Adaptation and Resilience in the Context of Change (ARCC) network
Early Career Researcher knowledge co-production activities

URBAN HEAT VULNERABILITY MAPPING TEAM PLACEMENT: Hounslow London Borough Council

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Executive Summary

With the frequency and severity of hot weather and heatwaves projected to increase in the UK due to climate change, there is an increased need to research heat exposure risk and mitigation, as well as promote collaborations between researchers and policy groups that enable research outcomes to be operationalised. Heat exposure risk may be modified by the type of housing that an individual inhabits – and its tendency to overheat during periods of hot weather - and in urban environments the Urban Heat Island (UHI), which acts to increase outdoor temperatures in urban areas relative to surrounding rural areas. The mortality or morbidity risk to individuals from heat may also vary, with the elderly more vulnerable to negative health consequences during hot weather than the young. Research into potential health outcomes due to housing, UHI, and age-related heat vulnerability has been undertaken at UCL as part of the LUCID and HPRU projects (the so-called ‘triple jeopardy’ maps) and at King’s College London, however, there has been little work to date to convert these research outcomes into policy and action.

This report describes an Adaptation and Resilience in the Context of Change (ARCC) network funded project carried out by the UCL Institute for Environmental Design and Engineering (UCL IEDE). The project sought to disseminate overheating research outcomes to external organisations and policymakers, and to cooperate with the London Borough of Hounslow to provide modelled overheating risk data at building and address level that could be integrated into their existing emergency management systems. Using the latest UCL dwelling overheating model, indoor temperature risks at different outdoor temperatures were estimated for individual addresses in Hounslow. This allowed for the production of a number of visualisations that show the 2D and 3D spatial variation in dwelling overheating risk and UHI temperatures during hot weather. Animations demonstrating the temporal and spatial variation in overheating risk due to climate, housing and UHI variations; and maps demonstrating the spatial variation of populations vulnerable to heat, including the location of nursing homes within the UHI were produced. The modelled indoor temperature risk data was provided to Hounslow using two different building stock models as a basis, including:

1) a dataset containing estimates of relative overheating risk which could be linked directly to buildings based on an Ordnance Survey Unique Property Reference Number, using the Verisk Build Class dataset as a basis, or
2) a more refined estimate of indoor temperatures at individual address level, which would be possible to link with existing Hounslow datasets based on the physical address using a semi-automated matching procedure, derived using Hounslow Energy Performance Certificate (EPC) data.

Finally, a prototype tool was developed and demonstrated that used real time historical, current, and forecast weather data to estimate individual dwelling overheating risks and heat related mortality in Hounslow and across London.

This project provided a unique opportunity to liaise with the public and a London borough to help educate and operationalise research outputs. A number of key lessons were learnt during the project, including ensuring that all key stakeholders are present from the beginning of the project, the need for flexibility in order to work within the time and personnel resource constraints experienced by the borough, an understanding of the datasets and emergency planning tools held within the council, and how UCL data might be best prepared to integrate into these systems. Further work will develop the dwelling overheating model with a focus on producing data that may be integrated into existing borough systems.

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1. Introduction

1.1 Heat risk in London

The frequency of heatwave events is predicted to increase in temperate regions due to climate change, increasing the risk of heat related mortality in climates where cold related mortality has typically been the largest concern (Murphy et al., 2010). Heatwaves such as that in 2003, which led to approximately 2,000 excess deaths in England and Wales (Johnson et al., 2005) and 70,000 across Europe (Robine et al., 2008), are predicted to become typical of summer by the 2040s (CCC ASC, 2014). Studies into heat related mortality in Europe have indicated that the most vulnerable individuals are the elderly, those with preexisting health issues, the socially isolated, those living in top floor flats and in dwellings with a lack of thermal insulation, and those living in care homes (Hajat et al., 2007). Studies in many cities worldwide have found evidence supporting the role of Urban Heat Islands (UHI) on increased mortality risk (Fernandez Milan & Creutzig, 2015; Santamouris & Kolokotsa, 2015). In addition, studies of indoor temperatures in dwellings show a range of indoor overheating risks, supporting the epidemiological findings that dwelling characteristics and occupant behaviour play a role in the risk of mortality (Porritt et al., 2012; Mavrogianni et al., 2014). A number of empirical studies indicate that UK dwelling types have varying overheating risks, with top floor flats in multi-dwelling buildings particularly prone to high indoor temperatures (Firth et al., 2007; Beizaee et al., 2013; Lomas & Kane, 2013; Pathan et al., 2017). Built form, the level of retrofit of the building fabric, orientation, and the availability and performance of ventilation and other building characteristics may influence the overheating risk of buildings, while occupant behaviour and climate region can influence the relative overheating risk within building types.

Current policies encouraging energy efficient retrofit of existing dwellings and new, more stringent new-build energy efficiency requirements may result in an increased relative overheating risk, if suitable overheating adaptations are not implemented (Dengel & Swainson, 2012); consequently, future risks may be due to a combination of a warmer climate with more frequent heat waves and a housing stock adapted to conserve energy, but with a greater risk of overheating. Given that the 2005 UK Time Use Survey estimates that those over 65 years of age spend around 82% of their time in their own homes, compared to 70% for the whole population (Lader et al., 2006), buildings are likely to act as important modifiers of exposure to high temperatures for vulnerable populations. *'Policy 5.9: Overheating and Cooling'* in the London Plan (MOL, 2016) sets out how the Mayor of London seeks to reduce the impact of the UHI effect in London and encourage the design of places and spaces to avoid overheating and excessive heat generation, and to reduce overheating due to the impacts of climate change and the UHI effect on an area wide basis. There is, however, little research on estimating the heat vulnerability of populations based on a combination of population and environmental variables in the UK and London, in particular.

1.2 Introduction to London triple heat jeopardy work

Researchers at King's College London used Principal Component Analysis (PCA) to create a Heat Vulnerability Index (HVI) that accounted for UHI, living in a flat, population density, age, illness, socioeconomic status, social isolation, and ethnic minority status, identifying areas of high heat vulnerability in Central and East London (Wolf & McGregor, 2013; Wolf et al., 2013). Our research team at University College London (UCL) examined the spatial distribution of mortality risk from high temperatures in London based on weather data, a modelled UHI, and building physics models simulating indoor temperatures for 2.65 million dwellings in a building stock database (Taylor et al., 2015). This work is, therefore, differentiated from previous research by combining monitored weather data, UHI temperatures and indoor temperatures for individual buildings for a specific time period and weather conditions. The population attributable burden of heat death due to the three factors (age, UHI, and dwellings) was calculated at the ward level, and the results mapped using Geographical Information Systems (GIS). This work built on previous research conducted as part of the EPSRC funded project *'The Development of a Local Urban Climate Model and its Application to the Intelligent Design of Cities'* (LUCID, EP/E016375/1), from which the UHI and the basis of the building physics models describing indoor temperatures were obtained.

As part of the LUCID project's *'triple heat jeopardy'* investigation and the ongoing National Institute for Health Research (NIHR) funded *Health Protection Research Unit* (HPRU) in *Environmental Change and Health, Theme 2: Sustainable Cities*, research on the combined effects of housing, UHI and population age on heat related mortality has been performed. Research has initially focused on London and the West Midlands, and is currently being expanded to other regions and future climate and housing scenarios on an England wide level. The HPRU work is capable of estimating indoor temperature risks at different outdoor temperatures (including UHI temperatures) at individual dwelling level using a range of different housing stock datasets, and therefore the potential to integrate the model with alternative housing stock and UHI models is high.

Research outputs have been mainly published in academic journals, with others to follow, and as such are i) generally inaccessible without an academic subscription to the journal, and ii) published maps are static, and cannot be used as a tool to help mitigate heat related mortality. Additional work is required in order to translate the project outputs into a format that would be useful to policymakers and relevant stakeholders at the Local Authority level.

1.3 Aim and objectives of the work

Taking the above into consideration, we identified an opportunity for knowledge exchange activities that will enable local councils and government to evaluate local health risks and identify the dwellings and locations in which heat risk may be elevated. By way of a formal academic placement at the Hounslow London Borough Council, this project aimed to accelerate impact and facilitate external engagement between academics, policymakers, and local community stakeholders regarding the future resilience of the London population and urban built environment.

Building on the Government's recently published Climate Change Risk Assessment (CCRA) (CCC, 2017), the aim outlined above was achieved through the following objectives:

1. to exchange knowledge and expertise with regard to the heat vulnerability of the population and housing stock of the Borough using outputs from the HPRU and previous research projects,
2. to work closely with the seasonal health and housing teams of the Borough to evaluate the potential of the three underlying datasets of the UCL's triple heat jeopardy framework to be integrated into their systems as individual parts or as a whole,
3. to tailor existing UCL datasets to the needs of the Borough, and
4. to build the foundations for a future collaboration with the Borough to identify pathways for climate change adaptation, with a focus on heatwave vulnerable neighbourhoods, dwellings and individuals.

1.4 Team profiles

The Adaptation and Resilience in the Context of Change (ARCC) network supported two Early Career Researchers (ECRs), members of the UCL IEDE team, to work alongside the seasonal health and housing teams of the Hounslow London Borough Council to identify pathways for climate change adaptation, with a focus on heatwave vulnerable neighbourhoods, dwellings and individuals. The ECRs worked in close collaboration with the relevant Borough teams, in particular Emergency Planning, Public Health, Adult Social Care, Housing, as well as other stakeholders at the Greater London Authority (GLA) and Public Health England (PHE). Students from the Worcester Polytechnic Institute in the USA were hosted by the Borough towards the end of the project as part of an Interactive Qualifying Project.

The 1.5 month of work included the full time allocation of the two ECRs to the project, as well as time for meetings with the Borough to ensure that the tool met their requirements. The team placement also provided an active learning case study for the ARCC IAA project *'Improving climate resilience in the urban environment: Enhancing the uptake and use of building scale to city scale decision support models by policymakers and industry'.*

This opportunity was planned for Dr Jonathon Taylor and Dr Clive Shrubsole, with inputs from Dr Anna Mavrogianni (all based at UCL IEDE). All three have:

- experience working with PHE, the GLA, and industry, and publicly disseminating research outcomes related to overheating, flooding, and indoor air quality, and
- familiarity with industry and policy concerns and sensitivities based on collective experience of working with policymakers, industrial partners and third sector organisations on the topic of overheating.

Dr Jonathon Taylor is a Senior Research Associate in Indoor Environment Modelling. His doctoral research at UCL, completed in 2012, examined the long term damp and microbial risk in London following flooding by combining microbiological modelling from lab based experimentation, hygrothermal building simulation, and GIS mapping. He was involved in the NERC funded *'Air Pollution and Weather related Health Impacts'* (AWESOME) project, developing a spatially varying model of indoor overheating and pollution risk for dwellings in the UK for use as modifiers in epidemiological analysis. His research interests include combining spatial data, building simulation tools, and biological systems to understand the health of urban populations, and using building physics tools to examine the role of buildings on occupant health, including exposure to heat and cold, indoor air pollution, damp, and disease transmission. He is currently involved in the NIHR HPRU *Environmental Change and Health, Theme 2: Sustainable Cities*, developing models to predict current and future overheating and indoor air pollution risks for the English housing stock under a range of dwelling retrofit, adaptation, and climate scenarios. He is also involved in the Wellcome Trust funded *'Sustainable Healthy Urban Environments'* (SHUE) project, developing a database of globally distributed world cities with the objective of analysing the interrelationships between city characteristics, energy and resource use, and health related behaviours and exposures.

Dr Clive Shrubsole is a Senior Research Associate in Healthy Homes, currently investigating the total performance of low carbon buildings in China and the UK through indoor airborne pollutant monitoring. His PhD thesis was entitled *'Changes in Exposure to $PM_{2.5}$ in English Dwellings: An Unintended Consequence of Energy Efficient Refurbishment of the Housing Stock'.* He is interested in the consequences of and adaptation to climate change within the built environment and specialises in the formation, movement and impact of airborne pollutants particularly as this affects the indoor environment and health. Utilising complex microenvironmental modelling approaches to investigate changes in the indoor environment in the context of policy objectives, he explores the adaptation of the built environment to a warming climate using energy efficient retrofit technologies and ventilation strategies. He also has a wide range of industrial and professional management expertise gained within the construction sector primarily involving project management and the application of specialist material science and technologies. He was a member of the multiple awarding winning Carbon8 Systems Ltd., developing zero carbon building materials from various waste streams using carbon dioxide sequestration technology.

Dr Anna Mavrogianni is a Senior Lecturer in Sustainable Building and Urban Design. She is an expert in indoor environmental quality, building energy retrofit and climate change adaptation of the built environment sector, with a focus on overheating and heatwave vulnerability at the building and urban scale. Anna trained as an architect engineer specialising in building physics and environmental design at the School of Architecture at the National Technical University of Athens and the Bartlett School of Graduate Studies, UCL and has several years of experience in architectural design and environmental consultancy. Within the context of her PhD, she developed a methodological framework that quantifies the effect of London's urban heat island on domestic space heating demand, indoor overheating and heat related health risk, as part of the EPSRC funded LUCID project. The outcomes of this work informed the GLA's *Climate Change Adaptation Strategy* and the UK Government's CCRA report. Anna was the academic Principal Investigator in the *'Seasonal Health, Ageing and Resilience in Urban Populations and Environments'* (SHARPER) project funded by NERC and the Arup Global Research Challenge, and is currently a Co-Investigator in the NIHR funded HPRU in *Environmental Change and Health, Theme 2: Sustainable Cities* and the ESPRC funded *'Airport Capacity Consequences Leveraging Aviation Integrated Modelling'* (ACCLAIM) project. She often works with policymakers and other stakeholders on ways to improve the climate resilience of urban environments. She has published more than 60 peer reviewed articles to date and has contributed to several book chapters, reports and evaluations. She was a contributing author in the *'Investigation into Overheating in Buildings'* report for DCLG, the *'Defining Overheating in Buildings'* detailed evidence review for the Zero Carbon Hub and the Government's 2017 CCRA report.

1.5 Project progression

The project was carried out from September 2016 to June 2017, with work undertaken by UCL according to the availability and feedback from Hounslow staff and support from students from the Worcester Polytechnic Institute, who were undertaking a summer placement at Hounslow Council. Meetings and the timeline of the project can be seen in Figure 1.

Figure 1. Project timeline and progression.

2. Deliverables

2.1 Housing overheating model

The building physics model used in the Triple Jeopardy publication was based on a series of EnergyPlus models of building variants broadly representative of the London building stock, with hourly indoor temperatures used to calculate the average indoor temperature when outdoor temperatures exceeded the heat mortality threshold for London. This model has been since been improved (Symonds et al., 2016), and now uses a metamodeling approach based on a large number of EnergyPlus simulations with input parameters randomly selected from ranges of values representative of the English housing stock. This new model enables the rapid calculation of indoor temperature exposures at different outdoor temperatures under a range of different energy efficiency of overheating adaptation scenarios.

2.2 Building and address level data for Hounslow

Following meetings with PHE and representatives from Hounslow, it was determined that the strengths of the triple jeopardy dataset were the temperature exposure estimates for dwellings and the UHI, whereas the Council held more precise age and vulnerability data than the 2011 Census data used in the triple jeopardy calculations. As such, it was arranged to provide individual dwelling level temperature exposure estimates for the Borough in a manner which could be integrated into the Council's existing GIS systems. This could then be used alongside Council held population data to predict locations where heat related mortality risk may be greatest.

The Geoinformation Group / Verisk Build Class dataset of housing age and types used in the triple jeopardy analysis is linked to the Ordnance Survey (OS) AddressPoint Plus dataset, which contains Unique Property Reference Numbers (UPRN) for each address. Hounslow also licenses OS datasets, making the UPRN a convenient link between the two datasets. The updated version of the overheating model was run for the 86,700 dwellings in Hounslow in the Build Class dataset. The model produced estimates of two-day rolling mean maximum *indoor* temperatures for UPRN linked dwellings within different bins of two-day rolling mean maximum *outdoor* temperature (< 18 ^{o}C, 18-20 ^{o}C, 20-22 ^{o}C, 22-24 ^{o}C, 24-26 ^{o}C, 26-28 ^{o}C, > 28 ^{o}C). These estimates were then generalised to risk quintiles (bottom 20%: very low, 20-40%: low, 40-60%: average, 60-80%: high, 80-100%: very high) using the Borough wide distribution of indoor temperatures within each outdoor temperature bin; this was done to prevent any back-engineering of licensed Build Class dwelling age and type data based on specific building temperature values. As the OS and Build Class datasets do not have any information on the level of flats in multiple occupancy dwellings, an estimate was provided for each flat at bottom, middle, and top floor levels (referred to as building level).

In addition to the Build Class dataset, the recent release of Energy Performance Certificate (EPC) data provides opportunities to model dwelling overheating risk with greater dwelling fabric and dimensional data, such as U-values, floor area, ceiling height, and floor level of flats in multiple occupancy dwellings. The EPC data lacks a UPRN that may be used to link the data to an existing spatial database within the Hounslow systems, but does contains a complete address which may enable semi-automated linking based on text strings as well as postcode data.

To be able to run the overheating model on the EPC dataset, the individual buildings were parameterised by converting EPC descriptors of building geometry, fabric U-values, floor area, and ceiling height into input parameters that can be used by the overheating model. Dwelling permeability was calculated based on available EPC data using the UK Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP) (BRE, 2009). The model was then used to estimate overheating risk at different outdoor temperature bins for the 49,200 individual addresses with available data, accounting for the level of the dwelling in multiple-occupancy buildings (address level). This data was also provided to Hounslow as a prototype of the latest modelling capabilities with specific indoor temperature estimates for each dwelling, as the EPC data is openly available. Further work has been discussed, including providing similar data to Lambeth Council.

2.3 Participation in meetings and guidance for students

Students from the Worcester Polytechnic Institute (USA), were available to support Hounslow Borough as part of an engagement project. While not identified originally in the programme, this provided Hounslow with the additional capability to review the various models datasets held in-house at Hounslow. UCL participated in and facilitated several meetings with the students, Hounslow, and PHE over the course of the students' stay in London. UCL provided guidance on the relevant background literature for them to read, data including the estimated indoor temperatures from the EPCs and Build Class datasets, and UHI data for Hounslow. Regular meetings were held between UCL staff and the students to give them the background knowledge to use the data appropriately. UCL staff also read and commented on the students' final report. The flexibility to be able to coordinate and provide feedback and information to these students during their brief stay in London meant that the project was able to successfully provide data in suitable formats to Hounslow council.

2.4 Visualisations for Hounslow and Barking

A number of visualisations were created to demonstrate the overheating exposure and the data that has been developed over past research projects. A series of maps were generated at the beginning of the project to demonstrate to Hounslow the type of data available from our research. These included a map of the individual components of the London triple jeopardy work for Hounslow, including UHI (Figure 2) and population age as a proxy for vulnerability (Figure 3).

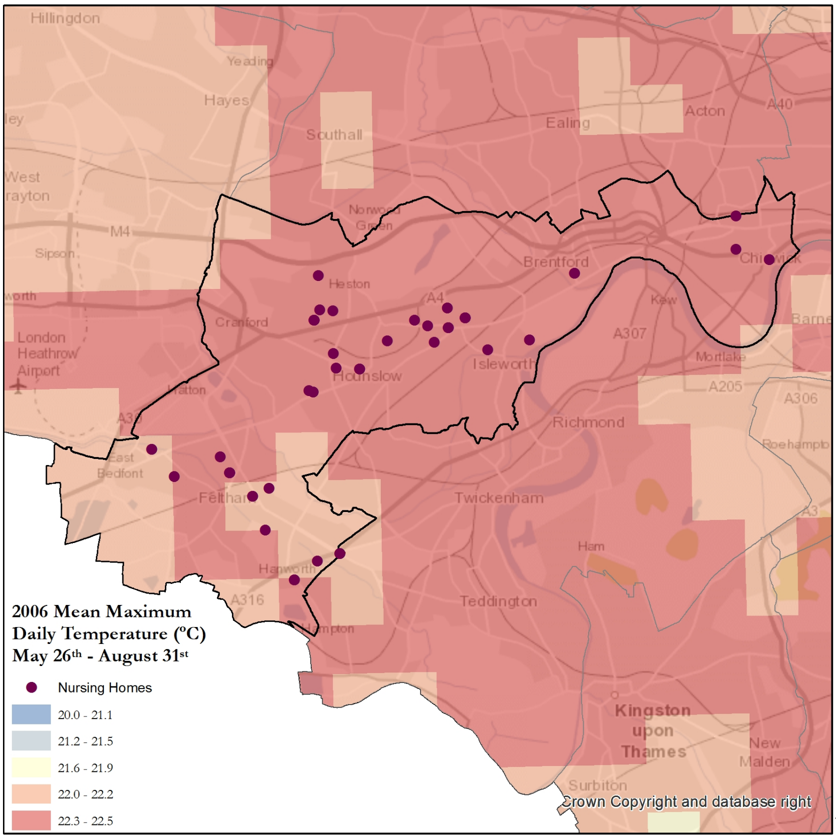

Figure 2. The LUCID modelled UHI mean maximum daily temperature for Hounslow Borough. The location of nursing homes is overlaid on top of the UHI data.

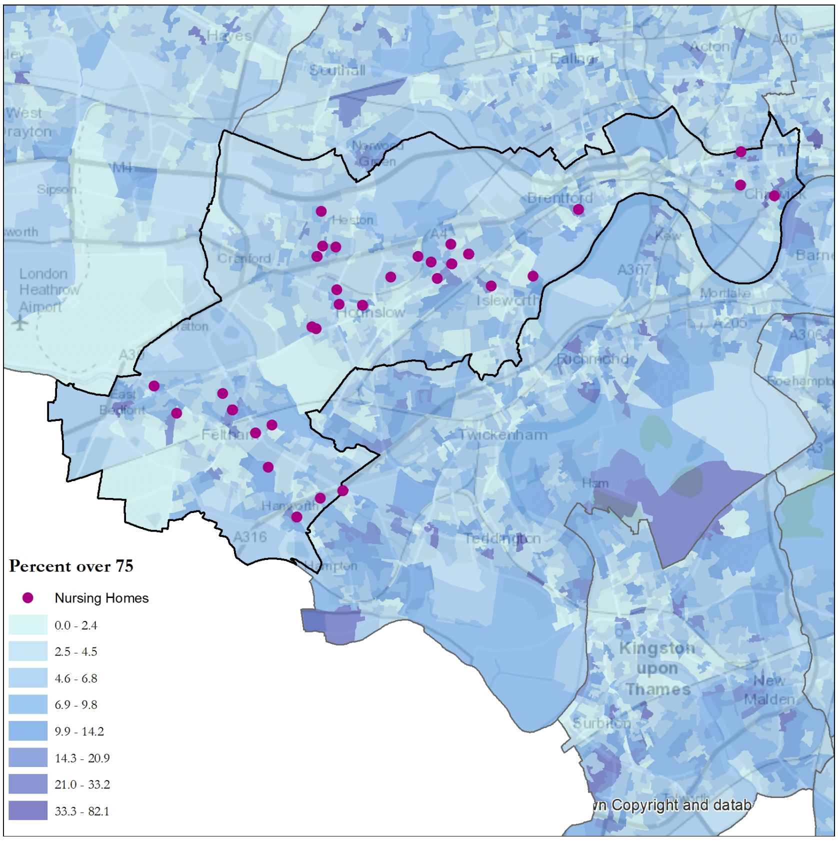

Figure 3. 2011 Census population age data showing Census Output areas by the percent of resident population over the age of 75, as a proxy for heat vulnerability. The location of nursing homes is overlaid on top of the population data.

In addition, dwelling overheating risk was mapped for selected areas in Hounslow in 3D to show the importance of flat level on overheating risk. To do this, the overheating model was used to estimate indoor temperatures for individual dwellings in the Build Class dataset at different outdoor temperatures, and the results uploaded to ArcGIS. Building height data was obtained from the OS, and the building polygons extruded to their specified height. Bottom, middle, and top floors were visualised separately based on assumptions about floor height in each dwelling. Results were mapped at static outdoor temperatures (Figure 4). The UHI temperatures were then used to estimate indoor temperatures for each dwelling under different modelled scenarios to produce a series of animations of indoor temperatures during the 2006 heatwave.

Similar maps and animations were developed using the same methodology for Barking as part of the Barking and Dagenham Healthy Towns event. The 2D maps of urban heat island, building overheating risk, and age were exported from ArcGIS in *.kml format and used to develop an interactive Google Map that allowed users to zoom into areas and overlay the three different elements of the triple jeopardy risk map (Figure 5). 3D maps were generated as per those in Hounslow (Figure 6), as well as fly-through animations of the Borough under hot weather scenarios.

During this process, the underlying data UHI data, building overheating data, and heat related mortality risk estimates were prepared and made publicly available through the London Datastore, at the request of the GLA.

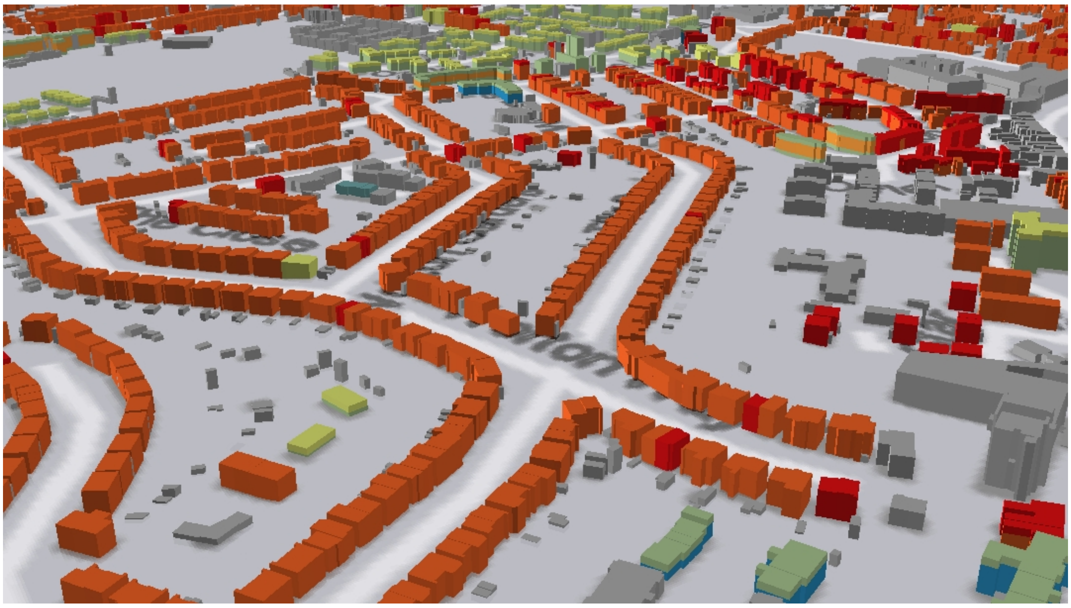

Figure 4. A 3D visualisation of an area of Hounslow, showing the overheating risk of dwellings around Worton Way, Hounslow, at 28°C. Blue dwellings represent the coolest, while red are the hottest.

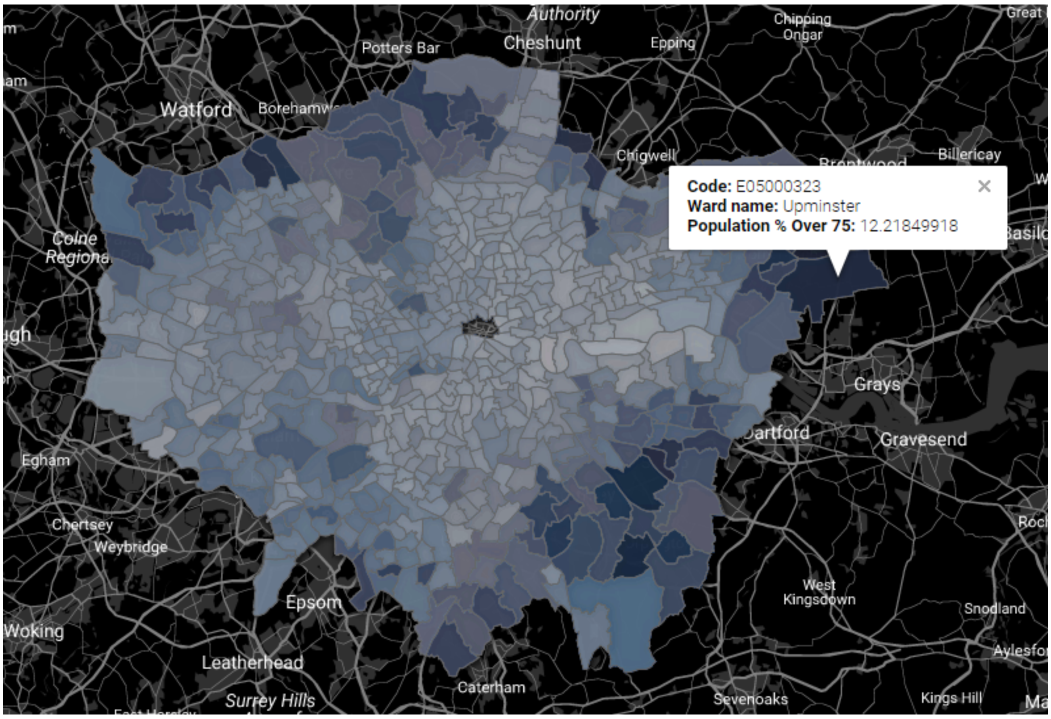

Figure 5. A custom, interactive Google Map with ward percent populations over the age of 75, derived from 2011 Census data.

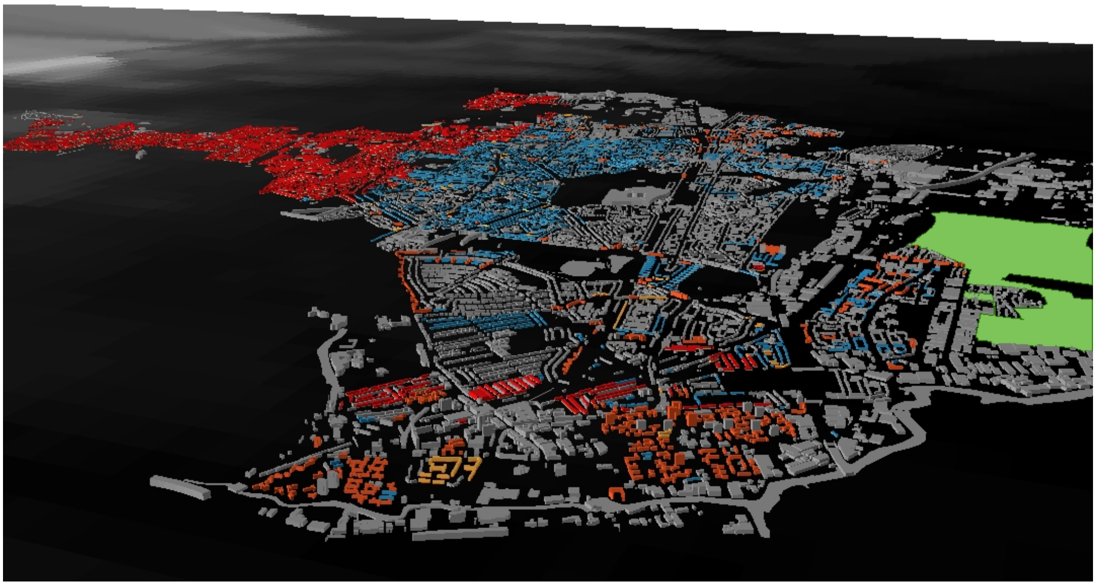

Figure 6. 3D visualisation of dwelling overheating risk for the Borough of Barking. Grey buildings are non domestic, while dwellings are coloured from low overheating risk (blue) to high overheating risk (red).

2.5 Prototype tool for real time heat mortality calculations

In line with the originally submitted proposal, a prototype tool was developed to enable heat risk to be calculated and visualised across the Borough. This tool sought to enable the quantification of heat related risk for individuals, and options for mitigating this risk will be developed based on the existing triple jeopardy heat mapping work carried out as part of the LUCID and HPRU projects and in collaboration with the GLA (Taylor et al. 2015).

The tool was designed as an overheating risk dashboard. Based on Google Apps Script, the tool downloaded hourly monitored outdoor temperatures from the previous four days and forecast hourly temperatures for the following four days from the Met Office Data Point service using an Application Programming Interface (API). From these temperatures, two-day rolling mean maximum temperatures for each day were calculated, and a heat warning presented if the conditions met the criteria.

Using the downloaded temperature data, a daily and forecast estimate of heat related mortality was then provided for London and a bar chart visualised the risk across the different Boroughs. The background of the dashboard changed colours if the risk of heat related mortality was high. A screenshot of this component of the tool can be seen in Figure 7, taken during a period of hot weather in September 2016.

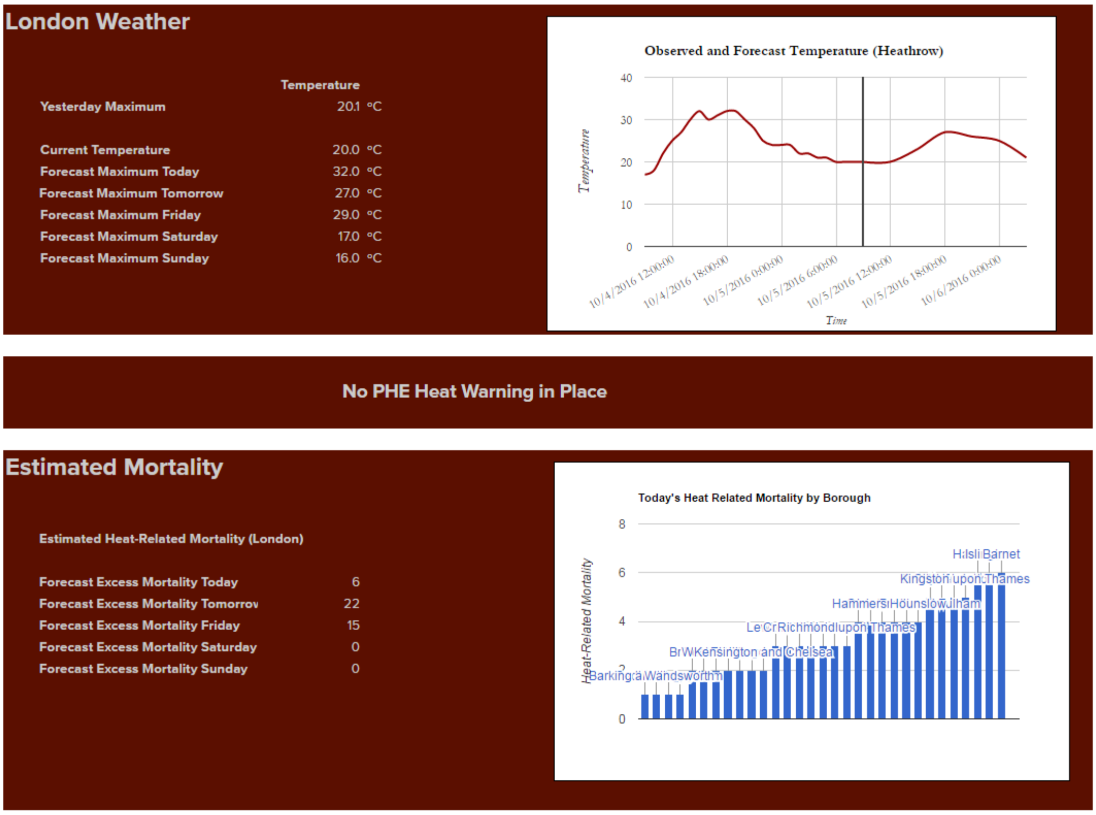

Figure 7. A screenshot of the heat mortality dashboard, taken during a period of hot weather. The values in the bar chart are holding values.

The dashboard also includes the possibility to estimate indoor temperature risk in dwelling variants given the current outdoor conditions. Using a drop-down menu, users may select a building age and type combination, and it will give an estimate of the current indoor temperature risk. Users may also select a ward (currently within Hounslow only), and the tool will give an estimate of the UHI temperature increment in the ward relative to the rest of London. Finally, the dashboard included the interactive Google maps of the triple jeopardy data, showing the UHI, locations of overheating buildings, and Census age data.

Concerns were raised by PHE regarding the tool after screenshots of the prototype were presented at an HPRU meeting early in its development. These concerns related to the potential for misinterpretation of the mortality data calculated, and the potential for the tool to inadvertently misdirect health protective actions during hot weather periods due to a lack of understanding of the limitations of the underlying modelling assumptions. Additionally, there was lack of clarity about how the tool might be adapted to fit within the current systems of Hounslow Council. As such, the tool has been left as a prototype, and serves as an example of the possibilities that exist to use real time and forecast weather conditions to predict areas of heat health risk across an urban area. Further work is required to transform this to a practical tool that can be used by the Borough. For example, ideally excess risks should be presented with uncertainty bounds.

3. Discussion

3.1 Obstacles encountered in the project

The project served as a valuable collaborative experience, and provides a good basis for ongoing cooperation between academics at UCL and public bodies to operationalise research outputs. In developing the collaborative relationship, a series of obstacles had to be overcome.

1) Due to work pressures, there was a lack of resources in terms of Borough staff able to meet and discuss how data and derived tools might be best provided to them. Prior to the students from Worcester Polytechnic arriving in London, there was difficulty in arranging times to meet and discuss the data and tools.

2) Coordination with stakeholders: There were a number of interested parties in use of the heat risk maps to improve policy and practice, but this project did not involve all stakeholders in the proposal development or all subsequent meetings. Early work was carried out on the prototype tool described in the bid prior to gaining stakeholder feedback; following feedback from PHE, the tool was restricted to a prototype and serves as a demonstration of the possibilities of combining data sources rather than a system that is in-use in the Borough.

3.2 Lessons learnt

A number of unanticipated outcomes were encountered and lessons were learnt during this collaboration:

1) As the proposal was being developed, input from a wider range of stakeholders would have helped. Despite enthusiasm and a desire to improve public health in the Borough, there was a lack of resources within the team leading to some delay in the delivery of communications and project outcomes. The project would have benefitted from having an initial scoping meeting with all technical members of the borough, PHE, and the UCL team present.
2) The involvement of PHE as stakeholders, and their existing familiarity with Hounslow Council, meant that UCL were able to quickly establish credibility with Hounslow, and generate interest from multiple departments (Emergency Planning and Housing).
3) UCL now has an understanding of the databases and GIS tools held within the Borough of Hounslow, and can generate dwelling and UHI outputs that can be integrated into existing systems. However, the population vulnerability data is held in separate datasets in Hounslow, and it is unclear whether these might be linked in a single system.
4) Time pressures meant that Hounslow had little resources to dedicate to this project. Events, such as the Grenfell Tower tragedy towards the end of the project, meant that even fewer resources were available. Therefore, the scheduling of future projects should recognise that such collaborations are secondary to the day-to-day operations of the Borough staff.
5) Dwelling overheating and UHI exposures were produced at the individual building or address level for Hounslow. The overheating risks for the Verisk dataset contained OS UPRNs, which enabled the data to be linked to the OS datasets licensed by Hounslow Council. This, however, was done at the building level as the Verisk dataset did not have floor level information. The overheating estimates from the EPC data had a physical address enabling matching to specific addresses, but would need to be done semi-automatically or aggregated at the postcode level. As OS UPRNs are the default standard for identifying and matching addresses, it would be best if future data was provided with this information included. Developing semi-automated address matching methods or utilising an application programming interface (API) to geolocate EPC addresses would, therefore, be useful in the future.

3.3 Ongoing work and collaboration with GLA and Boroughs

Direct benefits: This placement offered a unique opportunity for the ECRs to gain a better understanding of the policy environment at the Local Authority level, and the boundaries between research and policy. It allowed them to tailor research project outputs to the practical needs of the Borough policymakers, as well as help shape future research activities in the area of urban climate resilience, thus accelerating the impact of UCL IEDE research. They, thus, gained first hand insight and experience into the delivery of policies related to urban housing heat resilience that will contribute significantly to their future as academics focused on built environment climate adaptation. UCL IEDE's interdisciplinary expertise offered the Borough of Hounslow access to the LUCID, AWESOME and HPRU project outcomes, including data of the London UHI and indoor thermal performance of the housing stock at a fine spatial resolution using state-of-the-art local urban climate and building dynamic thermal modelling methods. We hope that these datasets will aid daily decision making and facilitate a strategic approach to prioritising high risk areas and identifying interventions to put in place to reduce risk to people and infrastructure at both strategic and Borough levels. In the longer term, it will also enable the Borough to build a long term sustainable relationship with UCL IEDE. It is hoped that the Borough will be able to use this collaboration experience to inform their resilience plans, and assist with the management of heat risk particularly affecting vulnerable groups such as children, the elderly, the homeless and those with preexisting cardio and respiratory health conditions.

Wider benefits: Despite the various challenges in the completion of the project outlined above, we believe that this ECR placement has significantly enhance our understanding of how to foster sustainable links between academia, Local Authorities, policymakers and other stakeholders. We hope that this collaboration could be a starting point for future collaborations with other London Boroughs to undertake further work. The project outcomes will be of interest to a wide range of stakeholders and beneficiaries, including public health, health protection, emergency planners, prevention and care management and emergency preparedness teams, as well as the PHE and the GLA, potentially offering useful insights for the development of the new *London Plan.*

According to Annette Figueiredo, Principal Policy and Programme Officer, GLA:

> *"The journey of transitioning from modelling to policy and then delivery, working with a borough, has provided some very useful insights into the challenges and opportunities of enhancing local resilience to extreme weather events. I am confident that an outcome will lead to enhanced resilience, the example of which should then be able to be replicated to other boroughs."*

4. Conclusions

The above project provided an opportunity to disseminate overheating risk research to a wide range of potential stakeholders through the creation of presentation of maps at different events and to different audiences. It also provided an opportunity to explore how address or building-level overheating risk estimates may be operationalised in the provision of emergency heat-risk services. While the project was hampered by time constraints at Hounslow Council, it was possible to develop a series of overheating risk datasets that may be integrated into their emergency services systems, and that can act as an input into ongoing collaborations with PHE. Ongoing research at UCL will further develop the overheating model using EPC data at the national-level, and such data may be made available for other councils upon request.

5. Acknowledgements

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Appendix

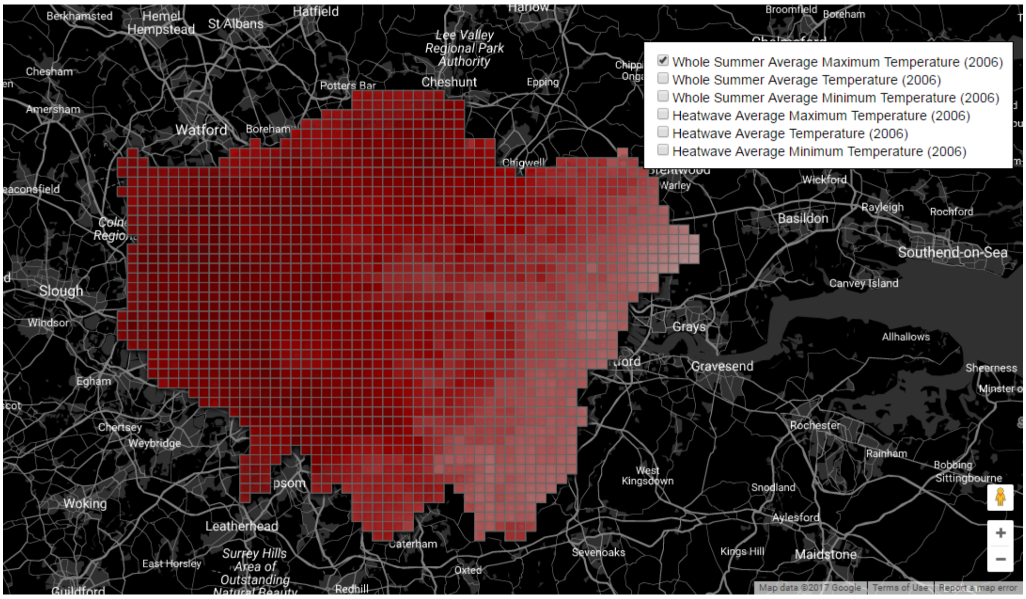

Figure A1. UHI data for London in an interactive map, provided for the prototype web tool and the Barking and Dagenham Healthy Towns event.

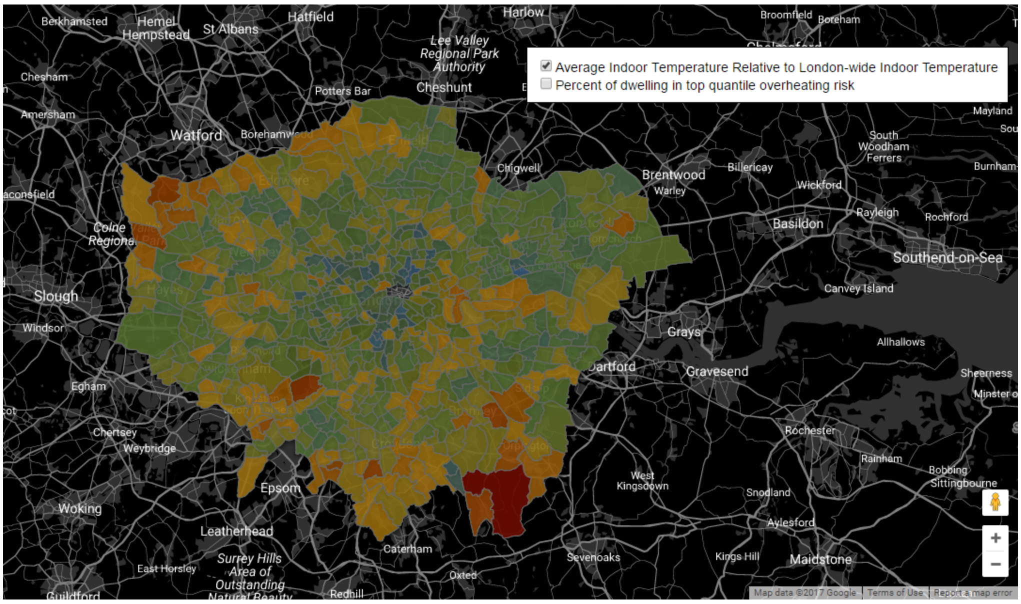

Figure A2. Dwelling overheating data for London in an interactive map, provided for the prototype web tool and the Barking and Dagenham Healthy Towns event.