Suburban Neighbourhood Adaptation for a Changing Climate (SNACC)

Final Report

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The overall Programme contributes to the Living with Environmental Change (LWEC) Infrastructure Challenge which aims to make infrastructure, the built environment and transport systems resilient to environmental change, less carbon intensive and more socially acceptable. For more information on SNACC, ARCC and LWEC please see:

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A full list of project partners can be found at www.snacc-research.org

Why do suburbs need to be adapted to mitigate further climate change and withstand ongoing changes?

- **In England, over 85% of the population lives in areas classified as 'suburban'**. Suburbs are most commonly thought of as areas that are: predominantly residential, towards the edge of towns and cities, mainly owner-occupied, and often (but not always) characterised by medium-low density development and detached or semi-detached housing. However, suburbs differ in terms of their physical characteristics, and the socio-economic and cultural characteristics of their residents.

- **It is in suburbs that the majority of the population will be affected by climate change**. The main climate changes that people will experience are hotter and drier summers (with more heat-waves), and milder, wetter winters. There will be more storms and the potential for more flooding.

- **The impacts of these changes will be felt by people, in terms of, for example, increased heat stress and reduced comfort during hot spells, restrictions on water use, reduced air quality, and stress and costs associated with flooding and storm damage**. The impacts will also be evident in the physical environment, through effects such as deterioration of public green spaces and gardens, flood damage and increased risks of subsidence (in some places).

- **A number of physical changes could be made to homes, gardens and the public realm in suburbs to mitigate further climate change, and withstand ongoing changes**. These changes range from small-scale adaptations to homes (such as adding insulation or shutters) and gardens (such as growing food and installing water butts), to large-scale modifications at the neighbourhood level (such as greening schemes or developing sustainable urban drainage systems).

- **Yet, processes of change in the physical environment within suburbs are complex**. A range of stakeholders are responsible for different aspects of the built and natural environment, and for different climate risks. Stakeholders include local authorities, utilities, regulatory authorities, developers, built and natural environment professionals, individuals and communities. These stakeholders have various resources, powers and knowledge, and their actions take place in different local policy and governance contexts.

What is the current situation in English suburbs with respect to adapting to reduce further impacts of climate change and withstand ongoing changes?

- **At the home and garden scales some mitigation and adaptation actions are taking place, but for the majority of residents climate change is a non-issue**. The adaptations that are being implemented, such as installing insulation or triple glazing, setting aside land for growing vegetables, or collecting rainwater are generally being done to save money, or because they are linked to DIY or gardening as hobbies. Most residents: do not think about climate change in terms of needing to adapt to future weather; are sceptical of the extent of climate change; welcome an increase in summer temperatures; and do not see the need to prioritise spending money on adaptations.

- **At the neighbourhood scale, very little adaptive action is taking place**. Some adaptive measures are linked with regeneration projects or area-wide greening strategies, but very little is explicitly related to adapting to future conditions.

- **There is no clear process, or delivery mechanism, for adaptation and/or mitigation at the suburban neighbourhood scale**. Many of the most effective measures are not currently being carried out in existing areas nor is large-scale retrofitting likely to occur.

How can suburbs be best adapted to reduce further impacts of climate change and withstand ongoing changes?

- The best adaptations are those that are: effective (i.e. do the job they are designed to do, e.g. reduce flood risks or cool a home), without adverse impacts; feasible (i.e. possible to implement in a particular place, given the existing local conditions) and acceptable to those who have to implement, or live with, them (i.e. the adaptation is satisfactory in terms of cost and/or visual appearance).

- There is no 'best' 'one size fits all' adaptation package that will work in every suburb. The best adaptations depend on the type of suburb (and type of housing within it), the climate threats in that suburb (e.g. some suburbs are at risk of flooding, others are more prone to overheating), and the response capacity in that suburb (e.g. the economic and social conditions, and resources available).

- Effective adaptations must combine 'adaptive retrofitting' with 'low carbon retrofitting'. There is a danger that some low carbon adaptations may make suburbs less able to cope with future weather conditions, for example some forms of insulation, in some homes, may exacerbate the risk of overheating.

- Although the UK is projected to remain a heating dominated climate, wherein improving the thermal properties of building fabric will be essential, other adaptive measures to reduce the risk of future overheating on a house level are urgently needed. A fabric-based future proofing approach comprising mitigation and adaptation measures is required for large-scale refurbishment of existing housing.

- At both the neighbourhood, and individual home and garden scales adaptation 'packages' are more effective than single measures. Adaptation packages were found to be effective in reducing the risk of overheating in homes, and a range of greening, landscaping and engineering measures would make neighbourhoods more liveable in future climate conditions.

- Some neighbourhood adaptation options would be effective in adapting most suburbs for future climate threats. For example, 'greening' streets and public spaces (adding street trees, allotments, new green spaces), introducing sustainable urban drainage features, and changing to energy-efficient street lighting would be effective (and acceptable) in the majority of suburbs.

- Some residential adaptation measures are suitable for all housing, but others are only feasible for specific dwelling types. For example, most homes would benefit from roof insulation, window shading, and water-saving devices. Yet measures such as cavity wall insulation are clearly not feasible for homes built with solid walls. Some measures, although they could be implemented in all housing types, are more effective and likely to be carried out in particular suburbs. For example, growing food and shading outdoor space are more effective and likely in homes with larger gardens.

- For residents, the 'best' adaptations tend to be cheap, convenient, practical (given the type of home they have), attractive, and have some other lifestyle benefit. Householders are also more likely to implement dual-purpose adaptations such as those that meet mitigation and adaptation criteria (e.g. insulation), or those that improve comfort and are visually attractive (e.g. greenery).

What are the best adaptations for mitigating further climate change?

- Home energy saving adaptations (roof and wall insulation, double/triple glazing, photovoltaics and solar panels) were found to be effective in almost all suburbs (notwithstanding some concerns about overheating), and are well understood by residents and stakeholders. However, there are uncertainties around their acceptability and likelihood of implementation.

- Increased greening of homes and gardens (including food growing) is effective and has multiple benefits in suburbs. Residents are positive about it and likely to increase greenery in their own homes and gardens. Neighbourhood greening is welcomed, but there are resource issues and practical problems in implementing it.

What are the best adaptations for flooding?

- Effective adaptations to reduce the risk and impact of floods in suburbs need to address pluvial flooding from inadequate storm water drainage, as much as fluvial flooding from waterways. This is because the former may contribute to a greater proportion of flooding problems in the future with increased rain intensity and storm activity expected from climate change. Ensuring porous surfaces are retained is important (for example, restricting paving over front gardens and laying large patios), as is the development of sustainable urban drainage systems (SUDS). However, retrofitting SUDS in suburbs can be both disruptive and expensive.

- A number of individual house-scale adaptations can be effective in limiting some damage from floods (e.g. air brick covers, flood-proof doors, flood gates). However, they are unlikely to be implemented by residents, even if they have experienced flooding or live in an area at risk. Householders are concerned that drawing attention to the fact that their home might flood will decrease its market value.

- Effective adaptations are those which leave the neighbourhood or home more resilient after a flooding event than it was before. This can mean that the neighbourhood is protected from further flooding, or that flood damage is limited. However such adaptations are often difficult to implement because insurance companies often only replace 'like with like': they do not pay for more resilient adaptations.

What are the best adaptations for summertime overheating?

- A number of adaptation options are effective in combating overheating in homes, but the effectiveness of these options depends on the characteristics of the home. The most technically effective adaptive approach is to reduce solar radiation into, and onto, the home. This can be done in a number of ways on different scales, e.g. planting of trees in the streets and wider neighbourhood, and/or installing external shading on homes. Natural ventilation of the home is also extremely effective. Combining adaptation options into packages is the most effective method of reducing the risk of overheating.

- Overall, external shading (e.g. fixed outdoor window shades or external shutters) is more effective than internal shading (e.g. blinds). External shutters are the most effective as they keep solar radiation off window surfaces but this requires keeping shutters closed during summer days (reducing natural light in homes). Planting green wall cover, garden trees or street trees is also an effective shading measure for homes although care needs to be taken in selecting appropriate species of trees and plants.

- Increasing the reflectivity of the exterior surfaces of homes, e.g. a bright white render for the exterior walls can also reduce overheating risk, and residents are quite likely to implement it, if it does not unduly alter the image of their neighbourhood.

- Addition of thermal mass to the home, e.g. replacing a timber floor with a concrete floor reduces potential overheating dependent on the location of mass and the capacity to release heat through night time natural ventilation. However, thermal mass is poorly understood by residents and they are unlikely to take action.

- External insulation is effective in either reducing overheating risk or minimising the increase in overheating risk that would happen as a result of installing insulation in homes. Internal wall insulation can increase the risk of overheating. However, external wall insulation is not popular with residents and they are unlikely to implement it.

- Reducing internal gains from sources such as hot water heating tanks and pipe work in the home is a very effective and cheap way to reduce the risk of overheating and increase energy savings.

- At the neighbourhood scale, the introduction of blue and green infrastructure is likely to bring cooling benefits and is welcomed by residents. However, there is uncertainty over implementation, particularly about cost and responsibility for installation and management.

- 'Community cool rooms' could be effective in heat waves, but few residents or local stakeholders perceive a need for them, or would be likely to implement them.

What are the best adaptations for storms and driving rain?

- A number of adaptations are effective in protecting homes, gardens and neighbourhoods from storm damage (e.g. weather-proofing treatments to external walls, trickle vents, retaining porous surfaces). However, residents are unlikely to implement these specifically to protect their homes from storm damage. They are more likely to engage in routine maintenance (e.g. clearing gutters, replacing lose roof tiles, ensuring garden fences were well constructed) to address storms. At the neighbourhood scale, few adaptations are even considered in respect to storm damage.

What are the best adaptations for droughts and water scarcity?

- Effective adaptations to homes and gardens include rainwater harvesting systems, and simple measures such as water butts. However, rainwater harvesting is poorly understood and unlikely to be implemented in most suburbs. Water butts are popular and already commonly used. Residents understand water scarcity but this does not make them more likely to plant drought resistant plants or change the type of fruit and vegetables they grow.

- At the neighbourhood scale, planting that can withstand climate changes and requires less water is seen as an effective measure and is likely to become more commonly implemented by local authorities.

- SUDS can be effective, and are more feasible in lower density suburbs with more porous surfaces, but they can be both expensive and disruptive to retrofit.

What might motivate residents and other stakeholders to mitigate further climate change and adapt to ongoing changes?

- **More experience of climate change (gradual changes and extreme events)**. Currently, climate change is not a motivator for change in suburbs. Householders find it hard to relate to because they have not generally experienced problems. As the public are not overly concerned, the issue is not high on the political agenda either. However, as England experiences more heat waves, floods and extreme weather it is likely that responding to these risks will become a higher priority politically and practically.

- **Normalising of simultaneous mitigation and adaptation practices, and their introduction into organisations' long-term planning and day-to-day activities**. As experiences of climate change become 'real', and mitigation and adaptation measures are introduced they are likely to become part of normal decision making processes for householders and other stakeholders. As adaptations become more visible, they are likely to become more acceptable.

- **Integrating adaptation into existing public and policy agendas**. Adapting to ongoing climate change is likely to be most successfully addressed by linking it to other issues such as low-carbon and healthy community agendas. Incorporating climate change adaptation to the rationale for implementing change to the built environment for these other agendas could generate increased impetus to the political will for adopting some of these measures. It would also be essential to ensure action for other agendas does not conflict with the need to adapt to the anticipated climatic changes.

- **A better understanding of the multiple pathways, involving a range of stakeholders, that could deliver effective suburban adaptation**. There is no single 'process' of effective adaptation. It is likely that a combination of individual, community, government-led, and partnership actions will be required. The potential for community action needs to be maximised. Building on existing community capacity (not necessarily around climate change issues) could be an effective way of integrating adaptation activity into neighbourhoods.

- **Prioritising resources for adaptation. Currently both householders and local and national government are not prioritising resources for climate change mitigation or adaptation to effectively adapt suburbs**. This is partly because many of the changes needed are costly and have medium-long term benefits.

- **Clearer responsibilities for adaptation. At the suburban scale one of the key problems in effective mitigation lies in understanding who is responsible for change**. There is confusion over the scale at which risk should be managed and ownership patterns in suburbs, and there are misunderstandings about the nature of risk and insurance. Without significant clarification various agencies will do nothing in many suburbs, and leave neighbourhoods vulnerable.

- **Communicating climate change and its risks effectively for different audiences**. Different actors involved in, or affected by, suburban adaptation engage with it in different ways. Hence, framing changes to homes and local neighbourhoods purely in terms of 'climate change' and 'risk' is not always effective in motivating action. Stakeholders with the responsibility for informing the public about climate change risks will need to find effective ways of communicating. 'Climate change' messages can create resistance to action, so householders may need to be engaged through messages about the practical and immediate benefits of installing adaptation measures, and the cost-effectiveness and 'quality of life/comfort' benefits.

- **Ensuring practical information about adaptations is communicated at the right time and by trusted people/organisations**. It is important that householders get the right advice or information when they may be about to make changes to their properties e.g. when they first move into a new home, when they are doing other home improvements, or when they are applying for planning permission or building regulation approval. It is also important that frontline contact points, e.g. builders, DIY store staff, planning and building regulation staff and utilities can help with accurate information.

- **Ensuring adaptation is embedded in planning policies and practices and building regulations. Planning policies and building regulations need to ensure that future climatic conditions are considered when changes to the physical environment of suburbs are proposed**. Neither have much power to pro-actively bring about change: but they could be more powerful in stopping future problems from emerging. A key example is that newer homes (i.e. those built to meet improved fabric regulations) are more sensitive to potential overheating than older homes. As the current UK building regulations and retrofitting programmes are mainly concerned with heat retention (and CO_2 reduction), it is essential that future revisions to building regulations and other policy measures tackle the risks of, and potential for adapting to, climate change driven overheating to ensure a comfortable environment for occupants.

- **Learning from places where neighbourhood action (and/or adaptive action) is successful**. Although cases of fully adapted neighbourhoods are rare, there are examples of good practice in terms of neighbourhood level action that could be applied to the suburban context. There are also examples of built environment solutions from countries with climates similar to that projected for England that could inform local strategies here.

- **Ensuring that central government-controlled mechanisms such as grants and subsidies are appropriate to deliver effective adaptation**. Government initiatives and funding are welcomed, but poorly understood by most householders. It is important that initiatives are appropriately framed, perhaps linking to peoples' interest in home improvement and money saving, more than to climate change and risk. The initiatives also need to be clearly explained and simply administered.

Contents

1.1 Introduction

This report presents findings from the Suburban Neighbourhood Adaptation for a Changing Climate (SNACC) research project. The project aimed to answer the questions:

- How can existing suburban neighbourhoods in England be 'best' adapted to reduce further impacts of climate change and withstand ongoing changes? and;

- What are the processes that bring about climate-change motivated adaptation in suburban areas? Specifically: what might motivate residents and other stakeholders to adapt to present and future climate threats?

Hence, we sought to find out which adaptations to the physical environment of homes, gardens and suburban public spaces work best and how can they be delivered. In testing which adaptations were 'best' we determined if they were:

- Effective, by which we meant the adaptation did the job it was designed to do (e.g. reduce flood risks or cool a home), without adverse impacts.
- Feasible, by which we meant the adaptation was possible to implement in a particular place, given the existing local conditions.
- Acceptable, by which we meant the adaptation was one that stakeholders were likely to implement or would welcome in either their neighbourhood or their home and garden. This meant that, for example, the adaptation was 'acceptable' in terms of cost, visual appearance, and absence of negative side-effects.

This report gives a brief overview of the project's approach and methods and summarises its findings. First, it sets the context for suburban adaptation in England and explains how the project conceptualised the adaptation challenge.

1.2 The context for suburban adaptation in England

It is widely accepted that our existing built environments are both contributing to, and adapting poorly for, climate change. Our building stock is ill-equipped for either gradual changes in average climatic conditions or extreme events, such as heat waves. Suburban areas are often seen as major contributors to climate change, and as places that are poorly adapted at present. They tend to be characterised by low-medium density housing that is energy- and land-rich, and built in layouts that encourage car use and discourage walking and cycling (HoC, 2008). In terms of the urban sustainability debate, they are vilified as individualised, single-use, wasteful places, where a combination of lifestyles and urban form compound problems.

Yet, suburbs are here to stay. The built environment changes at a rate of about 1% a year, so the majority of suburban buildings will still be here in 50-100 years, with plot structures, roads layouts, and major infrastructure being more enduring. People are also likely to want to carry on living in suburbs, with almost all attitudinal research showing that suburbs are still the preferred residential location of the majority of households (Williams, 2007).

In England, over 85% of the population live in areas classified as 'suburbs' DETR (2000). Suburbs are commonly understood as urban areas that are: predominantly residential, towards the edge of towns and cities, relatively low density, and often characterised by detached or semi-detached housing (URBED and SEERA, 2004). They serve adjacent urban centres and other nearby settlements, and are predominantly owner-occupied. However, other than these basic characteristics suburbs vary greatly. They have been developed over time and have different architectural styles and layouts (Williams et al. 2010; URBED, 2002; 2006). The mix of land uses in suburbs also varies: some are almost wholly residential while many are relatively mixed, with amenities and economic uses, such as shops and small businesses. The socio-economic status of suburbs can also be very different. Some suburbs accommodate wealthy households, others house populations from lower socio-economic groups, and others still are home to middle-income families (Gwilliam et al 1998; Peacock et al, 2007; Bond and Insalaco, 2007; and McManus and Ethington, 2007).

It is in these varied suburban settings that the majority of the population will be affected by climate change. People spend most of their time in their homes, and will therefore be affected in their domestic lives in the suburbs. The main climate changes that residents will experience are: hotter and drier summers, with more heat-waves and winters that are milder, and wetter. There is also the potential for more storms and for more flooding (UKCP09; DEFRA, 2012).

The impacts of these changes will be felt by suburbanites, in terms of, for example, increased heat stress and reduced comfort during hot spells, increases in respiratory problems, restrictions on water use, and personal stress and costs associated with flooding and storm damage. The effects will also be evident in the physical environment, through impacts such as deterioration of public green spaces and gardens, flood damage, increases in damp and mould, and increased risks of subsidence (on certain types of soil) (DEFRA, 2012b; Gupta and Gregg, 2011; Williams et al. 2012). There may also be some impacts that are seen as positive, for example, more warm days to spend outside, prolonged growing seasons for some plants, and warmer winters that reduce heating requirements. Given this context, it is likely that some aspects of the suburban environment need to be adapted in order to ensure they are liveable in the future. Unless changes are made, the human experience of living in suburbs, and the fabric of the built and natural environments, will all suffer.

1.3 The climate change adaptation challenge

If progress is to be made on suburban adaptation, some key contextual factors have to be considered. Only by understanding the existing nature of suburbs and suburban change is it possible to develop effective strategies for adaptation. Hence, the starting point for the study was the acknowledgement of some of the key factors affecting suburban adaptation:

- **The nature of existing suburbs:** Whilst it is possible to make some generalisations about suburbs, there are significant differences between them that impact on their exposure to climate risks, their vulnerability and the capacity of residents or other stakeholders to adapt. These variables include:

  a. The era in which they were built and their morphology, e.g. historic inner suburb; planned suburb; social housing suburb (URBED, 2006);
  b. the existing quality, form and ownership patterns of their physical environment;
  c. the mix of land uses within them (e.g. spread of domestic, non-domestic, green space and built land);
  d. their location within different climatic regions and water catchment areas (different climatic futures are likely in different regions);
  e. the socio-economic and cultural characteristics of the people who live in them, and;
  f. the institutional/governance arrangements by which they are managed.

- **The nature of change in suburbs:** Although residential built environments change relatively slowly, incremental adaptations take place continually in suburbs. In addition, English suburbs are under pressure to accommodate a large number of new homes in the next 30 years. Hence, there is some potential for significant, positive adaptation and re-design through new building and retrofitting.

- **The number and diversity of people and organisations that make changes in suburbs:** Suburbs are co-produced over time by homeowners, public bodies and private companies, through dual processes of autonomous adaptation (i.e. undertaken by private householders, or companies, for their individual benefits) and 'planned' adaptation (undertaken by public bodies, usually Local Authorities, for the public good). In addition, suburbs may also, on occasion, be partially adapted through 'communal' actions by residents. Hence, there are a number of important stakeholders that can bring about change in suburban areas.

- **The nature of potential adaptations:** There are numerous changes that could be made to the physical environment of suburbs to enable them to mitigate against and adapt to climate change.

These adaptations can be applied to homes, gardens and public spaces (e.g. streets and parks) in suburbs. Autonomous adaptations affecting resilience and mitigation can include actions like planting trees to increase shading, installing ponds and domestic rain-water systems, improving passive ventilation and insulation, and ensuring additions and extensions to homes include resilient ducting, cabling and drainage. Planned or communal adaptations of the public realm could include measures such as, providing additional public open space, 'greening' public spaces, or implementing green roofs at a neighbourhood scale.

- The anticipatory and long term nature of change required. A key issue for many climate change actions is that they are, in the main, anticipatory, rather than reactive. Effective adaptation may also need to be achieved through a mix of private and joint adaptations. However, it is well established that there are serious problems in getting people to act in anticipation of predicted climate change, i.e. for autonomous adaptations, and this is particularly the case in capital intensive sectors, such as the built environment (Few et al, 2006). Furthermore suburban areas tend to lack the means for co-ordinating planned or communal changes (in terms of management structures, fragmented property ownership patterns and institutional capacity).

1.4 A conceptual rationale of suburban adaptation

Given this context, the SNACC project developed a conceptual rationale which informed its research design (Figure 1.1). This explains the logic of our research questions and focus, and underpins our choice of methods.

The starting point is the realisation that England's suburbs will be affected by climate change for the foreseeable future (A, in Figure 1.1). These impacts will be on both 'place' and 'people'. Places (homes, gardens, streets and open spaces) will be affected by, for example droughts, and flood and storm damage. People will be affected through issues such as comfort, cost of damage to buildings, and health impacts. The impacts may be gradual (e.g. brought about by increases in summer temperatures) or the result of extreme events, such as floods and heat waves. In order to minimise future climate change, suburbs will also need to become less energy rich and reduce emissions. Hence, mitigation and adaptation need to be considered together at all times.

To ensure suburbs are well adapted, a range of measures to modify the physical environment to cope with, and mitigate, future change could be employed (B, in Figure 1.1). These measures range from small scale changes to homes, such as attaching shutters to external walls, to major remodelling and landscaping projects, such as introducing sustainable urban drainage systems. Different adaptation measures can be employed against different climate threats, and not all will be appropriate in all suburbs.

From this range of potential adaptation measures, the 'best' (effective, feasible and acceptable) options need to be implemented if suburbs are to become resilient and liveable. Yet, the ability to make changes in suburbs is a function of their 'response capacity' (C, in Figure 1.1). Response capacities will vary depending on a number of factors. The existing location and nature of the physical environment will be significant, but the economic, governance, knowledge and cultural conditions are also likely to shape what is possible in suburban areas. Within these contexts, a number of potential stakeholders could be involved in making the required changes. Major players are likely to include residents, communities, landlords and local authorities. However, their reasons (including ability and motivation) for acting are likely to be complex, and will shape the response capacity of any given neighbourhood.

The purpose of the project is to determine, from this contextual starting point, which adaptation measures are 'best' in different suburban contexts (D, in Figure 1.1). It is also important to understand the processes of change, and identify the conditions that might hinder or facilitate effective adaptation.

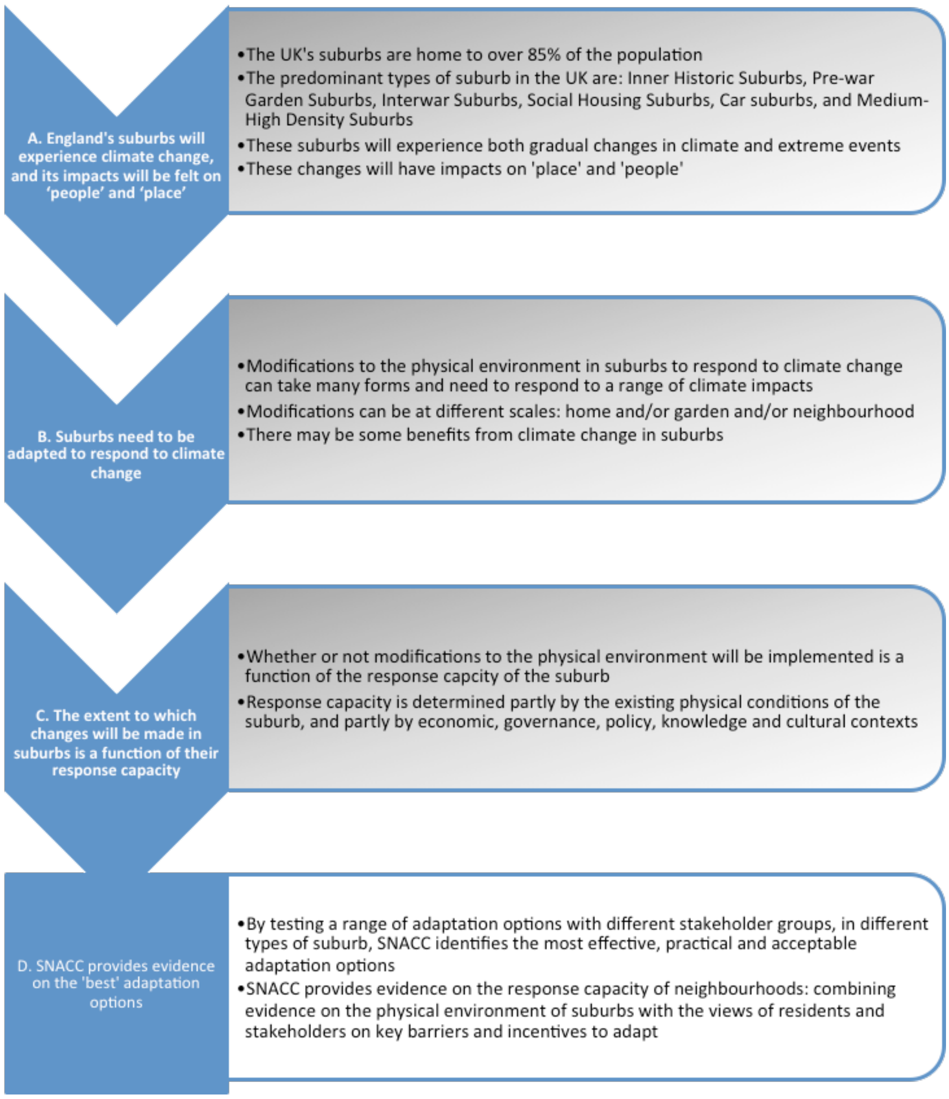


Figure 1.1 *A conceptual rationale for the conditions and challenges underlying suburban adaptation*

1.5 The structure of the report

The report now sets out, in more detail, the overall approach of the SNACC project and the methods employed in the research (Chapter 2). It then summarises how the project defined English suburbs (and developed a typology for use in the research) (Chapter 3), and sets out the potential adaptations that could be implemented in English suburbs (Chapter 4). The policy context for suburban change is then described (Chapter 5).

The report then sets out the empirical work of the study. It describes studies from six English suburbs and outlines the climate threats that they face and the potential adaptations that they could employ (Chapter 6). It then gives the key findings on the potential for overheating in suburbs (Chapter 7), and on residents' and other stakeholders' responses to adaptation (Chapters 8 and 9). The report concludes with key messages about the 'best' suburban adaptation solutions, and the challenges of bringing about suburban change (Chapter 10).

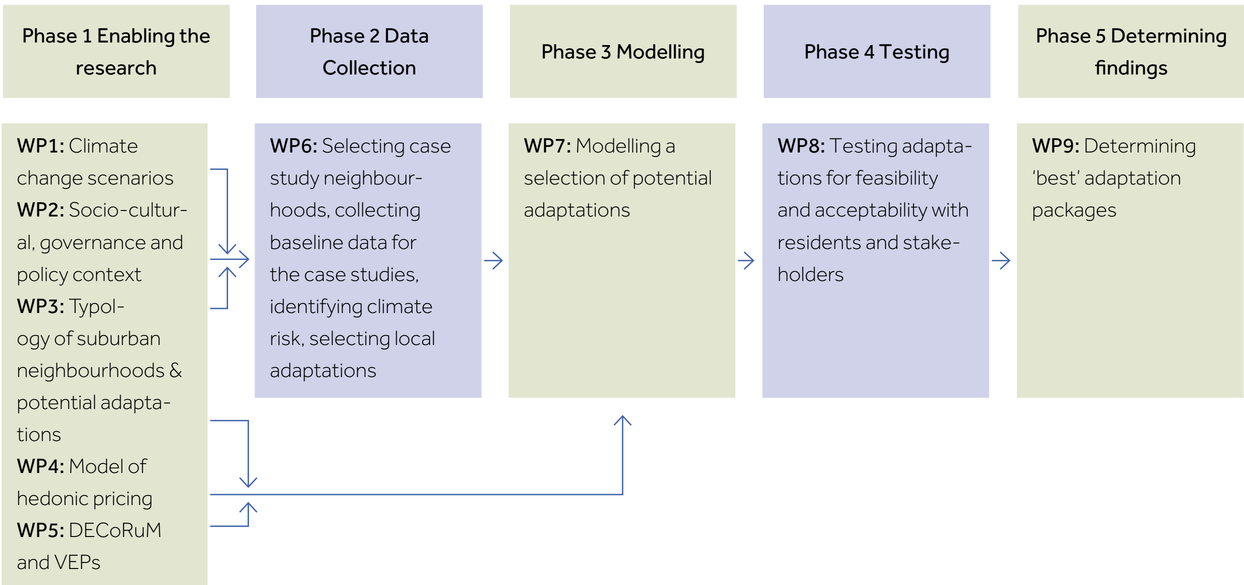
2.1 Introduction

This section provides a brief summary of the approach and methods adopted by the SNACC project. The project adopted a 'socio-technical' approach to establish the performance of a number of potential climate change adaption and mitigation measures for suburbs and to test their feasibility and acceptability with a range of stakeholders likely to be involved in their implementation. The research methods are a combination of modelling, visualisations and residents' and stakeholders' workshops. The research was undertaken in six suburbs (representing different suburban typologies, see Chapter 3) in three cities: Oxford, Stockport and Bristol. The research was undertaken in five phases (Figure 2.1).

The effectiveness of the proposed adaptations was assessed through modelling (for some measures) and by using existing data (for others). We were seeking to find out which adaptation measures 'worked', i.e. did the job they were designed to do, be it, for example, cooling or allowing storm water to drain away, without negative impacts such as increasing carbon emissions in the long term.

For each case study suburb the climate risks were assessed and a set of potential adaptations was identified. In each case the effective measures were then taken forward and presented to residents in that suburb to determine their views on the feasibility and acceptability of the adaptation options.

Figure 2.1 *SNACC project phases*



2.2 Overall approach (summary)

SNACC's overall approach was to develop and then test (for **effectiveness, feasibility and acceptability**) a range of adaptation options (singularly and in 'packages') for different types of suburb in England. In so doing, we also sought to understand how and why different adaptations may or may not be implemented (now and in the future): i.e. we sought to understand more about the processes of suburban adaptation.

To facilitate meaningful discussions at the workshops, some of the adaptations were visualised using computer graphics to help residents see what either their house or garden or their neighbourhood looked like with the proposed adaptation option. We also explored the effects on property values of some adaptations (using a hedonic house pricing model) and, where appropriate, this information was also presented to residents. At the workshops, the participants were also presented with the results from modelling that showed the overheating risks to their homes and the effectiveness of different adaptations with respect to cooling. For ease of understanding for participants, we summarised the adaptation options into: 'mitigation: home and garden', 'summer: home and garden' (dealing mainly with adaptations around heat stress and water shortages) and 'winter: home and garden' (dealing mainly with adaptations around storms, increased precipitation and flooding). We then discussed neighbourhood issues around 'streets' and 'green spaces'. For the neighbourhood scale we dealt with mitigation and adaptation issues simultaneously. We acknowledge that these groupings are an oversimplification of climate change patterns, but they were a necessary short hand for engaging with residents and stakeholders. At the workshops the residents gave their views on climate change and the adaptations we showed them.

The findings from the residents' workshops were then presented to local institutional stakeholders (including representatives from local government, NGOs, and built environmental professions) at a stakeholder workshop in each city to find out their responses to both the adaptations and to the residents' views. Through this process we determined the effective, feasible and acceptable adaptation solutions from the perspective of institutional stakeholders, and learnt about what was helping and/or hindering adaptation, and about how to enable or promote adaptive action. For clarity:

- By **effective** we meant: the adaptation did the job it was designed to do, without adverse impacts (i.e. it cooled a home, or prevented storm damage without adverse effects).
- By **feasible** we meant: the adaptation was possible to implement in a particular place, given the existing neighbourhood morphology and housing conditions (i.e. we did not test cavity wall insulation in suburbs with solid walls). Another consideration was that the scale of the adaptation was appropriate for the suburb in question (i.e. we did not test major flood barriers or large-scale infrastructure changes as these were not feasible at the local scale of our case study suburbs).
- By **acceptable** we meant: the adaptation was one that stakeholders would be likely to implement or welcome in their neighbourhood. This meant that, for example, that it was 'acceptable' in terms of cost, visual appearance, and absence of negative side-effects.

2.3 The research methodology

The methodology was split into five phases and nine work packages (WPs), (Figure 2.1). This section describes the key elements of each.

The research started in September 2009. Prior to the research commencing an **Advisory Board** was set up to help steer the research and shape the nature of enquiry. At a very early stage we also held an **International Visiting Researchers Conference**, which was attended by experts in suburban adaptation from the USA, Portugal, Australia and Sweden to share their experiences of different climatic conditions, adaptation actions, policies and governance conditions. All Advisory Board members and contributions to this conference can be found at www.snacc-research.org.uk.

Phase 1 (Year 1) involved a range of background work that was needed to enable the case studies to take place and to help understand the problem of adapting suburbs. It was also necessary to generate the data required to undertake the modelling and visualisation work, and to develop the modelling and visualisation tools. Hence, in this phase we:

- **Developed climate change scenarios for our three case study cities** (WP1). These are set out in Chapter 6.
- **Developed an understanding of the socio-cultural and governance issues** surrounding suburban adaptation, which could have an impact on response capacity (WP2). This phase informed our selection of case studies. We also **documented the current English policy context** for suburban adaptation (WP2). This is presented in Chapter 5.
- **Developed a typology of English suburbs and a 'master list' of potential adaptation options** that could be implemented in English suburbs (WP3). This was achieved following a literature and policy review, and is presented in Chapters 3 and 4, and Appendix D and E.
- **Developed a model of hedonic pricing**, that explored the impact on property values of a range of adaptation options and suburban conditions (WP4). Where appropriate, the findings of this work were used in the residents' and stakeholders'

workshops. A detailed explanation of the model and its findings is given in Appendix A, but a summary is presented here.

The **hedonic pricing modelling** aimed to determine which neighbourhood adaptation features, house energy consumption attributes and environmental characteristics (of the wider neighbourhood) are capitalised into the value of residential property. Hence the hedonic pricing model was developed to analyse potential housing market responses to suburban adaptation options. However, because many of the adaptations we are interested in are not widely applied, it is not yet possible to model the full range of adaptations (e.g. there are few community cool rooms or green roofs in England). In addition, many of the changes we are looking at are too subtle to significantly influence price (for example, elevation of electrical sockets). However, through a review of existing literature and analysis of extensive databases of property transactions/values it was possible to throw some light on the impact on house prices of street trees, gardens, accessibility to open space, flooding, neighbourhood characteristics and layout, and physical adaptations that improve energy efficiency (insulation, double glazing, solar panels etc). In terms of the modelling, the empirical study focused on the impact of energy efficiency (SAP) rating, insulation, double glazing, heating systems, gardens and accessibility to open space. Generally the measures assessed had a positive effect on house values (i.e. better adapted houses in better adapted neighbourhoods sell for higher prices than mal-adapted ones, all other things being equal). We then tested whether this was a motivator for householders to invest in such measures, or to support their introduction, during the workshops.

- **Developed two existing models (DECoRuM© [Domestic Energy, Carbon counting and carbon Reduction Model] and VEPS [Virtual Environmental Planning System]) for use in the SNACC project (WP5)**. An explanation of the development of the models is given in Appendices B and C. However, a brief summary of each is useful here to understand their purpose and scope.

DECoRuM© (Domestic Energy, Carbon counting and carbon Reduction Model) is a GIS-based toolkit for carbon emissions reduction planning with the capability to estimate current energy-related CO_2 emissions and the effectiveness of mitigation strategies in existing UK dwellings. The results can be aggregated to a street, district and city level (Gupta, 2008; Gupta, 2009). The aggregated method of simulation and map-based presentation allows the results to be scaled up for larger application and assessment.

For the SNACC project, DECoRuM was further developed as DECoRuM-Adapt© to analyse the impact of climate change on energy use and comfort. DECoRuM-Adapt uses downscaled climate data from UKCP09 (DEFRA, 2012a) to estimate probabilistic future overheating potential and the effectiveness of adaptation strategies for modelled dwellings. To inform the model, actual home and neighbourhood characteristics need to be gathered from maps, on-site assessments and literature describing home characteristics based on age and typology. The model can export a wealth of statistical information. For SNACC we were interested in annual CO_2 emissions, running costs and overheating potential (particularly the potential once various adaptation packages had been applied). Figure 2.2 shows outputs (in this case CO_2 emissions) from the model for two neighbourhoods in Bristol.

Figure 2.2: *DECoRuM maps showing CO_2 emissions for two neighbourhoods in Bristol (Source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Models reproduced under the terms of the Contractor's Licence for the Use of Ordnance Survey Data between UWE, Bristol and Bristol City Council. Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

The VEPs (Virtual Environmental Planning System) is a Geographical Information System (GIS) based visualisation that creates interactive and accurate images of 3D urban environments. The aim of the visualisation was to enable residents and stakeholders to view and analyse proposed adaptation options in order to understand their effects on the existing housing and neighbourhood and make decisions about their acceptability (Figure 2.3). We used the visualisation to enable the workshop participants to grasp complex information about potential adaptations, and to assess their acceptability, including their visual impact, on the existing environment. The images show 'snapshots' from the dynamic model.

Figure 2.3: *Virtual environment of one of the Bristol case studies, showing a neighbourhood before and after adaptation. Models reproduced under the terms of the Contractor's Licence for the Use of Ordnance Survey Data between UWE, Bristol and Bristol City Council, Maps © Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

Phases 2 and 3 of the project (Year 2) involved selecting the case studies, gathering baseline data on them, identifying the climate risks in each case, and identifying the range of adaptations to be tested in each of the different types of suburb (WP6). This work is presented in Chapter 6. We then modelled a range of potential adaptation options (using DECoRuM), specifically to determine their overheating risk, and to find out which adaptation packages might reduce that risk (WP7). This is presented in Chapter 7.

Phases 4 and 5 (Year 3) involved testing the feasibility and acceptability of the adaptation packages with residents and stakeholders at structured workshops. We drew together all the previous information we had gathered on adaptations for each case study from the literature and policy review, from the modelling (from the Hedonic Pricing Model and the DECoRuM model), and from the visualisations (using the VEPS) and presented this to both resident and institutional stakeholders. The residents were shown, for example, their neighbourhoods' risk of overheating and which adaptations might help reduce the risk. They were also shown the range of adaptations that might, for example, prevent damage from floods or storms, help them conserve water, and mitigate against further climate change. They were given information on what these adaptations do, how much they cost, and what they look like. The institutional stakeholders reflected on their own experiences of working on adaptation in each city, but also on the responses that the residents had given in the two case study suburbs in their city.

We held seven residents workshops in six suburbs (we held two in the same suburb in Bristol because of local demand). The groups were of between 6 and 15 people. They were recruited using a postal invitation.

At the workshops we discussed:

- residents' experiences of different weather events (heat waves, floods, storms);
- their attitudes towards climate change;
- their familiarity with the range of adaptation measures that could be effective in their neighbourhood (at the home, garden and neighbourhood scales);
- whether they have (or would consider) implementing these measures, and their reasons for doing so, and;
- if they would not consider implementing the measures, then what the key barriers and incentives might be.

The findings from the residents workshops are presented in Chapter 8.

We then held three stakeholder workshops (one in each city). The stakeholders included representatives from a wide range of organisations including: local authorities (both officers from development control, climate change, strategic housing, drainage management and elected councillors); the Environment Agency; regional bodies with an interest in climate change adaptation (Climate South East); the National Health Service (public health); United Utilities (water); Non-Governmental Organisations (London Flooding Alliance, Bristol Green Doors, Bristol Housing Foundation); the building and construction industry (the Federation of Master Builders and architectural practices engaged in domestic work); and community groups (with interests in low carbon issues and flood protection).

At these workshops we discussed:

- The findings from the residents' workshops in each city, and the stakeholders' experiences of working with households locally;
- The role of communities in adaptation;
- How the stakeholders are currently tackling adaptation;
- The role of planning and building regulations in adaptations;
- The best mechanisms for delivering adapted suburbs.

The findings of the stakeholder workshops are presented in Chapter 9.

Phase 5 (Year 3) of the research involved synthesising the information from all the previous strands of the research to determine the 'best' adaptation packages for the different types of suburb. This phase also drew out key findings about the processes of adaptation and how to enable more effective adaptation in the future. This synthesis and conclusions are presented in Chapter 10.

3.1 Introduction

In order to understand how best to adapt suburbs, it is important to determine precisely what a suburb is. However, this is not straightforward: as the RICS and CABE commented: 'One of the key challenges affecting our understanding of suburbia is the failure of definition and classification' (RICS and CABE, 2008). Historically, suburbs have been defined either by their physical characteristics, usually dominated by morphology, related to the era in which they were built, (see for example Gwilliam et al., 1998), or by the characteristics of their populations (socio-demographic typologies have been developed, for example by Bond and Insalaco, 2007), or by characterisations of physical and social demographic criteria in combination (McManus and Ethington, 2007).

SNACC has adopted an overarching definition of 'a suburb', but has also devised a typology, based mainly on physical characteristics (adapted from Gwilliam et al., 1998). The project uses URBED and SEERA's (2004) definition of a suburb, which recognises both similarities and differences in area characteristics as the basis of identifying and distinguishing between suburban neighbourhoods. Figure 3.1 sets out these characteristics with the left hand column showing the common elements found in most suburbs and the right hand column giving the differentiating characteristics. Based on these characteristics we are taking English suburbs to be areas that are: largely residential; peripheral (to the city centre); medium-low density; mainly owner-occupied; and dominated by family housing. However, this characteristation highlights that suburban neighbourhoods can be distinguished in relation to differences in age, location, linkages, layouts, accessibility and so on. Although emphasising physical features, the characteristics set out in Figure 3.1 do include some socio-economic elements (such as home ownership).

Some of the common characteristics in this Figure have been challenged by suburban scholars. For example: rather than being predominately residential, some suburbs are now very 'mixed' in terms of use (Francis and Wheeler, 2006); some recently developed suburbs are medium-high density, rather than 'low' density areas (Joynt, 2011); and some suburbs are inhabited by more retired households than families with children. However, at present, such cases remain exceptions and do not invalidate the characterisation. This said, future demographic and urban form trends will clearly make revisions necessary in years to come.

Figure 3.1 *Defining characteristics of suburbs*

Characteristics in common	Important differences
Predominantly residential areas	Desirability and value
Towards the edge of towns and cities	Age
Primarily favored by and for families	Location
Serving an urban area(s)	Access to public transport
Relatively low density housing	Parking provision
Mainly owner occupied	Linkages with other places
Often with green, public space	Road layout e.g. extent of culs-de-sac
'Detached' or semi-detached in terms of preferred living style	Access to (and quality of) services (schools, health facilities, shops)
	Quality and quantity of open space

Source: adapted from URBED and SEERA, 2004

3.2 Defining England's suburbs: developing a typology for use in the research

The typology of suburbs used in SNACC is shown in Figure 3.2. It is adapted from Gwilliam et al. (1998) who developed the categorisation based on built form and neighbourhood setting. Gwilliam et al.'s typology is the most widely cited in British suburban studies (e.g. Francis and wheeler, 2006, URBED, 2002, 2006; Kochan, 2007). The types of suburb identified are; historic inner suburb, planned suburb, suburban town, public transport suburb and car suburb. We have updated and slightly refined this typology to include: inner-historic suburb, pre-war 'garden suburb', interwar suburb, social housing suburb, car suburb and medium-high density suburb (partly after URBED, 2002). The addition of 'medium-high density suburbs' covers the policy-led trend for more intensive built form development since the mid 1990s. To assist in clarifying the typologies, photographs have also been added of each of the types described.

In using this typology it is also recognised that suburbs are not static environments: they are continually changing, and there are those who argue that many suburbs are now so 'mixed' in terms of building type that morphological typologies are redundant (McManus and Ethington, 2007). It is also the case that the non-physical differences between suburbs, in terms of socio-economic and governance conditions are important, particularly in framing responses to climate change. However, as a basis for understanding the possibilities for change to the physical conditions of different suburbs, it is important to identify the predominant built forms present in England, and to test adaptation measures in these different settings (SNACC's six case study suburbs are representative of each of these types). Suburbs clearly do change from their original forms, but in most instances the original layouts and dwellings continue to influence development, and it is for these enduring elements that adaptation solutions need to be found.

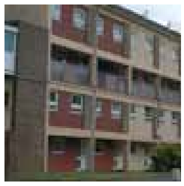
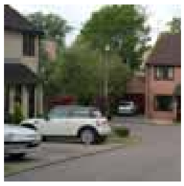
Type	Characteristics	Era	Examples
Inner Historic Suburb	Established terraced or semi-detached developments. These areas display mainly urban qualities, including high densities, a mix of uses, good pedestrian and public transport links	Victorian / Edwardian - up to 1919	 
Pre-War 'Garden Suburb'	Medium-large semi and detached homes with large gardens. Former enclaves that have been absorbed by the town or city (usually successfully)	1900s-1930s	 
'Interwar Period':	Medium density, homogeneous speculative suburbs, usually semi-detached, in a closely structured urban fabric	1920s-1930s	 
Social Housing Suburb	'Council Estates' with a mix of house types including detached and semi-detached houses, short terraces and medium rise blocks	1950-1970s	 
Car Suburb	Low density, detached housing in homogenous house types. Developer–led, speculative suburbs, often located within 'open' townscape fringe areas including within close proximity to motorways, and out-of-town shopping centres. Sprawling suburbs, including culs-de-sac.	Late 1970s-2000s	 
Medium - High Density Suburbs	Medium-high density, often with a mix of house types including town houses, detached and semi-detached houses, terraces and apartments. An outcome of the policy drive for more intensive development in urban extensions and within existing suburbs	Mid-1990s - present	 

Figure 3.2 *Typology of English suburbs (adapted from Gwilliam et al., 1998 and URBED, 2002)*

4.1 Climate change in suburbs

This chapter summarises the potential threats of climate change in English suburbs. It then sets out a range of adaptations that could be implemented at the home, garden and neighbourhood scales.

The principal impacts of climate change that English suburbs are likely to experience in the future are:

- Higher average temperatures (suburbs will not only be affected by average temperature increases, but will experience an enhanced increase through the urban heat island effect);
- Increased extreme heat events (or heat waves);
- Increase in extreme weather events or 'storminess' (including rain, wind, hail);
- Increased average winter rainfall;
- Decreased average summer rainfall;
- Sea level rise and increased storm surge height (we did not include risks from sea level rise in our study due to the relatively small number of suburbs affected, and the specialist adaptations required).

Of course, not all suburbs will experience these impacts equally: there are regional variations and differences due to local conditions, such as topography and morphology, which generate micro-climates. Probabilistic data are available for most of these changes from UKCP09: these data were used at the city and case study scale in SNACC (see Chapter 6). In suburbs, these climate changes are experienced by people mainly through the secondary risks and some potential benefits that they pose. Some examples of these impacts are given below (Figure 4.1) (categorised, as in the workshops, into 'summer' and 'winter' effects).

Likely climate changes	Impacts on 'place'	Impacts on 'people'
'Summer' impacts (hotter and drier)	• Deterioration of green space, gardens, playing fields and public parks • Longer growing season for some plants and vegetables • Reduced air quality • Changes in biodiversity (although may allow a greater variety of garden crops) • Increased likelihood of subsidence due to soil shrinkage (particularly on clay soils) • Reduced design life of non/mal-adapted buildings	• Reduced comfort: heat stroke, difficulty sleeping and carrying out general domestic activities (indoors and outside) • Reduced productivity (for home workers, employees in suburbs) • Increased respiratory problems • Reduced security due to use of natural ventilation • Increased costs related to building subsidence • Increased costs due to mechanical cooling • Water shortages: restrictions on domestic supplies and quality reduction • More warm days to enjoy outdoor activities
'Winter impacts' (slightly warmer, but wetter, with more storms)	• Flood damage • Storm damage to buildings, natural landscape and infrastructure • Increase in damp and mould	• Human impacts of flood damage: displacement, trauma, costs (worse for some groups, e.g. elderly people) • Increased costs of repairing flood and storm damage and maintaining homes • Investments in homes less stable after floods • Health problems linked to poorer indoor air quality: respiratory problems • May be cost saving on winter fuel

Figure 4.1
Examples of expected climate change impacts in English suburbs

4.2 Determining the range of adaptation and mitigation options that could be implemented in suburbs to address a range of climate threats

In order to both mitigate against further climate change, and to adapt to inevitable changes, a range of adaptation measures could be implemented. A literature review identified over 100 possible changes that could be made to the physical environment in suburbs to respond to the changes outlined above. These adaptations range from very small scale changes to the home, such as elevating electrical sockets to reduce damage from flooding, to large scale strategies, such as demolishing whole neighbourhoods in flood plains. We compiled a 'master list' of adaptations to test in SNACC. We are not advocating that these adaptations would be effective in all circumstances, we are merely listing them as possible actions in at least some suburban neighbourhoods.

The full 'master list' of adaptation options can be found in Appendix D. It details the adaptations which were identified as appropriate for the neighbourhood types selected in the case studies. Not all of the adaptations were appropriate for all of the suburbs, but each of the adaptations presented is appropriate for at least one of them. The options were chosen to address either the mitigation of future climate

Figure 4.2
Examples of potential adaptation and/or mitigation options that could be implemented in England's suburbs

Built environment scale/element	Examples of potential adaptation and/or mitigation options
Neighbourhood	• Increase greenery: green infrastructure • Improve water/drainage features: install Sustainable Urban Drainage Systems • Install localised flood defences: to protect a single dwelling or group of dwellings in a neighbourhood • Restrict infill development on soils with potentially high infiltration and flood plains • Adapt public amenities: add shade and storm protection to public buildings, bus stops, cycle paths etc. introduce community cool rooms • Replace pavements and roads with porous, 'cool' materials • Introduce infrastructure to encourage walking and cycling, reduce parking spaces, add cycle paths • Allocate communal land for food growing • Install community energy generating infrastructure • Install energy efficient street lighting
Garden	• Increase greenery: plant trees with large canopies and heat tolerant plants • Install water features • Install rainwater harvesting systems • Remove non-porous surfaces • Set aside space for food growing • Improve/maintain garden structures (fences, sheds etc. against storm damage)
Home	• Regulate temperature: e.g. add external shutters, shades or canopies to walls, install solar shading, interpane glazing, solar film, install windows that lock open to aid ventilation, solar chimney or downdraught evaporative cooling towers, introduce thermal mass, add green/brown roof • Protect home from storms and floods: e.g. weatherproof doors, windows, walls, floors and roof; elevate entry thresholds, internal sockets and services; install air brick covers and flash flood doors • Improve air quality: e.g. use UV light or antimicrobial solutions to prevent mould, improve natural ventilation • Install water efficiency systems (e.g. grey water recycling) • Mitigate against further climate change: e.g. insulate walls and lofts, draft proof homes, introduce micro CHP, ground source heat pumps, solar PV and water heating

change or adaptation to the future risks of climate change. Only adaptations which offered either a neutral or positive impact on the production of greenhouse gases were considered and some very large scale adaptations, e.g. those relating to major infrastructure were omitted. Some of the adaptations also have more than one benefit and this is noted (for example, extending the eaves on a building adds shading, as well as protecting properties from the impact of heavy rain).

The adaptations are presented as applicable to homes and gardens (walls, roofs, windows, floors, heating, cooling, power, ventilation systems, water systems and gardens) and neighbourhoods (green and blue infrastructure, protecting existing assets, community provisions, streets and pavements, and land uses – e.g. for food production). Figure 4.2 gives a summary of some adaptations that could be implemented (taken from the master list). It presents them at neighbourhood, garden and home scales.

For the purposes of the residents' and stakeholders' workshops, we presented adaptation options that were appropriate for each suburb taking into account the climate risks, and the urban design of, and housing types in, the neighbourhood.

5.1 Introduction

Suburban neighbourhoods are complex and diverse places that are likely to experience a variation of impacts arising from climate change. Reflecting this diversity, the agencies and organisations implicated in ensuring that both suburban housing and suburban neighbourhoods continue to be safe, healthy and serviced places in the face of climate change cover a wide range of policy sectors and territorial levels. This chapter describes the policy and governance contexts that frame the possibilities for adapting suburban neighbourhoods and housing in England. It sets out the roles and responsibilities of central and local government, the impact of the statutory planning system and the implementation of retrofitting programmes in the existing housing stock.

5.2 Central and local government and climate change adaptation in suburban neighbourhoods

The policy context for the adaptation of residential housing (and neighbourhoods) in England to the challenges of climate change is both complex and has been subject to on-going change through the 2000s and to the present day. Responsibilities for engaging and ensuring the appropriate quality of the English housing stock and residential urban areas are split across a number of different government departments (see Figure 5.1). Whereas the Department for Environment, Food and Rural Affairs (DEFRA) retains the overall remit to monitor climate change adaptation, it is the Department for Communities and Local Government that most directly retains responsibility for ensuring the quality

Department	Policy theme/sector
DCLG (Communities and Local Govern-ment)	Sustainable communities, statutory planning system, building regulations (and codes including energy performance certification), social (and affordable) housing, local government (in general touching on parks, roads and services), regeneration, lifetime homes, emergency services
DEFRA (Environment, Food and Rural Affairs)	Climate change adaptation (in general), pollution and waste, flooding and drainage, market transformation programme (promotion of sustainable products)
DECC (Energy and Climate Change)	Climate change mitigation (carbon emissions issues), fuel poverty, energy policy (micro generation), Green Deal
DBIS (Business Innova-tion and Skills)	Construction industry (productivity, profitability and competitiveness of sector), growth of low carbon construction industry, (sponsorship of) Technologies Strategy Board
Treasury	House prices, housing finance, fiscal incentives, setting of council tax and stamp duty
Department of Health	Housing for older people and people in need of care

Figure 5.1 *Central government departments and suburban adaptation.*

of both the housing stock and the built environment through local government, spatial planning policy, and building regulations. Equally, over recent years the work of the Department of Energy and Climate Change (DECC) on reducing carbon emissions has come to be an important driver for retrofitting the English housing stock to increase energy efficiency and to decrease fuel poverty.

The key structuring policy device for understanding climate change adaptation in England in both central and local government arises from the Climate Change Act 2008 (HM Govt, 2008). For the most part the Act is concerned with reducing carbon emissions from the UK as a whole but it does include provisions: for the setting up of an Adaptation Sub-Committee of the Committee on Climate Change to scrutinise the adaptation work of the UK Government; and for the definition of a 'reporting duty' for public bodies and statutory undertakers on risks associated with climate change (NAO, 2009a). For the public bodies and statutory undertakers this duty amounts to a requirement to report to the Committee every five years on the actions they have taken to face up to the climate change challenge. These reports form part of the process of climate change risk assessment (CCRA), and a National Adaptation Plan (NAP) within which the built environment is a specific theme for attention (DEFRA, 2012b).

English local authorities have a wide range of roles and responsibilities, many of which touch upon neighbourhoods and housing. Local authorities are responsible for local planning (both in terms of plan-making and granting permission to develop). They are also responsible for the maintenance and upkeep of local roads, municipal parks and flood defences, and are local drainage authorities. Local authorities can be significant social landlords and are likely to be major land owners with regards to the services they provide (including schools and community centres). Local authorities are key agencies in setting out emergency response plans (to flooding or heat waves for example). Between 2000 and 2012 English local authorities also had a power of well-being that could be deployed to allow them to engage in any activity (not prohibited by statute) that improved the well-being of their residents.

During the period 2008-10, local authorities were expected to report their activities in support of tackling climate change against a performance measure known as national indicator 188 (or NI188). Local authority performance on NI188 was assessed on a scale of 0 ('getting started') to 4 ('Implementation, monitoring and continuous review'). However, since November 2010 local authorities in England have no longer needed to report progress on tackling climate change to Central Government. However DCLG outlines that its 'shared vision' with respect to climate change adaptation 'is that most adaptation action happens or needs to happen at the local scale' (DCLG 2011, p.10).

Local authorities have continued to aquire responsibilities that will be implicated by changes in the climate. For example the Floods and Water Management Act 2010 (HM Govt, 2010) establishes a Sustainable Drainage Systems Approving Body in unitary or county councils such that local government needs to approve drainage schemes for both new development and for refurbished development (local authorities have also acquired a responsibility for public health issues). Hence local authorities still need to address the implications of climate change across their areas including within residential neighbourhoods even if this is less explicitly labelled as a 'climate change' issue than might have been the case prior to 2010.

5.3 Spatial planning and the housing stock

Anything other than very minor changes in the suburban environment are now carried out under the National Planning Policy Framework (NPPF) (DCLG, 2012b), and through compliance with building control regulations. The NPPF includes adaptation and mitigation as planning objectives: adaptation is specifically highlighted as a priority in relation to flood risk. But the Framework provides little detail or policy driven mechanisms to support retrofitting the built environment to adapt to climate threats.

The NPPF replaces a suite of Planning Policy Statements (PPS) that were more detailed and prescriptive in relation to climate change. A revised planning policy statement (PPS1) was published in December 2007 to set out objectives in relation to climate change (DCLG, 2007a). Shortly after, Area Based Grants (payments to local planning authorities in order to carry out various planning roles) were increased to reflect additional work around the issue of climate change. PPS1 stressed the importance of dealing with climate change adaptation (as well as climate change mitigation measures) whereby new development (including housing) 'should be planned to minimise future vulnerability in a changing climate' (2007, p.10). However, PPS1 also stated that demands upon developers to deal with climate change should be 'proportionate to the scale of the proposed development [and] its likely impact on and vulnerability to climate change' (2007a, p.11). This left planning officers in a problematic position given that developers were not always supportive of a plan-led approach to tackling climate change: of 11 developers who responded to the climate change PPS consultation, ten did not agree with the proposition that there was a need for urgent climate action (DCLG, 2007b).

In addition, there was also an increased awareness of preventing development in areas that are at risk of flooding (defined as a 1 in a 100 year event under current climatic conditions). Planning Policy Statement 25 (PPS25) (DCLG, 2010) introduced a risk-based procedure by which planners might judge the appropriateness of development proposals for flood plain development as well as ensuring that the Environment Agency is consulted on all development proposals on the flood plain. This risk-based approach has been retained in the NPPF.

In terms of affecting adaptation in existing suburbs however, the planning system is relatively limited. Its can only affect the housing stock in two ways: it can

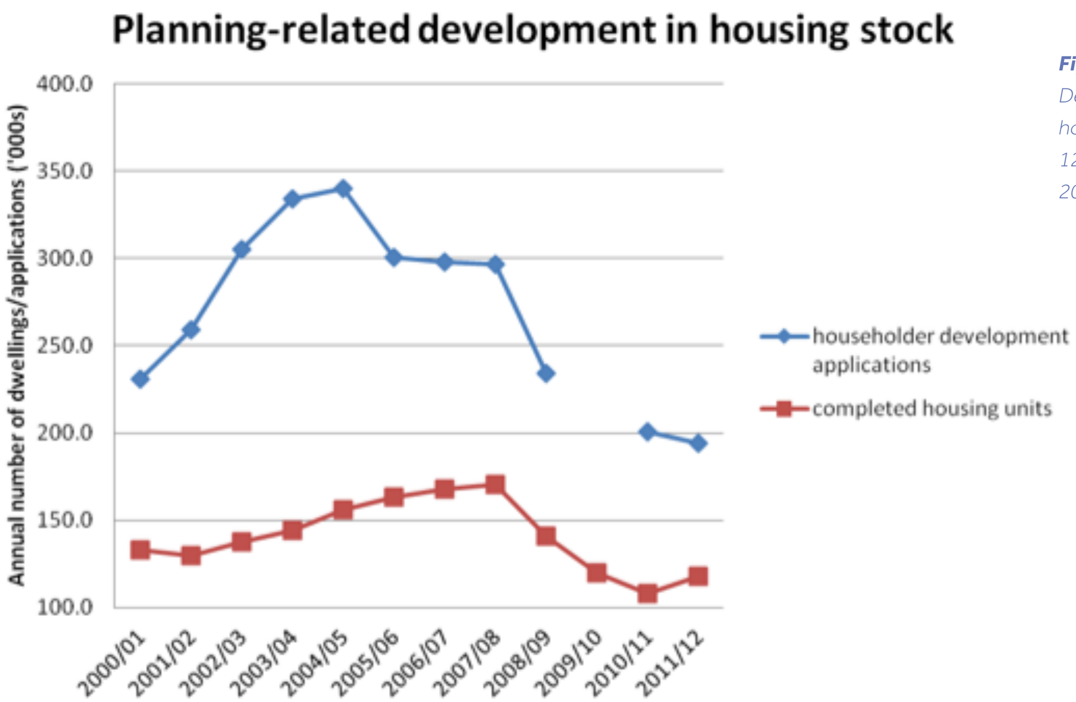


Figure 5.2 *Development in housing stock 2000-12 (source: DCLG, 2012c)*

regulate new housing (which in existing suburbs is likely to be infill, 'back land' or redevelopment and; it can regulate major changes (such as extensions and remodelling) in existing homes. In both cases planning permission is required. Hence, the planning system cannot force home-owners to adapt their property, but can only shape development when someone (resident, builder and/or developer) wants to make a change.

Figure 5.2 shows the degree of impact of the planning system on the English housing stock since 2000. The number of new houses built on an annual basis is shown (in red) and the number of planning applications made by householders to carry out work on their home (in blue). Given that the annual number of planning applications for householder development are between 200,000 and just under 350,000, this accounts for between 1% and 2.3% of the owner occupied housing stock in England. Hence, the capacity of the statutory planning system to rapidly re-shape the existing suburban housing stock is at best limited.

5.4 Policies and programmes shaping the building and maintenance of housing in England

In England, building regulations define the appropriate level of performance from the built environment. Building regulations are made up of primary legislation in the form of the Building Act 1984 (HM Govt, 1984), secondary legislation in the form of the amended building regulations (2000) and a series of other 'approved documents'. Building regulations only impact on new or 'significantly altered' buildings requiring planning permission (see Figure 5.2). In relation to climate change issues building regulations have mainly taken into consideration the issue of carbon emissions (either in terms of the construction method or the operational use of the building). In particular Part L1b (2010) is the approved document that specifically deals with the conservation of fuel and power in existing dwellings, and Part F deals with ventilation issues. In the 2012 review of the building regulations there may be a reinforcement to face up to issues of excessive solar gain.

Over and above the on-going revision of building regulations, Central Government also produced a Code for Sustainable Homes (DCLG, 2006) that set out a broader vision of what constitutes a 'sustainable home' introducing minimum standards in relation to energy and water efficiency, notions of well-being and lifetime adaptability of the housing stock. However this code is only applied to new building and for the most part it has been effectively applied in either social housing projects (Housing Associations and other registered social landlords) or within affordable housing projects (that might include some elements of owner-occupied homes). Unlike building regulations, the performance measures in the Code for Sustainable Homes are not legally enforceable.

In parallel to both changes in the building regulations and the publication and subsequent piecemeal implementation of the Code for Sustainable Homes, there has been an on-going concern in government in relation to fuel poverty. 'Warm Front' was a programme for up-grading the homes of fuel-poor households with better insulation and heating systems to allow disadvantaged households to stay warm affordably. The Warm Front programme was initiated in 2000 with a revision for the period 2005-08. For the period 2001-04, the scheme assisted around 900,000 vulnerable households (Green and Gilbertson, 2008) whilst for 2005-08 it is estimated that the programme intervened in 635,000 dwellings at a cost of around £852 million (National Audit Office, 2009b).

The 'Green Deal' is an emerging vehicle for funding the on-going retrofitting of English housing with regards to energy efficiency that will be open to a wider range of householders (DECC, 2010). One of the features of the proposed 'Deal' is that energy efficiency measures carried out on properties are funded through a loan to be paid back as a levy on householder energy bills after the works have been completed. The liability associated with the energy efficiency measures is linked to the dwelling and not the householder such that if the householder moves, it is the incoming householder who takes responsibility for paying back the Green Deal loan. However in explaining the Green Deal, DECC has outlined a 'golden rule' that might be applied to retrofitting any individual dwelling in this way: 'the charge attached to the [energy] bill [received by the applicant after the works] should not exceed the expected savings, and the length of the payment period should not exceed the expected lifetime of the measures' (DECC, 2010, p.11).

Thus there have been a series of on-going reforms both to the regulations and codes that define what is an 'appropriate' standard of housing in England and a series of funded programmes that have attempted to make changes in the existing housing stock more energy efficient (especially in relation to heating).

It is important that these regulations and programme interventions ensure the housing stock is better adapted to the projected climate over the next 50-80 years.

The SNACC Case Studies: selection, climate change projections and suburb profiles

6.1 Introduction

This Chapter explains how we chose the case study neighbourhoods for SNACC. It sets out the criteria we used, and presents the cases in relation to these. It then presents the climate change projections for each of the three cities studied. Finally, we present profiles of the six case studies, showing the climate risks they face, their existing physical conditions, and the adaptations selected to test in each one.
In order to examine suburban adaptation in England in the most comprehensive way as was possible we chose to study six different suburbs reflecting the six suburban typologies described in Chapter 3: inner historic, pre-war, garden city, interwar, social housing, car suburb, and medium-high density.

Three further criteria also informed our selections. It was deemed important to select suburbs that had different levels of economic resources, in terms of the wealth of the households, as this was identified as a potentially significant factor in determining the response capacity in the suburb. Hence we chose suburbs characterised by differing income levels (lower and medium-high). However, we also wanted to explore if and how levels of community activity (for example, around environmental issues) impacted on responses to climate change. Hence, we selected some suburbs with a history of community activity and others with none. This was determined by working with our local authority partners. In addition, it was important to select suburbs that had experienced some degree of flooding (or at least flood risk), so we could fully explore flooding adaptation options at the local level. The chosen set of case studies is shown in Figure 6.1.

Suburb type	Case study	Income	Community activity	Flooding
Inner historic	St Werburghs, Bristol	Lower income	Active	Localised fluvial
Pre-war garden city	Summertown, Oxford	Medium-higher income	Weak – emerging	Fluvial (gardens only)
Interwar	Botley, Oxford	Medium-higher income	Active	Fluvial (on low ground)
Social housing	Cheadle, Stockport	Lower income	Active	Localised exposure (blocked culvert)
Car	Bramhall, Stockport	Medium-higher income	Active	None
Medium-high density	Upper Horfield, Bristol	Lower income	Weak - emerging	None

Figure 6.1 *The SNACC case studies and the selection criteria.*

6.2 Determining climate change projections for Bristol, Oxford and Stockport

For each of the case studies, we needed to determine the likely changes to the climate. This was required to quantify the risks and to inform the range of adaptation strategies studied in each suburb. The first stage in this process was to determine the risks for each city, then to identify specific risks associated with each suburb, given the baseline data about the local conditions.

Climate change projections for a large number of weather variables are available at 25km grid squares for the entire UK for the 21st Century. As climate projections are temporally presented in climate periods (of 30-years), the SNACC project chose to focus on the 2030s and 2050s climate periods to cover the impact of climate change for the first half of the century. To assess probabilistic risk for each climate period from emissions scenarios and modelling uncertainty, the ranges 'medium emissions, 50% probability – high emissions, 90% probability' are used (Figure 6.2).

Ultimately, the inclination is to focus on the more pessimistic projections currently available which in theory tend to present greater risk, i.e. projections in the high emissions scenarios. This decision is attributed to current research which suggests that the current global CO_2 emissions trend is above and beyond the high emissions scenario trajectory (UKCP09 equivalent to the Intergovernmental Panel on Climate Change's A1FI emissions scenario) (Betts et al., 2009). Furthermore given the current global political and economic track, it is suggested that there is little to no chance of maintaining a rise in global mean surface temperature at or below 2°C and that the impacts associated with this threshold are now considered to have been severely underestimated (Anderson and Bows, 2011). According to this methodology, the following Figures (6.3 – 6.5) present the climate change projections for the SNACC case study cities.

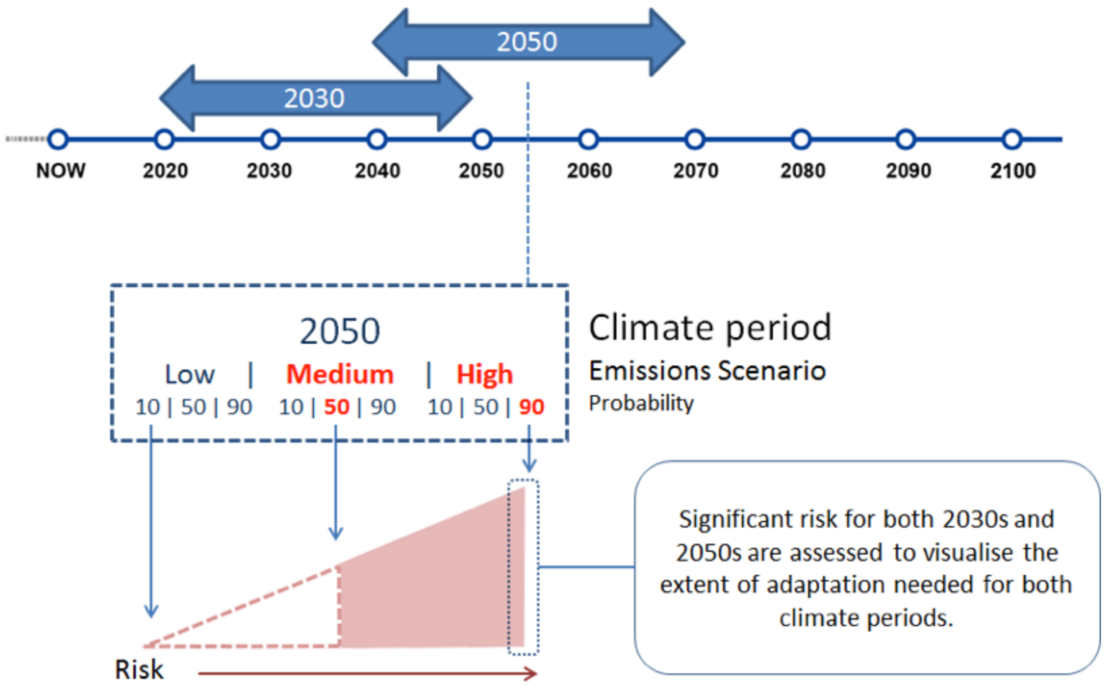


Figure 6.2
Climate projections and probabilistic ranges used for modelling and simulation of future impact

Bristol Change in...	2030 M 50%	2030 H 90%	2050 M 50%	2050 H 90%
Summer mean temperature °C	2.0	3.4	2.8	5.2
Summer mean daily maximum temperature °C	2.6	4.7	3.7	7.3
Winter mean temperature °C	1.5	2.4	2.1	3.5
Summer mean precipitation %	-10	-31*	-19	-43*
Winter mean precipitation %	9	22	15	37
Summer mean solar radiation W/m2	6	19	8	24

Figure 6.3
Climate change projections for Bristol (DEFRA, 2011). Values from grid square 1582.

Oxford Change in...	2030 M 50%	2030 H 90%	2050 M 50%	2050 H 90%
Summer mean temperature °C	2.0	3.8	3.0	5.4
Summer mean daily maximum temperature °C	2.4	4.4	3.5	7.0
Winter mean temperature °C	1.6	3.0	2.2	4.4
Summer mean precipitation %	-9	-29*	-18	-42*
Winter mean precipitation %	9	22	15	36
Summer mean solar radiation W/m2	7	17	9	22

Figure 6.4
Climate change projections for Oxford (DEFRA, 2011). Values from grid square 1547.

Stockport Change in...	2030 M 50%	2030 H 90%	2050 M 50%	2050 H 90%
Summer mean temperature °C	1.7	2.9	2.4	4.4
Summer mean daily maximum temperature °C	2.2	4.0	3.1	6.1
Winter mean temperature °C	1.5	2.5	2.1	4.5
Summer mean precipitation %	-8	-24*	-15	-35*
Winter mean precipitation %	7	16	11	27
Summer mean solar radiation W/m2	5	15	7	19

Figure 6.5
Climate change projections for Stockport (DEFRA, 2011). Values from grid square 1274.

** To reflect projected tendency for drier summers and the overall reduction of precipitation the extreme values follow the value 'very unlikely to be less than.'*

6.3 The case studies, their current and future climate risks, and proposed adaptations

6.3.1 The Bristol Case Studies

In Bristol the current and future climate risks are as follows (for the 2030s climate period, covering 2020-2049, under high greenhouse gas emissions).

Summer in Bristol	Winter in Bristol
Summer daily temperature increase of up to 4.7°C • Increased risk of overheating at home and in the neighbourhood • Higher temperatures and more exposure to UV radiation may affect building materials • Urban Heat Island risk/ Heat risk from extreme heat events due to extent of hard surfacing and dense configuration of housing **Summer rainfall decrease of up to 31% (Water stress)** • Reductions in summer precipitation may lead to hosepipe bans and water stress • Gardens may be at risk of drying out • Changing rainfall patterns may increase shrinkage of clay soils: low to moderate risk for Bristol	**Winter rainfall/snow etc increase of up to 22%** • Increased surface flooding risk • Extreme weather risk- south west generally set to get wetter and more extreme weather events emanating from the Atlantic • Increased storms (wind/driving rain) • Older buildings are at greater risk of wind damage - Bristol can experience severe wind driven rain at times (56.5 – less than 100 litres/m2 per spell). With winter precipitation increase, winter driving rain may increase • Potential pluvial flood risks from surface run off in the event that drainage network fails in an extreme weather event

Figure 6.6
Current and future climate risks in Bristol

Inner historic suburb: St Werburghs

Figure 6.7 *St Werburghs case study area. Models reproduced under the terms of the Contractor's Licence for the Use of Ordnance Survey Data between UWE, Bristol and Bristol City Council. Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

St Werburghs is a relatively small neighbourhood approximately 1.5 km to the north east of Bristol city centre. The area is dominated by residential development, characterized as medium/high density, terraced housing built at the turn of the twentieth century as part of the industrialisation of the city. The streetscape is dominated by hard paving, and cars are generally double parked along the narrow Victorian road structures. However, the northern part of St. Werburghs accommodates large areas of allotments, woods and other green spaces, giving this area, known as Ashley Vale, a distinctly 'rural' cityscape.

Existing green infrastructure

- Limited private outdoor space
- Some lowland calcareous grassland to the north of St Werburghs, adjacent to the two railway lines known as Narroways Millennium Green Nature Reserve. The Land Use Plan highlights an area of approximately 1.6 hectares; however the 'green' does extend east of the railway lines towards Rousham Road. The area of the green merges with adjacent landscape areas that are of a different character, generally being wooded and inaccessible due to overgrowth and steep gradients
- Lynmouth Road Allotments
- New Roots Allotments, Between Briavels Grove and Ashley Hill
- St Werburghs City Farm. This is located on both sides of Watercress Road and includes a stable building, animal enclosures, greenhouses and small pond to the south of the road. To the north the farm includes a prefabricated office building, small community space used, mainly by local children's' groups, a café and a play area
- Ashley Vale Allotments
- Trees (saved from network rail- to north of railway line)
- St Andrews Park to the west
- Community gardens at the junction of St Werburgh's Park (road) and Mina Road. The park occupies 1.4ha in the centre of the study area and is made up of a number of distinct zones: children's play area, gated play area and an open Park dominated by mature trees.

Existing blue infrastructure

- Much of the south western boundary is delineated by a stream, although a small area of the park is located to the west of the stream
- There is a small stream tributary to the river Frome and an ancient Conduit near Junction 3, M32, at the south of the area.

Existing community profile

The community of St Werburghs is renowned in Bristol for their commitment to supporting local ventures, many of which have a sustainable ethos, such as the City Farm and community allotments etc. This proactive feature of the community enhanced the interest by the research group, as a good bench mark for the limits to which adaptations would be acceptable and/ or undertaken by individuals and as a collective group at the neighbourhood scale.

Future CO_2 emissions 2030

The mean domestic emissions rate for St. Werburghs under current conditions was calculated to be 50 $kgCO_2/m^2/yr$, this was projected to drop to 46 $kgCO_2/m^2/yr$ in the period 2030s.

Climate change induced risk

Risk of overheating

Future overheating risk for the St Werburghs neighbourhood was calculated to be very high. In the case study area it was calculated that almost all of the properties within the neighbourhood would be likely to overheat.

Flooding and extreme weather

- Flood risk identified from river flooding (Environment Agency) - ancient Conduit nr. Junc 3, M32 and the tributary stream of the Frome
- There are also problems with the drainage at the junction of Watercress and Mina Roads, leading to ponding and limited flooding during heavy rainfall
- Urban Heat Island risk/ heat risk from extreme heat events due to extent of hard surfacing and dense configuration of housing
- Extreme weather risk- south west generally set to get wetter with more extreme weather events emanating from the Atlantic.

Adaptations

Based on the risks outlined above the following adaptations were proposed for St Werburghs. Also presented are the mitigation responses to prevent the impact of further climate change. This does not equate to an exhaustive list of potential options, but indicates the options most appropriate for the housing and neighbourhood type, based on the risks presented above and the profile of the community.

House and Garden			Neighbourhood
Mitigation of future climate change	Summer	Winter	
• Photovoltaic /Solar panels • Grow food • External wall insulation • Double/triple glazing • Roof insulation • Air source heat pump	Shading • External solar shading • Internal shutters • Solar film • External shutters Cooling & ventilation • Lock- open windows • Wall greenery Drought resistance • Rainwater harvesting • Drought resistant planting	Extreme weather- wind and driving rain • Maintain guttering • Water-proof window seals • Trickle vents Flooding • Flood-proof door • Flood gate • Air brick covers • Elevate electrical sockets • Flood skirting	Shading, localised cooling and drought resistance • Street trees Flooding • Flood defenses • Reconfigure street drainage Mitigation of future climate change • Energy efficient street lighting

Figure 6.8
Proposed adaptations for the inner historic suburb: St Werburghs

Medium/high density suburb: Upper Horfield

Figure 6.9 *Upper Horfield case study area. Maps reproduced under the terms of the Contractor's Licence for the Use of Ordnance Survey Data between UWE, Bristol and Bristol City Council. Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

Upper Horfield is a relatively newly built suburb. The new houses replaced a council-built estate of semi-detached housing and were built between 2006-2010. The council houses which appear on the 1940's map suffered from 'concrete cancer'. The abutting area is a mix of social housing stock built approximately between the 1940s and 1950s. Known locally as the Rowling Gate Development, the rebuilt Shakespeare Avenue is a Home Zone area (using landscaping and traffic calming to shift the priority away from the car). It is a 45 acre regeneration project providing 400 affordable homes and 400 private homes. The development has a mix of house types including town houses, detached and semi-detached houses. An outcome of the policy drive for more intensive development in urban extensions and in existing built up areas. The roads are configured as a 'home zone', with little delineation between the pedestrian walkways and the road, and no painted road markings. There is also strategically placed planting and a variety of surface finishes within the road to encourage more careful driving.

Existing green infrastructure

- Based behind the Eden Grove Methodist Church in Horfield, the Upper Horfield Community Garden, volunteers have developed a large space at Eden Grove for the growing of fruit, herbs and vegetables and a space for nature to flourish available to members and volunteers to use. This is slightly outside of the case study area, but was the location for the resident workshops so was included as the residents considered it be part of the neighbourhood.
- Likewise, on the opposite side of Filton Ave, still adjacent to the new build properties but outside of the specific case study area, is a railway embankment which has some scrub cover. This is classified as contaminated land so will restrict options such as allotments, and may also be subject to personal safety risks, so would only be viable for low maintenance and minimal access measures.
- Poets Park is a small play park with two distinct areas, one contains children's play equipment, and the other is a grassed area with trees planted around the perimeter.
- The majority of the properties within the case study area have private gardens at the rear, and some have planting at the front of their properties, there are also raised beds and trees planted along the streets as part of the 'home zone'.

Existing blue infrastructure

- There is no obvious existing blue infrastructure, however there is a water capture tank buried below Poets Park.

Existing community profile

The area has a well-developed community trust, which has worked in association with Bristol City Council during the redevelopment of the area. The main focus for this is the Upper Horfield Community Trust based at the Community centre at the top of Eden Grove. The main focus of this group is housing based, and thus presents a good opportunity to engage with private owners and renters, the latter of which would not be able to adapt their houses significantly, but still have a stake in the neighbourhood adaptations, and some small scale house ones. Although there is an active community within Upper Horfield, many of the residents in the Rowling Gate development rent through social housing landlords. This offers the opportunity for some interesting findings to contrast the opinions of home owners and tenants.

Future CO_2 emissions 2030

Overall Upper Horfield will be responsible for less CO_2 emissions than average (current mean domestic emission rate of 43 $kgCO_2/m^2$) because of the higher standards of insulation in most of the homes. This will be particularly noticeable in the winter when daily temperature may increase up to 2.4°C which will result in heating energy use decreases and therefore result in less CO_2 emissions, the case study mean of CO_2 predicted to be omitted by the period 2030 was calculated as 37 $kgCO_2$ /m^2. This is a potential positive impact of climate change assuming that air-conditioning is not adopted.

Climate change induced risk

Risk of overheating

- Urban Heat Island risk/heat risk from extreme heat events due to extent of hard surfacing and dense configuration of housing
- High standards of insulation due to new build could cause overheating if appropriate ventilation was not installed.

Flooding and extreme weather

- Extreme weather risk- south west generally set to get wetter and more extreme weather events emanating from the Atlantic.
- Potential pluvial flood risks from surface run off in the event that drainage network fails in an extreme weather event
- There are no reported fluvial flood risks according to the Environment Agency, however local residents reported historical pluvial flooding in the area.

House and Garden			Neighbourhood
Mitigation of future climate change	**Summer**	**Winter**	
• Photovoltaic panels • Solar panels • Grow food • External wall insulation • Double/triple glazing • Roof insulation	Shading • External solar shading • Internal shutters • Solar film • Shaded outdoor space • Extend eaves Cooling & ventilation • Internal thermal mass • Wall greenery • Lock-open windows • White roof and walls • Drought resistance • Rainwater harvesting system • Water butt	Extreme weather- wind and driving rain • External render Flooding • Flood-proof door • Flood gate • Air brick covers	Shading, localised cooling and drought resistance • Street trees • Shading in green space • Blue infrastructure • Drought-resistant trees Flooding • Reconfigure street drainage Mitigation of future climate change • Energy efficient street lighting

Figure 6.10
Proposed adaptations for the medium/high density suburb: Upper Horfield

6.3.2 The Oxford Case Studies

In Oxford the current and future climate risks are as follows (for the 2030s climate period, covering 2020-2049, under high greenhouse gas emissions).

Summer in Oxford	Winter in Oxford
Summer mean daily maximum temperature increase: very unlikely to be greater than 4.4°C • Increased risk of overheating at home and in the neighbourhood • Higher temperatures and more exposure to UV radiation may affect building materials **Summer rainfall reduction: very unlikely to be less than 29% (Water stress)** • Reductions in summer precipitation may lead to hosepipe bans and water stress. • Gardens may be at risk of drying out. • Changing rainfall patterns may increase shrinkage of clay soils: high risk for Oxford	**Winter rainfall/snow etc. increase: very unlikely to be greater than 22%** • Increased surface flooding risk **Increased storms (wind/driving rain)** • Older buildings are at greater risk of wind damage - Oxford can experience moderate wind driven rain at times (33– less than 56.5 litres/m2 per spell). With winter precipitation increase, winter driving rain may increase. **Winter mean daily maximum temperature increase: very unlikely to be greater than 2.6°C**

Figure 6.11 *Current and future climate risks in Oxford*

Interwar period suburb: Botley, West Oxford

Figure 6.12 *The Botley Case Study Area. Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

Botley, in West Oxford, was built as a medium density, homogeneous speculative suburb. Although there are parts of 'Old Botley' that date back to the 16th Century, the area chosen for the fieldwork was in what is known locally as 'New Botley'. It is located approximately a mile west of Oxford, and the housing stock is typically semi-detached brick and tile built properties from 1930-1939.

Existing green infrastructure

The existing green infrastructure in the immediate case study area is made up of large private front and back gardens, typical of properties built in this era. Although significantly, most of the properties in the case study area have turned at least part of their front lawn over to concrete or other hard standing surfaces. The rear gardens are largely all grass and tree covered, the gardens are on average approximately 500m2.

At the centre of St Paul's crescent is a large area of grassed open space, which is used as a public amenity by the inhabitants of the surrounding properties for recreational purposes i.e. to play sports, exercise dogs and have picnics. This area had been identified for potential allotments, but this was strongly contested by the local residents, as they felt this would privatize their public amenity space. There is also a small copse of trees to the south west of the area known as Hutchcombs Copse.

Existing blue infrastructure

A small stream flows to the south west of the area at the rear of Hutchcomb Road, this is only above ground for approximately 10-20m before re-submerging. There is also a small stream to the north west of the area, at the top of Owlington Close which flows above ground for approximately 20m before re-submerging. The largest body of water in the area is the Hinksey Stream, a tributary of the Thames, which runs 500m to the east of the case study area on the far side of the A34 trunk road.

Existing community profile

Housing in Botley is largely privately owned, but there is a market for private rentals for young professionals. The area is relatively affluent, with a large proportion of professional workers and young families. Botley has some evidence of community activism, with the presence of Low Carbon West Oxford and the West Oxford Community Association.

Future CO_2 emissions 2030

The mean domestic emission rate under current conditions was calculated to be 65 $kgCO_2/m^2/yr$, this was projected to drop to 55 $kgCO_2/m^2/yr$ in the period 2030s.

Of the 362 properties assessed with current conditions, only 39 would be below average CO_2 emissions, this grew to 231 in the period 2030s assuming no mechanical cooling was adopted.

Climate change induced risk

Risk of overheating

Risk of overheating in Botley (Oxford in general) is the highest for all SNACC case study neighbourhoods. This is particularly attributed to the existing warmer climate the southeast experiences. A large majority of the homes were calculated to have a high risk of overheating at 50% probability and all homes were calculated to have a high risk of overheating at 90% probability.

Flooding and extreme weather

Botley has a significant flood risk as identified by the Environment Agency. The risk is from the River Thames and its tributary streams in the area. Despite the neighbourhood risk of flooding, the residents sample was drawn from a group of addresses with limited flood risk, due to their location at the top of the hill. For the limited number of residents in the sample from the bottom of the hill, they had experienced fluvial flooding in their properties.
In addition higher temperatures and more exposure to UV radiation may affect building materials
Older buildings are at greater risk of wind damage - Oxford can experience moderate wind driven rain at times (33– less than 56.5 litres/m2 per spell). With winter precipitation increase, winter driving rain may increase.

Adaptations

Proposed adaptations for Botley are shown in figure 6.3.

House and Garden			Neighbourhood
Mitigation of future climate change	**Summer**	**Winter**	
• Photovoltaic panels • Solar panels • Grow food • External wall insulation • Double/triple glazing • Roof insulation • Cavity wall insulation	Shading • Internal shutters • Solar film • Shaded outdoor space • Extend eaves • External solar shading Cooling & ventilation • White roof and walls • Wall greenery • Green roof Drought resistance • Rainwater harvesting system • Water butt	Extreme weather- wind and driving rain • External render • Trickle vents Flooding • Replace non-porous driveways • Flood-proof door • Flood gate • Air brick covers • Elevate electrical sockets	Shading, localised cooling and drought resistance • Street trees • Shading in green space • Blue infrastructure • Community cool room Flooding • Reconfigure street drainage Mitigation of future climate change • Energy efficient street lighting • Allotments

Figure 6.13 *Proposed adaptations for the interwar period suburb: Botley, West Oxford.*

Pre-War 'garden city' type suburb: Summertown, North Oxford

Figure 6.14 *Summertown case study area. Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

Summertown is characterised by medium-large semis and detached homes with large gardens. Of all the case study areas, this was the one with the greatest variation in the housing stock form and construction. The area is approximately 2.5 miles north of the centre of Oxford, and has some mixed use with businesses and shops in close proximity to the houses. It also has good transport links to the city centre, with both the ring road linking to the motorway networks and a main arterial route to the city centre nearby.

Existing green infrastructure

Although there is limited public open green infrastructure in Sunnymead, with the exception of Summerfields School to the south of the area, the area is very green. This is largely due to mature street planting, extensive grassed frontages to shops and businesses and large mature private gardens to the rear of the properties. At the front of the properties many of the front gardens have been replaced by hard standing to accommodate cars, however, there are trees and bushes around the perimeter of most of these gardens.

Existing blue infrastructure

Sunnymead is located on the perimeter of the River Cherwell flood risk zone which runs to the east of the case study area. There are also a few private swimming pools and ponds within the perimeter of some of the properties in the case study area.

Existing community profile

The area is very affluent with a large proportion of retired professionals living in large family homes. Although some younger families were represented in our case study group. There is evidence of community activism including the presence of 'Low Carbon North Oxford'.

Future CO_2 emissions 2030

The mean domestic emission rate in the case study area are projected to drop from: 52 $kgCO_2/m^2/yr$ to 43 $kgCO_2/m^2/yr$ from the present time to the period 2030s. In comparison to the other typologies, this type have relatively low carbon dioxide emissions, this is due to the house configuration existing thermal properties. It is projected in the period 2030 that a further 96 homes in the case study area will have carbon dioxide emissions below average.

Climate change induced risk

Risk of overheating

Risk of overheating in Summertown (Oxford in general) is also higher than most case studies. Almost half of the homes were calculated to have a high risk of overheating at 50% probability and all homes were calculated to have a high risk of overheating at 90% probability.

There is an increased risk of overheating at home and in the neighbourhood. In addition to a reduction in rainfall which will cause water stress and may lead to hosepipe bans and water stress.

In oxford there is a high risk of the changing rainfall patterns causing shrinkage of clay soils and related building subsidence.

Flooding and extreme weather

River flooding will increase during the winter months due to wetter ground conditions and an increase in daily rainfall. The proximity of the area to the river Cherwell flood zone, in addition to the dense urban configuration of the neighbourhood and frequency of front gardens turned over to hard standing may increase the localised flood risk from both fluvial (river) and pluvial (surface) flooding.

Higher temperatures and more exposure to UV radiation may affect building materials. Older buildings are at greater risk of wind damage - Oxford can experience moderate wind driven rain at times (33– less than 56.5 litres/m2 per spell). With winter precipitation increase, winter driving rain may increase.

Adaptations

Proposed adaptations for Summertown are shown in figure 6.15.

House and Garden			Neighbourhood
Mitigation of future climate change	Summer	Winter	
• Photovoltaic panels • Solar panels • Grow food • External wall insulation • Double/triple glazing • Roof insulation • Cavity wall insulation	Shading • Internal shutters • Solar film • Shaded outdoor space • Extend eaves Cooling & ventilation • Internal thermal mass • White roof and walls • Lock-open windows • Green roof Drought resistance • Underpin house • Rainwater harvesting system	Extreme weather- wind and driving rain • External render • Trickle vents Flooding • Replace non-porous driveways • Flood-proof door • Flood gate • Air brick covers • Elevate electrical sockets	Shading, localised cooling and drought resistance • Street trees • Shading in green space • Blue infrastructure • Community cool room • Drought-resistant trees Flooding • Reconfigure street drainage • Flood defences Mitigation of future climate change • Energy efficient street lighting • Allotments

Figure 6.15 *Proposed adaptations for the Pre-War 'garden city' type suburb: Summertown, North Oxford*

6.3.3 Stockport Case Studies

In Stockport the current and **future climate risks are as follows (for the 2030s climate period, covering 2020-2049, under high greenhouse gas emissions).**

Summer in Stockport	Winter in Stockport
Summer mean daily maximum temperature increase: very unlikely to be greater than 4.0°C • Increased risk of overheating at home and in the neighbourhood • Higher temperatures and more exposure to UV radiation may affect building materials **Summer rainfall reduction: very unlikely to be less than 24% (Water stress)** • Reductions in summer precipitation may lead to hosepipe bans and water stress. • Gardens may be at risk of drying out. • Changing rainfall patterns may increase shrinkage of clay soils: moderate/low risk for Stockport	**Winter rainfall/snow etc. increase: very unlikely to be greater than 16%** • Increased surface flooding risk **Increased storms (wind/driving rain)** • Older buildings are at greater risk of wind damage - Stockport can experience moderate wind driven rain at times (between 33 and 56.5 litres/m2 per spell). With winter precipitation increase, winter driving rain may increase. **Winter mean daily maximum temperature increase: very unlikely to be greater than 2.5°C**

Figure 6.16 *Current and future climate risks in Stockport.*

Social Housing suburb: Cheadle, Stockport

Figure 6.17 *The Cheadle case study area. Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

This case study is in the area of Adswood Road, Cheadle Hulme, Cheadle, Stockport. The properties in the case study area are mainly terraced and semi-detached houses built in the 1950s out of rendered brick and tile. The housing is relatively low density, with front gardens and a large rear gardens. Some of the previously owned council properties are now owned privately. However, the group which represented the area in the workshops was a mix of home owners and social housing tenants. The area was selected due to its exposure to previous flooding and its relatively less affluent occupants. The flooding which affected 11 properties within the case study area was caused by a blocked culvert which flooded the ground floors and gardens of the affected homes. There is also some risk of pluvial flooding according to the environment agency, stemming from Micker Brook to the south of the site. The area is bordered by train lines to the east and south east, and is located approximately two miles south west of Stockport centre.

Existing green infrastructure

The existing green infrastructure within the immediate neighbourhood of the case study area includes large rear gardens with mature trees and front gardens, most of which are partly paved to accommodate cars, with the remainder being grassed. There is a pocket park located on the corner of Kent Avenue and Larkhill lane. There is also a large area of open grassland at the rear of Dorset Avenue, and bordering the mainline railway line.

Existing blue infrastructure

Micker brook which is a tributary to the River Mersey, and is prone to flooding, is located to the south west of the case study area, there is also a culvert to the north west of the area.

Existing community profile

The Cheadle case study area was representative of a less affluent area, with most residents living on lower incomes. The area is bordered by affluent areas to the north and west, and less affluent areas to the south and east.

Future CO_2 emissions 2030

The existing mean domestic emission rate for the Cheadle neighbourhood was 56 $kgCO_2/m^2/yr$ this was projected to fall to 48 $kgCO_2/m^2/yr$ by the period 2030.

Climate change induced risk

Risk of overheating

Risk of overheating in Cheadle (Stockport in general) is the lowest of all SNACC case studies. A little over half of the homes were calculated to have a high risk of overheating at 90% probability and none at 50% probability.

Flooding and extreme weather

Stockport is predicted to experience considerable increases in winter precipitation (up to 16%). This will cause fluvial flood risk. The Cheadle case study area is already located on the Environment Agency flood risk map, and therefore the risk of flooding from Micker Brook is predicted to increase.

Adaptations

Proposed adaptations for Stockport are shown in figure 6.18.

House and Garden			Neighbourhood
Mitigation of future climate change	Summer	Winter	
• Photovoltaic panels • Solar panels • Grow food • External wall insulation • Double/triple glazing • Roof insulation • Cavity wall insulation	Shading • Wall greenery • Green roof • Shaded outdoor space • External solar shading • Internal shutters • Solar film • Extend eaves Cooling & ventilation • Lock-open windows • Internal thermal mass • White roof and walls Drought resistance • Underpin house • Water butt • Rainwater harvesting system	Extreme weather- wind and driving rain • External render • Trickle vents Flooding • Flood-proof door • Flood gate • Replace non-porous driveways • Air brick covers • Elevate electrical sockets • Replace internal flooring	Shading, localised cooling and drought resistance • Street trees • Blue infrastructure • Shading in green space • Community cool room Flooding • Reconfigure street drainage • Flood defences Mitigation of future climate change • Energy efficient street lighting • Allotments

Figure 6.18
Proposed adaptations for the Social Housing suburb: Cheadle, Stockport

Car Suburb: Bramhall, Stockport

Figure 6.19 *Bramhall case study area (Source: Stockport Metropolitan Borough Council: OS Mastermap) Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

Bramhall typified the low density, car-oriented, developer-led neighbourhood with some culs-de-sac. Built in the late 1970s, the case study area is known locally as 'Little Australia', due to the streets being named after Australian cities. The streets are wide with street trees, and the buildings and surrounding areas are relatively low density. The boundary of the case study area is bordered by a railway line linking to Manchester Piccadilly via Stockport to the north and sewage works to the south east. The surrounding streets had properties built in the pre-war period in the arts and crafts style. A large recreation ground is located on the western boundary of the area with football pitches and a children's play park, a large community hall (Bramhall Village Club), was also located at this point. Bramhall itself lies approximately three miles south west of Stockport and is an affluent area popular with older families and retired people living in large family homes.

Existing green infrastructure

The case study area had significant amounts of green coverage both within the boundaries of the properties in the form of mature gardens, and along the road with street trees. To the north east of the area lies Bramhall golf course, with several acres of greens, and on the western boundary of the area is the recreation ground with two large football pitches and trees around the children's playground perimeter.

Existing blue infrastructure

There are several streams and ponds on the farmland to the south east of the area. There is also reportedly some ponding under the properties, and consequently some of them are already built on floating concrete foundations. There is also a minor stream to the north and north east of the case area, however, the railway line is elevated on a bank between the stream and the houses providing protection against flooding.

Existing community profile

Bramhall is home to mainly wealthy working families with mortgages. These are mostly affluent families, with school age children, enjoying a good lifestyle. Employment is largely in senior managerial and professional occupations, and many of the households in this type have both adults working. Car ownership is high, with two or more cars common. Within the case study area, the workshop was attended by residents who fitted this description as well as a large proportion of retired professionals with grown up families. The area is known to have a neighbourhood watch group but there are few other community groups, unlike the areas found in Bristol and Oxford.

Future CO_2 emissions 2030

The existing mean domestic emission rate in the Bramhall case study for CO_2 release was 75 $kgCO_2/m^2/yr$ this was projected to fall to 62 $kgCO_2/m^2/yr$ by the period 2030. Despite the drop, which can be attributed to a reduction in space heating demand by 2030s, the housing type (and location) performed worse than all other types.

Climate change induced risk

Risk of overheating

Risk of overheating in Bramhall (Stockport in general) is lower than most case study neighbourhoods. Roughly three-quarters of the homes were calculated to have a high risk of overheating at 90%.

In Bramhall the average summer maximum temperature in the period 2030s is projected to increase by 2.5°C. In addition to this there will be increased incidence of heat waves which will result in a high likelihood of properties and neighbourhoods overheating: (12 %). There is also predicted to be an increase in solar radiation with peaks in August which will impact upon the built fabric of the properties.

Flooding and extreme weather

The risk of fluvial flooding is not significant in this area of Bramhall. However, as a result of increased winter precipitation of up to 15%, which will in part fall in deluges, there is a probability of some pluvial flooding. This will be exacerbated by the prevalence of hard paved front gardens, and the existing saturation of the ground in parts, due to high water table. The projected summer decrease in rainfall will cause drought conditions which will result in water stress.

Adaptations

Proposed adaptations for Bramhall are shown in figure 6.20.

House and Garden			Neighbourhood
Mitigation of future climate change	**Summer**	**Winter**	
• Photovoltaic panels • Solar panels • Grow food • External wall insulation • Double/triple glazing • Roof insulation	Shading • External solar shading • Internal shutters • Solar film • Shaded outdoor space • Extend eaves Cooling & ventilation • Internal thermal mass • White roof and walls • Wall greenery • Green roof • Lock-open windows Drought resistance • Rainwater harvesting system • Water butt	Extreme weather- wind and driving rain • External render • Re-point brickwork • Wood protectors • Trickle vents • Maintain guttering Flooding • Replace non-porous driveways	Shading, localised cooling and drought resistance • Street trees • Shading in green space • Blue infrastructure • Community cool room Flooding • Reconfigure street drainage Mitigation of future climate change • Energy efficient street lighting • Allotments

Figure 6.20
Proposed adaptations for the Car Suburb: Bramhall, Stockport

This chapter presents the overheating potential and the effective adaptation options and packages for the six case study neighbourhoods. We chose to focus on overheating given the policy interest, the current need for evidence, and the potential unintended consequences that some current and future policy measures could have on future overheating in English homes. Given the current evidence that the future climate is projected to warm, understanding the implications this may have on the thermal conditions in homes and neighbourhoods is essential to meet the UK government's carbon reduction goals, to retain a standard of thermal comfort and to reduce the risk to lives that heat waves have historically imposed.

Before adaptation options are modelled for the individual neighbourhoods, the overheating potential of each neighbourhood is assessed and visualised. The DECoRuM-Adapt simulation indicates that there are a number of home characteristic indicators that lead to overheating and can sometimes be a complex arrangement of characteristics for each home. The overarching concept to understanding the problem of overheating in dwellings, however, can be summed up as management of gains (internal and solar) and heat transfer. The characteristics that have been found to contribute to a higher likelihood of overheating are:

Built form:

- Type of home: e.g., a mid-terrace home will overheat before an end of terrace (assuming all other characteristics are as similar as possible between the two)
- Number of stories: homes with fewer stories tend to overheat before those with more, particularly flats
- Overall form: being in a compact form (as opposed to having a greater area of exposed sides)
- Extent of glazing: having a greater glazing area vs. less glazing area (solar gain was found to have a significant impact on internal heat gain)
- Location of glazing: the presence of skylights (can have a greater overheating potential than larger non-roof glazed areas)

Age dependent characteristics and management of gains:

- Older homes are assumed to have less or no insulation and or controls on equipment such as the hot water tank and primary pipework leading to high internal gains and overheating as a result.
- Newer homes are assumed to have lower air permeability and higher insulation standards on both the systems and fabric leading to overheating from both internal and solar gains. According to the thermal simulation of insulation values (understood as simply u-values), DECoRuM-Adapt projects overheating as a result of higher fabric insulation.
- Orientation: east and west facing homes are found to overeat to a greater degree than homes that are south or north facing.
- From a neighbourhood perspective, homes on exposed streets (lack of foliage cover) have a higher likelihood of overheating.

From these findings the development of adaptation options follows three key principles:

- Reduce external temperatures by managing the microclimate (non-fabric changes)
- Design to exclude or minimise the effect of direct or indirect solar radiation into the home (fabric changes)
- Limit or control heat within the building (e.g. reduced internal gains or manage heat with mass), can include ventilation.

The thermal adaptation options which were tested for the neighbourhoods in DECoRuM-Adapt are listed in Figure 7.1. Some adaptation options were presented to the stakeholders in various forms, e.g. external shading was presented as louvers, awnings, extended eaves, tree cover, etc. Further adaptation options including high albedo external wall and roof surfaces and addition of thermal mass were tested in individual detailed home simulations.

Package 1: Fabric (deals with solar gain and thermal conductivity)	Purpose	A	M
Wall insulation (Cavity wall filled to whole wall U-value of 0.52 W/m2K, Solid wall externally insulated to 0.3 W/m2K) (EST, 2012)	Improved U-values	A	M
Roof insulation (U-value 0.2 – 0.16 W/m2K) (EST, 2012)	Improved U-values	A	M
Floor insulation (U-value 0.25 W/m2K) (EST, 2012)	Improved U-values	A	M
External shading of glazing (user-controlled – not modelled to be in place during heating season)	Reduce solar gains in the home	A	
Glazing upgrade (low-e soft coat double glazing – U-value 1.8 W/m2K, Solar transmittance 50%) in place of all existing single glazing except north facing (includes draught sealing)	Improved U-values and reduction of solar gains in the home	A	M
Low-e solar film (Solar transmittance 50% over existing double glazing, all but north facing)	Reduce solar gains in the home	A	
Package 2: Fabric + Energy efficiency (deals with internal heat gain)			
Package 1 + the following:			
Boiler upgrade	Reduce energy use		M
Hot water tank insulation (80mm jacket)	Reduce energy use and internal gains	A	M
Improved heating controls: Hot water tank temperature control and room thermostats	Reduce energy use and internal gains	A	M
Primary pipework insulation	Reduce energy use and internal gains	A	M
Energy efficient lighting (LED)	Reduce energy use and internal gains	A	M
Package 3: Fabric + Energy efficiency + Solar energy systems (adaptation to increased solar irradiation)			
Package 1 + Package 2 + the following:			
Solar Photovoltaic	Reduce energy use		M
Solar hot water (evacuated tube)	Reduce energy use		M

Figure 7.1 *Adaptation options grouped into compounding packages*

Note: all packages include a moderate level of natural ventilation as it is assumed that this user behaviour is already in wide use. The far right columns labelled 'A' and 'M' indicate the option's influence over adaptation or mitigation or both. Though mitigation is considered an adaptation, these indicators are used as shorthand, i.e. mitigation only reduces energy use and adaptation only reduces overheating potential.

Figure 7.2 shows the CO_2 reductions per case study neighbourhood as an impact of 1) climate change at 2050 high emissions, 90% probability and 2) after the adaptation packages have been applied at 2050 high emissions. 90% probability.

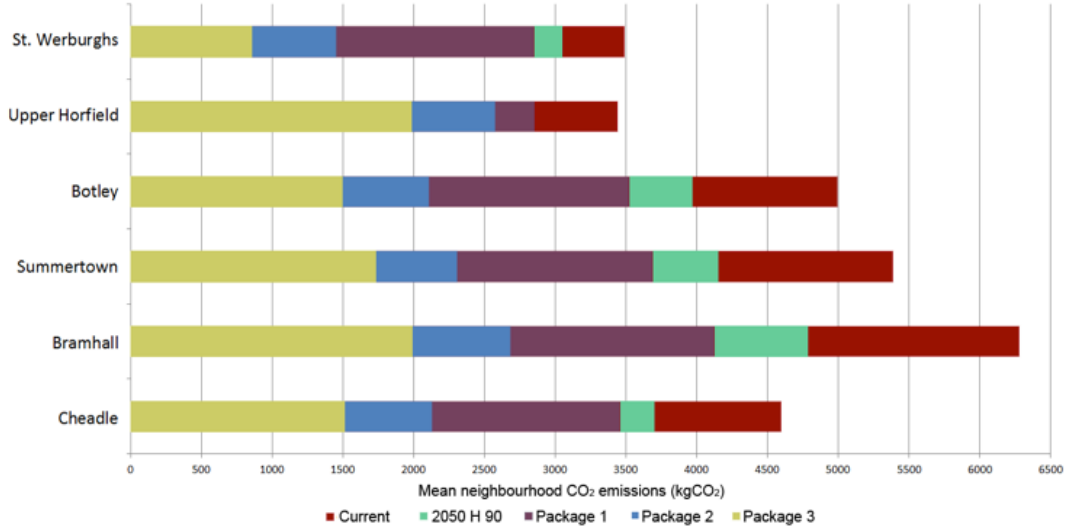


Figure 7.2 *Mean neighbourhood CO_2 emissions change as an impact of climate change and adaptations*

The following sub sections divide the overheating and adaptation findings for the neighbourhoods per city. As DECoRuM-Adapt simulates results using monthly data, the use or non-use of ventilation must be simulated separately. Therefore, the initial overheating maps indicate overheating in a 'sealed' state; the air permeability of the home provides the only natural airflow in and out of the home. This is considered useful as an example where the occupant is away from the home during the day and arrives to an overheated home that has not been ventilated. Natural ventilation is applied alongside, as an individual measure, and with the adaptation packages. As explained in section 6.1, the projection with the greatest risk is of interest as adaptations will be effective in projections with less risk. For this reason the adaptation packages are applied to the neighbourhoods during the 2050s climate period at high emissions, 90% probability.

7.1 Bristol

The probabilistic overheating results of the case study neighbourhoods of Bristol, St. Werburghs and Upper Horfield are shown in figures 7.3 and 7.4

Figure 7.3 *Climate change impact as overheating potential for St. Werburghs at 2030s and 2050s climate periods, medium to high emissions, 50% to 90% probabilities (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Models reproduced under the terms of the Contractor's Licence for the Use of Ordnance Survey Data between UWE, Bristol and Bristol City Council. Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

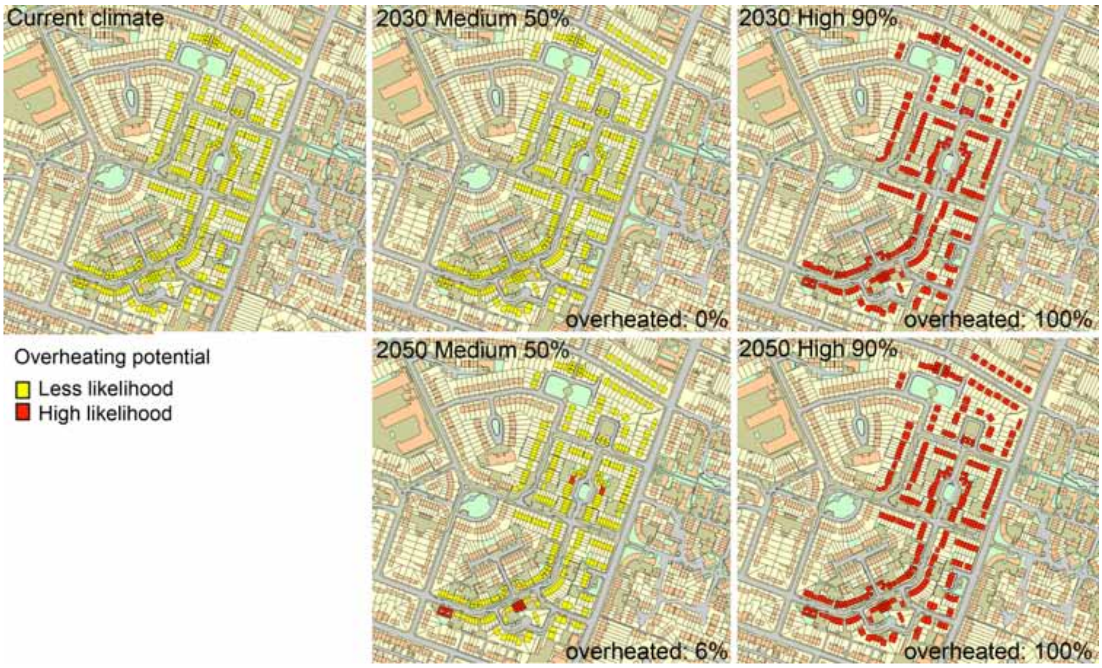


Figure 7.4 *Climate change impact as overheating potential for Upper Horfield at 2030s and 2050s climate periods, medium to high emissions, 50% to 90% probabilities (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Models reproduced under the terms of the Contractor's Licence for the Use of Ordnance Survey Data between UWE, Bristol and Bristol City Council. Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

As the maps in Figures 7.3 and 7.4 indicate there is a 71-100% high likelihood of overheating for St. Werburghs and a 6-100% high likelihood for Upper Horfield during the 2050s climate period. Greater overheating potential in St. Werburghs can be attributed to the combination of greater compact urban form (with less exposed external wall area), greater exposure to solar radiation (less tree cover) and higher internal heat gains. St. Werburghs also has a greater number of homes with fully exposed skylights. To adapt the homes for both mitigation of further climate change and mitigation of overheating, the packages outlined in Figure 7.1 are applied to the neighbourhoods. The results are shown in Figures 7.5 and 7.6.

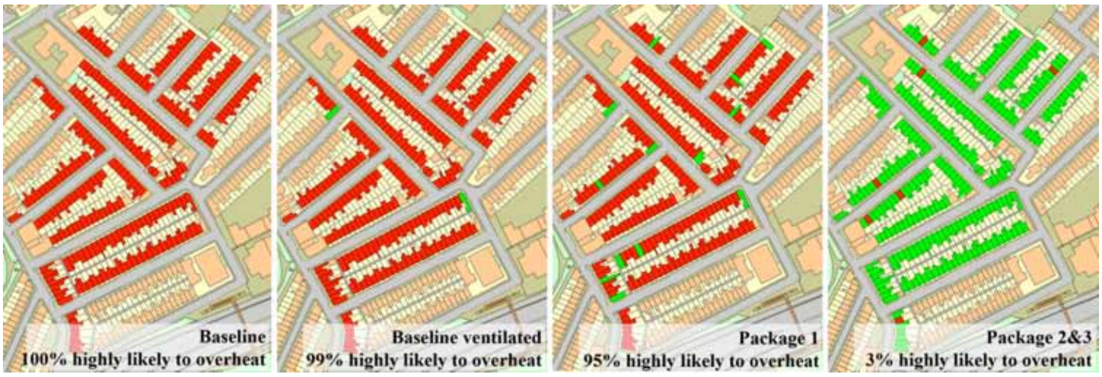


Figure 7.5 *Adaptation package results for 2050s, high emissions, 90% probability in St. Werburghs. Note: packages 2 and 3 do not differ in overheating reduction as package 3 is defined by the inclusion of solar energy systems alone (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Models reproduced under the terms of the Contractor's Licence for the Use of Ordnance Survey Data between UWE, Bristol and Bristol City Council. Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

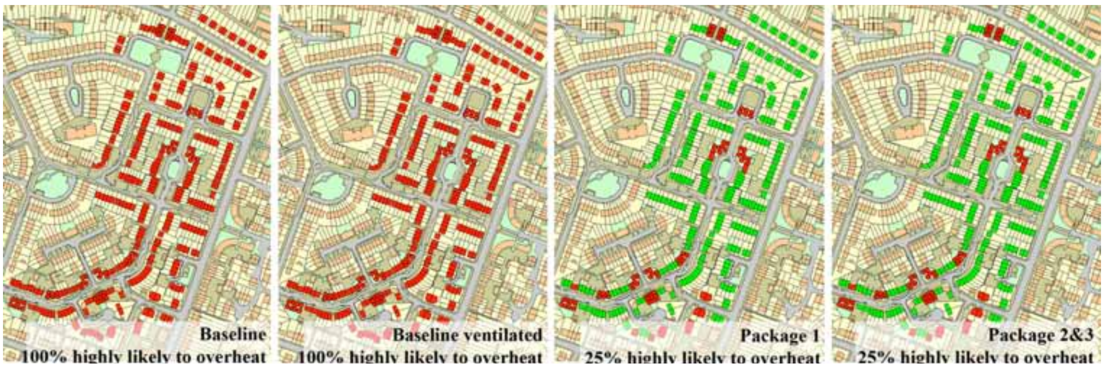


Figure 7.6 *Adaptation package results for 2050s, high emissions, 90% probability in Upper Horfield. Note: packages 2 and 3 do not differ in overheating reduction as package 3 is defined by the inclusion of solar energy systems alone (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Models reproduced under the terms of the Contractor's Licence for the Use of Ordnance Survey Data between UWE, Bristol and Bristol City Council Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

The adaptation packages are successful in mitigating potential overheating in the neighbourhoods. The homes in St. Werburghs that remain overheated after the application of package 2&3 all have converted lofts with multiple large skylights. These types of windows can be difficult to shade and cause the home to be vulnerable to solar gain. The homes that remain overheated in Upper Horfield on the other hand are most noticeably the flats and other single story dwellings with less effective ventilation capacity.

7.2 Oxford

The probabilistic overheating results of the case study neighbourhoods of Oxford, Botley and Summertown are shown in Figures 7.7 and 7.8.

Figure 7.7 *Climate change impact as overheating potential for Botley at 2030s and 2050s climate periods, medium to high emissions, 50% to 90% probabilities (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Map© Crown Copyright/ database right 2012. An Ordnance Survey/EDINA supplied service.*

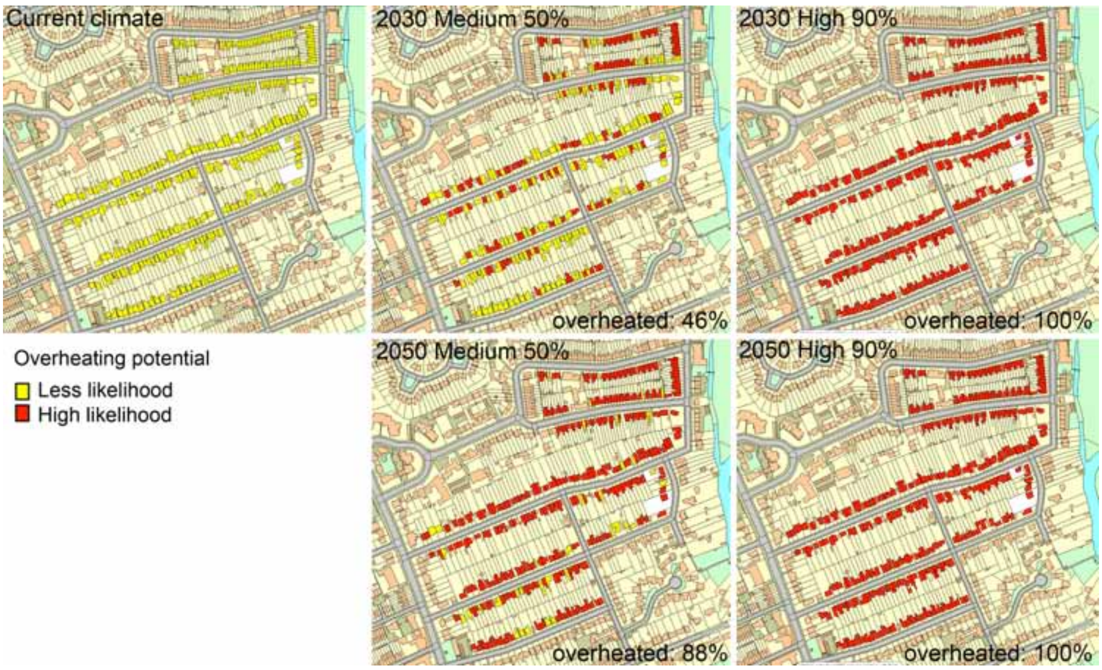


Figure 7.8 *Climate change impact as overheating potential for Summertown at 2030s and 2050s climate periods, medium to high emissions, 50% to 90% probabilities (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

As the maps in Figures 7.7 and 7.8 indicate there is a 98-100% high likelihood of overheating for Botley and an 88-100% high likelihood for Summertown during the 2050s climate period. These likelihoods are higher than that of Bristol due to the higher mean summer temperatures (current and future). Greater overheating potential in Botley can be attributed to the homes having a larger window to exposed wall ratio. This relationship in older homes indicates more potential for solar gain to enter the home as compared to the home's overall wall area (not transferring direct solar gain into the home). Summertown as a neighbourhood represents the most diverse of the case study neighbourhoods in terms of age and built form variation. This variation can clearly be seen in the overheating potential during the 2030s medium emissions, 50% percentile (Figure 7.8) where there is higher proportion of homes grouped together in the upper right side of the image. These homes have a high likelihood of overheating and are all terraced housing whereas much of the rest of the neighbourhood are detached and semi-detached. To adapt the homes for both mitigation of further climate change and mitigation of overheating, the packages outlined in Figure 7.1 are applied to the neighbourhoods. The results are shown in Figures 7.9 and 7.10.

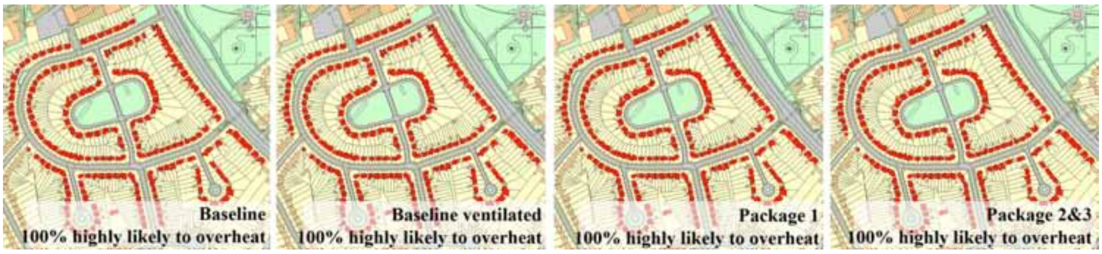


Figure 7.9 *Adaptation package results for 2050s, high emissions, 90% probability in Botley. Note: packages 2 and 3 do not differ in overheating reduction as package 3 is defined by the inclusion of solar energy systems alone (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

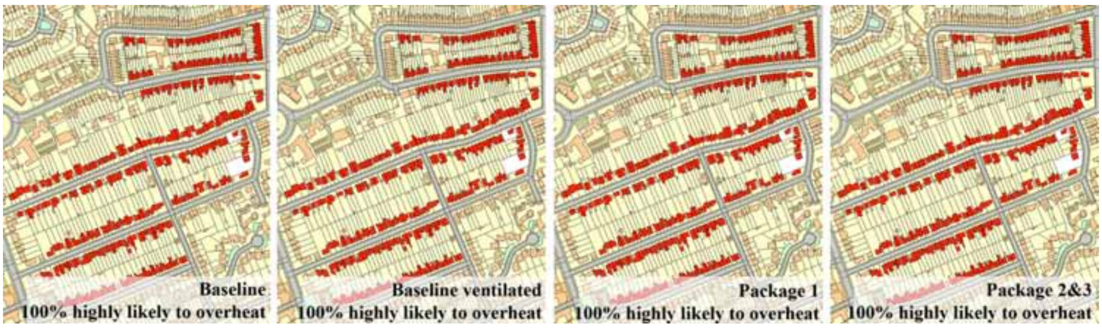


Figure 7.10 *Adaptation package results for 2050s, high emissions, 90% probability in Summertown. Note: packages 2 and 3 do not differ in overheating reduction as package 3 is defined by the inclusion of solar energy systems alone (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

The adaptation packages are unsuccessful in mitigating potential overheating in the neighbourhoods. It is important to note however that an 'extreme case' projection is being simulated. The risk is 'very unlikely to be greater than' the results being presented, however additional adaptive solutions may be necessary. This might include active cooling with an air-source heat pump driven by photovoltaic panels. When the simulation is expanded to view the probabilistic range results for the 2050s climate period there is evidence that the adaptation packages will provide overheating mitigation for the neighbourhoods in Oxford under less extreme conditions (Figure 7.11).

Oxford 2050s	Baseline				Package 1				Package 2 & 3			
	Medium		High		Medium		High		Medium		High	
Probability	50%	90%	50%	90%	50%	90%	50%	90%	50%	90%	50%	90%
Botley	98%	100%	99%	100%	3%	19%	3%	100%	0%	2%	0%	100%
Summertown	88%	100%	98%	100%	0%	5%	1%	100%	0%	0%	0%	100%

Figure 7.11 *Probabilistic adaptation overheating results for the 2050s in Oxford*

7.3 Stockport

The probabilistic overheating results of the case study neighbourhoods of Stockport, Bramhall and Cheadle are shown in Figures 7.12 and 7.13.

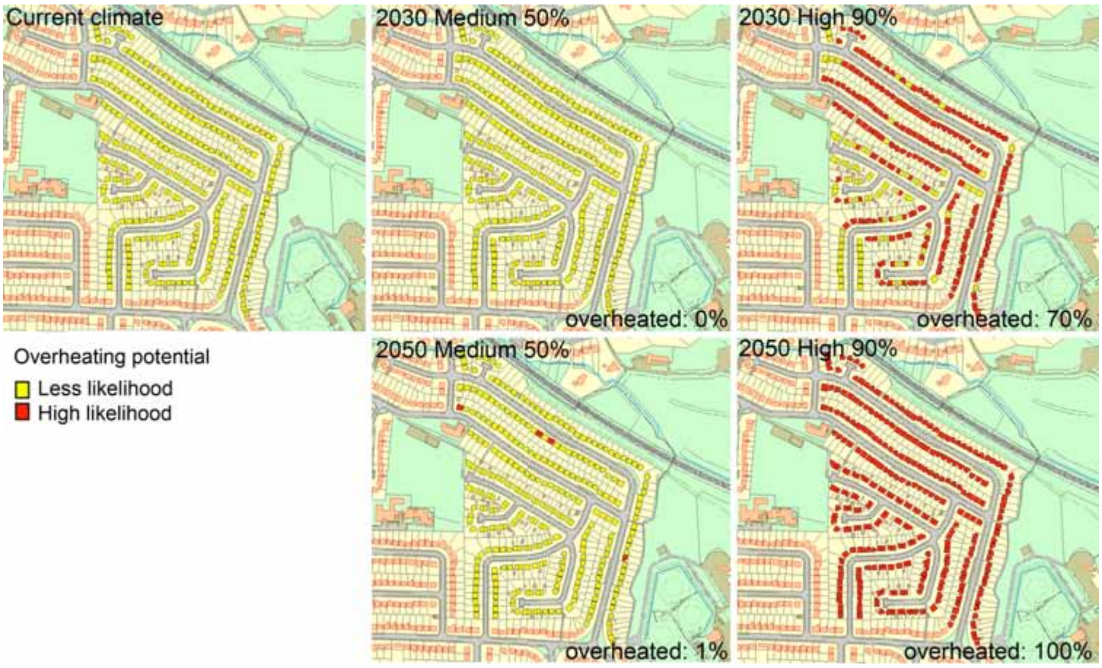


Figure 7.12 *Climate change impact as overheating potential for Bramhall at 2030s and 2050s climate periods, medium to high emissions, 50% to 90% probabilities (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

Figure 7.13 *Climate change impact as overheating potential for Cheadle at 2030s and 2050s climate periods, medium to high emissions, 50% to 90% probabilities (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

As the maps in figure 7.12 and 7.13 indicate there is a 1-100% high likelihood of overheating for Bramhall and a 0-100% high likelihood for Cheadle during the 2050s climate period. To adapt the homes for both mitigation of further climate change and mitigation of overheating, the packages outlined in Figure 7.1 are applied to the neighbourhoods. The results are shown in Figures 7.14 and 7.15.

Figure 7.14 *Adaptation package results for 2050s, high emissions, 90% probability in Bramhall. Note: packages 2 and 3 do not differ in overheating reduction as package 3 is defined by the inclusion of solar energy systems alone (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

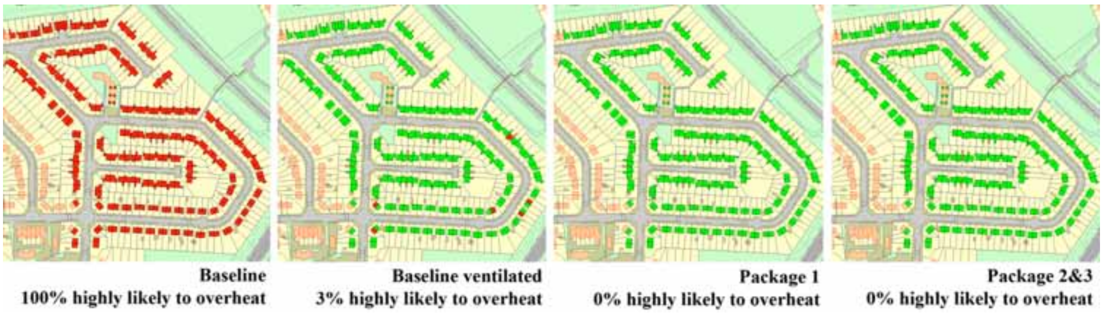


Figure 7.15 *Adaptation package results for 2050s, high emissions, 90% probability in Cheadle. Note: packages 2 and 3 do not differ in overheating reduction as package 3 is defined by the inclusion of solar energy systems alone (source: Digimap, 2012; The DECoRuM-Adapt model, 2012). Map© Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.*

The adaptation packages are extremely successful in mitigating potential overheating in the neighbourhoods. In fact, before any adaptation packages are applied, simply having a safe and effective ventilation strategy for the homes in Stockport appears to mitigate the overheating problem in a majority of the homes by the 2050s.

Figure 7.16 lists the impact of the packages with and without ventilation. The relatively lower climate change impact in Stockport provides a majority of the homes in the neighbourhoods with the unique advantage of adapting without daytime ventilation. This can of course change if airtightness is increased.

Stockport 2050 High 90%	Baseline		Package 1		Package 2 & 3	
	Sealed	Ventilated	Sealed	Ventilated	Sealed	Ventilated
Bramhall	100%	11%	100%	0%	2%	0%
Cheadle	100%	3%	95%	0%	4%	0%

Figure 7.16 *Probabilistic adaptation overheating results for the 2050s in Stockport*

7.4 Conclusion

The testing phase of the project has indicated that there are a number of effective adaptation options. The most technically effective adaptive approach is to reduce solar radiation into the home and onto the fabric of the home. This can be done in a number of ways on different scales, e.g. planting of trees at a neighbourhood scale to installing external shading devices on an individual home basis.

As is seen through the effective packaging of both, adaptation and mitigation of climate change in suburban homes should be considered together as many measures to address these concerns are mutually beneficial. Although the UK is projected to remain a heating dominated climate, wherein improving the thermal properties of building fabric will be essential, other adaptive measures to reduce the risk of future overheating on a house level are urgently needed. Therefore a fabric-based future proofing approach comprising mitigation and adaptation measures (as demonstrated above for example) is recommended for large-scale refurbishment of existing housing.

Internal gains aside, newer homes, i.e. dwellings built to meet improved fabric regulations, are more sensitive to potential overheating than older homes. This is likely to be the greatest conflict as the UK strives to meet Government CO_2 targets by retrofitting and building new homes that are only, at best, climatically responsive to the current climate. As the current UK Building Regulations and retrofitting programmes are mainly concerned with heat retention (and CO_2 reduction), it is essential that future revisions to Building Regulations and other policy measures tackle the risks of, and potential for adapting to, climate change driven overheating to ensure a comfortable environment for occupants.

8.1 Introduction

This Chapter presents the findings from the residents' workshops in the six case study suburbs. At the workshops we discussed:

- residents' experiences of different weather events (heat waves, floods, storms);
- their attitudes towards climate change;
- their familiarity with the range of adaptation measures that could be effective in their neighbourhood (at the home, garden and neighbourhood scales);
- whether they have (or would consider) implementing these measures together with their reasons for doing so, and;
- if they would not consider implementing the measures, then what are the key barriers to adopting them and what incentives might enhance their attractiveness.

The findings are presented below.

8.2 How do residents perceive climate change and its impacts?

Some residents disputed the climate change projections based on the science behind the projections and/or their personal experience of weather over their lifetime. In general the threats from stormier winters and hotter drier summers did not seem to raise much concern for residents. They considered overheating a low-urgency, non-immediate threat that could be addressed reactively when it became problematic. Flooding was generally not considered a threat (even in areas which had experienced nearby flooding). Drought was considered a moderate threat because most residents had experienced hose-pipe bans. There was a general willingness amongst residents to cope with weather discomfort at certain times of year. In Stockport residents simply did not see adaptation as an issue of relevance because of their existing weather experiences (they welcomed hotter weather in the summer, and are already used to wet winters). In Bristol and Oxford there was a moderate level of interest in measures to mitigate summer temperatures (because they already experience some level of discomfort in summertime), however the most common view was that they would adopt some of these measures only when the weather became uncomfortable and not in anticipation of hotter summers. Even when residents were shown the results of the DECoRuM modelling which revealed the potential extent of overheating at the level of individual homes, they were not unduly concerned.

Climate change scepticism

Are you saying it's getting warmer now than what it was 30 odd years ago? Because when I was a kiddie when I was on school summer holidays I couldn't walk on the pavements...and yet you can here now in the summer.

Well in the future that is debatable as to what might happen...there is a totally alternate scenario which says we will go much colder as a result of climate change.

Heat not seen as a serious problem

I think it wouldn't be relevant as at the moment there isn't really a great need for it because we haven't got high temperatures.

We have the heating on in the summer!

Heat welcomed by some in Stockport

I find it very difficult to perceive what this might actually be like, because as far as I am concerned at the moment, bring it on!

Heat seen as a problem by some residents in Bristol and Oxford

We need to put green back into the district, we really do because the last couple of years if you walked down Filton Ave on a hot day it is like walking through the Gobi Desert, it is boiling.

Willingness to cope with occasional heat

That's life isn't it? You have got a few days of the year when it's going to be extremely hot, enjoy them while you can because the rest of the time it's going to be cold.

Flooding not considered a serious risk

There's quite a few years you know since we had a flood up here so it seems a bit over the top for our houses (flood prevention measures)

Climate impacts a future issue only

I suppose over a fifty year span it is likely that windows which are currently installed will need replacing, and I suppose at that point these kind of things would be coming in.

I think like most other people I would react. If there is a need for it I would do it, if there wasn't a need for it at the time I wouldn't do it.

Figure 8.1 *Quotations about climate change by residents*

8.3 Residential property adaptation

8.3.1 What are residents' attitudes to mitigation options?

Residents were presented with a selection of mitigation measures appropriate for their property type and asked whether they were likely or unlikely to implement any of these measures in their home and garden (Figure 8.2). The most likely adaptations are double/triple glazing, roof insulation and food growing. Air source heat pumps, external wall insulation and solar panels are much less likely to be considered by residents. Some residents have already implemented mitigation measures because of grants and subsidies, hobbies (e.g. gardening), routine upgrades (e.g. new windows) and environmental concerns (e.g. photovoltaics). Cost-savings and environmental concerns are the key drivers for residents wanting to install mitigation measures. Reasons for not implementing measures were cost, payback period, maintenance, and potential reduction in house value. Resident support for some of the mitigation measures varies according to case study area. There was less support for photovoltaics and solar panels in Stockport compared to the southern cities of Bristol and Oxford.

Suburb typology	Inner historic	Pre-war Garden	Inter-war	Social housing	Car	Medium-high
Case study	St Werburghs	Summertown, Oxford	Botley Oxford	Cheadle Stockport	Bramhall Stockport	Horfield Bristol
Photovoltaic panels	✔	-	✗	✗	-	✔
Solar panels	-	-	✗	✗	-	-
Grow food	✔	✔	✔	-	✔	✔
External wall insulation	✗	-	✗	-	✗	✗
Double/triple glazing	✔	✗	✔	✔	✔	✔
Roof insulation	✔	✔	✔	✔	✔	✔
Cavity wall insulation		✔	-	✔		-
Air source heat pump	✗					

Likelihood of implementation: Likely ✔ Mixed - Unlikely ✗
Shaded areas: adaptation not tested in that case study

Figure 8.2 *Residents' likelihood of implementing mitigation measures by case study suburb*

8.3.2 What are residents' attitudes to 'summer' adaptation options?

Residents were presented with a selection of summer adaptation measures appropriate for their property type and asked whether they were likely or unlikely to implement any of these measures in their home and garden (Figure 8.3). As heat is not seen as a serious problem, adaptations are either seen as unnecessary (particularly in the north where climate change is welcomed) or behavioural adaptations are seen as sufficient. Drought and water prudence is better understood so water butts are particularly favoured. The most likely adaptations are simple water saving measures (water butts) and measures which have a shading/cooling function (wall greenery, lock-open windows, external shading, shading outdoor space). The least likely adaptations relate to internal thermal mass, green roofs and underpinning homes. Adaptations would be made for aesthetic, enjoyment reasons, and to save rainwater. The main reason for not implementing summer adaptation measures was the strong opinion that they simply were not needed.

Suburb typology	Inner historic	Pre-war Garden	Inter-war	Social housing	Car	Medium-high
Case study	St Werburghs	Summertown, Oxford	Botley Oxford	Cheadle Stockport	Bramhall Stockport	Horfield Bristol
External solar shading	✗	-	-	✗	✗	✔
Internal shutters		✗	✗	-	✗	-
External shutters	✗					
Solar film	✔	-	✗	✔	✗	✔
Wall greenery	✔		✔	-	✗	
Green roof	✗	✗	-	✗	✗	-
Shaded outdoor space	✗	✔	✔	✔	-	-
Water butt		✔	✔	✔	✔	✔
Rainwater harvesting system	✔	-	✗	✗	✗	✗
Internal thermal mass		✗		-	✗	-
White roof and walls		✔	✗	✗	✗	
Extend eaves		✗	✗	✗		
Lock-open windows	✔	✔		✔	✔	✔
Underpin house		✗	✗	✗		
Drought-resistant planting	✔					

Likelihood of implementation: Likely ✔ Mixed - Unlikely ✗
Shaded areas: adaptation not tested in that case study

Figure 8.3 *Residents' likelihood of implementing 'summer' adaptation measures by case study suburb*

8.3.3 What are residents' attitudes to 'winter' adaptation options?

Residents were presented with a selection of winter adaptation measures appropriate for their property type and asked whether they were likely or unlikely to implement any of these measures in their home and garden (Figure 8.4). There is less support for these measures than mitigation and summer adaptations. Even those who have experienced flooding (either directly or nearby) are not very likely to implement flooding adaptations, although a small number would consider flood-gates and flood-doors. There is a moderate level of interest in replacing non-porous drives. The most likely adaptations are simple measures such as trickle vents, air brick covers and maintaining guttering. There is a lack of awareness among residents of winter adaptation options and confusion over the benefits of protecting an individual home from flooding in contrast to relying either on insurance attached to the property and/or local authority flood defences.

Suburb typology	Inner historic	Pre-war Garden	Inter-war	Social housing	Car	Medium-high
Case study	St Werburghs	Summertown, Oxford	Botley Oxford	Cheadle Stockport	Bramhall Stockport	Horfield Bristol
External render		✔	-	✗	✗	✗
Re-pointing brickwork		-			✔	
Replace non-porous driveways		✔	✔	✗	-	
Wood protectors					✔	
Trickle vents	✔	-	✔	✗	✗	
Maintain guttering					✔	
Flood-proof door	✗	✗	✗	✗		✗
Flood gate	✗	✗	✗	-		✗
Air brick covers	✗	✔	✗	✔		
Elevate electrical sockets	✗	✗	✗	✗		
Replace internal flooring				-		
Flood skirting	✗					
Water-proof window seals	✗					

Likelihood of implementation: Likely ✔ Mixed - Unlikely ✗
Shaded areas: adaptation not tested in that case study

Figure 8.4 *Residents' likelihood of implementing 'winter' adaptation measures by case study suburb*

8.3.4 What are the factors that determine whether residents would or would not adopt an adaptation measure?

The likelihood of residents adopting adaptation measures is influenced by a number of factors including the initial cost, convenience and visual appearance of measures and the longer term payback period and other lifestyle and environmental benefits. Adaptation options that appeal the most to residents are those that offer multiple benefits (e.g. are cost-saving, visually attractive and improve climate comfort). Measures that produced additional benefits were favoured such as double/triple glazing (noise reduction), growing food (enjoyable/hobby) and wall greenery (visually attractive). Solar film was strongly supported in the Bristol case studies because it is cheap, can be fitted quickly by DIY (and removed if desired), and does not significantly change the visual appearance of a property. People were more likely to adopt a measure (or had already done so) if it was likely to coincide with other home renovations, reducing the costs and minimising disruption from building works.

Reasons for not being supportive of adaptation measures included potential damage to property (wall greenery), inappropriate housing orientation (solar panels needing south facing roofs), lacking sunlit garden space (growing food), not planning to stay in their home long-term (to make outlay costs worthwhile) and not having the capacity to implement measures needing approval from Housing Association or management board (solar panels) or water utility companies (rainwater harvesting).

Residents' were particularly quick to point out behavioural alternatives to adapt to some of the changing weather conditions, such as closing curtains during the daytime and opening windows in the evening (or even not using particular rooms) to reduce internal house temperatures in the summer. These common sense measures could reduce the need for technical measures and/or changes to the built fabric of their individual properties. Residents' responses to adaptation measures were also influenced by:

- Previous weather experience – whether their home had flooded before, if they had felt uncomfortably hot in their homes or experienced overheating in friends'/family's homes;
- Familiarity with the options – whether they had heard of them before and how effective they were perceived to be; and
- Responsibility for addressing climate risk – whether they thought that individual householders or other stakeholders were responsible for taking action to reduce the impact of climate change.

Figure 8.5 gives a summary of residents' reasons for being more or less likely to adapt.

Reasons for being likely to choose an adaptation measure

- Inexpensive
- Convenient to install (i.e. DIY)
- Looks attractive
- Lifestyle benefits (enjoyable, reduces noise)
- Provides energy cost-savings
- Environmentally friendly (reduces carbon emissions)
- Improves current climate comfort
- Is more efficient
- Potential for financial support (grants and subsidies)
- Could be done easily with other home renovations

Reasons for being less likely to choose an adaptation measure

- Too expensive as initial cost
- Major building works required
- Bulky and unattractive
- Potential damage to property from measure
- Loss of house space
- Inappropriate housing orientation for measure
- Lack of space or sunlight required for measure
- Simpler behavioural alternative
- Requiring external approval (e.g. from housing association)

Figure 8.5 *Residents' reasons for being more or less likely to choose an adaptation option*

8.3.5 How does the likelihood to implement adaptation measures vary between case studies?

Residents' likelihood of implementing adaptation measures varies between case studies based on the **type of the house and suburb** and the **characteristics of the community.**

Housing and suburb type: some adaptation measures are more popular in certain case study areas depending on the housing type and the suburb typology. For example shaded outdoor space is much more popular in suburbs with larger gardens even though it is applicable to all the housing types.

Community characteristics: although cost was a major factor in all case studies, the highest and lowest income neighbourhoods were most likely to be primarily influenced by financial factors. The lowest income neighbourhood could not afford the initial cost of many measures, and the wealthier neighbourhoods would not choose to spend the money on measures that did not guarantee a financial return within a short-medium term timeframe. The wealthier neighbourhoods were more resistant to making changes for the sake of, or in response to, climate change, and were much more motivated by financial or lifestyle benefits from carrying out improvements to their properties. The low-middle income neighbourhoods were more environmentally motivated and could also see the practical benefits in adaptation measures to improving the climate comfort of their homes.

The wealth of residents also influenced the preferences they had between different adaptation measures that achieved the same climate benefit. For example, although solar film on windows was very popular in the low-medium income neighbourhoods, the wealthier neighbourhoods favoured more expensive window shading measures due to concerns that solar film might look cheap and devalue their property.

Figure 8.6 summarises the community characteristics of each case study area that influenced residents' likelihood of implementing adaptation measures.

St Werburghs, Bristol
Low-medium income owner-occupier neighbourhood. High environmental awareness among residents. Good knowledge of their property characteristics and how applicable adaptation measures might be.

Summertown, Oxford
Medium-high income owner-occupier neighbourhood. Residents were sceptical of climate change projections and saw little need for adaptation.

Botley, Oxford
Medium-high income owner-occupier neighbourhood. Residents were sceptical about climate change and saw little need for adaptation. Some interest in measures that increase climate comfort during warm summer days.

Cheadle, Stockport
Very low income social housing neighbourhood. Some mitigation measures already been carried out in their properties by the housing association. Residents hypothetically interested in adaptation measures if they had the money to fund them.

Bramhall, Stockport
High income owner-occupier neighbourhood. Residents sceptical about climate change projections and were less willing to consider adaptation measures because of lack of direct experience of hot weather. Strongly motivated by cost and would only consider measures with subsidies that would provide a financial return or lifestyle benefit.

Horfield, Bristol
Low income mix-tenure neighbourhood. Housing association undertaken some mitigation measures in homes. Residents interested in learning more about adaptation measures.

Figure 8.6 *Community characteristics of the suburb and their influence on residents' likelihood of implementing adaptation measures*

8.4 Neighbourhood adaptation

In addition to asking residents about changes to their own homes we were also interested in their views on changes to their neighbourhoods. Because residents may or may not be responsible for implementing such changes we asked them about their potential role in such adaptations and also about their acceptance of them if implemented by another agency (e.g. Local Authority). Residents were presented with a selection of neighbourhood adaptation measures appropriate for their suburb type for streets and green spaces and asked whether they were likely or unlikely to accept any of these measures in their neighbourhood.

8.4.1 What is the level of support for adaptation measures at the neighbourhood scale?

Figure 8.7 shows the level of resident support for neighbourhood adaptations in each case study. Residents are mainly positive about schemes to adapt their neighbourhood. They are most positive about street trees, energy efficient street lighting, blue infrastructure in green spaces and reconfiguring the street to improve drainage (SUDS). There are mixed views on community cool rooms based on perceived need for such facilities, and in one case study residents did not support allotments because they considered there to be enough already in the local area. The only strong negative opinions to neighbourhood adaptation were found in one case study where residents were resistant to any changes to a valued local green space.

Suburb typology	Inner historic	Inter-war	Social housing	Car	Medium-high
Case study	St Werburghs	Botley Oxford	Cheadle Stockport	Bramhall Stockport	Horfield Bristol
			Shading, localised cooling and drought resistance		
Street trees	✔	✔	✔	✔	-
Shading in green space		✗	✔	-	-
Blue infrastructure		-	✔	✔	
Community cool room		-	✔	-	✔
Drought-resistant trees					-
Shared space			-	-	
			Flooding		
Reconfigure street drainage	✔	✔	✔	✔	✔
Flood defences	✔		✔		
			Mitigation of future climate change		
Energy efficient street lighting	✔	✔	✔	✔	✔
Allotments		✗	-	✔	

Acceptability of option: Acceptable ✔ Mixed - Unacceptable ✗
Shaded areas: adaptation not tested in that case study

Figure 8.7 *Residents' support for neighbourhood adaptations by case study suburb*

Neighbourhood adaptations were supported because they would make neighbourhoods more attractive (street trees), improve energy efficiency (lighting) and reduce surface water flooding risk (reconfigure street drainage, flood defences). Some concerns were raised by residents about the impact of installing these measures and the effect of the changes on the neighbourhood, particularly with street trees. Issues of maintenance, the potential damage of tree roots to footpaths and roads, and the danger of obscuring visibility for reduced road safety and anti-social behaviour were mentioned. The question of who would pay for introducing these measures was also identified, with residents concerned about increased taxation or management charges.

8.4.2 What factors determine residents' acceptance of adaptation measures at the neighbourhood scale?

Support for adaptation measures at the neighbourhood scale in streets and green spaces were influenced by the history of community action in the local area, residents' experiences with previous local authority retrofitting initiatives and current social issues in the neighbourhood. Figure 8.8 summarises the key factors that determined the level of support for adaptation at this scale.

St Werburghs, Bristol
High level of support for neighbourhood adaptations. History of positive community action around environmental issues.

Botley, Oxford
Low level of support for neighbourhood adaptations. Opposition to recent local authority initiative to modify local green space.

Cheadle, Stockport
High level of support for neighbourhood adaptations. History of community action around social issues and government-led regeneration experienced as having positive impacts on the local area.

Bramhall, Stockport
High level of support for neighbourhood adaptations but sceptical of measures being implemented. Lack of history of local authority initiatives in local area and loss of community leader for collective action.

Horfield, Bristol
Moderate level of support for neighbourhood adaptations. Neighbourhood history of social problems created concerns over security and anti-social behaviour from some neighbourhood adaptations. Disruption and maintenance

Figure 8.8 *Neighbourhood factors that affected level of support for neighbourhood adaptation*

8.5 Responsibility for delivering adaptation

A key issue in considering adaptation is where responsibility lies for taking action. The residents discussed this issue at length and their views are summarised here.

8.5.1 Who do residents think should be responsible for adaptation?

Residents consider overheating an individual's responsibility and adopting adaptation measures is an issue of personal choice to improve comfort levels within the home. The impacts of increased temperature may be too long-term and gradual to motivate proactive action in the short-term unless residents already experience uncomfortably hot weather in their homes. With regard to flooding, residents consider preventative measures a local authority or central government responsibility, partly due to the perceived ineffectiveness of individual action in addressing the threat and partly due to attitudes on personal and government areas of responsibility. But residents consider reactive flooding measures something to possibly consider after a flood event through insurance compensations. There is no speculation by residents that insurance companies might stop insuring against floods in the future. Even those that have previous personal experience of flooding do not necessarily see the need to take action themselves. Residents felt responsible for damage to their homes from storms/wind etc.

8.5.2 What role do residents think collective action could have in delivering adaptation?

Residents identified the need for some measures to be undertaken by householders at the neighbourhood scale. For example, some flood measures introduced at the house level would only be effective if everyone in the street implements them. Other measures, such as external insulation, would need to be installed on every house on the street to maintain visual continuity and be more cost efficient.

The role of community groups was raised as important for delivering neighbourhood adaptations. Residents identified the importance of individuals in neighbourhoods that acted as community leaders to initiate projects and rally community involvement and support. The recent loss of such a leader in one community was noted as reducing community capacity for collective action. Local churches, community trusts, residents' action groups and tenants' associations were discussed as being important avenues for tackling neighbourhood issues.

The existing community capacity in most neighbourhoods is not currently being used to address climate change adaptation but in some of the case study areas there is existing community activity targeting mitigation and a variety of other issues (such as anti-social behaviour) that could be tapped into for adaptation.

8.6 Conclusions

This chapter has presented a summary of residents' responses to adaptation in their homes, gardens and neighbourhoods. The findings are revealing in highlighting residents' awareness of climate change and their views on it. They also shed light on which adaptations residents may implement autonomously, and which they would not. Residents' reasons for acting and/or not acting are useful in framing strategies for suburban adaptation.

9.1 Introduction

This chapter reports the findings from the three workshops held with stakeholders in Oxford, Bristol and Stockport. The range of stakeholder attendees has been described in Chapter 4. They included representation from local authorities (officers and members), the construction industry, the community and NGO sector as well as other public bodies. Around 30 stakeholders attended the workshops across the three cities and although this cannot claim to be representative of all views held by key stakeholders involved in suburban adaptation, it does give a clear perspective on the types of view held.

At the workshops the participants discussed:

- The findings from the residents' workshops in each city, and the stakeholders' experiences of working with households locally;
- The role of communities in adaptation;
- How the stakeholders are currently tackling adaptation;
- The role of planning and building regulations in adaptations;
- The best mechanisms for delivering adapted suburbs.

The findings from the workshops are summarised here.

9.2 Stakeholders experiences of working with residents

Many of the stakeholders work directly or indirectly with householders in mitigation and/or adaptation actions. Others are involved with residents dealing with the impacts of, for example droughts, flooding and overheating. The stakeholders experiences of working with residents is summarised here.

9.2.1 What are stakeholders' experiences of how residents understand adaptation?

The stakeholders reported a lack of residents' awareness of climate change and, in particular, a lack of concern over adaptation. They were not surprised that we had found that homeowners lacked awareness about specific adaptation solutions that go beyond measures that also act to mitigate climate change, such as insulation and double-glazing. The stakeholders had also experienced householders' lack of awareness, particularly of more technical issues, such as thermal mass. In many instances, residents have never even heard of particular measures and often require professionals to explain them. This said, some of the architectural stakeholders reported that some of their clients are concerned about the effects of insulation on overheating and air quality. These concerns are associated with current thermal comfort, and not a need to adapt for future climate change. Most stakeholders agreed that climate change is not likely to be the key driver for the implementation of adaptation measures in residential properties.

9.2.2 What drives residents to install adaptation measures in their homes? And what is likely to drive them to install adaptation measures in the future?

Stakeholders' experiences were that residents were motivated to install mitigation measures mainly by cost savings. However, the payback period on adaptations is an important driver for householders. Solar panels were given as an example where people are seeing them as an investment which gives them a return over a long period.

Stakeholders felt that the key driver for residents in the future would be an increase in energy bills. Such increases may make some adaptations more popular. They also thought that peoples' experiences of climate change would need to be more 'extreme' before they act.

9.2.3 What stops residents from adapting their homes? And what would stop residents from adapting their homes in the future?

The stakeholders' experiences were that householders are unlikely to take anticipatory action if they are not experiencing problems. For example, temperatures would need to rise significantly before householders take action to install adaptation measures. They described people as 'market-laggers' who will resist doing anything until they have to. They had also found that many people (and communities) distrust government information and free services, and this limits mitigation and adaptation uptake. In addition, financial constraints often mean that adaptation (or any home improvement) is not a priority. They also reported that many residents simply do not make the connection between climate change, adaptation and their home or neighbourhood environment. And, in relation to this, there is little advice for homeowners on this issue. Architectural firms that understand the need for adaptation and can advise on measures are only used by people spending a lot of money on major house extensions. Homeowners usually go directly to suppliers and builders who deliver an 'end product', rather than seeking architectural advice about how to make 'climate proof' adaptations.

In terms of future changes, stakeholders noted a number of key reasons that residents may not adapt. First, they concurred with our findings that in general people saw temperature increases as positive and not something to worry about. Increased summer temperatures are welcomed by some in the North, limiting the perceived need for adaptation to prevent overheating in homes. Second, they did not feel that current pricing mechanisms around climate change issues were effective in making people consider adaptations. For example, currently water is relatively cheap, and the price mechanisms for dealing with surface water are not effective. Third, they found that people put off changes to their homes because they do not like the disruption.

Stakeholders reflected on the nature of suburbs and suburban adaptation, arguing that some adaptations represent too much of a cultural change to the look of suburban housing for residents to find them desirable. They also commented (as did the residents) that installing some adaptation measures (such as flood protection) could draw attention to potential problems in homes, so this was also problematic.

9.2.4 What is needed to facilitate householders to make adaptations to their homes?

The stakeholders drew on their experiences to offer insights into what they felt would facilitate householders to adapt. Their suggestions were:

- Get the messages right: 'climate change' messages can create resistance to action, so engage householders with the practical and immediate benefits of installing adaptation measures, and stress cost-effectiveness and 'quality of life/comfort' benefits. People need to be engaged in the tangible and immediate benefits of action, not on vague notions of future benefit. Stakeholders perceive that residents are most likely to be motivated by cost-savings and comfort, so messages of cost-effective house maintenance and improving liveability may be effective. They thought lessons could be learnt from the success of climate change action where low-carbon behaviour is framed as a money-saving activity not just an environmental solution.

- Provide advice or information during 'windows of opportunity'. There are windows of opportunity when homeowners are more likely to make changes to their homes, e.g. when they first move into a new home and when they are doing other home improvements such as extensions or replacing windows. These are key times to convey messages about climate change mitigation and adaptation.

- Provide training to the main contact points for home improvements. Train the frontline contact points, e.g. builders, DIY store staff, estate agents as they can help with suggestions for home improvements at critical times.

- Target information to areas that have already experienced flooding or overheating. People may be more motivated to implement adaptation measures if they have already experienced the negative impacts of climate change (although our findings from the residents' workshops show that this may not be the case with respect to flooding).

- Develop demonstration projects of good adaptation. Few examples of good adaptation exist. People need to be shown good examples of an adapted house (or neighbourhood) and to see adaptation measures working effectively and looking attractive to be interested in making changes to their own properties.

9.3 Stakeholders experiences of working with communities

In addition to householders acting independently, we were interested in community responses to adaptation. The stakeholders had some experience of working with communities and their views are summarised here.

9.3.1 What drives communities to undertake collective action for adaptation and mitigation? And what deters them?

The stakeholders had experience of non-environmental community groups with complementary agendas working to encourage householders to make changes to their homes. These groups could have a focus on social inclusion, older peoples' welfare or fuel poverty, but the outcomes were the same (i.e. some adaptations to the home).

In other circumstances community action had been used to access central government funding that local authorities cannot. This community and neighbourhood 'autonomy' is being played out through policy agendas such as the 'Big Society'. A more collaborative relationship with local authorities, for example through the development of neighbourhood plans which contain adaptation measures, might also be a way forward. However there was little direction from stakeholders on how this might happen.

Currently stakeholders' experiences were that very active communities, interested in both climate change mitigation and adaptation, were rare. Low carbon or low energy objectives were more common, and adaptation to climate change and resilience measures were not promoted by low-carbon groups. In addition community groups that are currently engaged in community work around flooding do not necessarily engage with the topic of climate change and the trend that flooding is likely to worsen in the future. Overall, community campaigning groups tend to have a single-issue focus with an agenda for either adaptation (less likely) or mitigation (more likely), but not both.

9.3.2 What is needed to facilitate communities to undertake collective action for adaptation?

Stakeholders' suggested several key actions that might engage communities in adaptation actions:

- Encourage Local Authorities to build local capacity for collective community action: Local Authorities can encourage the formation of community groups through capacity-building activities and provide advice on accessing government grants.
- Build adaptation into low-carbon activities already being carried out by community groups: Building on the existing activity and momentum within community groups oriented on carbon reduction would be an effective way to deliver adaptation.

9.4 Adaptations by stakeholders

As well as working with residents and communities, some stakeholders are directly involved in implementing suburban adaptation. This section explores their experiences.

9.4.1 How do stakeholders perceive climate change in relation to their work on adaptation?

The stakeholders in our workshops had a good understanding of climate change. They may not regularly use climate change data, but operate from a generic understanding that weather conditions in the UK are going to get warmer and wetter. Most considered flooding a current problem that is likely to get worse through climate change. Overheating and drought were seen as a problem in Oxford and Bristol but less so in Stockport. In general, overheating is a comparatively new concern for stakeholders and there is a degree of uncertainty about how severe the problem will be and when. In fact, many of the stakeholders reported that the long-term timeframes of climate change impacts provide a reason to justify the delay in taking action in the present.

Many stakeholders in our workshops focused, professionally, on a single climate change risk: flooding, overheating or drought. Fewer had responsibilities for a range of threats. They all distinguished between current climate problems and those connected with climate change. Most assessed climate risks and the need for action relative to other parts of the country.

9.4.2 What is the relationship between 'mitigation' and 'adaptation' for stakeholders? And how are stakeholders currently tackling adaptation?

Until recently, the policy focus in England has been on climate change mitigation, particularly reducing carbon emissions through improving the energy efficiency of homes and reducing the need for heating in winter. Adaptation is seen as an emergent policy agenda. Perhaps because of this, adaptation is not a high priority for many stakeholders compared to mitigation.

Many of the stakeholders are engaged in trying to encourage mitigation and adaptation through community action. Others work in the delivery of the built environment, and here they report that the focus has been on new build development, rather than retrofitting existing housing stock. Local authorities do currently engage and encourage the private owner-occupier housing sector to install low-carbon measures such as cavity wall and loft insulation, and some are trying to encourage the private rental sector to insulate homes through active landlord forums. However, the stakeholders' experiences were that Housing Associations currently lead the way on mitigation measures. They upgrade existing housing stock and have been particularly at the forefront with installing solar panels. They are much more likely than private householders to seek architectural advice for these improvements.

9.4.3 What role do building regulations and planning have in delivering adaptation?

During the discussions some specific points were made around the role of building regulations and planning in England. First, many stakeholders argued that in terms of mitigation and adaptation, the scope of building regulations is quite limited. They are only applicable for new build or substantial additions to existing buildings. Hence, modifications that impact on climate change (positively or negatively) can happen outside of the regulations. Second, building regulations use minimum standards so they do not necessarily encourage best practice or ideal adaptation solutions. Third, they (along with most of the building industry) are very much focused on reducing heating in winter. Thinking about future summer conditions generated from climate change will require a different set of regulations that also accounts for potential overheating risks.

In terms of planning, it was noted that there are some serious limitations in addressing mitigation and adaption. First, there are limits to what the statutory planning system can do to address climate change. The only leverage the system has to regulate for adaptation is when householders are undertaking significant home extensions or loft conversions where planning approval is required. It cannot require adaptations retrospectively for previous extensions or loft conversions. There are also limits to what can be required of householders through conditional planning permission. If too many conditions are placed on home extensions then the work may not be financially feasible and there is a risk of making it unaffordable. In addition, some adaptation measures are potentially outside the remit of planning and more appropriately carried out through building regulations. There are also problems with enforcing regulations (for example, local authorities do not have the capacity to enforce permeable surfaces being laid in front gardens).

This said, planning legislation does have the potential to ensure that some climate change adaptation problems do not get worse (e.g. there are now regulations against front lawns being paved over with impermeable surfaces, although there remain clear enforcement issues). And some local authorities already require low-carbon measures as part of planning approvals for loft conversions and home extensions to encourage homeowners to make energy-efficiency improvements. However, there are limits to what can be reasonably required in existing housing stock (see Chapter 5). It is likely that local policymakers will need to prioritise mitigation and adaptation conditions on planning approval.

9.5 What are potential mechanisms for enabling suburban adaptation?

As well as understanding the problems inherent in adapting suburbs, we also sought insights from the stakeholders on how suburban adaptation might be best enabled. There was some uncertainly about what the best measures were, but suggestions were:

- Awareness needs to be raised about the connection between mitigation and adaptation: more community and policymaker awareness-raising is needed about the link between mitigation and adaptation and the benefits of retrofit.

- Adaptation and mitigation solutions needed to be normalised: i.e. residents should be incentivised to adapt their houses now in order to make the idea of retrofitting normal and not the exception.

- Adaptation needs to be integrated into existing public and policy agendas: adaptation is likely to be most successfully addressed by linking it to other issues such as low-carbon and healthy community agendas. Incorporating climate change adaptation to the rationale for implementing change to the built environment for these other agendas could generate increased impetus to the political will for adopting some of these measures. It would also be essential to ensure action for other agendas does not conflict with the need to adapt to the anticipated climatic changes.

- Adaptation will require a combination of individual, government-led and partnership actions: the likely governance processes for achieving adaptation would be a combination of individual householder-led and government-led actions. Householders are likely to be responsible for improvements to the climate comfort of their individual properties. Local authorities and flood authorities would be responsible for delivering adaptation measures required at a neighbourhood (and wider urban/catchment area) scale, including flood prevention. These organisations would also use their existing regulatory frameworks to place conditions on planning approvals to encourage adaptation and undertake promotion and advice initiatives to support individual action. Multi-level and multi-agency partnership approaches will be required, for example, in managing flooding risk, because of the multiple ownership of infrastructure and the complexity of managing surface water.

- Frontline channels of information for householders making home improvements need to be better informed: in a finding similar to that of the residents' workshops stakeholders thought that builders, DIY stores and estate agents are effective channels of information for encouraging homeowners to implement adaptation measures in their properties.

- Effective communication of climate risks will become critical: stakeholders with the responsibility for informing the public about climate change risks will need to find effective ways of communicating these risks. Information about different levels of risk will need to be presented in a meaningful and useful format without scaremongering.

- Central government-controlled mechanisms such as grants and subsidies are key mechanisms to deliver adaptation: they have to be appropriately framed and simply administered. For example, the introduction of the 'Green Deal' could provide an opportunity to incorporate adaptation measures to enable householders to retrofit their homes for both energy efficiency and climate comfort without the initial outlay cost. In particular, there is a need to ensure that measures for energy efficiency do not increase the likelihood of overheating in homes during summer, avoiding mal-adaptation.

- Local mechanisms for enabling adaption have potential but require more resources: local promotion initiatives, advice and general community capacity-building activities are valuable.

- Pricing mechanisms for water and energy are, potentially, key drivers of individual behaviour change: (notwithstanding the limitations described above).

- **Demonstration projects have a real value**: they show householders and professionals how adapted homes, gardens and neighbourhoods look and function. Local authorities could lead the way by adapting public buildings as flagships.

- **More opportunities need to be taken of 'economies of scale'**: retrofitting housing en masse is likely to be cost-efficient, delivering benefits for individual property owners. Terrace housing blocks in particular could be targeted for street block retrofitting, particularly if external insulation is to be fitted to homes.

Conclusions

This chapter has summarised stakeholders' experiences of suburban adaptation and their insights in to what might motivate change. It is important to say that their suggestions for motivating action have not been tested for effectiveness independently in the SNACC project, but they are based on a wealth of experience of day-to-day working in climate adaptation.

Chapter 10

Synthesis of findings and conclusions – effective, feasible and acceptable suburban adaptations and pathways to achieving them

10.1 Introduction

This chapter presents some key conclusions from the research. It revisits the research questions posed in Chapter 1, and draws findings from across the study to provide new insights into the challenges and opportunities for suburban adaptation. The questions posed were:

- How can existing suburban neighbourhoods in England be 'best' adapted to reduce further impacts of climate change and withstand ongoing changes? By 'best' we meant: which suburban adaptations would be effective, feasible and acceptable? and;

- What are the processes that bring about change in suburban areas? Specifically: what might motivate residents and other stakeholders to adapt to present and future climate threats?

These questions are answered in turn.

10.2 How can existing suburban neighbourhoods in England be 'best' adapted to reduce further impacts of climate change and withstand ongoing changes?

10.2.1 Overarching findings about the 'best' adaptations

The research resulted in some specific findings about the best adaptations for specific climate risks, and in specific types of suburb (see below). However, it also produced some overarching findings about the 'best' adaptations for suburbs, which are presented first.

- **There is no 'best' 'one size fits all' adaptation package that will work in every suburb.** The 'best' adaptation depends on the type of suburb (and type of housing within it), the climate threats in that suburb (e.g. some suburbs are at risk of flooding, some overheating), and the response capacity in that suburb (e.g. the economic and social conditions, and resources available in the suburb).

- **Effective adaptations must combine 'adaptive retrofitting' with 'low carbon retrofitting'.** There is a danger that some low carbon adaptations may make suburbs less able to cope with future weather conditions, for example some forms of insulation, in some homes, may exacerbate the risk of overheating (See Appendix E for a table of potential synergies and conflicts between adaptation measures) .

- **At both the neighbourhood and individual home scales, adaptation packages are more effective than single measures.** Adaptation packages were found to be effective in reducing the risk of overheating, and a range of greening, landscaping and engineering measures would make neighbourhoods more liveable in future climate conditions.

- **Some neighbourhood adaptation options would be effective in adapting most suburbs for future climate threats.** For example, 'greening' streets and public spaces (adding street trees, allotments, new green spaces), introducing sustainable urban drainage features, and changing to energy-efficient street lighting would be effective (and acceptable) in the majority of suburbs.

- **Some residential adaptation measures are suitable for all housing, but others are only feasible for specific dwelling types.** For example, most homes would benefit from roof insulation, window shading, and water-saving devices. Yet measures such as cavity wall insulation are clearly not feasible for homes built with solid walls. Some measures, although they could be implemented in all housing types, are more effective and likely to be carried out in particular suburbs. For example, growing food and shading outdoor space are more effective and likely in homes with larger gardens.

- **For residents, the 'best' adaptations tend to be cheap, convenient, practical (given the type of home they have), attractive, and have some other lifestyle benefit.** Householders are also more likely to implement dual-purpose adaptations such as those that meet mitigation and adaptation criteria (e.g. insulation) or those that improve comfort and are visually attractive (e.g. greenery).

10.2.2 Key findings on the 'best' adaptations for mitigation and for different climate threats

In addition to these general findings, the research provided some key findings on the 'best' adaptations to mitigate future climate change, and for different climate threats. These are summarised here.

Findings on the 'best' adaptations for **mitigating further climate change.**

- **Home energy saving adaptations (roof and wall insulation, double/triple glazing, PVs and solar panels) were found to be effective in almost all suburbs** (notwithstanding some concerns about overheating, see below), and well understood by residents and stakeholders. However, there were mixed views on their acceptability and likelihood of implementation.

- **Increased greening of homes and gardens (including food growing) is effective and has multiple benefits in suburbs.** Residents are positive about it and likely to increase greenery in their own homes and gardens. Neighbourhood greening is welcomed, but there are resource and practical problems in implementing it.

Findings on the 'best' adaptations for **flooding**

- **Effective adaptations to reduce the risk and impact of floods in suburbs need to address pluvial flooding from inadequate storm water drainage, as much as fluvial flooding from waterways.** This is because the former may contribute to a greater proportion of flooding problems in the future with increased rain intensity and storm activity expected from climate change. Ensuring porous surfaces are retained is important (for example, restricting paving over front gardens and laying large patios), as is the development of sustainable urban drainage systems. However, retrofitting SUDS in suburbs can be disruptive and expensive.

- **A number of individual house-scale adaptations can be effective in limiting some damage from floods** (e.g. air brick covers, flood-proof doors, flood gates). However, they are unlikely to be implemented by residents, even if they have experienced flooding or live in an area at risk.

- **Effective adaptations are those which leave the neighbourhood or home more resilient after a flooding event than it was before.** This can mean that the neighbourhood is protected from further flooding, or that flood damage is limited. However such adaptations are often difficult to implement because insurance companies often only replace 'like with like': they do not pay for more resilient adaptations.

Findings on the 'best' adaptations for **summertime overheating**

- **A number of adaptation options are effective in combating overheating in homes, but the effectiveness of these options depends on the characteristics of the home.** The most technically effective adaptive approach is to reduce solar radiation into, and onto, the home. This can be done in a number of ways on different scales, e.g. planting of trees in the streets and wider neighbourhood, and/or installing external shading on homes. Natural ventilation of the home is also found to be extremely effective. Combining adaptation options into packages was found to be the most effective method of reducing the risk of overheating.

- **Overall external shading (e.g. fixed outdoor window shades or external shutters) is more effective than internal shading (e.g. blinds).** External shutters are the most effective as they keep solar radiation off window surfaces but this measure requires keeping shutters closed during summer days (reducing natural light in homes). Planting green wall cover, garden trees or street trees is also an effective shading measure for homes.

- **Increasing the reflectivity of the exterior surfaces of homes, e.g. a bright white render for the exterior walls can also reduce overheating risk,** and residents are quite likely to implement it, if it does not unduly alter the image of their neighbourhood.

- **Addition of thermal mass to the home, e.g. replacing a timber floor with a concrete floor** reduces potential overheating dependent on location of mass and the capacity to release heat through night time natural ventilation. However, thermal mass is poorly understood by residents and they are unlikely to take action.

- **External insulation is effective in either reducing overheating risk or minimising the increase in overheating risk that would happen as a result of installing insulation in homes.** Internal wall insulation can increase the risk of overheating. However, external wall insulation is not popular with residents and they are unlikely to implement it.

- **Reducing internal gains from sources such as hot water heating tanks and pipe work in the home is a very effective and inexpensive way to reduce the risk of overheating** and increase energy savings.

- **At the neighbourhood scale, the introduction of blue and green infrastructure is likely to bring cooling benefits and is welcomed by residents**. However, there is uncertainty over implementation, particularly about cost and responsibility for installation and management.

- **'Community cool rooms'** could be effective in heat waves, but few residents or stakeholders perceived a need for them, or would be likely to implement them.

Findings on the 'best' adaptations for **storms and driving rain**

- **A number of adaptations were effective in protecting homes, gardens and neighbourhoods from storm damage (e.g. weather-proofing treatments to external walls, trickle vents, retaining porous surfaces)**. However, residents were unlikely to implement these specifically to protect their homes from storm damage. They felt routine maintenance (e.g. clearing gutters, replacing lose roof tiles, ensuring garden fences were well constructed) were more important. Likewise at the neighbourhood scale, few adaptations were considered in respect to storm damage.

Findings on the 'best' adaptations for **droughts and water scarcity**

- **Effective adaptations to homes and gardens include rainwater harvesting systems, and simple measures such as water butts.** Rainwater harvesting was poorly understood and unlikely to be implemented in most suburbs. Water butts were popular and already commonly used. Residents understood water scarcity because they had experienced hose pipe bans, but this had not made them more likely to plant drought resistant plants or change the type of fruit and vegetables they grow.

- **At the neighbourhood scale planting that can withstand climate changes and requires less water is seen as an effective measure**, and is likely to become more commonly implemented by local authorities.

- **Sustainable Urban Drainage Systems can be effective**, and are more feasible in lower density suburbs with more porous surfaces, but they can be expensive and disruptive to retrofit.

10.2.3 Findings on the 'best' adaptation for each of the case study suburbs

The research tested adaptation options in six types of English suburb. It is possible to draw some simple conclusions by using this typology, but it is not possible to generalise from one case study of each type, or to make suburb-specific recommendations. Each of the cases had a unique geographical location, population, history and set of experiences of the weather and of community activity that influenced the residents' and local stakeholders opinions. However, it is possible to summarise the findings about which adaptation options were effective, feasible and acceptable in each case study and to comment of these, using insights from the workshops.

The figures below offer an 'at a glance' summary of which adaptation options were deemed effective, feasible and acceptable in the case study suburbs. All of the adaptations that appear in the figures are already deemed potentially effective for that particular case study. They were then tested for feasibility and acceptability. The figures employ a 'traffic light' system:

- Red indicates that the adaptation option is not feasible for practical reasons or not acceptable to residents or other stakeholders (because for example, it is too costly, unattractive, or out of character with the suburb);
- Amber indicates that either there are mixed views about the feasibility or acceptability of the adaptation, or uncertainly around implementation. These adaptations are not ruled out by residents and stakeholders but there is ambiguity around if and how they would be implemented;
- Green indicates that either the adaptation has already been implemented, or is likely to be so by residents and/or other stakeholders.

House and Garden			Neighbourhood
Mitigation of future climate change	Summer	Winter	
Photovoltaic panels/Solar panels Grow food External wall insulation Double/triple glazing Roof insulation Air source heat pump	Shading External solar shading External shutters Solar film Cooling & ventilation Wall greenery Lock-open windows Drought resistance Rainwater harvesting Drought resistant planting	Extreme weather- wind and driving rain Water-proof window seals Trickle vents Flooding Flood-proof door Flood gate Air brick covers Elevate electrical sockets Flood skirting	Shading, localised cooling and drought resistance Street trees Flooding Flood defenses Reconfigure street drainage Mitigation of future climate change Energy efficient street lighting

Figure 10.1 *Inner historic suburb: St Werburghs*

House and Garden			Neighbourhood
Mitigation of future climate change	**Summer**	**Winter**	
Photovoltaic panels Solar panels Grow food External wall insulation Double/triple glazing Roof insulation	Shading External solar shading Internal shutters Solar film Shaded outdoor space Extended eaves Cooling & ventilation Internal thermal mass Lock-open windows Green roof White roof and walls Drought resistance Rainwater harvesting Water butt	Extreme weather- wind and driving rain External render Flooding Flood-proof door Flood gate Air brick covers	Shading, localised cooling and drought resistance Street trees Shading in green space Blue infrastructure Drought resistant trees Community cool room Flooding Reconfigure street drainage Mitigation of future climate change Energy efficient street lighting

Figure 10.2 *Medium/high density suburb: Upper Horfield*

House and Garden			Neighbourhood
Mitigation of future climate change	**Summer**	**Winter**	
Photovoltaic panels/Solar panels Grow food External wall insulation Double/triple glazing Roof insulation Cavity wall insulation	Shading Internal shutters Solar film Shaded outdoor space Extend eaves External solar shading Cooling & ventilation White roof and walls Wall greenery Green roof Drought resistance Rainwater harvesting Water butt	Extreme weather- wind and driving rain External render Trickle vents Flooding Flood-proof door Flood gate Air brick covers Elevate electrical sockets	Shading, localised cooling and drought resistance Street trees Shading in green space Blue infrastructure Community cool room Flooding Reconfigure street drainage Mitigation of future climate change Energy efficient street lighting Allotments

Figure 10.3 *Interwar period suburb: Botley, West Oxford*

House and Garde			Neighbourhood
Mitigation of future climate change	Summer	Winter	
Photovoltaic panels Solar panels Grow food External wall insulation Double/triple glazing Roof insulation Cavity wall insulation	Shading External solar shading Internal shutters Solar film Shaded outdoor space Extended eaves Cooling & ventilation Internal thermal mass White roof and walls Lock-open windows Green roof Drought resistance Underpin house Rainwater harvesting system	Extreme weather- wind and driving rain External render Trickle vents Flooding Replace non-porous driveways Flood-proof door Flood gate Air brick covers Elevate electrical sockets	Shading, localised cooling and drought resistance Street trees Shading in green space Blue infrastructure Community cool room Drought-resistant trees Flooding Reconfigure street drainage Flood defences Mitigation of future climate change Energy efficient street lighting Allotments

Figure 10.4 *Pre-War 'garden city' type suburb: Summertown, North Oxford*

House and Garden			Neighbourhood
Mitigation of future climate change	Summer	Winter	
Photovoltaic panels Solar panels Grow food External wall insulation Double/triple glazing Roof insulation Cavity wall insulation	Shading Wall greenery Green roof Shaded outdoor space External solar shading Internal shutters Solar film Extend eaves Cooling & ventilation Lock-open windows Internal thermal mass White roof and walls Drought resistance Underpin house Water butt	Extreme weather- wind and driving rain External render Trickle vents Flooding Flood-proof door Flood gate Replace non-porous driveways Air brick covers Elevate electrical sockets Replace internal flooring	Shading, localised cooling and drought resistance Street trees Blue infrastructure Shading in green space Community cool room Flooding Reconfigure street drainage Flood defences Mitigation of future climate change Energy efficient street lighting Allotments

Figure 10.5 *Social Housing suburb: Cheadle, Stockport*

House and Garden			Neighbourhood
Mitigation of future climate change	Summer	Winter	
Photovoltaic panels Solar panels Grow food External wall insulation Double/triple glazing Roof insulation	Shading External solar shading Internal shutters Solar film Shaded outdoor space Extend eaves Cooling & ventilation Internal thermal mass White roof and walls Wall greenery Green roof Lock-open windows Drought resistance Rainwater harvesting system Water butt	Extreme weather- wind and driving rain External render Re-point brickwork Wood protectors Trickle vents Maintain guttering Flooding Replace non-porous driveways	Shading, localised cooling and drought resistance Street trees Shading in green space Blue infrastructure Community cool room Flooding Reconfigure street drainage Mitigation of future climate change Energy efficient street lighting Allotments

Figure 10.6 *Car Suburb: Bramhall, Stockport*

Overall these results show that:

- Small scale changes (such as water butts and wall greenery) are more likely to be implemented than large scale changes to the fabric of the home.
- Neighbourhood adaptation and mitigation measures are acceptable to communities, but (with the exception of energy efficient street lighting and some greening) are unlikely to be implemented.
- The most commonly implemented householder measures are those linked with residents' hobbies, lifestyle and money saving choices, or home improvement projects: they are not implemented to respond directly to climate change.

10.3 What are the processes that bring about change in suburban areas? Specifically: what might motivate residents and other stakeholders to adapt to present and future climate threats?

At the outset of the project we posed the question 'What are the processes that bring about change in suburban areas?' As the research progressed it was apparent that very little change was actually taking place: understanding this inertia was a necessary pre-requisite for understanding what might enable change in the future. Hence, the conclusions relate to the current context for suburban adaptation, before moving to the issue of motivating action. The research found that:

- **Suburbs are extremely varied entities, and change within them is complex.** There are various types of suburb, housing different communities in different locations, with a complex range of stakeholders responsible for different aspects of the built and natural environments, and for different climate risks.

- **At the home and garden scales some mitigation and adaptation actions are taking place, but for the majority of residents climate change is a non-issue.** Most residents: do not think about climate change in terms of needing to adapt to future weather; are sceptical of the extent of climate change; welcome an increase in summer temperatures; and do not see the need to prioritise spending money on adaptations.

- **At the neighbourhood scale, very little adaptive action is taking place**. Some adaptive measures are linked with regeneration projects or area-wide greening strategies, but very little is explicitly related to adapting to future conditions.

- **There is no clear process, or delivery mechanism, for adaptation and/or mitigation at the suburban neighbourhood scale**. Many of the most effective measures are not currently being carried out in existing areas nor is large-scale retrofitting likely to occur.

What might motivate residents and other stakeholders to adapt to present and future climate threats?

Action in a number of key areas could provide pathways for adaptation in suburbs. The following section summarises the key mechanisms that might motivate change.

- **More experience of climate change (gradual changes and extreme events)**. Currently, climate change is not a motivator for change in suburbs. Householders find it hard to relate to because they have not generally experienced problems. As the public are not overly concerned, the issue is not high on the political addenda either. However, as England experiences more heat waves, floods and extreme weather it is likely that responding to these risks will become a higher priority politically and practically.

- **Normalising of simultaneous mitigation and adaptation practices, and their introduction into organisations' long-term planning and day-to-day activities**. As experiences of climate change become 'real', and mitigation and adaptation measures are introduced they are likely to become part of normal decision making processes for householders and other stakeholders. As adaptations become more visible, they are likely to become more acceptable. For example, some local authorities are beginning to introduce adaptation measures as part of cycles of long-term planning and routine management. Adaptation is being built into street and park maintenance programmes where costs are marginal, e.g. where road surfacing has to be done anyway. Major retrofitting measures such as implementing SUDs need to be built into conventional systematic long-term planning and maintenance, e.g. street resurfacing activities. Local authority maintenance that takes into account adaptation could achieve effective change over the long-term.

- **A better understanding of the multiple pathways, involving a range of stakeholders, that could deliver effective suburban adaptation**. There is no single 'process' of effective adaptation. It is likely that a combination of individual, community, government-led, and partnership actions will be required. Householders are likely to be responsible for improvements to the climate comfort of their individual properties. Partnership approaches will be required, for example, in managing flooding risk, because of the multiple ownership of infrastructure and the complexity of managing surface water. The potential for community action also needs to be maximised. Some local authorities are heavily engaged in community capacity building activities for low-carbon projects, and building on these existing activities and community groups could be an effective way of integrating adaptation activity into neighbourhoods.

- **Prioritising resources for adaptation**. Currently both householders and local and national government are not prioritising resources for climate change mitigation or adaptation to effectively adapt suburbs. Many of the changes needed are costly, and have medium-long term benefits.

- **Clearer responsibilities for adaptation**. At the suburban scale one of the key problems in effective mitigation lies in understanding who is responsible for change. In terms of flood risk, in some places this is leading to paralysis. There is confusion over the scale at which the risk should be managed, the ownership patterns in suburbs, and misunderstandings about the nature of risk insurance. The introduction of neighbourhood planning, or place-based communal action could help to unravel some of these complexities, but without significant clarification various agencies in many suburbs will do nothing, and leave neighbourhoods vulnerable.

- **Communicating climate change and its risks effectively for different audiences**. Different actors involved in, or affected by, suburban adaptation engage with it in different ways. Hence, framing changes to homes and local neighbourhoods purely in terms of 'climate change' and 'risk' is not always effective in motivating action. Stakeholders with the responsibility for informing the public about climate change risks will need to find effective ways of communicating. 'Climate change' messages can create resistance to action, so householders may need to be engaged through messages about the practical and immediate benefits of installing adaptation measures, and the cost-effectiveness and 'quality of life/comfort' benefits.

- **Ensuring practical information about adaptations is communicated at the right time and by trusted people/organisations**. It is important that householders get the right advice or information when they may be about to make changes to their properties e.g. when they first move into a new home, or when they are doing other home improvements, when they are applying for planning permission or building regulation approval. This includes information about Government grants and schemes. It is also important that frontline contact points, e.g. builders, DIY store staff, Planning and Building Regulation staff, and utilities can help with accurate information. However, providing generic advice is not always effective, as many adaptations are property-specific. In these cases appropriate specialists (architects, builders) need to be easily available to households.

- **Ensuring adaptation is embedded in planning policies and practices and building regulations**. Planning policies and practices and building regulations need to ensure that future climatic conditions are considered when changes to the physical environment of suburbs are proposed. Neither have much power in pro-actively bringing about change: but they could be more powerful in stopping future problems.

- **Learning from places where neighbourhood action (and/or adaptive action) is successful**. Although cases of fully adapted neighbourhoods are rare, there are examples of good practice in terms of neighbourhood level action that could be applied to the suburban context. There are also examples of built environment solutions from countries with climates similar to that projected for England that could inform local strategies here.

- **Ensuring that central government-controlled mechanisms such as grants and subsidies are appropriate to deliver adaptation**. Government initiatives and funding is welcomed, but poorly understood by most householders. It is important that initiatives are appropriately framed (see findings about communication above), and simply administered.

Conclusions

The SNACC research project has answered some key questions about the future of English suburbs and how they might adapt to current and future climate conditions. It has unearthed some difficult truths about the capacity for stakeholders living in, and responsible for, suburbs to respond to climate change. It has also explored some potential pathways for progress: these now need to be tested and validated over time.

Overall, the research has shown that the response capacity in any given suburb is both complex and changing. However, a clear message is that to motivate people and achieve progress a positive vision of change has to be offered. Residents' are understandably emotionally and financially attached to their homes, and most value highly the character of their neighbourhoods. Change that is motivated by visions of a more liveable, attractive (and resilient) future, and that links to peoples' interests and values, has a better chance of engaging and motivating them to act than a vision driven by the language of climate change and risk.

Determining the impact on property values of a range of adaptation options: developing a hedonic pricing model

The SNACC project developed a series of adaptation and mitigation strategies that would require modifications/changes to individual properties and the neighbourhood within which the property is located (WP3). This part of the research aims to determine which neighbourhood adaptation features, house energy consumption attributes and environmental characteristics are capitalised into the value of residential property in the UK. To that effect Hedonic Pricing (HP) models are developed analysing the UK housing market.

Not all of the strategies or elements in WP3 can be analysed to determine the impact upon price, either because the usable datasets simply do not include the attribute, the technology is too new (for example, community cool room) or the change is too subtle to significantly influence price (for example, elevation of electrical sockets). However, through review of existing literature and analysis of extensive databases of property transactions/values we throw some light on the impact on house prices of street trees, gardens, accessibility to open space, flooding, neighbourhood characteristics and layout, and physical adaptations that improve energy efficiency (insulation, double glazing, solar panels etc).

Briefly from existing literature we find evidence that a number of strategies proposed in WP3 can positively influence house price. For example factors affecting house price positively are energy efficiency (Brounen and Kok, 2010), the presence of trees (Willis and Garrod, 1992), and access to open space (Dehring and Dunse, 2006). One significant negative factor is flooding. Previous studies suggest that properties located in a floodplain (and the subsequent fear of flood damage) are valued lower than comparable ones outside of a floodplain, (MacDonald et al. 1987; Skantz and Strickland, 1987; Donnelly, 1989; Speyrer and Ragas 1991). The significance of neighbourhood layout and street configuration has been less conclusive. For example, Matthews and Turnbull (2007) test features of New Urbansim, specifically, neighbourhood composition and street layout. They conclude that it does not necessarily have universal appeal to house purchasers.

Within this empirical study we focus upon the impact of energy efficiency (SAP) rating, insulation, double glazing, heating system, gardens and accessibility to open space.

The Hedonic Pricing Method

The hedonic price method considers housing a composite commodity, comprising the neighbourhood (including accessibility and socio-economic profile) and environmental characteristics of the locality, along with the structural characteristics of the property. This is a very popular method in the fields of real-estate research (e.g. Zuehlke, 1987; Watkins, 2001; Pryce and Gibb, 2006) and environmental economics (e.g. Day et al., 2007; Zabel and Kiel, 2000; Powe et al 1995). The data requirements of a hedonic model include a large and sufficiently diverse sample of housing transactions such that all attributes are observed and in different combinations and quantities.

The price P of the house m, in the kth residential location is given by:

$$Pmk = Pm\,(Sk, Nk, Ek) \qquad (1)$$

Where Smk are the structural characteristics of the house, Nk are the neighbourhood characteristics and Ek are the environmental characteristics. From equation 1 we can derive the implicit price for any given attribute or amenity. For example, the implicit price of higher energy efficiency would be the additional amount of money that will be paid for a housing package with a marginal increase in y. Model estimation then yields the price discount or premium associated with the effect.

Data

We employed data for the whole of England from the English Housing Condition Survey (EHCS), consisting of 15,515 household observations for 2005-06. The survey involves a physical inspection of property by professional surveyors, providing an accurate picture of the type and condition of housing in England, the people living there, and their views on housing and their neighbourhoods.

There is a wealth of relevant information available such as, tenure, structural characteristics of each house, local environmental attributes, accessibility and socio-economic characteristics of the local area. One important point for HP modelling is that the sale

Variable	Marginal Implicit Price (£)
Energy efficiency (SAP 2005) rating	76**
Residents perceive the area as polluted	-3,291***
Age of heating system over 12 years	-1,770**
High perceived effectiveness of insulation	4,329***
Green space between 0-10% in the area	1132
Green space between 10-25% in the area	-3,242***
Green space between 25-50% in the area	-3,883***
Green space between 50-100% in the area	Base category
Garden density 0 sqms per dwelling	-20,136***
Garden density 1-25 sqms per dwelling	2,039
Garden density 25-50 sqms per dwelling	-8,673***
Garden density 50-100 sqms per dwelling	-3,720***
Garden density 100-250 sqms per dwelling	Base category
Garden density over 250 sqms per dwelling	17,591***

*** statistically significant at 99% level, ** statistically significant at 95% level

Figure A1: *Examples of Monetary Values of Energy and Environmental Attributes*

price is not available in this data, but a valuation of the property that is employed as a proxy to the price. Furthermore, the energy rating definition used is the UK Government's Standard Assessment Procedure (SAP) for energy rating of buildings.

Findings

A semi-log specification is selected in our models, since it is the most widely used in the literature providing an excellent goodness-of-fit to the data. We estimate the following econometric model:

$$LnP_{ij} = \beta_j + S_{ij}\psi_j + N_{ij}\omega_j + E_{ij}\gamma_j + \varepsilon_{ij} \qquad (2)$$

Where LnP is the natural logarithm of the price/value for dwelling i in the jth housing market. ***S*** is a vector of the structural characteristics of the house i. ***N*** is a vector of the neighbourhood and socioeconomic characteristics. ***E*** is a vector of the environmental of the dwelling.

All the relevant variables are included in the modelling. The semi-log model had a good overall fit (R^2=0.76). Most of the coefficients were of the correct sign and statistically significant. Statistical tests showed the presence of heteroscedasticity. White's (1980) standard error correction was employed to correct for this.
The model produces estimates of neighbourhood adaptation characteristics, such as energy consumption attributes and environmental characteristics that are capitalised into the value of residential property in the UK. Some of these are presented in Figure A1, as monetary values or implicit prices.

The £75.9 in Figure A1 refers to the value placed in improving the SAP rating of a house by 1. The effectiveness of insulation, as perceived by the residents, provides a premium of £4328. The old heating system and perceived air-pollution in the area seem to decrease house values by £1769 and £3291 respectively.

The green space and garden density dummy variables need to be viewed with respect to their base categories. The base category for green space is "over 50% in the area". We see a significant decrease in house values for most categories with less green space. Similarly, compared with a base case of a garden of 100-250 sqms per dwelling, larger gardens command a significant premium of £17,591 over the base category while house values are negatively affected by smaller garden size to the base category (when the effect is statistically significant).

These findings of course would have implications for more radical forms of neighbourhood adaptation involving intensification and raising of densities.

It is clear from both the literature review and from the empirical analysis using EHCS that a range of elements within the adaptation and mitigation strategies could be expected to impact on housing values, although not all of the elements considered elsewhere in this research can be tested and not all would be expected to have detectable effects. Some of the effects as measured from 2005-06 data may actually be greater if measured on more recent data, insofar as public attention to, and information availability about, domestic energy efficiency (in particular) has increased. Generally the measures assessed here have been shown to have a positive effect on house values, although this would not be the case for intensification. This may be taken to be a motivator for householders to invest in such measures, or to support their general introduction, although whether sufficiently to induce them to make a significant cash investment is another question. It should of course be remembered that, in cases such as energy efficiency, the value enhancement is loosely associated with a prospective saving in annual energy bills.

Developing DECoRuM-Adapt© (a Domestic Energy, Carbon counting and carbon Reduction Model) to analyse the impact of climate change on energy use and comfort

DECoRuM© (Domestic Energy, Carbon counting and carbon Reduction Model) is a GIS-based toolkit for carbon emissions reduction planning with the capability to estimate current energy-related CO2 emissions and effectiveness of mitigation strategies in existing UK dwellings, aggregating the results to a street, district and city level (Gupta, 2008; Gupta, 2009). The aggregated method of simulation and map-based presentation allows the results to be scaled up for larger application and assessment. For the SNACC project, DECoRuM was further developed as DECoRuM-Adapt© to analyse the impact of climate change on energy use and comfort. DECoRuM-Adapt uses downscaled climate data from UKCP09 to estimate probabilistic future overheating potential and the effectiveness of adaptation strategies for modelled dwellings. To inform the model, actual home and neighbourhood characteristics are gathered from maps, on-site assessment and literature describing home characteristics based on age and typology. The background calculations of DECoRuM are performed by BREDEM-12 and SAP 2009 both of which are dynamically linked to create the model and perform the analysis. Figure B1 lists the categories and number of parameters that BREDEM-12 requires. There is a wealth of statistical information that can be exported including annual CO_2 emissions, running costs and overheating potential.

UKCP09 data had to be spatially and temporally downscaled via the UKCP09 Weather Generator in order to assess climate change impact through DECoRuM-Adapt. Spatially each neighbourhood is represented by a 25km square grid and the impacts are simulated using weather data (current and future) that is assigned to each individual grid square. Temporally, DECoRuM-Adapt assesses impact using the change in mean monthly temperature and mean monthly solar irradiation. The simulation process of DECoRuM-Adapt can be seen in Figure B2 where all data collected in Figure B1 is simulated using the varying climate inputs. The results are the impacts, e.g. annual CO_2 emissions, overheating potential. From the analysis of the various impacts, an assessment of the causes of overheating and change in CO_2 emissions leads to the development of adaptation options and ultimately adaptation packages. These changes (adaptations) are made to the homes and re-run though the climate projections resulting in new impact outcomes.

Category used for data reduction	Numbers of parameters	Percentage of parameters
Data common to all dwellings	50	52.7%
Data derived from built form	5	5.3%
Data derived from age	18	19.0%
Data collected for individual dwellings	22	23.0%
Total	95	100%

Figure B1 *List of categories used for data reduction in DECoRuM and DECoRuM-Adapt (Gupta, 2008)*

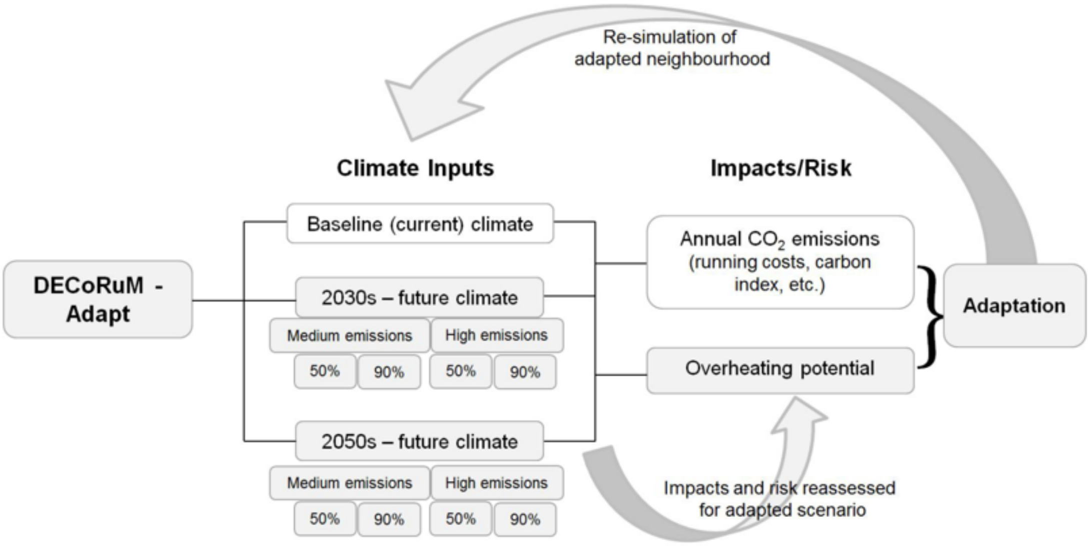


Figure B2 *Process of DECoRuM-Adapt (original DECoRuM analysis is limited to the boxes with white backgrounds however, mitigation measures are applied and the process is re-run.)*

DECoRuM-Adapt is a relatively quick method for the creation of maps indicating overall neighbourhood response to climate change and adaptation. These maps are ultimately useful for presentation and communication of probabilistic risk, energy saving potential and effectiveness of adaptation for decision-makers such as homeowners and local council members. Beyond DECoRuM-Adapt, more detailed energy modelling and simulation is performed on a number of select homes using IES' ModelIT and ApacheSim respectively. These simulations are performed to confirm results from DECoRuM-Adapt and to understand a selected house-by-house response to climate change and adaptation effectiveness. A notable difference in the two simulators is how climate data is processed. UKCP09 data had to be spatially and temporally downscaled via the UKCP09 Weather Generator in order to assess climate change impact through both simulation platforms, however the two require different scales of spatial and temporal detail. Temporally, DECoRuM-Adapt assesses impact using the change in mean monthly data whereas, IES uses a wide range of *hourly weather data* including wind speed. Spatially, the difference represents climate detail on a 25km grid square and a 5km grid square. The difference between the two spatial scales can be seen on the maps of the case study cities below (Figure B3).

Figure B3 *Maps showing the 25km grid square (orange) in relation to the 5km grid squares (purple) for Bristol, Oxford and Stockport. The red pin-point indicates the location of the six case study neighbourhoods (image adapted from DEFRA, 2011).*

The tool created in the SNACC project is a GIS based visualisation capable of creating interactive and accurate aspects of smaller sections of 3D urban environments that can be accessed, analysed and explored by multiple users simultaneously using a Web browser.

The aim of the SNACC visualisation was to develop a common and transferable web based visualisation system that enables people to view and analyse proposed adaptation options in order to understand their effects on the existing housing and neighbourhood and make decisions about their acceptability. The system has the potential to improve future public participation by making information about potential adaptation options more accessible and easier to understand for the general public.

The adopted approach was to use an interactive three-dimensional (3D) virtual reality (VR) visualisation to enable the viewer to grasp highly complex information without the need for training. This way the user can experience both the potential adaptations and assess their acceptability and visual impact on the existing environment. Moreover, since the system is associated with GIS maps, it allows for an accurate understanding of the extent of the changes as they have been recorded and entered using a GIS database.

VEPs and SNACC tool

The SNACC project visualisation of climate change adaptation options is based on the VEPS (Virtual Environmental Planning System), which was an Interreg IIIB funded European project. This system has been customised and adapted for the visualisation of suburban adaptations. The main differences between the ink based visualisation and the method used by the original VEPs application is the use of the WEBGL specification which allows interaction with 3D content in the web browser without the need for users to install any additional software. The scene compiler also gives more scope for adding surface features such as roads and pavements in the terrain model and then dynamically manipulating those features using scripts in a HTML web page.

Technical summary

Ink GIS is a cloud base Geographic Information System (GIS) that is a data base application which stores geospatial features such as points lines and polygons as well as their associated textual and numeric attributes. Features stored in a GIS format can then be accessed with spatial queries such as "where is the nearest?". It runs within a web browser developed using HTML 5 and Javascript. The geospatial data (2D line, points and polygons) is stored using the open source database MySQL using an Apache/PHP web server.

The VR tool-kit is used to create neighbourhood models by drawing and then extruding lines along the survey to incise them into an existing terrain model. X3D were placed on the surface by marking the locations on a GIS layer. Trees, bushes, shelters and street furniture were made using the free open source Blender modeler (www.blender.org). Housing (three-dimensional models) were produced using tools which generate building geometries algorithmically from footprint polygons.

The 3D formats supported are X3D and WebGL which are natively supported in Firefox, Chrome, Safari, Opera. IE8 & IE9 are supported using Instant

VEPs	SNACC
LiDAR data	Web GIS system (INK)
Aerial photography	Mastermap and DTM data
VRML format	X3D format of Virtual reality
Detailed CAD and 3DMax models	Photorealistic, interactive models
Additional software	Open source software
Personal computer users	A web site

Figure C1 *The differences between VEPs and the SNACC project visualisation*

Reality, an open source X3D plug-in developed at the Fraunhofer Institute.

Rendering of X3D within the browser is done using X3DOM (http://www.x3dom.org). This has been developed at the Fraunhofer institute and is freely available as open source) , a Javascript library for browsing X3D content in browsers which support WEBGL (http://www.khronos.org/webg). Browsers currently supporting WEBGL are Chrome 16+ and Firefox 10+.

Key Findings

An initial pilot study was used to gather the feedback from several groups of stakeholders in order to meet their needs and stimulate their engagement in the research process. The result of this process was stakeholder driven optimisation of the final system. Based on analysis of the outcomes from the pilot study detailed virtual neighbourhood environments with information such as types of paving, species of trees and shrubs were created for three case study areas. Each case study visualisation also included potential changes to house elevations, which were more desirable than sketchy, simplified images of adaptations. Although it is recognised that visualisation optimised for the web tends to offer lower levels of detail than CAD generated 3D models, in this investigation an attempt has been made to achieve the highest possible level of detail in x3d environments so that endorsable decisions are enhanced by photo-realism and it is possible to assess a range of potential interpretations by stakeholders.

For the two case studies (Botley in Oxford and Stockport in Manchester) an investigation was conducted to explore public perceptions and usefulness of this type of visualisation. Short questionnaires using Liker-like seven-point scales were employed to determine whether photorealistic virtual reality representations are regarded as accurate means of communicating neighbourhood adaptations and to assess the usefulness of this tool in the consultation process. Questionnaire responses were analysed using the SPSS software package.

The responses revealed strong preferences for more, rather than less, information about the adaptations. This is primarily because people need information to make informed decisions about investments in their homes and neighbourhoods. Members of the public also prefer to understand the possible extent of changes, and have some serious concerns about the impact of adaptation options. Overall, the majority of participants were 'fairly satisfied' with the visualisation as a tool and its ability to show the proposed changes to existing neighbourhoods.

Figure C2 *Virtual environment of one of the Bristol case studies, showing a neighbourhood before and after adaptation. Models reproduced under the terms of the Contractor's Licence for the Use of Ordnance Survey Data between UWE, Bristol and Bristol City Council, Maps © Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service*

Potential adaptation and mitigation options to be tested in SNACC

Figure D1 below details the master list of adaptations which were identified as appropriate for the neighbourhood types selected in the case studies. Not all of the adaptations were appropriate for all of the suburbs, but each of the adaptations presented below are appropriate for at least one of them. The options were chosen to address either, the mitigation of future climate change, or adaptation to the future risks of climate change. The Figure does not provide a definitive list for adapting all suburbs, but reflects options with a range of impacts, costs and benefits appropriate for the SNACC study . Only adaptations which offered either a neutral or positive impact on the production of greenhouse gases were considered.

Element of built environment being adapted	Measures for Adapting to impacts from, and mitigating future climate change	Climatic change that the adaptation is responding to	Reduce climate change? How	Effect that the adaptation has
		House and garden (individual dwellings)		
WALLS	Add external shutters, shades or canopies to walls	Heat, increased solar radiation on the surface	Yes, reduces potential cooling loads	Increases shading and cools properties inside and out
	Increase wall albedo: apply highly reflective material or coating to reduce solar absorption	Heat, increased solar radiation on the surface	Yes, has been found to reduce localised air temperatures when undertaken across neighbourhoods	Reduces solar absorption to cool internal and external areas
	Introduce thermal mass: e.g. interior walls 1) concrete blocks with plaster finish 2) exposed stone or concrete	Heat, overheating in buildings leading to possible increased energy use	Yes, thermal mass appropriately placed can both reduce heating energy use and cooling energy use. Thermal mass, inappropriately placed can have an adverse impact	This is achieved through the ability of thermal mass, in heavyweight floors and walls, to absorb internal heat gains during hot weather, helping stabilise the internal temperature and reduce cooling demand. The absorbed heat must be released and should be ventilated at night.
	Install vertical greenery and planting	Heat	Yes	Can cool the building inside and improve air quality. In warmer weather, green walls act like green roofs by reducing the surface temperature of a conventional wall through evapotranspiration and shading. Walls that use irrigation and hydroponic techniques provide additional cooling through evaporation.
	Air brick covers/ automatic air brick covers (smart air brick)	Flood	None	Prevents water ingress during flooding

	External wall weather proofing 1) thermally efficient external renders 2) rubber tanking 3) waterproof render 4) Repoint brickwork on external walls. Internal walls 5) sand/cement render mix with a waterproof additive 6) dry line internal walls 7) replace timber stud walls, which act as a water reservoir with masonry/block work 8) internally and externally: apply special finishes to walls (anticorrosion primers, polyurethane top coats)	Flood, storms, extreme weather	Yes, thermal efficiency produced from internal and external renders reduces energy reduction	Protects walls from storm damage, avoids water penetration and damage to mortar and brickwork.
	Flood resistant cavity fill insulation	Storms, flood	Yes, reduces building's thermal conductivity reducing energy demand	Water resistant: non water resistant insulation would be damaged in a flood and need replacement
	Elevate external doors, Fit rising hinges so doors can be removed	Flood resistance and resilience	No	Stops water ingress initially: removing internal doors in the event of flood ingress increases resilience.
	Flash flood doors, flood gates	Flood resistance and resilience	No	Stops water ingress
ROOF	Add green/ brown roof to regulate temperature	Heat: (could also slow water runoff and reduce flooding if done with groups of properties cumulatively, not in isolation)	Yes	Increases localised cooling, reduces rain water runoff. Increases CO_2 absorption and evapotranspiration to reduce urban heat island (UHI). Regulates temperature in building. Reduces solar heat gain in buildings (reduced heat penetration in buildings).
	Increase roof albedo: apply highly reflective material or coating to reduce solar absorption	Heat, Increased solar radiation on the surface	Yes, has been found to reduce localised air temperatures when undertaken across neighbourhoods	Reduces solar absorption to cool internal and external areas.

	Insulate roof	Heat (and cold)	Yes, reduces building's thermal conductivity reducing energy demand	Improves thermal performance: reduces heat loss, can contribute to overheating mitigation in summer and reduce energy bills
	Install photovoltaic/solar thermal panels (water heating)	Energy, increased solar radiation on the surface	Yes	Future proofing, to provide sustainable renewable energy
	Extended eaves	Increased rainfall and extreme weather	None: some (slight potential where cooling energy is used and extended eaves are able to provide some shading)	Limits rain contact with external wall surfaces. Can also be source of shading.
WINDOWS	Install windows that lock open to aid ventilation	Heat	Yes, replaces mechanical ventilation	Allows user: controlled natural ventilation
	Low: e-solar control glazing, double or triple pane	Heat, increased solar radiation on the surface	Yes, reduces heat demand in winter	Reduces heat loss during the winter and overheating in the summer. Greater noise reduction and better heat absorption
	Install solar shading: Horizontal or vertical external shading Shutters Interpane shading Solar film Manufactured shading (solar control for interior or exterior: blinds, shutters, awnings, louvered overhangs, etc.) (possible opportunity to integrate solar renewables)	Heat, increased solar radiation on the surface	Yes, reduces potential cooling loads	Mitigates overheating potential
FLOORS	Introduce thermal mass: e.g. floors 1) tiling over concrete floor with insulation below, 2) exposed stone or concrete	Heat, overheating in buildings leading to possible increased energy use	Yes, thermal mass appropriately placed can both reduce heating energy use and cooling energy use. Thermal mass, inappropriately placed can have an adverse impact	This is achieved through the ability of thermal mass, in heavyweight floors and walls, to absorb internal heat gains during hot weather, helping stabilise the internal temperature and reduce cooling demand. The absorbed heat must be released and should be ventilated at night.

	Treat floors for flooding: e.g. seal floors. Convert suspended floors to solid floors e.g. with hard nonporous flooring (concrete/ tiles)	Flooding	None: some (thermal mass could be incorporated here)	Reduces the impact of flooding
HEATING, COOLING, POWER, VENTILATION SYSTEMS and APPLIANCES	Install heat pumps	Heat (and cold) Potential to reduces winter heating energy requirement	Yes, potentially	Potential to cool the home (principle can be used with ground, air and water)
	Install trickle vents	Heat (reduce internal heat and humidity)	Yes, reduces potential cooling and dehumidification loads	Reduces humidity in the home, mitigating mould growth
	Elevate electrical sockets/wiring, metering and boiler	Flood	No	Reduces the impact and cost of flooding
WATER and GARDEN	Plant trees with large canopies: using caution not to compromise building stability	Heat, increased solar radiation on the surface	Yes, reduces potential cooling loads	Provides shading to cool the garden and adjacent house
	Install rainwater harvesting in the garden	Reduced summer rainfall	No	Makes efficient use of a limited resource
	Drought resistant plants	Reduced summer rainfall	No	Adding 10% greenspace (in a central area) kept temperatures at or below 1961:90 baseline (ASCCUE, 2012)
	Grow food	Summertime temperature increase and Summertime mean precipitation reduction (water stress but increased growing season)	Yes, reduces carbon footprint of food	Maximises the benefit of longer growing season and reduces food miles.
	Remove/ reduce nonporous garden surfaces. Replace with an alternative: grass-reinforcement concrete or plastic mesh, gravel, brick (with drainage channels), cellular paving, or lawn or vegetable plots	Winter mean precipitation increase : Increased flood vulnerability and water ingress for dwellings	No	The use of porous surfaces qualify as part of SUDS. The principle is to mimic natural drainage, reduce flow from hard impermeable surfaces and reduce flood risk.

NEIGHBOURHOOD ADAPTATIONS; street, parks, and public space and amenities						
Measures for Adapting to impacts from, and mitigating future climate change	**Climatic change that the adaptation is responding to**	**Climate change hazard**	**Climatic change impact**	**Direct climate change mitigation?**	**Effect that the adaptation has**	**How effective is the measure?**
Add new green space: Plant trees with large canopies (on streets and in public open spaces)	**HEAT**	Summertime temperature increase and measurable heat wave projections	Overheating in buildings, high urban temperatures leading to possible increased energy use	YES	Provides shading from sun	A park will cool the area equivalent to the size of the park surrounding it. (ASCCUE, 2012)
Plant heat, drought and pollution tolerant plants	**HEAT**	Summertime temperature increase and measurable heat wave projections	Overheating in buildings, high urban temperatures leading to possible increased energy use	YES	Provides attractive and functional greenery even in hotter weather, which gives shade	Provides added cooling in hotter weather (difficult to quantify generically)
Plant heat, drought and pollution tolerant plants	**DROUGHT**	Summertime mean precipitation reduction Wintertime mean precipitation increase	Water stress and/or drought Increased flood vulnerability and water ingress for dwellings	YES	Provides attractive and functional greenery that uses less water, and stabilises soils. Whilst retaining water and slowing runoff in flood conditions.	Minimises plants' exposure to winds to reduce the amount of water lost through the plant leaves and through evaporation from the soil. Modelling for Greater Manchester showed that a 10% increase in green cover can result in a 5% reduction in surface water run-off (ASCCUE, 2012).

Plant heat, drought and pollution tolerant plants	**AIR POLLUTION**	Summertime mean precipitation reduction	Increased dust pollution	YES	To provide attractive and functional greenery that can withstand increases in ait pollution (photochemical smog and VOCS)	In urban areas with 100% tree cover (i.e., contiguous forest stands), short term improvements in air quality (one hour) from pollution removal by trees were as high as 15% for ozone, 14% for sulphur dioxide, 13% for particulate matter, 8% for nitrogen dioxide, and 0.05% for carbon monoxide (Nowak, 2006).
Add greenery: to façades, walls	HEAT	Summertime temperature increase and measurable heat wave projections	Overheating in buildings, high urban temperatures leading to possible increased energy use	YES	Provides shading from sun	A park will cool the area equivalent to the size of the park surrounding it. (ASCCUE, 2012)
Green walls include:	HEAT	Summertime temperature increase and measurable heat wave projections	Overheating in buildings, high urban temperatures leading to possible increased energy use	YES	Provides attractive and functional greenery even in hotter weather, which gives shade	Provides added cooling in hotter weather (difficult to quantify generically)
Green facades, pots with vines on trellises	DROUGHT	Summertime mean precipitation reduction Wintertime mean precipitation increase	Water stress and/or drought Increased flood vulnerability and water ingress for dwellings	YES	Provides attractive and functional greenery that uses less water, and stabilises soils. Whilst retaining water and slowing runoff in flood conditions.	Minimises plants' exposure to winds to reduce the amount of water lost through the plant leaves and through evaporation from the soil. Modelling for Greater Manchester showed that a 10% increase in green cover can result in a 5% reduction in surface water run-off (ASCCUE, 2012).
Enhance vegetation if the soil has good infiltration qualities	HEAVY RAIN and FLOODS	Wintertime mean precipitation increase	Increased flood vulnerability and water ingress for buildings	YES	Provides cooling, porosity, links for biodiversity	

Install blue infrastructure: lakes, ponds, and other water landscape features	**HEAT**	Summertime temperature increase and measurable heat wave projections	Overheating in buildings further increased by urban heat island effects	NO	Helps reduce air temperature in neighbourhood	To provide localised cooling
Mini flood defence: to protect detached dwelling or group of dwellings in a neighbourhood. Flood barrier pushed up with saturation of the ground (DP)	**FLOOD**	Wintertime mean precipitation increase	Increased flood vulnerability and water ingress for buildings	NO	Springdam http://www.tiltdam.co.uk/Concepts.aspx. Gravity powered in situ flood defence, that acts as a walkway, pathway and tilts under flood conditions to form a barrier	A park will cool the area equivalent to the size of the park surrounding it. (ASCCUE, 2012)
Construct sustainable urban drainage systems (SUDS) (including capacity for water storage areas if appropriate)	**HEAVY RAIN and FLOOD**	Wintertime mean precipitation increase	Increased flood vulnerability and water ingress for buildings	NO	Ensures that increased runoff can be managed.	Use of swales, infiltration, detention and retention ponds in parks is effective. Running costs are low, particularly after the initial growing period (ASCCUE, 2012).
	DROUGHT	Summertime mean precipitation reduction	Water stress and/or drought	NO	Enhances local water catchment for reuse	Effective in suburban areas, given suitable land use patterns, and have an increased amenity and biodiversity value
	HEAT	Summertime temperature increase and measurable heat wave projections	Overheating in buildings further increased by urban heat island effects	NO	Provides local cooling (for people and surrounding air temperatures)	

	HEAVY	Summertime mean precipitation reduction	Increased dust pollution	YES	To provide attractive and functional greenery that can withstand increases in air pollution (photochemical smog and VOCS)	
Add seating in shaded areas, on streets and in public spaces	**HEAT**	Summertime temperature increase and measurable heat wave projections	Building overheating in summer leading to discomfort, ill health	NO	Allow for increased use of outdoor space, and adds to social capital	
Identify and allocate appropriate buildings as 'community cool rooms'	**HEAT WAVES**	Summertime temperature increase and measurable heat wave projections	Overheating in buildings further increased by urban heat island effects	NO	Provides respite from extreme heat, particularly for older residents or those with 'hot' homes and little outdoor space	Used effectively in Southern Europe in heat waves, for vulnerable groups.
Replace pavements and roads with porous, 'cool' materials	**HEAT and INCREASED RAIN AND STORMS**	Wintertime mean precipitation increase	Increased flood vulnerability and water ingress for buildings	YES	Cools neighbourhood and offers drainage to avoid flooding	Improved albedo: binder or aggregate of different colour; coating the pavement with a seal or surface of a lighter colour. Porous types let water percolate through and evaporation to take place. Permeable surfaces can be more conducive to cooling from convective airflow. Both asphalt and concrete pavements can be built with porous surfaces, and unbound surfaces (e.g., grass, gravel) can be constructed using grids for reinforcement. Pigments and seals to change the colour of an asphalt surface to make it lighter. Because concrete pavements are already light coloured, pigments are unlikely to improve their coolness. Whitetopping consists of a concrete pavement applied over an existing asphalt pavement as a form of maintenance or resurfacing.

Use energy efficient street lighting and/ or switch street lights off for periods of the night	MITIGATION	Peak summertime temperature increase	Higher temperatures cause increased cooling load increases energy demand and energy poverty	YES	Saves energy	Can reduce carbon emissions by 55% and annual energy consumption by 56%. LEDs can be dimmed, reducing unnecessary use of energy during non-peak times by up to 40%.

Synergies and conflicts between adaptation and mitigation measures

Adaptation measure	Primary intent	Synergies	In response to:	Conflicts	In response to:
Neighbourhood / Garden scale implementation					
Planting trees	Cooling Neighbourhood / garden (contributes to UHI reduction)	Cooling effect extends onto/into individual homes	Increased temperature and solar insolation	Reduction of solar gain for homes in winter (varies with species)	UK remains heating dominated climate
				Species planted currently may not be drought tolerant or able to cope with a changed climate	Increased temperature, solar insolation and reduced summer precipitation (drought conditions)
				Planting location matters: roots may exacerbate subsidence of homes	Seasonal precipitation extremes, increased temperature and solar irradiation
				Fallen trees due to wind or lightning during storms can damage homes	Typical risk: 'storminess', wind in some areas are already high
High albedo SUDS	Localised cooling – minimises the urban heat island effect	Cooling effect extends into homes			
	Increased temperature and solar insolation				
	Rainwater infiltration	Reduce the risk of local water pollution	Increased winter precipitation		
		Reduce the risk of pooling and pluvial flooding	Increased winter precipitation		
Planned flood defences, e.g. swales	Eliminate or reduce flood risk	Protect homes from flooding	Increased winter precipitation		
		Improve biodiversity		Swales or other planned flood zones could provide habitats for mosquitoes	Increased temperatures, flash flooding

Adaptation measure	Primary intent	Synergies	In response to:	Conflicts	In response to:
Home scale implementation					
Fixed shading vs. user operated shading	Reduce solar gain entering home - Numerous simulations have shown that shading is in many cases the most effective measure to reduce the risk of overheating in the home*		Increased temperature and solar insolation	Fixed shading, though designed for optimal seasonal solar angles can to some degree still reduce winter, spring and autumn solar gain	UK remains heating dominated climate
				Some shading approaches can have the negative impact of reduced daylight in the home, particularly fixed shading during the winter	Increased temperature, solar insolation and reduced summer precipitation (drought conditions)
Resorting to artificial lighting will increase energy use and contribute to internal heat gains	Summer: Increased temperature and solar insolation			Planting location matters: roots may exacerbate subsidence of homes	Seasonal precipitation extremes, increased temperature and solar irradiation
Winter: Decreased solar insolation				Fallen trees due to wind or lightning during storms can damage homes	Typical risk: 'storminess', wind in some areas are already high
Natural ventilation	Ventilation, particularly night ventilation can be effective as projected by a majority of the 21st century*			Ventilation, particularly night ventilation can be problematic with regard to occupant safety, air quality and a good night's sleep – where homes are in high traffic areas or on busy roads, next to pubs, etc., air and sound pollution can be an issue	Increased temperature

Adaptation measure	Primary intent	Synergies	In response to:	Conflicts	In response to:
Home scale implementation					
Increased insulation standards	Reduce heating energy demand		UK remains heating dominated climate	The mitigation measure with the most impact can have unintended consequences depending on location in the home – internal wall insulation and sometimes cavity wall insulation was found to increase the overheating potential in a number of homes*	Increased temperature and solar insolation
Cool walls and roof (high albedo fabric surfaces)	Reduce solar gain entering home through conduction	Combined cooling effect of many homes can reduce UHI	Increased temperature and solar insolation	Reduction of solar gain on roof and walls in winter	UK remains heating dominated climate
Replacing timber floors with or exposing (re-finishing) concrete floors for flood resilience	Easy post-minor flooding clean-up	Provides effective thermal mass	Increase summer temperatures		
Rainwater harvesting	Reduce potable water demand in the home and garden	Reduce rainwater runoff in garden and neighbourhood – reduce flood risk	Increased winter precipitation	Standing water in water butts (for example) could provide conditions for mosquito breeding	Increased summer temperatures and milder winters
Green roofs and walls	Cooling homes	Can reduce rainwater runoff and create localized cooling, reducing the UHI Reduce space heating demand in winter (dependent on thermal insulation of system)	Increased temperature and solar insolation Increased winter precipitation UK remains heating dominated climate	Some green cover on walls can be detrimental to the structural and aesthetic quality of the walls of homes, e.g. leading to moisture ingress (particularly where walls are already damaged). However, this problem can be avoided relatively easily	Increased winter precipitation

Adaptation measure	Primary intent	Synergies	In response to:	Conflicts	In response to:
Home scale implementation					
Flood gates, skirts, etc.	Home level flood resistance		Increased winter precipitation	Individual home resistance to flooding, even on a collective level, has the potential to exacerbate the impact elsewhere. An approach to flood resistance must be considered at large scale.	Increased winter precipitation

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