NEIGHBOURHOOD FUTURES

A framework for climate resilience and health equity

Impact on Urban Health

RAMBOLL

A joint initiative

CONTENTS

ABOUT THE AUTHORS

This project is a collaborative research initiative that merges complementary expertise in sustainability-driven development between two organisations:

IMPACT ON URBAN HEALTH is an independent health foundation based in the south London boroughs of Lambeth and Southwark.

RAMBOLL is a foundation-owned multidisciplinary consultancy specializing in built-environment engineering, design, and consultancy services. It combines a global knowledge base with local expertise. Within Ramboll, this research has been a collaborative endeavour, led by the UK's Regenerative Cities team, with Buildings Innovation Management, Strategic Sustainability Consulting, Building Physics and Advanced Simulations, the Design Excellence Board, Water, Transport, Infrastructure, and multiple other experts across the company.

ACKNOWLEDGEMENT

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FOREWORD

A stark consequence of our changing climate is too difficult to ignore: the climate crisis is already turning into a health crisis. As a society, we're severely under-prepared for its impact. The need to develop new ways for neighbourhoods to withstand the extreme temperatures, that will become more consistent as each year passes, is urgent.

This means adapting the way built environment professionals think about their work and providing a framework that enables practitioners to know what is needed to absorb the shock of climate change – and for communities to be resilient enough to respond to its pressures. We know that increasing temperatures mean an increase in heat-related illnesses and deaths - during five periods of extreme heat between June and August 2022, there were 6.2% more deaths in England and Wales than the five-year average. This is because exposure to high temperatures can impact people's circulatory, nervous, respiratory and renal systems – increasing their risk of dehydration, heat exhaustion and heatstroke.

We also know that the health effects of climate change are set to follow existing patterns of inequalities. The people most vulnerable to the impact of climate change will be forced to endure the hottest temperatures, and the places with the worst infrastructure to deal with a changing climate are most likely to be where people that experience the highest health inequities live and work. They often do the low-paid jobs that keeps our societies functioning and simply don't have the ability or resources to prepare for extreme temperatures.

Last year, we worked with the Bureau of Investigative Journalism to understand more about the impact of extreme temperatures on people's lives. Tenisha, a 39 year-old Wellbeing Support Worker explained whilst high temperatures cause mobility issues for her and seriously impact her ability to sleep, "with how expensive electricity is...you can't afford to have the fan on all night".

If we're serious about mitigating the health effects of climate change, we need to see collaboration across sectors; housing providers, local authorities, the health system, construction companies, community organisations and urban planners. The decisions they make today will impact people's health far into the future. The changing climate is already affecting our lives and we know it will continue to impact the health of our communities. Now is the time to make sure our neighbourhoods are as prepared for it as possible.

Peter Babudu
Executive Director
IMPACT ON URBAN HEALTH

2023 was the hottest year on record, with global average temperatures topping 1.5C above pre-industrial levels for the first time. This presents us with a genuinely existential threat and one of humanity's greatest challenges. As the climate crisis intensifies, we must continue to collaborate across traditional working boundaries to find long-term sustainable solutions that protect our diverse communities.

This represents one of humanity's greatest challenges, but the scale of the threat that climate change poses means that it is one that cannot be ignored. The solution involves a systems perspective on how to do it in a way that's actually going to have an impact while meeting complex demands. We used to speak about different threads of our global environmental crisis very separately from each other - climate change, biodiversity loss and the social vulnerability. Today we recognise the interconnectivity of these threads and are looking at 'One Crisis' and seeking realistic, holistic solutions - no easy task but a very important one. Our teams at Ramboll look to continuously drive innovation, to challenge business-as-usual and create systems level solutions.

When it comes to public health inequalities, and particularly those made worse by climate change, we are dealing with new forms of urban vulnerability that science has yet to fully understand. Nested within the complexities of urban systems, any solution will require systems level thinking and collaborative practices. By working in partnership with Impact on Urban Health, the Regenerative Cities team has brought a new coherence to urban resilience, taking an existing framework and expanding its scope to allow us to imagine how healthy and resilient neighbourhoods might perform. By sharing this framework, we hope that this becomes a living tool for resilience, inspiring more sustainable change.

This research has enabled us to explore our local neighbourhood; the Ramboll UK Head Office is based in Southwark, which experienced some of the hottest temperatures in the UK during the 2021 heatwave. It has allowed us to be part of the neighbourhood in a new and meaningful way, and we hope to continue this work with local stakeholders. In Ramboll we want to create real-world workable solutions to the climate crisis and are proud to have co-funded this collaborative research. We hope that this guidance supports Local Authorities, planners, and designers as they continue to develop holistic and inclusive climate adaptation strategies.

Philippa Spence
Managing Director, Environment & Health Global
RAMBOLL

EXECUTIVE SUMMARY

NEIGHBOURHOOD FUTURES

A framework for climate resilience and health equity

CHALLENGE

How can cities reduce climate vulnerability and health inequalities related to extreme weather events?

AMBITION

To support the development of holistic climate resilience strategies that are vulnerability-sensitive and health-focused.

STUDY

- Literature review of existing tools, frameworks and case studies;
- Fieldwork in London Borough of Southwark;
- Community engagement by the Bureau of Investigative Journalism[1];
- Climate modelling and multidisciplinary workshops to develop solutions based on heat and cold extremes.

FINDINGS

- Resilience is a rapidly developing field, but the term remains abstract and siloed;
- There is a gap in multiseasonal resilience solutions;
- There is a need for a method that can capture diverse vulnerabilities on the ground;
- A more systemic approach to resilience could generate integrated analysis and more equitable solutions.

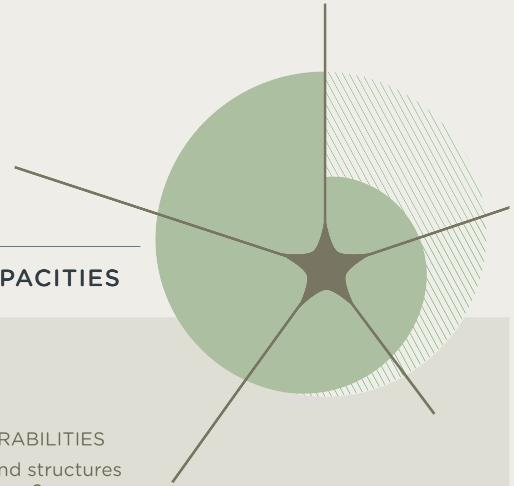
RESPONSE

Working at the neighbourhood scale provided an effective entry point where local authorities, planners and others can reconcile large-scale strategic objectives with local vulnerabilities, risks, needs, networks, and community experiences. To develop strategic local climate resilience, we adopted and adapted an existing framework that outlines five complementary capacities.[2]

The framework provides users with a heuristic device or map to resilience, which can prompt collaborative and integrated approaches to climate resilience and health equity. When applied together, the capacities generate a comprehensive set of responses to local vulnerabilities. Applying the framework on a local scale supports equitable spatial, social and governance change.

[1] Rachel Hamada et al. (2023). Revealed: Escalating Effects of Hot Summers on UK Housing.
[2] de Graaf-van Dinther, R., Ovink, H. (2021). The Five Pillars of Climate Resilience. In: de Graaf-van Dinther, R. (eds) Climate Resilient Urban Areas. London: Palgrave Macmillan.

FRAMEWORK: 5 RESILIENCE CAPACITIES



THRESHOLD CAPACITY

UNDERSTAND DIVERSE LOCAL VULNERABILITIES

What temperatures are people, places and structures vulnerable to and experience thermal stress?

COPING CAPACITY

STREAMLINE EMERGENCY RESPONSES AND RESOURCES

How is the neighbourhood prepared for extreme weather when temperatures exceed threshold levels?

RECOVERY CAPACITY

PREPARE TO RESTORE LIVEABILITY AND WELLBEING

How is it best to assess negative impacts and allocate resources to the people and places that have suffered most from extreme weather events?

ADAPTIVE CAPACITY

ADJUST THE SYSTEM TO PROTECT PEOPLE AND PLACES

How can we best protect people and places from extreme heat and cold waves when they occur?

TRANSFORMATIVE CAPACITY

REIMAGINE AND OVERHAUL THE SYSTEM

What massive change would transform the neighbourhood to make it more resilient and equitable?

Source: Created by the authors based on the *Five Pillars of Climate Resilience* (de Graaf-van Dinther and Ovink 2021)

INTRODUCTION

CHALLENGE

Cities are facing systemic challenges in managing extreme weather events and their negative impacts on people's health and wellbeing. Climate change has increased the frequency, length and intensity of heat and cold waves. Their impacts have therefore become more severe, deepening existing health inequalities and leading to a rise in temperature-related deaths. According to a recent study (Garcia-Leon et al 2024) excessive temperatures have led to an estimated 407,000 deaths per year across Europe (baseline period 1991-2020), with about 363,500 annual deaths from cold, and 43,700 from excessive heat. Projections show that in a 3°C warming scenario, there is likely to be a threefold increase in heat-related mortality. While winter is the fastest warming season and projected to become milder, cold snaps or deep freezes will continue to pose risks to vulnerable communities.

Climate vulnerability relating to thermal stress poses dangers to everyone, however its impacts are experienced unevenly, with underserved and marginalised communities most likely to be impacted. This uneven exposure and sensitivity to thermal stress is likely to entrench new and existing inequalities (UKHSA, 2024) that may stem from living in precarious housing conditions, being economically disadvantaged and/or suffering from long-term health conditions.

While our scientific understanding of diverse experiences of thermal stress is incomplete, new studies continue to reveal greater diversity and inequality (Schweiker et al. 2018). People living with disabilities, with chronic and underlying respiratory, kidney and heart conditions are especially vulnerable, as are racialised communities, children and the elderly, pregnant women, outdoor workers, people experiencing homelessness, and emergency responders, among others. Heat stress can also bring about heat exhaustion, heatstroke, or trigger sudden heart attacks or strokes.

Research also examines ever-growing risks within communities that already carry an unfair burden of health inequalities, such as perceptions of risk and responses (U.S. EPA, 2016; Sampson et al., 2013), social isolation, an inability to care for oneself (Berko et al. 2014), alcoholism, narcotics use, and certain prescription medications that cause dehydration (Ebi et al. 2021).

Health risks are exacerbated by environmental factors such as substandard housing, inadequate public spaces and social infrastructure. In dense urban areas, structures and surfaces absorb and amplify heat, preventing atmospheric cooling and increasing the urban heat island effect, made worse by poor air quality.

Heat and cold waves often challenge critical infrastructure and services, putting pressure on already strained transport, utilities, emergency response and health systems. This is particularly true in low-income areas where marginalised populations are more likely to reside and rely on continuous service provision for safety and protection. In addition, economic productivity often suffers during extreme weather conditions, posing additional risks for outdoor workers, and overall threatening income and employment, affecting mental and physical health.

The complexity of health-related climate vulnerability reveals the challenges ahead for local authorities and other urban practitioners. Reducing vulnerability can be achieved by increasing resilience - where systems are able to adapt to change and crises while continuing to function (see Meerow et al. 2016).

The concept of resilience, however, remains rather ambiguous. While this vagueness offers versatility - enabling different interpretations by diverse stakeholders (ibid.) - it also renders the concept more difficult to understand and apply.

In practice, resilience strategies are often created by multiple teams or agencies in siloes. In preparation for heatwaves, for example, health services may design an emergency response, social services prepare communications campaigns, while planning departments design cool paths or places. Without coordination and integration, the complex vulnerabilities of the urban system and its diverse communities, may not be reduced (Kearl and Vogel 2023).

AMBITION

As local governments and organisations are on the front line of resilience, how can we support them to better prepare for, respond to and recover from extreme weather events in a more integrated and equitable way?

This project aims to provide a holistic approach to climate resilience strategies. It looks to support vulnerability-sensitive and health-focused decision making related to heat, cold and other climate change impacts.

Designed to draw our focus towards local capacities for resilience, the purpose of the framework is to bridge between diverse actors, disciplines, challenges, and needs, all inextricably linked to equitable health and climate readiness.

INTRODUCTION

STUDY

Following a literature review on climate vulnerability and alleviation approaches, our teams noted the need for more neighbourhood-focused interventions. Studies often focused on national policies, city-wide adaptation and mitigation, and household level resilience.

From practice, we are cognisant of the neighbourhood's scale as a unique medium through which to reconcile strategic objectives with local needs (see Lamb and Vale 2024). Neighbourhoods are sites of active formal and informal social networks, anchored organisations, and interfaces with city-wide emergency systems and infrastructure. They are small enough to pilot new interventions, enabling accelerated and sensitive change on the ground, while large enough to assess projects for scalability.

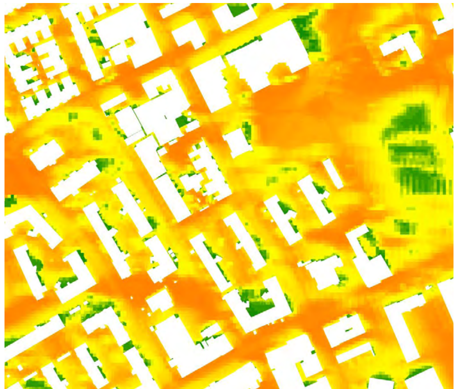
A case study neighbourhood was selected in the London Borough of Southwark just South of Elephant & Castle underground station. The site was selected according to three parameters:

- High climate vulnerabilities and health risks across the site based on the Urban Health Index (IoUH 2024) and climate data (ClimateJust 2022, GLA 2023);
- Social diversity, road and building typologies, and mixed use are highly representative of other inner-city neighbourhoods in the UK;
- Existing strong ties with local stakeholders and community organisations to enable engagement.

Mixed research methods were applied to understand local experiences, seasonal conditions, climate projections and plans:

- Modelling - digital microclimate and wind models (UTCI, CFD), incorporating building form, surface materials, flora, seasonal changes, historic and projected temperatures;
- Fieldwork - in person observations mapping spaces, functions, materials, character and behaviours;
- Engagement - community outreach, surveys and citizen science research on hot homes and the neighbourhood in summer 2023;
- Desktop research - literature review on climate vulnerability, health, indices frameworks, resilience, and climate action plans;
- Workshops - multidisciplinary analysis of microclimates and resilience solutions.

For more information on the case study process and outcomes, please see our Appendix, available in the online version of this report.



KEY FINDINGS

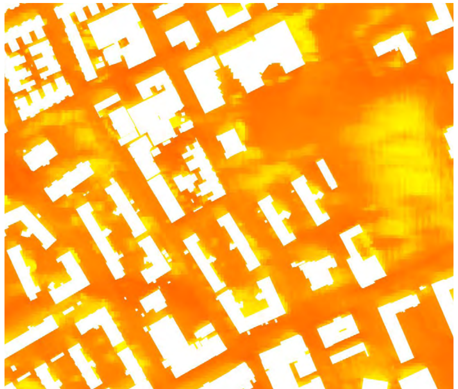
(i) Multiseasonal challenges
Designing for only heat or cold wave conditions may increase health risks, as what is good in hot temperatures may be dangerous in cold, and vice versa. For example, wind can reduce health risks and thermal stress in hot weather, but exacerbate stress in the cold. Some humidity may help to cool the body down in hot weather, though too much humidity doesn't allow our sweat to evaporate and our skin to cool down. In cold weather, humidity exacerbates the body's thermal stress. To reduce vulnerability and enhance equity, there is a need for integrated, multiseasonal solutions.

(ii) Neighbourhood experiences
Uneven microclimates across the neighbourhood had varied impacts on different resident groups. For example, spaces for children and youth in and around schoolyards, open parks and playgrounds were some of the warmest, while some naturally cooler areas - with greater air circulation between buildings - and designated cool spaces remained underused. There is further need for analytic frameworks that can capture social and spatial climate inequalities through more integrated analyses.

Images: Zoom in on our neighbourhood model combining Universal Thermal Comfort Index (UTCI) model with Computational Flow Dynamics (CFD) for wind. **Fig.1, Left:** Summer 2020, when mortality from heatwaves were highest since the introduction of the Heatwave Plan for England (NHS 2004). **Fig2., Right:** Projected Summer 2050 climate.

(iii) Modelling and Visualisation
Our multiseason and multi-dimensional climate modelling generated more detailed and comprehensive results than UK planning standards currently require, revealing more vulnerability than originally thought. Furthermore, we found that the Universal Thermal Climate Index (UTCI) is not socially representative. It applies an algorithm for physiological and cultural parameters that exclude populations, and importantly, the most vulnerable. These models obscure uneven vulnerabilities and risk generative knowledge gaps that subsequently guide in solution design.

(iv) Resilience thinking
Urban resilience remains a relatively abstract and broad term, often associated with adaption measures (Wardekker et al. 2020). There is a need to further embed multidimensional analyses and response in climate resilience strategies; the potential of resilience as a bridging concept that can connect multiple disciplines, stakeholders and interests, can be further unlocked (Wardekker 2017).



INTRODUCTION

RESPONSE

Our research identified the need for an actionable framework through which to understand resilience, address vulnerability, and alleviate temperature-related health inequities. To deliver this, we adopted and adapted an existing framework developed by de Graaf-van Dinther and Ovink (2021), The Five Pillars of Climate Resilience, based on their study of urban vulnerability and resilience, with a focus on flooding and water management in coastal cities.

Fig.3: Floating Pavilion in Rotterdam the Netherlands: example of a climate resilient innovation in a former port area (Source: de Graaf-van Dinther; Photo: René de Wit)

SUMMARY: 5 PILLARS OF CLIMATE RESILIENCE

Cities in particular are vulnerable to climate change impacts. With more than half of the global population currently living in cities, climate change already has a profound impact on society. Climate change is increasingly demonstrated in the number of extreme weather events across the world, most profoundly impacting urban regions. Given the current and expected climate impacts in urban areas, cities have started initiatives to respond to these threats. Based on our study, climate resilience in urban areas was defined as consisting of 5 pillars: **threshold capacity, coping capacity, recovery capacity, adaptive capacity, and transformative capacity** (see executive summary, and the following page of this report).

Resilience is an intrinsically inclusive and holistic concept that includes various themes, for instance technical resilience against natural hazards such as floods, droughts, and other extreme weather events. It also has strong social and governance dimensions, such as the presence and strength of neighbourhood social assistance networks in the event of disasters and stakeholders' capacity to innovate their working practice, enabling the transformation of their city.

For coastal cities, the challenge of the resilience journey means utilising scientific knowledge, but also the knowledge of citizens, indigenous peoples, and practitioners.

Measures and strategies on different scales are needed from national scale all the way down to neighbourhood, street, and building level. In some cases, optimising the existing urban infrastructure might be sufficient. More often, a transformation of the urban governance system is needed: resilience is by its essence systemic, and resilience interventions are also systemic. The systems level of impact often is not met with a suitable governance (formal and informal) system. For implementation and operations, this implies system changes in governance, collaborative models, and coalitions. The potential of innovative pilots to improve, replicate, and scale up is a key factor for transformative change.

We are in a transition in how urban areas respond to climate threats and internal social dynamics. The size and urgency of climate impact is such that adaptation is no longer considered sufficient. Instead, transformation of the entire urban system is needed to anticipate on climate change impacts. Four key elements can be extracted from our study.

1) Implementing innovations at appropriate scale and speed: system wide impact of innovations on an urban scale and global scale requires application at an appropriate scale and speed which is relevant compared to the magnitude and severity of urban climate change impacts.

2) Planning and collaboration: Inclusive transdisciplinary planning with local communities and experts is needed to mobilize the required local knowledge and support for the climate resilient transformation process.

3) Capacity building at a local level: Transformative climate resilience is characterised by community based local urban systems. Citizen empowerment and capacity building among local stakeholders are crucial success factors.

4) From sustainability to regeneration: Urban development and redevelopment processes contribute to restore damaged ecosystems, by providing habitat and linkages to other nature areas.

Building transformative capacity is about changing urban development and urban redevelopment practice. One of the ideas proposed in our study is to create Floating Communities as a climate resilient testing and learning environment for new transformative societal models, in order to contribute to the wider transition to climate resilient urban areas.

Dr. Rutger de Graaf-van Dinther
Co-Author of The Five Pillars of Climate Resilience

FRAMEWORK

OVERVIEW

As discussed in the previous section, the following framework sets out five distinct and complementary capacities, that together, generate an overarching resilient system (de Graaf-van Dinther and Ovink 2021): **• Threshold Capacity • Coping Capacity • Recovery Capacity • Adaptive Capacity • Transformative Capacity**

At the heart of this framework is an approach to creating **response diversity**. In ecology, response diversity refers to the multiple processes through which diverse species and habitats are able to maintain ecosystem function while responding and adapting to environmental change (Walker et al. 2023). In urban neighbourhoods, response diversity constitutes the pursuit of multiple pathways that would allow the local environment to deliver continuous services, shelter and safety from hazards.

This framework thus conceives of resilience as a range of integrated actions across the five capacities. By designing resilience as multiple responses, local flexibility can be enhanced as the neighbourhood and its communities can better adjust to uncertain future conditions and nonlinear change,

Each of the capacities focuses on different vulnerabilities, time-frames, resources, needs and performance objectives, and together, bring to light the diverse and uneven experiences of climate extremes. Thinking across the framework highlights diverse forms of vulnerability and can help generate more equitable impacts.

HOW TO USE THE FRAMEWORK

The capacities can be considered in any order and independently, however the idea is that together, they inspire multi-dimensional and holistic solutions. Users can apply the framework to:

(1) Examine local conditions
The framework is a lens for holistic baseline resilience analyses - understanding vulnerabilities, existing local capacities, and resilience gaps across different neighbourhood stakeholders, programmes, and places.

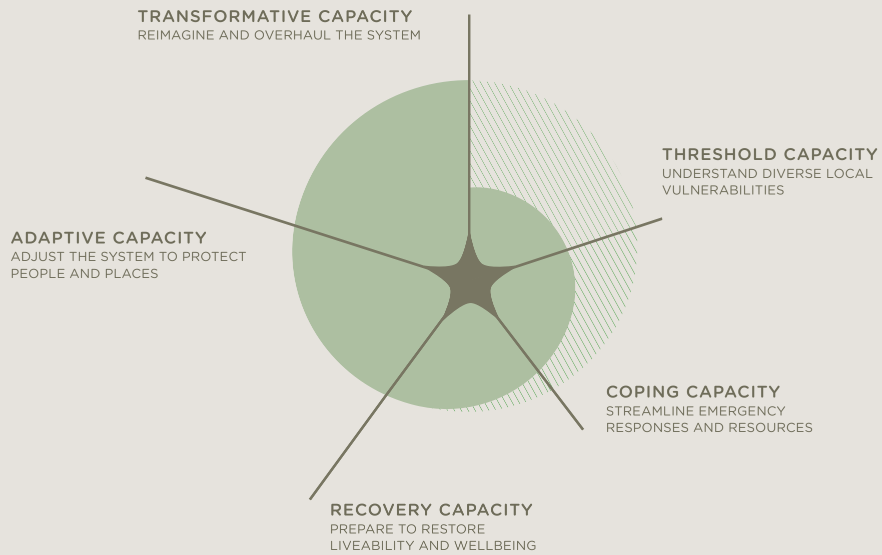
(2) Evaluate plans and strategies
Mapping existing strategies across the framework can provide an overview of prioritisation and funding patterns, helping identify any gaps and opportunities.

(3) Shape new projects
By applying the framework in the early stages of a strategy, it can help to develop a comprehensive approach.

WHO THIS IS FOR

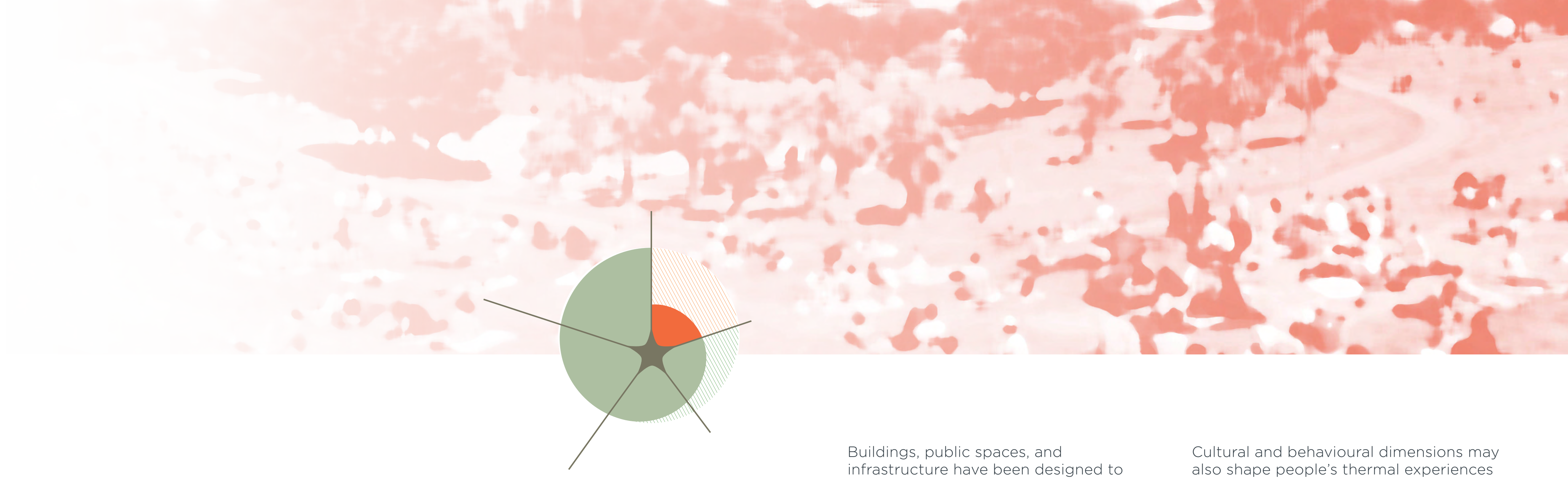
This framework has been written to support planners creating climate action and resilience strategies. Many will have programmes for some, if not all, capacities, though they may have been led by different teams. As a cross-disciplinary tool, the framework can bridge between different departments and sectors, for collaborative, comprehensive, and place-based interventions.

5 RESILIENCE CAPACITIES



The following section details each of the 5 resilience capacities - key questions, their significance for climate and health vulnerability, case studies, and examples of actions for consideration. While these are not exhaustive, they are intended to inspire dialogues and ideas.

Source: Created by the authors based on the *Five Pillars of Climate Resilience* (de Graaf-van Dinther and Ovink 2021)



THRESHOLD CAPACITY

UNDERSTAND LOCAL VULNERABILITIES

Who within the community and what spaces and structures are most vulnerable to temperature extremes? At what temperature levels do they experience thermal stress?

The threshold capacity refers to a neighbourhood's sensitivity to temperature changes and the thermal range it is designed to withstand without suffering negative impacts. A neighbourhood system will be home to diverse threshold capacities; people, spaces and structures will have different risks of exposure and sensitivity to extreme heat and cold. Threshold Capacity also refers to the neighbourhood's ability to capture changes within - for instance, shifts in people's health or living conditions, maintenance needs of built assets and infrastructure, etc. Therefore, establishing granular vulnerability indicators, conducting baseline studies and forming ongoing monitoring and evaluation processes can reveal a neighbourhood's threshold capacities and its changes on the ground.

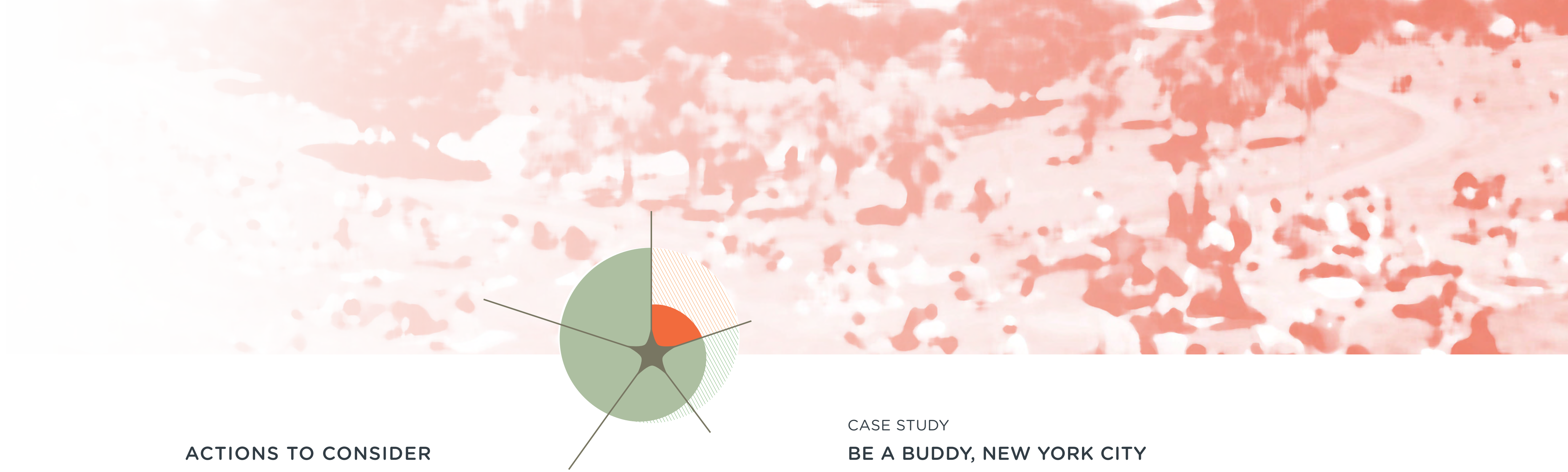
Buildings, public spaces, and infrastructure have been designed to withstand certain climatic ranges and will perform differently in more extreme temperature changes. These parameters can be assessed according to design documents, historic events and/or future predictions. In addition to the built form and open space network, other concerns may include ground cover and building elevation materials, air quality, density, building orientation and wind trajectories, energy systems, and transport systems, among others. Certain structures, surfaces, and spaces may be more prone to storing heat during the day and emitting it at night.

Diverse communities, those from ethnically marginalised backgrounds, and individuals living with chronic or acute health conditions will experience different physiological and mental health thresholds. While there are many gaps in our understanding of people's thermal stress and perception, and therefore their personal and social thresholds, it is safe to assume that children, older people, and people with chronic illnesses are less likely to be able to regulate their body temperatures, and must therefore be considered as being more vulnerable, with lower thermal stress thresholds.

Cultural and behavioural dimensions may also shape people's thermal experiences and uneven vulnerabilities. It is important to understand what spaces people have access to when they are too warm or too cold, how they access local information, what networks they participate in, their levels of physical activity, whether their dress codes enable seasonal clothing, or if they cannot use electricity at any time. These may be some factors that place some communities or their members at higher risk of thermal stress.

While this framework focuses on the public realm, it cannot overlook the critical role of housing in affecting vulnerability, and as an indicator for inequality such as access to services. Housing quality and the extent to which it shields people from thermal stress plays a large part in shaping local thresholds including people's health, quality of life, and social networks.

A neighbourhood's overall threshold capacity is therefore determined by the quality of the built environment, how it shapes diverse experiences of thermal stress, and how it monitors change. Demographic and health indices are crucial to understanding threshold levels and how the built environment reduces or increases local vulnerabilities.



ACTIONS TO CONSIDER

Ecology Assess your existing green infrastructure and habitats for temperature thresholds.

Social Collaborate with key anchor institutions and community groups that hold trust and already provide support services to vulnerable populations.

Energy Design vulnerability considerations into energy systems planning for the net-zero transition, and coordinate with local climate adaptation planning bodies.

Built Form Establish where in the neighbourhood there is passive cooling for public spaces, to incorporate in future strategies, by protecting them and maximising their use

Mobility Understand thermal conditions and risks along main active travel axes and at public transport stations.

Governance Engage communities in the development of vulnerability indicators and community-led monitoring to ensure they are designed to reflect the needs and experiences of people who are inhabiting the spaces.

CASE STUDY

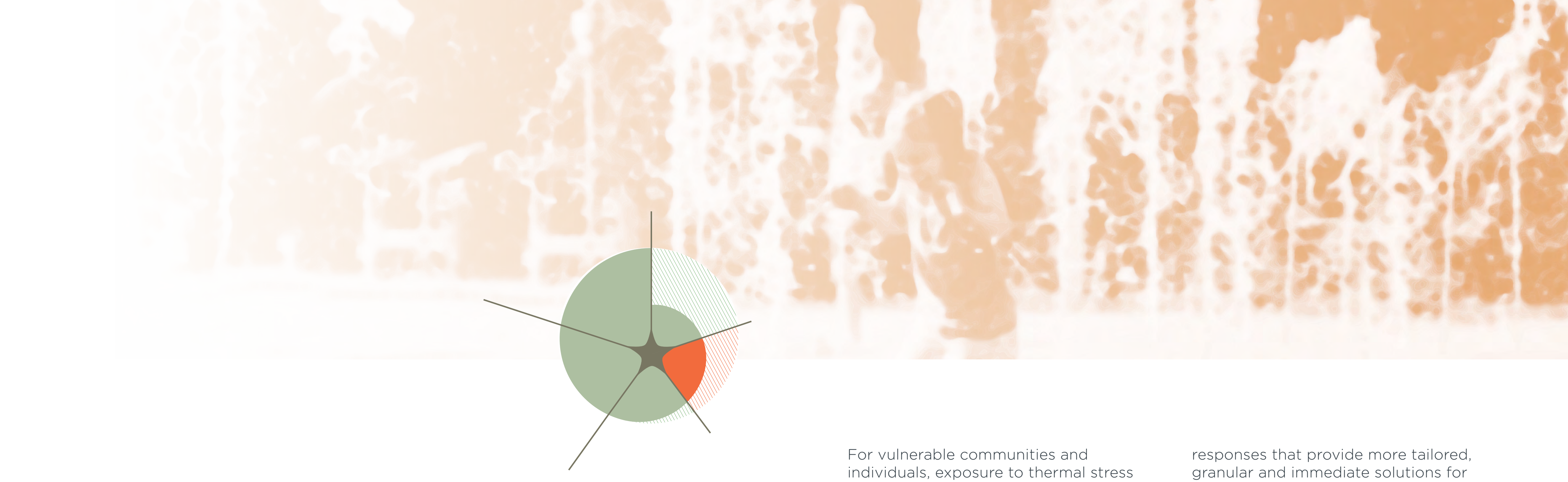
BE A BUDDY, NEW YORK CITY

Be a Buddy is a community-led climate vulnerability assessment programme that paired residents vulnerable to extreme heat and other weather emergencies with volunteers who provided wellness checks, established connections with relevant city services, and overall, coordinated a grassroots understanding of diverse thresholds conditions capable of monitoring and reporting changes in health and wellbeing over time.

The Be a Buddy programme was established in 2018 as part of New York City (NYC)'s city-wide Cool Neighbourhoods Strategy. It began as a two-year pilot working with community groups to promote social cohesion, prioritising key heat vulnerable communities in South Bronx, Central Brooklyn and Central and East Harlem.

The Cool Neighbourhoods Strategy acknowledges that thresholds vary across the city owing to differences in built-up density, distribution of vegetation, building typologies, surface materials, among others. The strategy first identified vulnerable neighbourhoods within NYC where there is need enhance climate resilience interventions. The programme then identify the most vulnerable populations within those neighbourhoods. Expecting people's threshold to change over time and recognising people's needs varies, the programme uses a more personable wellness check approach. The programme acts as a grassroots monitoring and feedback system, assisting the most vulnerable in activating their coping capacity when required (see next chapter for details regarding coping).

Through the 2-year pilot, the programme identified over 1,300 New Yorkers who are higher risk during extreme heat emergencies. With the support of the Health Department, neighbourhood-based organisations coordinated volunteers to conduct wellness checks. Buddies confirmed that the programme made them feel more supported and appreciated by their community. As populations at risk from extreme heat tend to also be vulnerable to other crises, the programme's improved local relationships extended support during other emergencies, like Covid-19.



COPING CAPACITY

STREAMLINE EMERGENCY RESPONSES AND RESOURCES

How is the neighbourhood prepared for extreme weather when temperatures exceed threshold levels? Who will require immediate attention, where and how?

When climatic variations exceed the thresholds, the neighbourhood's coping capacity constitutes its ability to mitigate impacts. The coping capacity relates to the multiple systems and networks activated during emergencies to provide temporary relief and safety from exposure to thermal extremes. This capacity creates mechanisms for rapid assessments to direct help to the most sensitive and activate responses to manage, tolerate and reduce thermal stress. Solutions address extreme conditions whose occurrence is relatively certain, particularly those that can be warned about in advance, providing time to prepare.

For vulnerable communities and individuals, exposure to thermal stress can amplify existing health conditions and entail additional risks, including disability and premature death. Excessive heat and cold often trigger public health emergencies, which sometimes lead to reduced capacities in the delivery of health services.

Coping capacities therefore need to be designed at different levels of intervention across the neighbourhood – providing individuals the knowledge, tools, and means to alleviate their exposure, creating an integrated plan for community preparedness, and activating wider institutional responses. There is a high risk that emergency responses are designed or delivered unevenly, overlooking diverse needs and constraints within communities. For example, people for whom thermal stress exacerbates existing conditions or raises risks, may require coolers, heaters or other devices coupled with financial support to cover increased energy costs.

A neighbourhood's coping capacity often relies on its position in the city's wider urban emergency response system. However, there is room to consider local responses that provide more tailored, granular and immediate solutions for vulnerable residents with heat and cold related health risks. Preparations for thermal stress may include activating a grassroots emergency relief network that attends to the most vulnerable individuals, providing integrated access to emergency spaces and services, provide vital information in appropriate methods to communities, and set up emergency response mechanisms bridging institutional and grassroots networks.

A neighbourhood's overall coping capacity may be determined by its ability to respond to two crises during extreme weather events. First, it requires plans for emergency responses to the health risks and needs of the most vulnerable within communities. Second, it requires plans to cope with the disruptions across energy, water, transport and health services, brought on by heat and cold waves. Collaborative planning across critical infrastructure, emergency services, health agencies, and local communities is required to ensure effective coping strategies that centre people, and their safety, are in place for extreme events.

ACTIONS TO CONSIDER

Ecology Create a prioritisation programme for watering or protecting key species that will not regenerate after an extreme event.

Social Coordinate support through existing social networks to vulnerable people.

Built Form Provide temporary solutions for extreme events, such as shading structures that can be maintained and managed by anchor intuitions in the neighbourhood.

Activate spaces that have passive cooling or are naturally sheltered from the cold, in particular paths and pavements where people need to walk.

Mobility Share and disseminate information about cool or sheltered routes and changes in service.

Governance Establish an accountable governance framework that coordinates critical infrastructure, emergency services, public health agencies, and community organisations to respond effectively and provide clear roles and responsibilities.

CASE STUDY

A HEAT SAFE CITY, MELBOURNE

To become a heat-safe city, Melbourne City Council developed an interactive tool to map and share cool routes open and free cool places, and change over time. By developing and sharing knowledge about this continuous spatial network, the city enhanced the local coping capacity, improving accessibility and inclusion to refuge from extreme heat events.

Through the tool, Melbourne City Council continues to remove barriers to safety and provide heat relief in high-exposure areas within communities. To raise the tool's impact and reach more vulnerable populations, the Cool Places map has been translated to the five most common languages in each neighbourhood, reducing language barriers and supporting coping behaviours. Melbourne has also implemented a Heatwave and Homelessness Programme since 2013 to provide highly vulnerable people with heat respite options.

With extended exposure, people's vulnerability to extreme temperatures increases. Melbourne increased its number of free drinking fountains, prioritising areas known for physical activity and recreation. There is also a nationwide campaign called 'Choose Tap' that maps locations for complimentary water bottle refill stations, to help reduce risk from dehydration. The city has further increased it's communities heat-related coping capacity by issuing advance warnings and extending their preparation time.

The City of Melbourne is developing a new heat hazard mapping tool that uses live weather and climate data to identify real-time heat risk and strengthen community's response to extreme heat events. The mapping of heat hotspots informed by social vulnerability and heat exposure data informs priority areas for cooling strategies and initiatives which enhances evidence-based planning and investment decision-making.

RECOVERY CAPACITY

PREPARE TO RESTORE LIVEABILITY AND WELLBEING

How is it best to assess negative impacts and allocate resources to the people and places that have suffered most from extreme weather events?

In the time immediately following an extreme event, the recovery capacity refers to the neighbourhood's abilities to reinstate or improve upon previous conditions, manage ongoing negative impacts and prompt pathways to restore liveability for all. The recovery capacity constitutes two key dimensions: a system's readiness to assess conditions on the ground following an extreme event, and sufficient agility in protocols to direct resources and responses where they are most needed, as quickly as possible.

Disaster recovery often entails time pressures and complex challenges to evaluate issues, determine priorities, and identify and align resources across the neighbourhood. These processes require a rapid and coordinated approach to delivering care with multiple stakeholders to address social, economic, built, and environmental wellbeing. There is often a need to redirect and seek out resources, restore essential services, rescue flora and fauna, repair infrastructure and support social systems that in turn, deliver emergency response.

Distributing responsibilities to different local stakeholder may provide opportunities to recover wellbeing in considered, inclusive and more sustainable ways. For example, they may enable personal health-based assessments and responses, deliver emergency care, and organise more integrated support for vulnerable people. This is important as physiological and psychological recovery from thermal stress can take several days or weeks. A sensitive approach is required, best delivered by linking institutional capacities with grassroots outreach to vulnerable individuals, neighbours, and community groups.

Consequently, individuals and agencies involved in disaster recovery require clear roles and mobilisation protocols through which to facilitate community recovery and development. These would build capacity and empower individuals and communities to manage recovery. Actions may include, for example, opening additional axes of communication, training for assessments and support, and designing new local services.

While policies have largely shifted away from recovery towards mitigative and adaptive actions, recovery immediately following a heatwave remains a crucial component of climate change readiness. Cities will be required to withstand uncertain temperature ranges and unknown hazards, and having recovery protocols in place will allow them to continuously interrogate changing conditions. The recovery capacity and the extent to which it embeds assessments and responses to material, technical, social, ecological and institutional negative impacts, establishes the effectiveness and timescales of responses to heat and cold waves.

ACTIONS TO CONSIDER

Ecology Prioritise the replacement of failed species with more suitable ones, and use signage to communicate plant conditions with the community.

Social Collaborate with key anchor institutions and community groups that hold trust to conduct rapid needs assessments and help to deliver services.

Energy Implement insurance mechanisms to expedite the recovery of temperature-affected infrastructure.

Mobility Develop assessment and prioritisation plan to repair affected infrastructure, and deploy alert systems to enable communication about service delay and community feedback.

Governance Develop policies that streamline the recovery process after extreme events, including rapid assessment and financial support for affected areas. Financial support must be distributed equitably and should prioritise vulnerable communities who might be disproportionally affected by extreme climate events.

CASE STUDY

DISASTER RECOVERY MAPPING, USA

From Federal to Local Government to community groups, US organisations use data-driven insights and real-time updates on GIS to streamline decisions and redirect resources for recovery from extreme climate events. GIS enables quick and informed decision-making during recovery periods by providing critical up-to-date information from different sources in one place, such as locations of vulnerable populations and neighbourhoods, weather forecasts and real-time critical infrastructure conditions. GIS also provides a single platform for multiple-stakeholders to use, making it easier to coordinate efforts.

The USA Federal Emergency Management Agency (FEMA) has a GIS portal that supports the emergency management community in its response to and recovery from extreme cold by providing ice and snow forecasts, winter storm reports, and time-aware hazard warnings. This information is crucial in assisting emergency services and communities to decide when to shift from coping to recovery and how to direct resources and responses to where they are needed the most.

GIS can also be used to assess and map conditions, providing a tool for effective inventory and applying spatial and historical information to critical infrastructure which is synced to information on the ground. By understanding where existing conditions are poorest and which assets are most critical to maintaining operations, it allows decision-makers to prioritise recovery efforts.

Priorities and recovery progress can be communicated to communities through mapping as well; Oklahoma and Iowa have a real-time winter road condition map and Texas Community Development Block Grant Programme created a Disaster Recovery Map. These allow citizens to understand where resources are being re-directed for recovery, receive timely updates on rotating power and water outages and travel bans. Communities with resilience hubs and plans can then use this information to coordinate local recovery efforts to complement city-wide efforts.

ADAPTIVE CAPACITY

MAKE SMALL CHANGES FOR PROTECTION

How can we best protect people and places from extreme heat and cold waves when they occur?

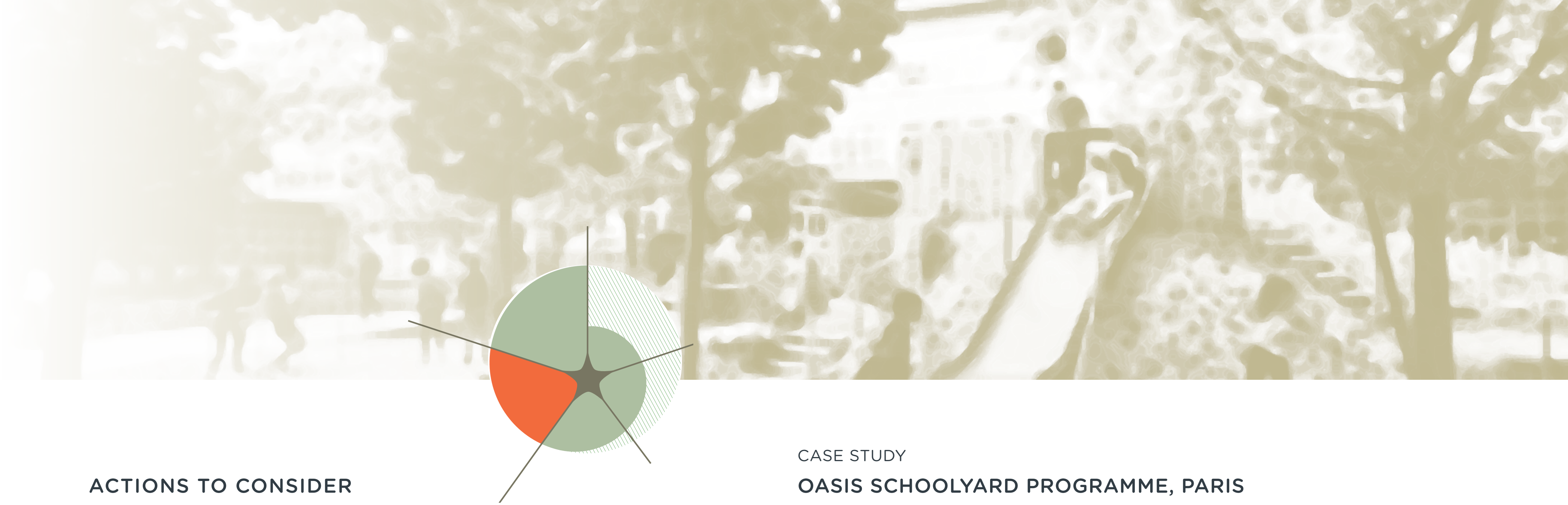
The neighbourhood's adaptive capacity reflects its systemic ability to adjust to climate change, moderating damages, reducing local thermal extremes and protecting people and places from thermal stress when temperatures exceed thresholds. This is achieved by making strategic, incremental adjustments to a neighbourhood either in response to or in anticipation of change. As the rate of change from climate emergency impacts is unprecedented with uncertain impacts, adaptive capacities are necessary to create more flexibility. Ultimately, enhancing adaptive capacities will reduce heat and cold vulnerabilities, enhance future flexibility, and thereby improve threshold capacities and reduce the need for coping and recovery capacities. These small and intentional interventions can test new ideas for ongoing learning.

Developing neighbourhood adaptive capacities constitutes reconciling short-term planning for discrete weather events, with long-term strategies that reorganise a system's behaviour. Systems with high adaptive capacities can harness collective material and social resources toward protecting the most climate vulnerable, reconfiguring themselves with minimum loss of function.

This capacity will likely grow in importance as neighbourhoods face increasing uncertainty, with extreme temperatures and hazards outside their coping range. Preparing for uncertainty requires two characteristics. First, it involves nurturing agility and diversity to harness creative problem-solving capabilities, develop new practices, and pilot innovative ideas. Second, it requires (re)designing systemic capabilities to generate, capture, analyse and apply new knowledge – a willingness to experiment and learn from experience, building up whole-system agility on the individual, household, community, and neighbourhood levels over time.

Temperature extremes will likely bring about abrupt ecosystem changes and unknown health effects, such as the introduction or re-emergence of diseases, for example, that will challenge all populations. Nevertheless, population vulnerabilities will continue to depend on exposure, sensitivity, and their ability to adapt to negative impacts. As centralised health care services and resources are likely to be increasingly strained in the midst of emergency conditions, adaptive capacities focus on developing new collaborations, technologies and services that can deliver outreach and care more directly to vulnerable residents. The role of the neighbourhood in extending and redistributing care may require rethinking administrative, legislative and operational boundaries in care systems, in order to provide multiple access points to climate vulnerability-related health services.

In recent years, adaptation has been the focus of numerous urban climate action strategies, advocating urgent adjustments to cities in preparation for climate impacts. At the neighbourhood level, this might include green and blue infrastructure network improvements to reduce the urban heat island effect, building retrofit, and disseminating knowledge on personal risks and solutions, among others. However, adaptive capacity refers to the ability of a system to actively enable successful and equitable adaptation interventions as part of strategy for continuous adjustments.



ACTIONS TO CONSIDER

Ecology Develop planting that will establish over the short, medium and long term, ensuring adequate maintenance and succession.

Social Co-create solutions as a means to share knowledge, increase uptake and develop stewardship.

Energy Consider alternative local energy production modes to provide back-up, and reduce waste.

Built Form Enable seasonal change of use and function in places according to microclimate conditions.

Mobility Design routes and stations with microclimates in mind, providing shelter and protection.

Governance Craft and update comprehensive local and national climate action plans in consultation with various stakeholders, including businesses, community groups, and environmental organisations. These should recognise and respect the knowledge and experiences of residents who understand the microclimates of their neighbourhoods

CASE STUDY

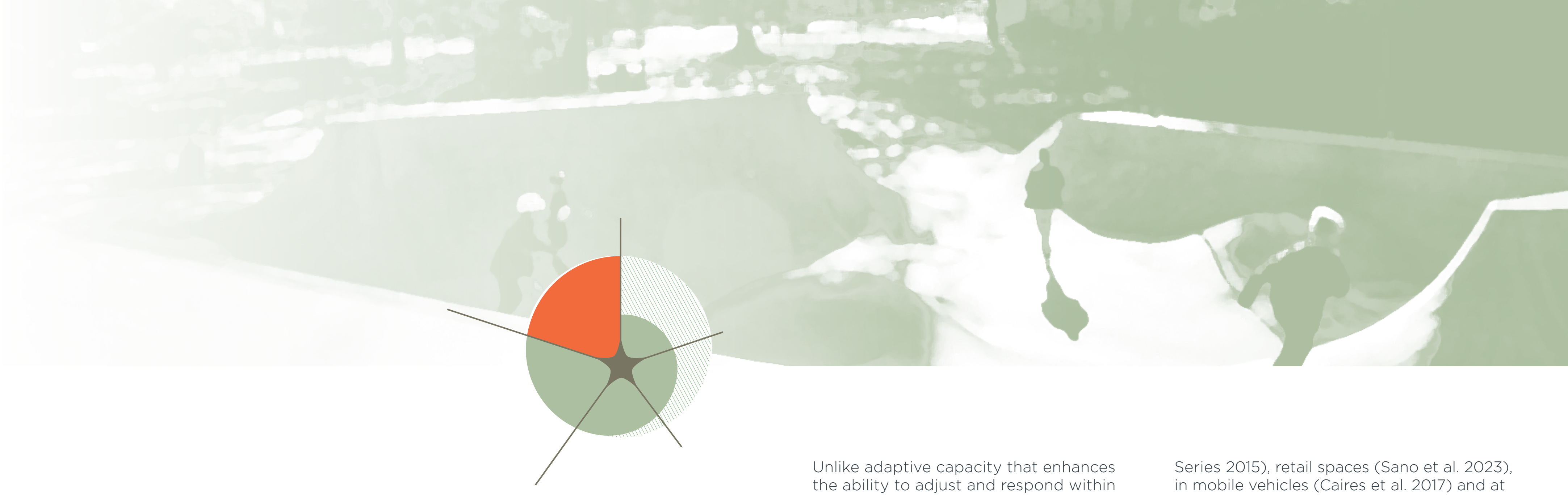
OASIS SCHOOLYARD PROGRAMME, PARIS

Paris has adapted 760 schoolyards into climate-friendly spaces where all residents can spend time and take refuge during hot summers. The schoolyards contribute to a wider network of cool 'islands' in Paris where existing spaces with enhanced passive cooling characteristics are leveraged.

As part of their Resilience Strategy, the Council of Paris launched the OASIS Schoolyard programme in 2019, transforming schoolyards into green oases to mitigate heatwave vulnerability. This strategy enhances Paris's adaptive capacity by changing the design and function of existing social infrastructure to reduce exposure and protect people against extreme weather events. O.A.S.I.S. stands for Openness, Adaptation, Sensitisation, Innovation and Social ties. The programme prioritises the wellbeing of children, a population vulnerable to heat waves, while fostering social cohesion within neighbourhoods and advocating for active community involvement.

Schoolyards, which are typically enclosed spaces, were selected as potential green oases due to their presence and equal distribution in all neighbourhoods and the proximity to potentially vulnerable communities. Everyone in Paris lives within 250m from a public school, and once all schoolyards have been adapted, they will all be within an approximately 2.5-minute walk from a free cool space that is open to the community outside of school hours.

During school hours, the schoolyards remain a closed play and educational space for attending children, creating a healthy and stimulating environment for pupils to learn about nature, climate resilience, heat vulnerability and community cohesion. Interventions such as drought-resistant plants, rainwater infiltration systems, water fountains and shaded play areas have increased the schoolyards' cooling capacities. The climate-friendly spaces are created through low-cost solutions that can be easily replicable and managed. The original 10 pilot projects have now been replicated across 760 urban schoolyards.



TRANSFORMATIVE CAPACITY

REIMAGINE AND OVERHAUL THE SYSTEM

What massive change would transform the neighbourhood to make it more resilient and equitable?

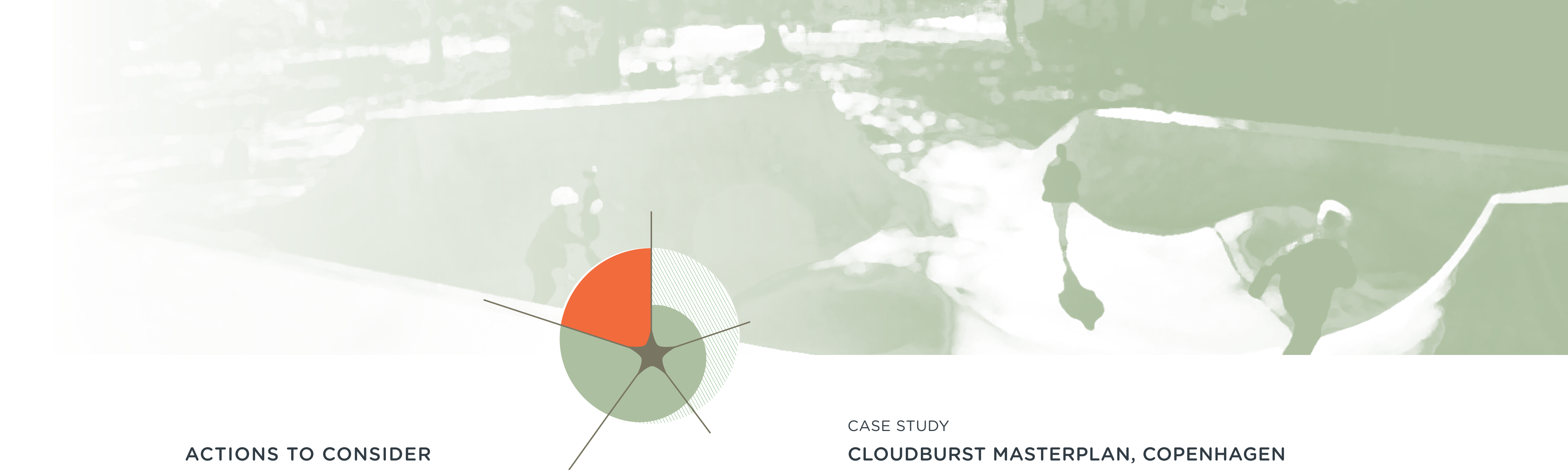
Transformative capacity takes a long-term and in-depth view of the neighbourhood system's ability to enact change. It looks to fundamentally change a neighbourhood system through material conditions, relationships, roles and shifting the boundaries of practice towards fully integrated solutions. Enhancing a transformative capacity looks to reimagine systems beyond the technical, incremental changes associated with adaptive capacity, to make deep-rooted shifts in the way systems operate, behave and learn (Wolfram et al. 2016, 2019). The objective is to reduce or remove the cause of risk, vulnerability, and inequity, enhancing overall thresholds.

Unlike adaptive capacity that enhances the ability to adjust and respond within an existing system, a transformative capacity takes the lessons learned from small-scale adaptation interventions, to scale up and mainstream wider change across the neighbourhood. This may be achieved through any number of shifts, such as: (i) placing climate vulnerability at the centre of planning and decision making; (ii) considering multiple, seemingly unrelated spaces and services together; (iii) coordinating top-down and bottom-up capacities simultaneously; (iv) transforming the collective goal, standards and parameters of success, mindsets; and (v) amplifying new voices, absorbing new data sources, increasing transparency and feedback loops (see Meadows 2008).

There is an increasing awareness that future climate-related health crises will likely surpass multiple care thresholds, and that we will need to rethink our existing service structures. This could mean enabling change across multiple roles and relationships in the neighbourhood, where health and care delivery may become, in some part, the responsibility of education, housing, transport, energy, commerce and other actors. For example, there are programmes that situate health services across other social infrastructure domains. They embed care in schools (Keeton et al. 2012), faith-based organisations (Lancet Series 2015), retail spaces (Sano et al. 2023), in mobile vehicles (Caires et al. 2017) and at home (Gray et al. 2015).

Bringing care to places where residents already spend time is a way to transform access and inclusion, and reduce vulnerability. It decouples service uptake from the need for social behaviour change, and shifts agency to new actors, building their capacity to respond to heat and cold waves. Merging new functions with existing activities and social networks decreases the risks of cultural stigmas on dependency, and reduces the need for communications campaigns as outreach. Finally, relocating functions around the neighbourhood or altering their active hours in response to outdoor microclimate conditions can leverage opportunities within the built fabric to reduce thermal stress.

One of the challenges this capacity addresses is lock-in characteristics from previous climate or other actions. When costly mitigation or adaptation projects have been implemented, for instance, investment may be reduced across other capacities. Land-use allocations, infrastructure networks, public service administration, and political cycles are some examples of existing systems that may lock-in climate action decisions, prioritising immediate wins over long-term vision (Urge-Vorsatz et al. 2018).



ACTIONS TO CONSIDER

Ecology Integrate public and private green spaces as a network and develop new material and planting standards to enhance ecosystem health that will contribute to human health.

Social Establish multifunctional service provision that nurture social networks and combine institutional interventions with grassroots initiatives.

Energy Apply vulnerability-reducing KPIs to district energy system designs beyond cost to end-user.

Built Form Establish criteria for regeneration and new development schemes, that optimise massing and layouts for healthy multiseason microclimates.

Mobility Design active mobility with green infrastructure networks.

Governance Implement policies that encourage the transformation of governance structures that prioritise co-creation and transparent solutions that address current and future challenges, foster a sense of ownership and shared responsibility among people and stakeholders, and encourage collective efforts.

CASE STUDY

CLOUDBURST MASTERPLAN, COPENHAGEN

Preparing Copenhagen for future flood and heat risks, the Cloudburst Masterplan adopts an interdisciplinary, and multi-functional approach. It spans across the city through a series of interventions, reimagining the relationship between the drainage system, green-blue infrastructure, and micro-climates. Merging built and nature-based solutions, the strategy creates large-scale transformative capacities for urban systems to respond to heat and storms, through a public realm that invites social and cultural vibrancy, more secure economic longevity in neighbourhoods, and enhancing collective quality of life.

Flooding from cloudburst events in 2011 caused massive damage, prompting the City of Copenhagen to re-examine its climate resilience. The local government recognised that extreme climate events transcend jurisdictional boundaries and require a collaborative effort and transformative approach. The Masterplan fundamentally reimagined the role of existing spaces and drainage, siloed practices between planners, utility providers, investors and local communities, and the position of climate adaptation within regulatory planning.

The Masterplan is based on eight typologies of water resilience interventions. While individually they would enhance a neighbourhood's adaptive capacity, interventions across more than 300 sites change the urban water system and enhance the city's transformative capacity.

Despite the focus starting with a drainage solution, the ambitious interdisciplinary and multifunctional design using blue-green infrastructure transformed the city beyond flooding prevention and has much wider co-benefits. It creates social corridors and mobility networks, green oases in neighbourhoods that reduce the urban heat island effect, and new healthy outdoor spaces including blue parks for recreational use. All of which improve people's quality of life and benefit their health and wellbeing.

Co-creation with local residents embeds stewardship and sense of place, prioritising safe new recreational and social spaces for all ages and genders. Public participation workshops also raise citizen awareness of climate risks, and provide a forum to discuss vulnerability and build capacity towards resilience.

NEXT STEPS

This framework sets out a structured approach to the complex concept of resilience. It looks to embed health equity and vulnerability in resilience strategies, and in so doing, contribute to the ongoing discourse and practices of urban development in the context of climate change. By unpacking resilience according to how they perform, and the functions they deliver we can be very intentional in the way we shape solutions. We recommend the following next steps:

- Apply the framework on neighbourhood plans, climate resilience strategies, masterplans and other urban projects to test its applicability and relevance, and continue to develop it as a resource.

- Within local authorities, begin the process of classifying and collecting data on existing projects that enhance one or more of the five capacities. This will allow cross-departmental knowledge sharing, benchmarking and evaluation.

- Create a database of case study interventions designed for each of the capacities across geographies, to encourage wider knowledge sharing.

- Develop policies to embed the five resilience capacities in strategic plans, identifying opportunities across built environment, social services, funding and investments, among others.

- Conduct research on the critical knowledge gaps as found in our study:
  - to understand thermal comfort bands for diverse vulnerable populations;
  - apply this understanding to new analytic modelling and visualisation tools to assess interventions for their sensitivity to diverse vulnerability profiles of people, places, and services;
  - develop digital tools that facilitate management and operations of response diversity and multiseasonal solutions to encourage integrated resilience strategies.

Our teams are interested in engaging in collective learning, developing the framework through application, sharing findings and recommendations. We would be happy to hear your thoughts and experiences.

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APPENDIX

Neighbourhood Study

The quality of outdoor spaces in cities is now more important than ever. Densification is a continuing trend and the urban heat island effect is only being made worse with increasing capacity of air conditioning and active cooling systems in our buildings. With rising summer temperatures, intense cold spells, flooding and more frequent storm events brought on by climate change, our urban fabric needs rethinking for resilience.

While we need to continue to retrofit existing housing stock to provide shelter and safety from the impacts of climate change, achieving this at scale will be costly and slow. It is therefore critical that we also redesign our neighbourhoods so they can support our health and wellbeing during extreme climate events. Interventions in public programmes and the public realm offer multiple entry points and stepped pathways to resilience that may be more actionable in the short-term.

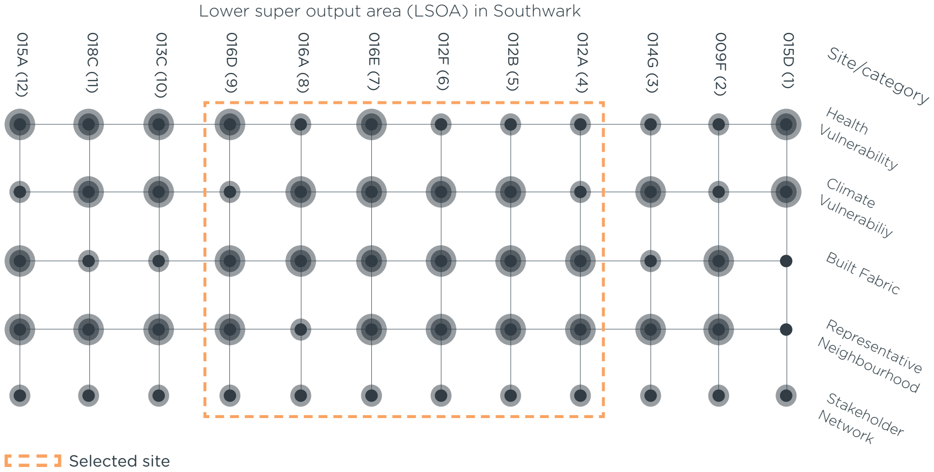
This appendix offers a summary of the neighbourhood analysis our teams completed in support of the resilience framework. Our fieldwork was based near the Ramboll and Impact on Urban Health London offices, as we share the ambition of collaborating and understanding the places and communities within which we are based.

Images: Case study site. **Fig.A1, Left:** Map of Impact on Urban Health and Ramboll office locations in the London Borough of Southwark. **Fig.A2, Right:** Views of the local street market.

Our research identified four critical gaps. The first is the need that our framework looks to address - for resilience thinking to be unpacked and made more actionable, collaborative and health equity-focused.

The following pages discuss the other three gaps identified:

- Developing knowledge on thermal comfort diversity for more inclusive metrics and visualisations in climate vulnerability analyses that better reflect communities;
- Improved analytic, policy and guidance tools that capture neighbourhood experiences of inequality.
- Increasing multi-seasonal resilience strategies and designs to account for local extreme climate events year-round, noting synergies and trade-offs to increase resilience overall.



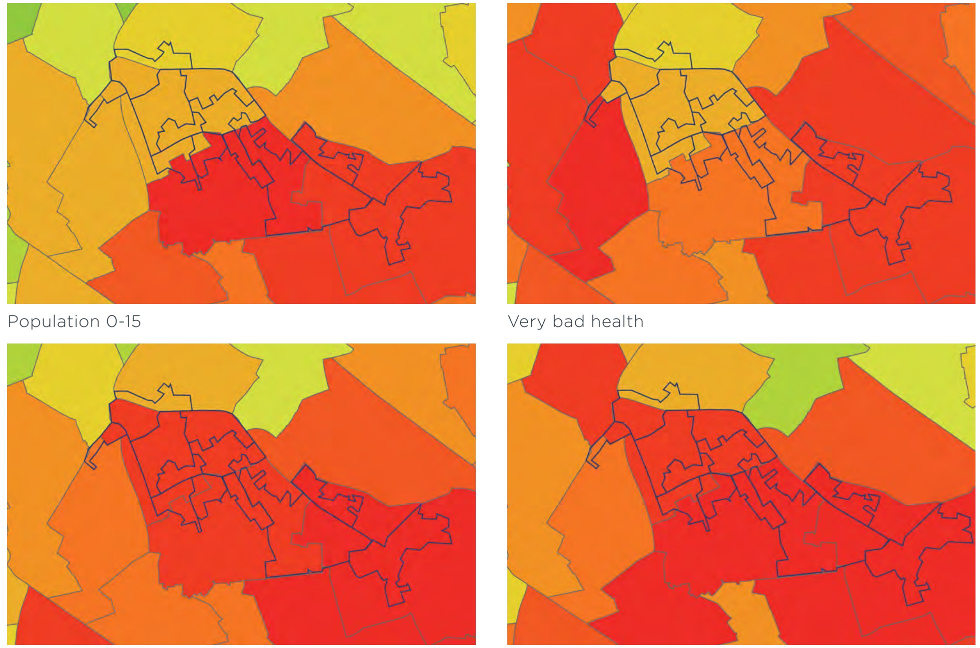
STUDY AREA SELECTION

With the objective of selecting a neighbourhood case study within the London Borough of Southwark, place-based assessments were carried out across five categories. Through this process, a neighbourhood was identified as representative for Southwark, Lambeth and London overall, so that lessons learnt will be applicable across the city and possibly other cities as well. Initially refined by LSOA due to the way data is collected, the assessment process demonstrated that no one LSOA fully encompasses all of the desired characteristics for a representative neighbourhood. We have therefore drawn a site boundary to span multiple LSOAs and characteristics.

The case study neighbourhood selected is situated south of Elephant & Castle underground station, between Rodney Road and Flint Street to the East, and Walworth Road to the West. Three main characteristics determined the boundary for the neighbourhood study:

The site is highly representative of other neighbourhoods
The site spans 0.25sqkm and is largely residential. It includes retail, green spaces and schools, among other local services located within its boundary. Home to a range of Georgian and Victorian terrace houses, pre- and post-war social housing, and new build developments, it reflects building and street typologies that are common in London and other cities in the UK. It has a mix of public realm and green spaces – a playground, pocket gardens, a neighbourhood park, a street market, major highway/commercial streets, among others.

Heat and climate vulnerability is diverse, though at relatively high risk
The site represents communities within an area that are all highly susceptible to climate hazards (including air quality, overheating and flooding), made worse by high levels of local deprivation. Local communities are therefore more vulnerable with a pressing need for climate justice interventions.

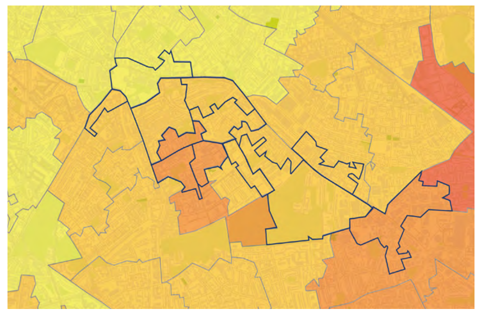


Population 0-15

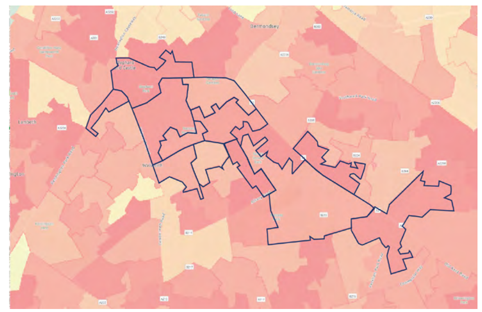
Very bad health

Cardiovascular disease

Net annual household income estimate after housing costs



Social-spatial vulnerability



Overall climate risk

Existing stakeholder and community links
The site is part of IoUH's area of previous and ongoing work, providing an existing understanding of social and health conditions, active community organisations, and the local social determinants of health. As this project has a relatively short timeline, these existing ties enabled in-depth local engagement, through citizen science, qualitative and quantitative research, led by the Bureau of Investigative Journalism (Eccles et al. 2023, Hamada et al. 2023).

Less vulnerable — More vulnerable

Images: Elements from the site selection process. **Fig.A3, Top Left:** Decision matrix. **Fig.A4, Top Right:** 4 Snapshots of LSOA Conditions, Source: IoUH's Urban Health Index (UHI). **Fig.A5, Bottom Left:** Map of social-spatial vulnerability, Source: ClimateJust. **Fig.A6, Bottom Right:** Map of overall climate vulnerability, Source: GLA

WORKSHOPS & REVIEWS

Multi-disciplinary stakeholder workshops were held between July 2023-February 2024. They included a wide number of experts from across Ramboll and Impact on Urban Health. The objectives of the workshops were to develop an understanding of how different disciplines approach resilience and their technical considerations, and to further consider comprehensive and trans-disciplinary solutions to neighbourhood resilience. Three main topics were discussed:

- Climate health vulnerability - definition, inclusive parameters, and existing gaps in approaches to resilience;
- Parameters by which strategic neighbourhood locations can be prioritised for interventions to yield positive impacts;
- Outdoor intervention design to enhance microclimate control in the public realm and thermal comfort within homes.

Follow-up workshops were held in smaller groups to review findings. Results and feedback from our experts have been embedded within the resulting framework. Our workshops included experts from different backgrounds and teams who contributed to the research and development process. We would like to thank experts from Impact on Urban Health and the following Ramboll teams: • Air Quality • Building Physics • Building Services • Building Structures • District Energy • Ecology • Impact Assessment • Integrated Infrastructure • Landscape • Management Consulting • Regenerative Cities • Strategic Sustainability • Water

DIGITAL MODELLING

In the context of climate change, there is a growing need to quantify how comfortable an outdoor space is to understand whether it improves on or worsens existing vulnerabilities.

Universal Thermal Climate Index (UTCI) is a standardised approach developed by an international working group of academics and industry experts to provide a consistent approach to measure comfort anywhere in the world. It is comprehensive in that it takes account of human physiology and our 'felt' response to the environment. Currently it is commonplace for microclimate studies on wind speed to be carried out around tall buildings in cities, to ensure pedestrian safety from very high wind speeds. In the future, Planning Councils will be requesting the use of UTCI more commonly, to assess the impact of urban development on comfort and ensure it is maximised throughout the year for the general public.

Ramboll building physics team have undertaken a UTCI study for the site in Southwark to understand how thermal comfort;

- changes throughout the year;
- is influenced by the urban form and fabric;
- is impacted by climate change.

KNOWLEDGE GAP 1: MODELLING VULNERABILITY

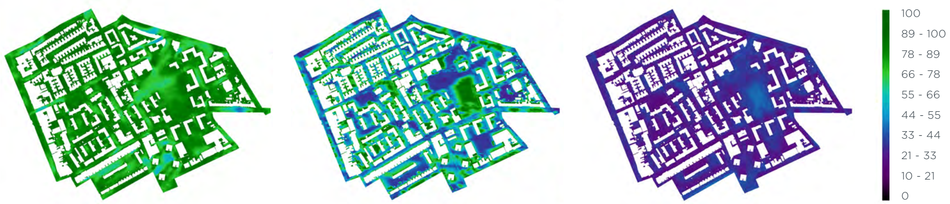
To map and capture the thermal comfort of the general public, UTCI modelling has a 'person setting'. The model applies a code for a 'universal average', with the metabolism and thermal comfort level set at that of a healthy man in his 30s with light brown skin, standing still and wearing clothing 'appropriate for the weather'.

This 'universal average' overlooks the most vulnerable, meaning that when we apply this methodology in our studies, we have data gaps on climate and health vulnerabilities. Demographics, biological sex, health conditions, cultural and religious practices, and physical activity, together with environmental conditions, alter a person's physiological threshold capacity for thermal stress. While, our teams attempted to change the settings, there is currently insufficient scientific evidence to support recoding thermal comfort for inclusivity.

Fig.A7: Infra-red/ thermogram image of the human body, which shows Female and children has a higher body temperature than the 'unviversal average' person (male in his 30s) and therefore experience thermal and cold stress differently. Source: BSIRA (2017)

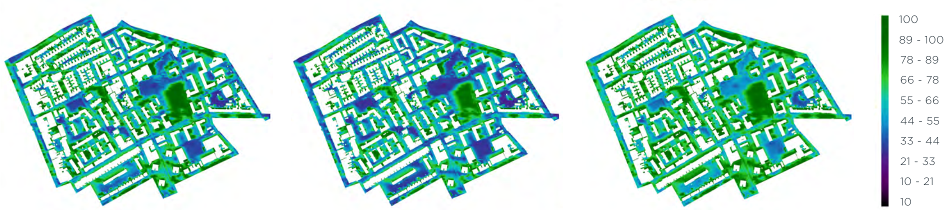
KNOWLEDGE GAP 2: INTEGRATED PLANNING GUIDANCE

Guidance from the City of London Outdoor Thermal Comfort Assessment (OTCA) recommends assessments based on a comfort range between 0°C and 32°C. This range includes moderate thermal stress levels for people with no health conditions. For our models to simulate more inclusive thermal comfort conditions, we have applied the recommended UTCI comfort range between 9°C and 26°C. By reducing the range based on European best practice guidance, our models are more sensitive to vulnerable populations. Furthermore, the OTCA has been written for new development microclimates, lacking requirements for monitoring and evaluation after delivery. When considering future scenarios, CIBSE future weather files have been applied, as set by global standards. We have noted, however, that the CIBSE future weather files only account for adjusted dry bulb temperatures and not potential change in wind speed and humidity. Our modelling experiences revealed the need for further developing integrated approaches that focus on neighbourhood inequality in analyses and guidance.



% of time a region exist between the comfortable range, between 9 - 26 degrees (April, July and January 2020)

% of time a region exist between the comfortable range, between 9 - 26 degrees (December, January and February 2020)



% of time a region exist between the comfortable range, between 9 - 26 degrees (June, July and August 2020)

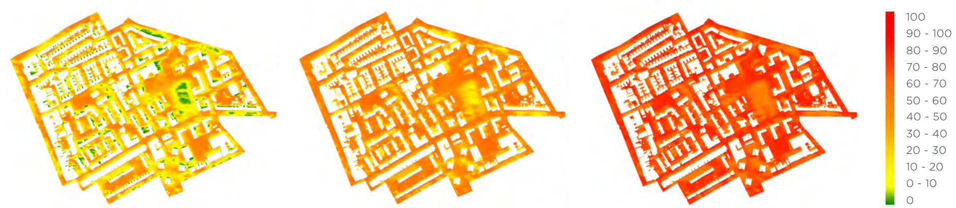
UTCI RESULTS

Our analyses demonstrate the extent of challenges from overheating over the summer period. However, it is worth noting that in relative terms, the winter period still generates the highest proportion of discomfort. This is particularly pertinent for the elderly or those with disabilities, who may find walking to local amenities too difficult and risky. Though much attention is paid to the impacts of climate change on overheating, when we look ahead to 2050 or 2080, the relative proportions of discomfort remain highest in the winter months.

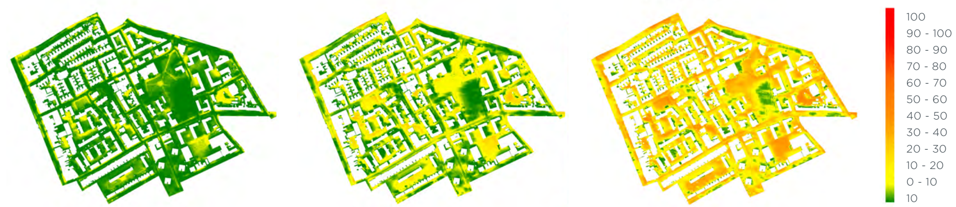
By 2080, it will also be very difficult for anyone to find comfortable spaces out of doors in August, even where plenty of shade is provided. This stark reality may require more drastic interventions at the urban scale, and perhaps more widespread behavioural change to develop new forms of resilience. During the shoulder seasons, we may see increased levels of comfort as temperatures rise, however, with the increasing rainfall predicted, this may not actually result in higher numbers of hours spent outdoors.

Images: UTCI Modelling results overview.
Fig.A8, Left: Comparative thermal comfort ranges
Fig.A9, Right: Summer, % of time a region exists above the comfortable region (>26°C).

% of time a region exists above the comfortable range, above 26 degrees (June, July and August 2020)



% of time a region exists above the comfortable range, above 26 degrees (2020, 2050, and 2080)



% of time a region exists above the London OTCA comfortable range, above 32 degrees (2020, 2050 and 2080)

The impacts of urban form and fabric are apparent in our models, primarily due to shading from taller buildings. Surface materiality has been taken into account in the models. For instance, parks and green spaces show a small reduction in felt temperature due to material characteristics, as opposed to concrete or tarmac, which generally absorb solar radiation and continue to heat up throughout the day. Access to green space with trees is absolutely paramount to providing good quality spaces in the summer months, ideally within good walking distance down shaded streets. In the winter the more comfortable spots are generally where the wind speed is reduced but solar access remains, allowing the warmth of the sun to slightly increase felt temperatures.

In the summer, the most effective strategy to reduce overheating is shade. This is evident from the areas with extensive tree cover. In these areas the reduction in felt temperature can be very high, resulting in comfort. There is also a benefit from wind speed, which can reduce felt temperatures. This effect can be particularly seen around street corners or narrow streets where the wind speed is higher due to funnelling effects. Although this is a welcome effect in the summer months, care must be taken that the same effect does not cause undue stress in winter, when cold temperatures are made worse by increasing wind speeds.

Images: Neighbourhood models combining Universal Thermal Comfort Index (UTCI) model with Computational Flow Dynamics (CFD) for wind. **Fig.A10, Left:** Winter, % of time a region exists below the comfortable region (<9°C) in January 2020. **Fig.A11, Right:** Summer, % of time a region exists above the comfortable region (>26°C) in August 2020.

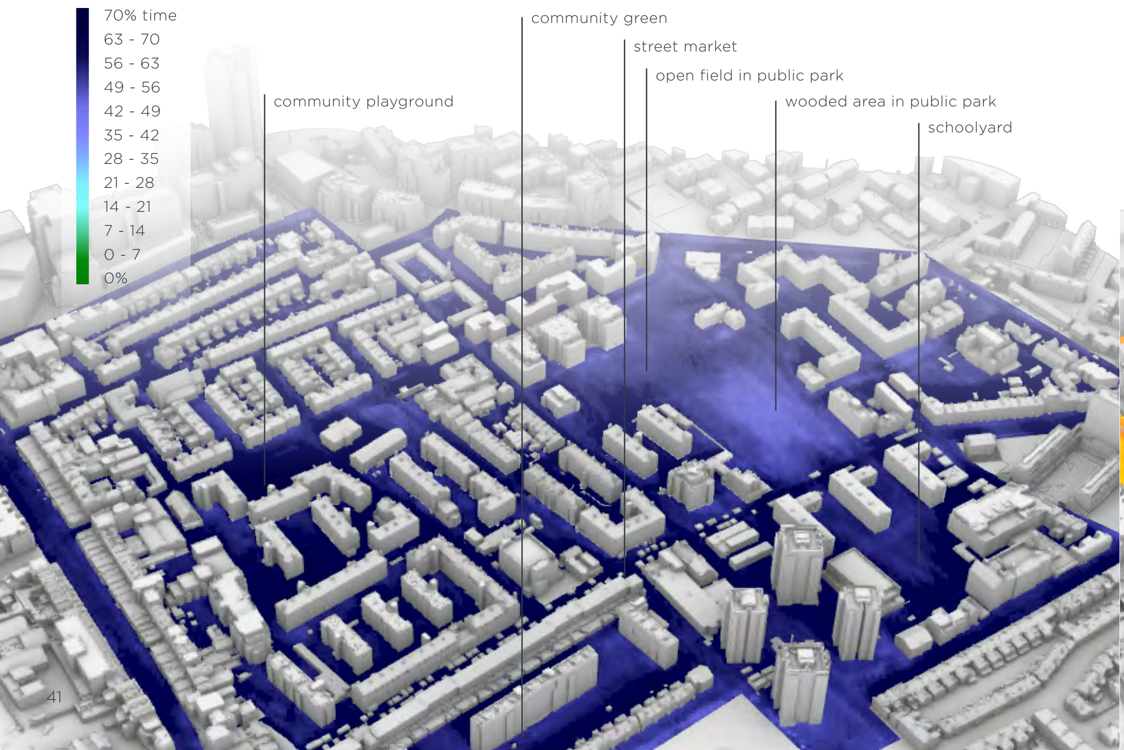
KNOWLEDGE GAP 3: MULTI-SEASONAL APPROACHES

Interventions that reduce heat stress may increase the risk of cold stress and vice versa. In our workshops and literature review, we noted that often cold and hot, drought and floods are considered separately.

However, our future designs will require adaptability across seasonal changes to leverage some conditions and mitigate others. It is therefore important to think about the neighbourhood as a whole system, and how it functions across seasons. Multi-seasonal analyses in the context of climate change will help us to further understand how neighbourhoods shape people's lives, and in particular, how they worsen or alleviate their vulnerability.

The modelling has provided a glimpse into the site's varying comfort levels throughout the year and into the future. It provides strong evidence for the case of modelling, visualising, and quantifying comfort levels before significant interventions at the neighbourhood, city and regional scale.

While the model has helped us identify patterns of relationships between spaces, behaviours and vulnerability, it has also revealed existing gaps. **Much of the data and guidance we found focused on solving microclimate as opposed to resolving barriers to resilience.** There is a need for more research on the multiple vulnerabilities our spaces, structures and communities have to the impacts of climate change to enable evidence-based and health equity-focused policy and design recommendations to be developed.



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