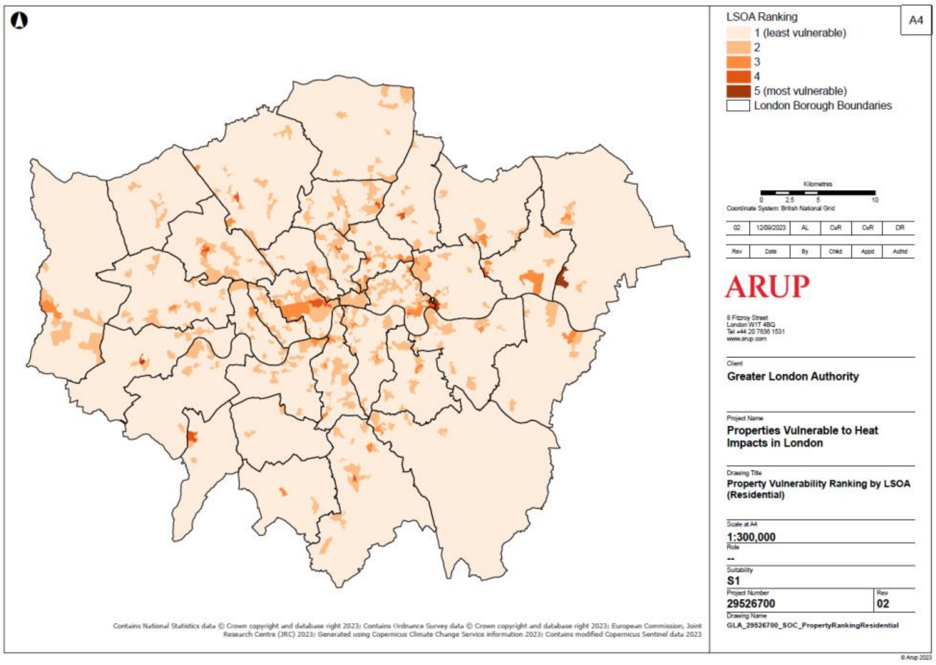
Property Vulnerability Ranking by LSOA (Schools)



Property Vulnerability Ranking by LSOA (Hospitals)

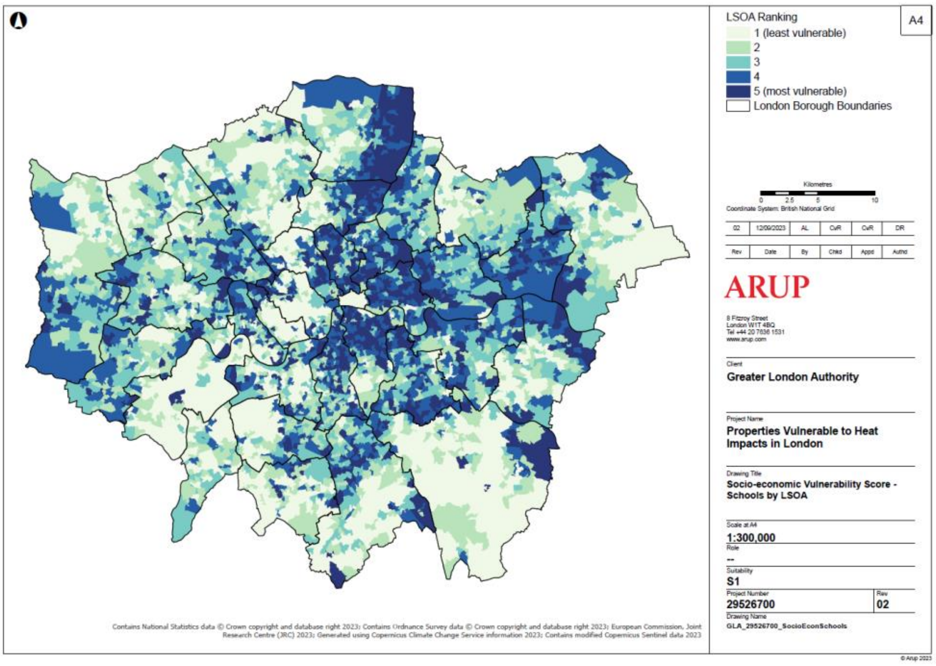


Property Vulnerability Ranking by LSOA (Care Homes)

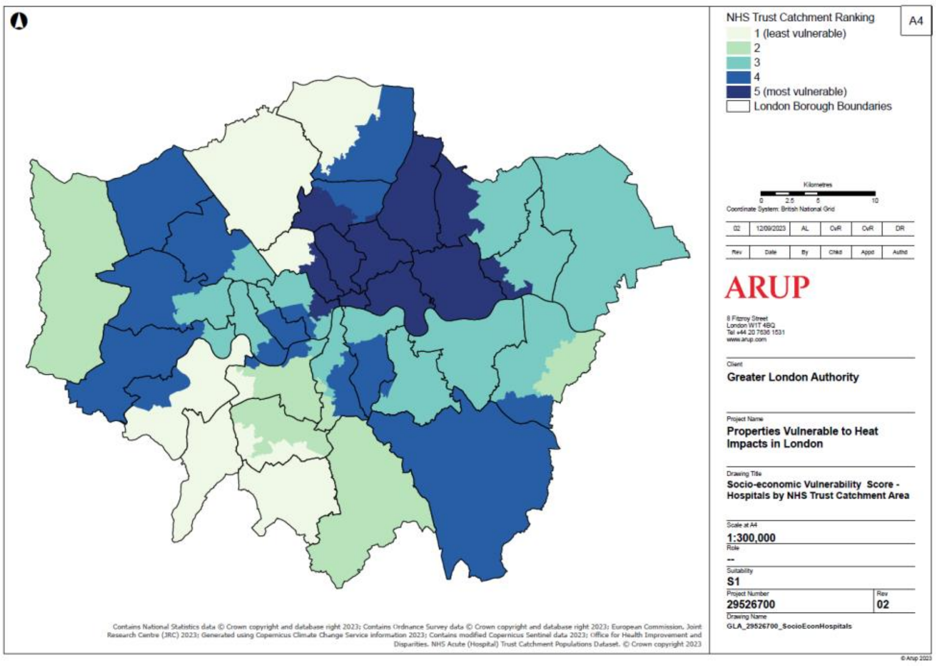


Property Vulnerability Ranking by LSOA (Residential)

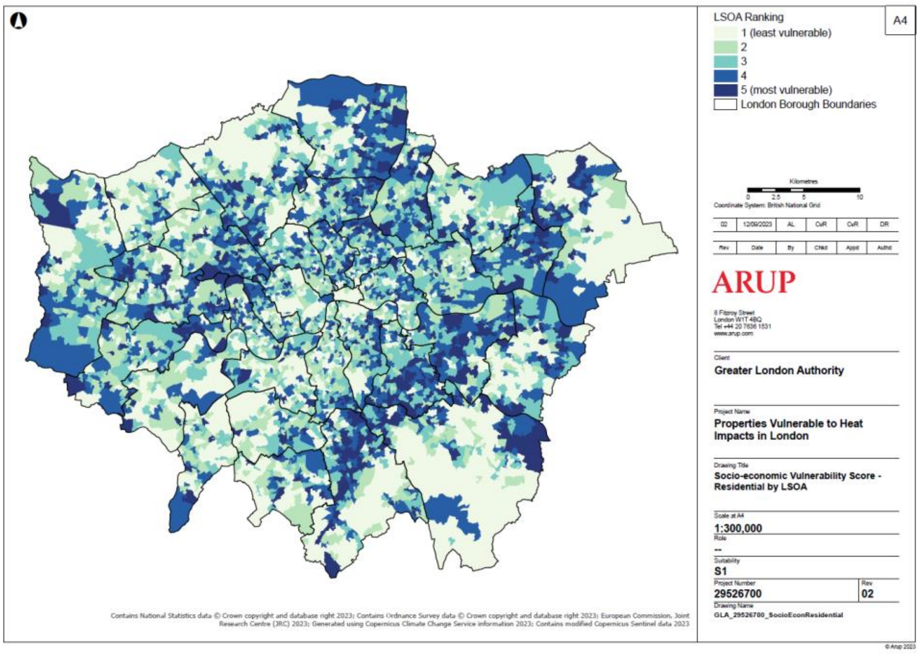
Socioeconomic Vulnerability Maps



Socioeconomic Vulnerability Score - Schools by LSOA

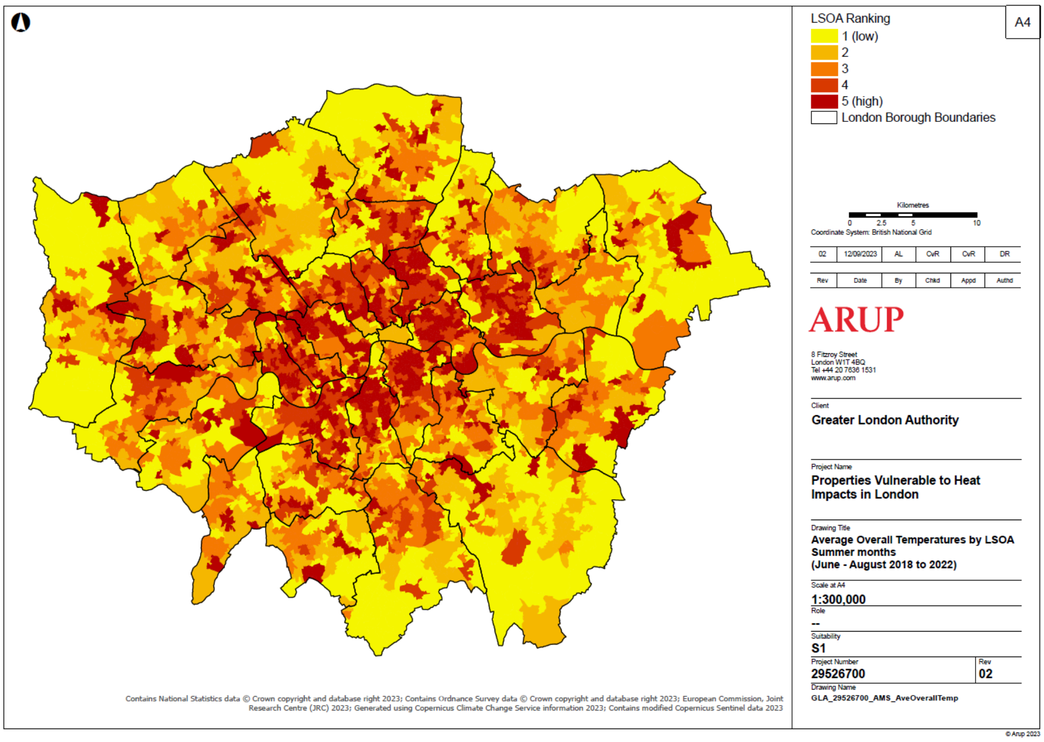


Socioeconomic Vulnerability Score - Hospitals by NHS Trust Catchment Area



Socioeconomic Vulnerability Score - Residential by LSOA

Heat Hazard Map



References

Arup - Commissioned by CCC. (2022). Addressing overheating risk in existing UK homes.

Aubrecht, C. and Özceylan, D. (2013) 'Identification of heat risk patterns in the U.S. National Capital Region by integrating heat stress and related vulnerability', Environment International. Pergamon, 56, pp. 65–77. doi: 10.1016/J.ENVINT.2013.03.005.

Baborska-Narozny, M. and Grudzinska, M. (2017) 'Overheating in a UK High-rise Retrofit Apartment Block -Ranking of Measures Available to Case Study Occupants Based on Modelling', in Energy Procedia, pp. 568–577. doi: 10.1016/j.egypro.2017.03.219.

Barclay, M., Kang, J. and Sharples, S. (2012) 'Combining noise mapping and ventilation performance for non-domestic buildings in an urban area', Building and Environment. Pergamon, 52, pp. 68–76. doi: 10.1016/J.BUILDENV.2011.12.015

Basu, R. and Ostro, B. D. (2008) 'A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California', American Journal of Epidemiology, 168(6), pp. 632–637. doi: 10.1093/AJE/KWN170.

BEIS. (2021). Energy Follow Up Survey: thermal comfort, damp and ventilation Final Report. BEIS.

Bradford, K. et al. (2015) 'A Heat Vulnerability Index and Adaptation Solutions for Pittsburgh, Pennsylvania', Environmental Science and Technology. American Chemical Society, 49(19), pp. 11303–11311. doi: 10.1021/ACS.EST.5B03127.

Buoite Stella, A. et al. (2020) 'Heat risk exacerbation potential for neurology patients during the COVID-19 pandemic and related isolation', International Journal of Biometeorology 2020 65:4. Springer, 65(4), pp. 627–630. doi: 10.1007/S00484-020-02044-2.

Burt, J. Stewart, D. Preston, S. Costley, T. (2015) Monitor of Engagement with the Natural Environment Survey (2009–2012): Difference in Access to the Natural Environment between Social Groups within the Adult English Population. Available online: http://publications.naturalengland.org.uk/publication/4646400

Care Quality Commission. (2023). Care Quality Commission Provider Portal. Retrieved from Care Quality Commission: https://www.cqc.org.uk/search/all?filters%5B%5D=services%3Acare-home&radius=all

CIBSE. (2021). CIBSE Guide A Environmental Design.

Conlon, K. C. et al. (2020) ‘Mapping Human Vulnerability to Extreme Heat: A Critical Assessment of Heat Vulnerability Indices Created Using Principal Components Analysis’, Environmental Health Perspectives. Environmental Health Perspectives, 128(9), pp. 1–14. doi: 10.1289/EHP4030.

Conti, S. et al. (2005) ‘Epidemiologic study of mortality during the Summer 2003 heat wave in Italy’, Environmental research. Environ Res, 98(3), pp. 390–399. doi: 10.1016/J.ENVRES.2004.10.009.

Curriero, F. C. et al. (2002) ‘Temperature and Mortality in 11 Cities of the Eastern United States’, American Journal of Epidemiology. Oxford Academic, 155(1), pp. 80–87. doi: 10.1093/AJE/155.1.80.

Daniel Fosas, D. A.-G. (2018). Mitigation versus adaptation: Does insulating dwellings increase overheating risk? Building and Environment. doi:https://doi.org/10.1016/j.buildenv.2018.07.033

Department of Education (2020) https://explore-education-statistics.service.gov.uk/find-statistics/free-school-meals-autumn-term/2020-21-autumn-term

Ebi, K.L. et al (2021) ‘Hot weather and heat extremes: Health risks’, The Lancet. Volume 398, Issue 10301, pp. 698-708. doi: 10.1016/S0140-6736(21)01208-3

Epidemiology (Cambridge, Mass.). Epidemiology, 16(1), pp. 67–72. doi: 10.1097/01.EDE.0000147114.25957.71.

Estoque, R. C. et al. (2020) ‘Heat health risk assessment in Philippine cities using remotely sensed data and social-ecological indicators’, Nature Communications 2020 11:1. Nature Publishing Group, 11(1), pp. 1–12. doi: 10.1038/s41467-020-15218-8.

Fang, Y. and Gu, K. (2022) ‘Exploring coupling effect between urban heat island effect and PM2.5 concentrations from the perspective of spatial environment’, Environmental Engineering Research. Korean Society of Environmental Engineers, 27(2), pp. 200559–0. doi: 10.4491/EER.2020.559.

Flynn, A., McGreevy, C. and Mulkerrin, E. C. (2005) ‘Why do older patients die in a heatwave?’, QJM: An International Journal of Medicine. Oxford Academic, 98(3), pp. 227–229. doi: 10.1093/QJMED/HCI025

Fouillet, A. et al. (2006) ‘Excess mortality related to the August 2003 heat wave in France’, International Archives of Occupational and Environmental Health, 80(1), pp. 16–24. doi: 10.1007/S00420-006-0089-4.

GLA. (2023). London.gov. Retrieved from Climate Resilient Schools: https://www.london.gov.uk/programmes-strategies/environment-and-climate-change/climate-change/climate-adaptation/climate-resilient-schools

Good Homes Alliance. (2019). OVERHEATING IN NEW HOMES Tool and guidance for identifying and mitigating early-stage overheating risks in new homes.

Hankey, S. and Marshall, J. D. (2017) ‘Urban Form, Air Pollution, and Health’, Current environmental health reports. Springer, 4(4), pp. 491–503. doi: 10.1007/S40572-017-0167-7/TABLES/3

Hatvani-Kovacs, G. and Boland, J. (2015) ‘Retrofitting Precincts for Heatwave Resilience: Challenges and Barriers in Australian Context’, Challenges, 6, pp. 3–25. doi: 10.3390/challe6010003.

HM Government. (2010). The Building Regulations 2010 Overheating: Approved Document O. HM Government.

Hu, K. et al. (2017) ‘Spatially Explicit Mapping of Heat Health Risk Utilizing Environmental and Socioeconomic Data’, Environmental Science and Technology. American Chemical Society, 51(3), pp. 1498–1507. doi: 10.1021/ACS.EST.6B04355.

Hutter, H. et al. (2007) ‘Heatwaves in Vienna: effects on mortality’, Wiener klinische Wochenschrift. Wien Klin Wochenschr, 119(7–8), pp. 223–227. doi: 10.1007/S00508-006-0742-7.

Huynen, M. M. et al. (2001) ‘The impact of heat waves and cold spells on mortality rates in the Dutch population.’, Environmental Health Perspectives. National Institute of Environmental Health Sciences, 109(5), p. 463. doi: 10.1289/EHP.01109463

inequalities in districts of England and Wales, 2001–2011’, Urban Studies. SAGE Publications Ltd, 54(11), pp. 2540–2560. doi: 10.1177/0042098016653725.

Jonathon Taylor, R. M.-R. (2023). Ten questions concerning residential overheating in Central and. Building and Environment. doi:https://doi.org/10.1016/j.buildenv.2023.110154.

Kaiser, R. et al. (2001) ‘Heat-related death and mental illness during the 1999 Cincinnati heat wave’, The American journal of forensic medicine and pathology. Am J Forensic Med Pathol, 22(3), pp. 303– 307. doi: 10.1097/00000433-200109000-00022.

Kim, Y. and Joh, J. (2006) ‘A vulnerability study of the low-income elderly in the context of high temperature and mortality in Seoul, Korea’, Science of the Total Environment. Sci Total Environ, 371(1–3), pp. 82–88. doi: 10.1016/J.SCITOTENV.2006.08.014.

Klein Rosenthal, J., Kinney, P. L. and Metzger, K. B. (2014) ‘Intra-urban vulnerability to heat-related mortality in New York City, 1997–2006’, Health & Place. Pergamon, 30, pp. 45–60. doi: 10.1016/J.HEALTHPLACE.2014.07.014

Knowlton, K. et al. (2009) ‘The 2006 California heat wave: impacts on hospitalizations and emergency department visits’, Environmental health perspectives. Environ Health Perspect, 117(1), pp. 61–67. doi: 10.1289/EHP.11594.

Konkel, L. (2020) ‘Diabetes in Brazil: The Association between Extreme Heat and Hospitalization’, Environmental Health Perspectives. Environmental Health Perspectives, 128(7), pp. 1–2. doi: 10.1289/EHP6853.

Kovats, R. S. and Hajat, S. (2008) ‘Heat stress and public health: a critical review’, Annual review of public health. Annu Rev Public Health, 29, pp. 41–55. doi: 10.1146/ANNUREV.PUBLHEALTH.29.020907.090843.

Kovats, S., Hajat, S. and Wilkinson, P. (2004) ‘Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK’, Occupational and environmental medicine. Occup Environ Med, 61(11), pp. 893–898. doi: 10.1136/OEM.2003.012047.

Layton, J. B. et al. (2020) ‘Heatwaves, medications, and heat-related hospitalization in older Medicare beneficiaries with chronic conditions’, PLOS ONE. Public Library of Science, 15(12), p. e0243665. doi: 10.1371/JOURNAL.PONE.0243665.

Li, H. et al. (2019) ‘Quantifying urban heat island intensity and its physical mechanism using WRF/UCM’, Science of The Total Environment. Elsevier, 650, pp. 3110–3119. doi: 10.1016/J.SCITOTENV.2018.10.025.

Liu, X. et al. (2020) ‘Mapping Urban Heat Vulnerability of Extreme Heat in Hangzhou via Comparing Two Approaches’, Complexity. Hindawi Limited, 2020. doi: 10.1155/2020/9717658.

Lymperopoulou, K. and Finney, N. (2017) ‘Socio-spatial factors associated with ethnic.

Macnee, R. G. D. and Tokai, A. (2016) ‘Heat wave vulnerability and exposure mapping for Osaka City, Japan’, Environment Systems and Decisions. Springer New York LLC, 36(4), pp. 368–376. doi: 10.1007/S10669-016-9607-4

Madrigano, J. et al. (2015) ‘A Case-Only Study of Vulnerability to Heat Wave–Related Mortality in New York City (2000–2011)’, Environmental Health Perspectives. National Institute of Environmental Health Sciences, 123(7), p. 672. doi: 10.1289/EHP.1408178

Malmquist, A. et al. (2021) ‘Vulnerability and adaptation to heat waves in preschools: Experiences, impacts and responses by unit heads, educators and parents’, Climate Risk Management. Elsevier, 31, p. 100271. doi: 10.1016/J.CRM.2020.100271.

Mavrogianni, A. et al. (2017) ‘Inhabitant actions and summer overheating risk in London dwellings’, Building Research and Information, 45(1–2), pp. 119–142. doi: 10.1080/09613218.2016.1208431.

McGeehin, M. A. and Mirabelli, M. (2001) ‘The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States.’, Environmental Health Perspectives. National Institute of Environmental Health Sciences, 109, p. 185. doi: 10.1289/EHP.109- 1240665.

Medina-Ramón, M. et al. (2006) ‘Extreme Temperatures and Mortality: Assessing Effect Modification by Personal Characteristics and Specific Cause of Death in a Multi-City Case-Only Analysis’, Environmental Health Perspectives. National Institute of Environmental Health Sciences, 114(9), p. 1331. doi: 10.1289/EHP.9074.

Ministry of Housing, Communities & Local Government. (2019). The English Indices of Deprivation 2019. Retrieved from Gov.uk: https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019

Naughton, M. et al. (2002) ‘Heat-related mortality during a 1999 heat wave in Chicago’, American Journal of Preventive Medicine. Am J Prev Med, 22(4), pp. 221–227. doi: 10.1016/S0749- 3797(02)00421-X

NHBC Foundation. (2012). Understanding overheating – where to start An introduction for house builders and designers. Milton Keynes: NHBC Foundation.

Poumadère, M. et al. (2005) ‘The 2003 Heat Wave in France: Dangerous Climate Change Here and Now’, Risk Analysis. John Wiley & Sons, Ltd, 25(6), pp. 1483–1494. doi: 10.1111/J.1539- 6924.2005.00694.X.

Reid, C. et al. (2009) ‘Mapping community determinants of heat vulnerability’, Environmental Health Perspectives. Environ Health Perspect, 117(11), pp. 1730–1736. doi: 10.1289/EHP.0900683.

Rinner, C. et al. (2010) ‘The role of maps in neighbourhood-level heat vulnerability assessment for the city of Toronto’, Cartography and Geographic Information Science, 37(1), pp. 31–44. doi: 10.1559/152304010790588089.

Schwartz, J. (2005a) ‘Who is sensitive to extremes of temperature? A case-only analysis’,

Semenza, J. et al. (1999) ‘Excess hospital admissions during the July 1995 heat wave in Chicago’, American Journal of Preventive Medicine. Am J Prev Med, 16(4), pp. 269–277. doi: 10.1016/S0749- 3797(99)00025-2.

Semenza, Jan;. (1999). Excess Hospital Admissions During the July 1995 Heat Wave in Chicago. American Journal of Preventive, https://d1wqtxts1xzle7.cloudfront.net/50700727/s0749-3797_2899_2900025-220161203-9921-15hj6mi-libre.pdf?1480817500=&response-content-disposition=inline%3B+filename%3DExcess_hospital_admissions_during_the_Ju.pdf&Expires=1691487343&Signature=a892hGhv2d5zIa2.

Song, J. et al. (2020) 'Fine-scale mapping of an evidence-based heat health risk index for high density cities: Hong Kong as a case study', Science of The Total Environment. Elsevier, 718, p. 137226. doi: 10.1016/J.SCITOTENV.2020.137226

Stafoggia, M. et al. (2008) 'Factors affecting in-hospital heat-related mortality: a multi-city casecrossover analysis', Journal of Epidemiology and Community Health. J Epidemiol Community Health, 62(3), pp. 209–215. doi: 10.1136/JECH.2007.060715.

SUEWS. (2023). SUEWS: Surface Urban Energy and Water Balance Scheme. (SUEWS Development Team led by Prof Sue Grimmond) Retrieved from SUEWS: Surface Urban Energy and Water Balance Scheme: https://suews.readthedocs.io/en/latest/

Tan, J. (2008) 'Commentary: People's vulnerability to heat wave', International Journal of Epidemiology. Oxford Academic, 37(2), pp. 318–320. doi: 10.1093/IJE/DYN023.

Taylor, J. (2023). Ten questions concerning residential overheating in Central and Northern Europe. Building and Environment.

Thompson, R. et al. (2022) 'Heatwave mortality in Summer 2020 in England: an observational study', Int J Environ Res Public Health, 18;19(10):6123. doi: 10.3390/ijerph19106123

Two Spatial Assessment Frameworks Approaches', International Journal of Environmental Research and Public Health 2020, Vol. 17, Page 6584. Multidisciplinary Digital Publishing Institute, 17(18), p. 6584. doi: 10.3390/IJERPH17186584.

Uejio, C. et al. (2011) 'Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability', Health & Place. Health Place, 17(2), pp. 498–507. doi: 10.1016/J.HEALTHPLACE.2010.12.005.

Whitman, S. et al. (1997) 'Mortality in Chicago attributed to the July 1995 heat wave', American Journal of Public Health. Am J Public Health, 87(9), pp. 1515–1518. doi: 10.2105/AJPH.87.9.1515.

Wolf, T. and McGregor, G. (2013) 'The development of a heat wave vulnerability index for London, United Kingdom', Weather and Climate Extremes. Elsevier, 1, pp. 59–68. doi: 10.1016/J.WACE.2013.07.004.

Wong, M. S. et al. (2016) 'Spatially Analyzing the Inequity of the Hong Kong Urban Heat Island by Socio-Demographic Characteristics', International Journal of Environmental Research and Public Health. Int J Environ Res Public Health, 13(3). doi: 10.3390/IJERPH13030317.

WSP Supported by GLA. (2020). HEAT RISK IN LONDON – DETAILED METHODOLOGY DOCUMENT.

Xu, Z. et al. (2017) ‘Heatwave and infants’ hospital admissions under different heatwave definitions’, Environmental Pollution. Elsevier, 229, pp. 525–530. doi: 10.1016/J.ENVPOL.2017.06.030.

Yin, P. et al. (2018) ‘The added effects of heatwaves on cause-specific mortality: A nationwide analysis in 272 Chinese cities’, Environment International. Pergamon, 121, pp. 898–905. doi: 10.1016/J.ENVINT.2018.10.016.

Zheng, M. et al. (2020) ‘Mapping Heat-Related Risks in Northern Jiangxi Province of China Based on Two Spatial Assessment Frameworks Approaches’, International Journal of Environmental Research and Public Health 2020, Vol. 17, Page 6584. Multidisciplinary Digital Publishing Institute, 17(18), p. 6584. doi: 10.3390/IJERPH17186584.

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