The Economics of Climate Resilience Buildings and Infrastructure Theme: Overheating in Residential Housing

CA0401

A REPORT PREPARED FOR DEFRA AND THE DEVOLVED ADMINISTRATIONS

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Context of this report

The Economics of Climate Resilience (ECR) has been commissioned by Defra and the Devolved Administrations (DAs) to develop evidence to inform the National Adaptation Programme and the adaptation plans of the DAs. The report should be read in the context of other programmes of work on adaptation being taken forward separately.

The scope of the ECR

The ECR follows the publication of the UK Climate Change Risk Assessment (CCRA) in January 2012 and differs in scope from work envisaged prior to that date. While its original aim was to consider individual climate change risk metrics from the CCRA and specific adaptation options, this evolved as the project was considered across government departments. The current ECR therefore focuses on broader policy questions, with each report covering multiple climate risks and CCRA risk metrics. In this context, the economic assessment is broader than a quantitative assessment of costs and benefits – it concerns identifying and assessing market failures and other barriers to effective adaptation action, seeking to understand drivers of behaviour which hinder or promote the adoption of adaptation actions. The framework for assessing the costs and benefits of adaptation actions is considered in a separate phase of the ECR.

Questions addressed

The questions addressed by the ECR were chosen following cross-government engagement by Defra. They ask whether there is a case for further intervention to deliver effective adaptation given the current context – i.e. the current adaptive capacity of those involved and the policy framework. Criteria for the choice of questions by policy officials include: the current and projected degree of the climate change risk; priorities for additional evidence gathering beyond that already being considered in other work-streams, and the data and evidence currently available. Questions were deliberately broad to allow the wider context to be considered, rather than just individual climate metrics. However, this approach prevents a detailed evaluation of individual risks or localised issues being made. Detailed assessments of climate thresholds and the limits of specific adaptation options have also not been possible.

Analysis undertaken

The analysis has sought to build on existing assessments of current and projected climate change risks (such as the CCRA). The context in which sectors operate has been assessed, including the current adaptive capacity of relevant actors and the policy framework in which those actors function. Categories of actions currently being taken to adapt to climate change have been explored, including those which build adaptive capacity where it is currently low, and those which limit the adverse impacts or maximise opportunities, allowing identification of barriers to effective adaptation. The case for intervention is then presented.

The degree to which an adaptation action is likely to be cost-effective requires more detailed assessment, reflecting the particular context in which adaptation is being considered.

Executive Summary

This report is underpinned by stakeholder engagement, comprising a series of semi-structured interviews with sector experts and a range of other stakeholders. This has enabled the experiences of those who undertake adaptation actions on the ground to be better understood. We are grateful to all those who have given their time.

Executive Summary

1 Executive Summary

A changing climate is projected to bring a gradual increase in mean summer temperature in the UK. In addition, the frequency and intensity of heat waves could increase in future, particularly in southern parts of England. As a result, heat-related death and morbidity costs could increase significantly in the future. The UK Climate Change Risk Assessment (CCRA) estimated that such costs could potentially increase from the current level by around £84m-£183m (in 2010 prices) per year by 2050 (Hames and Vardoulakis, 2012).

In response to these issues, policy leads across government set the following question to be addressed in this report: "**Given projected climate change and likely adaptation, what is the case for further action in relation to the heat impacts on people in residential buildings?"**

We have been asked by Defra to focus on four important areas:

- Potential future take up and use of cooling systems;
- The energy and carbon emissions impacts of using cooling systems;
- Alternative methods of avoiding overheating impacts; and,
- Overheating impacts on those not taking up cooling.

This report should be read alongside the ECR report on Health and Wellbeing which contains additional information on overheating impacts on vulnerable people (particularly the elderly).

Scale of the challenge

Analysis for two case study areas of London and the West Midlands suggests that, if the uptake of air conditioning systems continues at today's low rate of increase so that, by 2050, around 1% of households in those areas have cooling (compared with 0.6% in 2010)[1], energy demand for cooling could triple between 2010 and 2050 in both areas. If 50% of households were to install air conditioning systems by 2050, energy demand for cooling could be 37 times greater in 2050 than it would in a low uptake case in that year. If, in an extreme case, all households in the two areas were to install air conditioning systems by 2050, energy demand for cooling could be more than 84 times greater in 2050 than in a low uptake case in that year.

[1] This is under the p50 medium emissions scenario.

How prepared is the sector to respond?

The ability of individuals and organisations in the housing sector to prepare for the effects of overheating – referred to as 'adaptive capacity' – is generally low. The sector is characterised by the long lifetimes of dwellings, which limit opportunities to adapt because the buildings last for many decades irrespective of how the surrounding climate changes, and it is expensive to undertake retrofits.

Currently there is limited consumer demand in the UK for residential cooling equipment, with the result that there appears to be a general lack of skills and expertise among cooling service providers (particularly in relation to providing tailored advice and cost-effective cooling solutions) as well as a limited supply chain for retrofitting cooling measures. Overheating is not generally perceived to be a risk among householders, and they have limited awareness of cost-effective cooling options. The variability in the housing stock across dwelling types, ages, orientation and ownership structure makes the sector complex and weakens its ability to adapt.

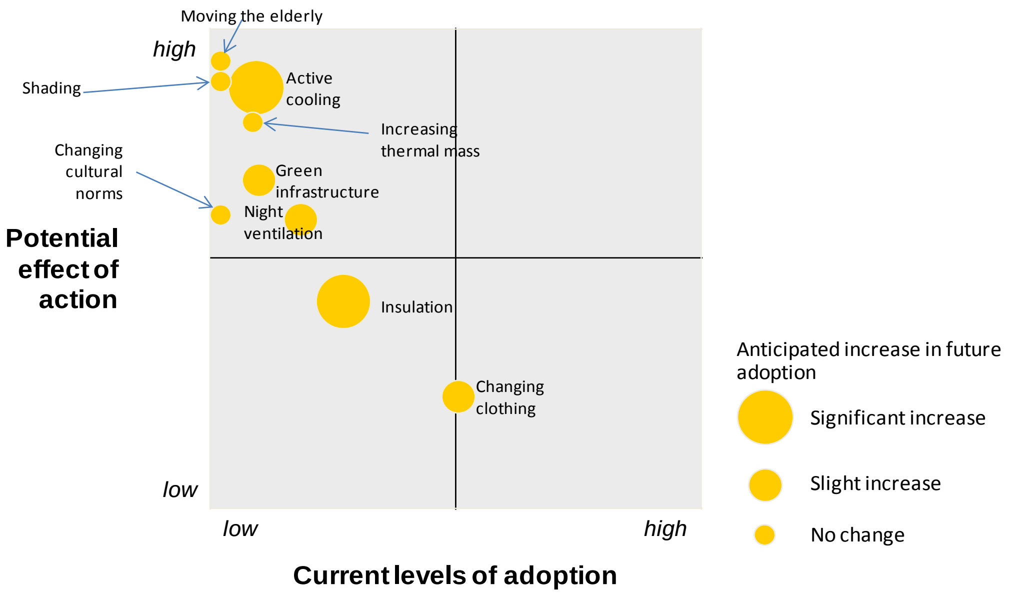
Potential adaptation measures and their effectiveness

Potential adaptation actions for cooling include:

- **Active cooling** (e.g. use of air conditioning systems);
- **Passive design measures** (e.g. increased thermal mass in new builds; insulation; reducing solar gain by shading or reflective surfaces; and ventilation);
- **Behavioural responses** (e.g. changing clothes; avoiding putting vulnerable people in dwellings particularly susceptible to overheating; and changing cultural norms such as comfort temperature); and,
- **External cooling with green infrastructure** (e.g. planting trees).

Figure 1 shows that, although many of these categories of actions (represented by the yellow markers) can be effective responses, the majority are not currently widespread. Uptake in the near term – to around 2020 – is not anticipated to increase significantly without further intervention.

Figure 1. Impact of adaptation actions and the extent to which they are anticipated to be used.



Source: Based on published evidence and stakeholder views.

Please note that changes in uptake are made relative to a low current starting point

Modelling of the effect of several **passive measures suggests they could reduce energy demand for cooling and associated CO_2 emissions by between 14% and 41%.** The size of the reduction is dependent on location, the uptake rate of cooling systems, the climate change emissions scenario, and, importantly, the extent of adoption of passive measures.

However, there are significant barriers to the implementation of effective adaptation actions; this is indicated by the majority of the actions being effective, yet adoption of them being limited (top-left quadrant of **Figure 1**). Where barriers can be overcome, this would facilitate effective adaptation actions to be implemented in line with an adaptive management approach (defined in Section 6). Illustrative roadmaps are described that are consistent with this approach. They demonstrate that actions need to be taken in line with a strategic vision and ensure those actions are monitored and reviewed to facilitate learning over time and modifications to be made.

There is a clear and urgent need for action to be taken, given the potential scale of impact on energy for cooling and associated CO_2 emissions in response to rising temperatures, and the potential gain from passive measures where they are implemented. Buildings are long-life assets, so opportunities should be taken to adapt effectively over time (e.g. through building design). The analysis identifies the following barriers and makes recommendations for interventions to address them.

Barriers and recommended interventions

Market failures

Externalities (one action imposes a cost or benefit on another that is not accounted for in decision making): these have been identified in two forms:

- **Builders and developers of new properties have little incentive to incorporate design to address overheating risk in new-build residential properties.** This is particularly problematic because of the long-life nature of buildings: there is a clear missed opportunity by not incorporating appropriate heat-risk mitigation into the design to avoid costly retrofitting.

- **Landlords have little incentive to invest in appropriate cooling measures, as they are not likely to realise the return from doing so**.

Information failures: this is an important category of market failure and occurs in several forms:

- People in areas that are likely to experience rising mean average temperatures, and in particular extreme temperatures (heat-waves), may not have **access to information that allows them to assess the their own risk of overheating**.

- **Lack of information in a timely and accessible form about the actions householders and others can take to alleviate overheating impacts.** This includes the lack of ex ante appraisal evidence on the costs and benefits of interventions, including green infrastructure; and ex post monitoring and review of actions, including design, low-cost retrofits.

- **Lack of knowledge, skills or experience in the supply chain about what the most effective and appropriate forms of cooling system are** for particular households.

To address these barriers a series of interventions have been recommended.

Recommendations

- **Build adaptive capacity of the sector by increasing the skills and knowledge of the organisations within the supply chain** so that new build properties are designed to take account of climate change risks, including overheating.

- **Build adaptive capacity of the sector by developing the supply chain for retrofits**, to ensure that builders and architects have access to equipment and information that enables them to advise on effective adaptation, and that residents have access to advice on how to adapt houses effectively. Particular focus should be on behavioural change and passive measures, which are likely to be lower cost and not maladaptive.

- **Build adaptive capacity by undertaking analysis of the impacts, costs and benefits of alternative cooling options** and the conditions under which they are effective. This must include green infrastructure options. Use this to build best practice over time.

- **Undertake ex post evaluations of interventions such as design, low-cost retrofits and green infrastructure.** Use the emerging evidence to learn and develop best practice approaches and to disseminate guidance to those at risk.

- **Address information failures** by ensuring targeted and engaging information is accessible to those at risk of overheating, along with simple guidance on appropriate actions to lower their risk.

Policy failures

The Building Regulations do not appear to account for risk of overheating in those geographical areas where it would be appropriate.

There appears to be a disproportionate focus on climate change mitigation compared with adaptation.

- **Review the housing policy framework to ensure that adaptation is considered alongside mitigation in a retrofit package. Address policy imbalances** where the focus is on mitigation actions only and not adaptation.

- **Allow for flexibility in relevant building regulations at a local level so that cooling options can be better explored to prevent the need for costly retrofits.** Consideration should be given to be flexible to the types of buildings and specific locations.

- **Facilitate energy efficiency improvements** through appropriate review of the relevant policy framework to ensure it remains supportive.

Behavioural constraints

Tenants and transient populations with short-term tenancies may not have the incentive to invest in passive cooling systems. As noted above, landlords also have little incentive to take action as they do not directly benefit, so these groups present particular barriers.

- **Build adaptive capacity of residents** through ensuring greater provision of targeted education and information on behaviour change and passive measures, such as keeping curtains closed during the day, opening windows at night etc.

Governance constraints

National planning policy expects local planning authorities to adopt proactive strategies to mitigate and adapt to climate change.

- **Facilitate and support the effective implementation of planning policy by local authorities to ensure decisions adequately account for adaptation** and consider efficient cooling options, where appropriate. This includes passive measures as well as green space.

2 Residential buildings theme

2.1 The focus of this report

Given projected climate change, policy officials identified a need for additional evidence relating to the potential demand for cooling in residential property. The following question was therefore set as the focus of this report.

"Given projected climate change and likely adaptation, what is the case for further intervention in relation to the heat impacts on people in residential buildings?"

We have been asked by Defra to focus on four important areas:

- Potential future take up and use of cooling systems;
- The energy and carbon emissions impacts of using cooling systems;
- Alternative methods of avoiding overheating impacts; and,
- Overheating impacts on those not taking up cooling.

2.2 Approach

This report reflects analysis undertaken over a period of two months and draws on a wide, published evidence base as well as evidence from stakeholder engagement.

2.2.1 Stakeholder engagement

The work has been advised and reviewed by Professor Michael Davies from University College London. In addition to official expert input and review, Tony Day of TEAM Energy Services Ltd and Stephen Porritt of the Community Resilience to Extreme Weather (CREW) project provided invaluable input. Broader stakeholder engagement has also been undertaken to shape this work, drawing on the expertise of representatives across industry, research, academia, and technology experts, among others. Around 20 in-depth semi-structured interviews were held with stakeholders. Findings of the work were discussed and tested with leading experts.

Stakeholders are listed in **Annex 1**.

2.2.2 Analysis

The assessment draws on a wide evidence base informed by in-depth analysis of published literature and statistics, complemented with stakeholder views and expertise as noted above. We explore the adaptive capacity of relevant actors and the types of actions that could be taken to adapt to the risk of overheating in residential buildings. Where there are barriers to effective action being taken, these are considered in terms of the following categories:

- **Market failures**: those relating to pricing signals; externalities[2]; ownership of risk and assets which lead to misaligned incentives; and where information may not be timely, accurate, relevant or is incomplete;
- **Policy**: the framework of regulation and policy mechanisms
- **Behavioural**: short sightedness and willingness to act; and,
- **Governance**: institutional decision-making processes.

The analysis briefly summarises the key points from the CCRA, with the main focus on the modelling of future scenarios of energy demand for cooling. Throughout the report it is assumed that all energy demand for cooling is electricity. These scenarios are presented in **Section** 3 and demonstrate how energy demand for cooling could develop in the future under different assumptions.

2.2.3 Structure of the report

The report is structured as follows:

- Section 3 presents the scale of the challenge posed to the sector by projected climate change;
- Section 4 discusses the context for adaptation in terms of the role of government in adaptation and adaptive capacity of key actors;
- Section 5 presents an assessment of the range of actions that are already being taken, or are likely in the near-term (to 2020). Barriers to effective adaptation are identified;
- Section 6 presents the case for intervention, including illustrative adaptation roadmaps consistent with the concept of adaptive management. To support these, 'what if?' scenarios are shown to illustrate the potential effectiveness of particular actions.

[2] Where there are costs or benefits imposed on others that are not accounted for in individual decision making.

3 Scale of the challenge

Key messages

- **A changing climate is projected to bring a gradual increase in mean summer temperature.** By the 2050s, for the central estimate p50 of the UKCP09 medium emissions scenario, the southern part of England could see temperature rises of between 2.3 °C and 2.7°C (Murphy et al, 2009). The projected summer minimum mean air temperature over the whole UK ranges from 0.8°C in the p10 low emissions scenario to 5.7°C in the p90 high emissions scenario for the 2050s (UKCP09).

- Our analysis for two case study areas of London and the West Midlands indicates that under the p50 low emissions scenario:

  - Relative to the current relatively low level, energy demand for cooling could triple between 2010 and 2050 in both case study areas, even if uptake of air conditioning systems is low (i.e. rising from only 0.6% of households with cooling in 2010 to 1% by 2050)[3].

  - Illustratively, under the same assumptions, if 50% of households install air conditioning systems by 2050, energy demand for cooling in each case study area could be 37 times greater in 2050 than in a low uptake scenario for that year. In an extreme case, if all households in the case study areas install air conditioning systems, energy demand for cooling could be more than 84 times greater in 2050 than in a low uptake scenario in that year.

3.1 Climate threats facing the sector to the 2050s

This Section focuses on projections, first at the national scale, and then at the level of two case study areas in England. For further information, please refer to the ECR Report on Health and Wellbeing that discusses the current and projected impacts of rising temperatures on the incidence of heat-related premature death and hospital admissions.

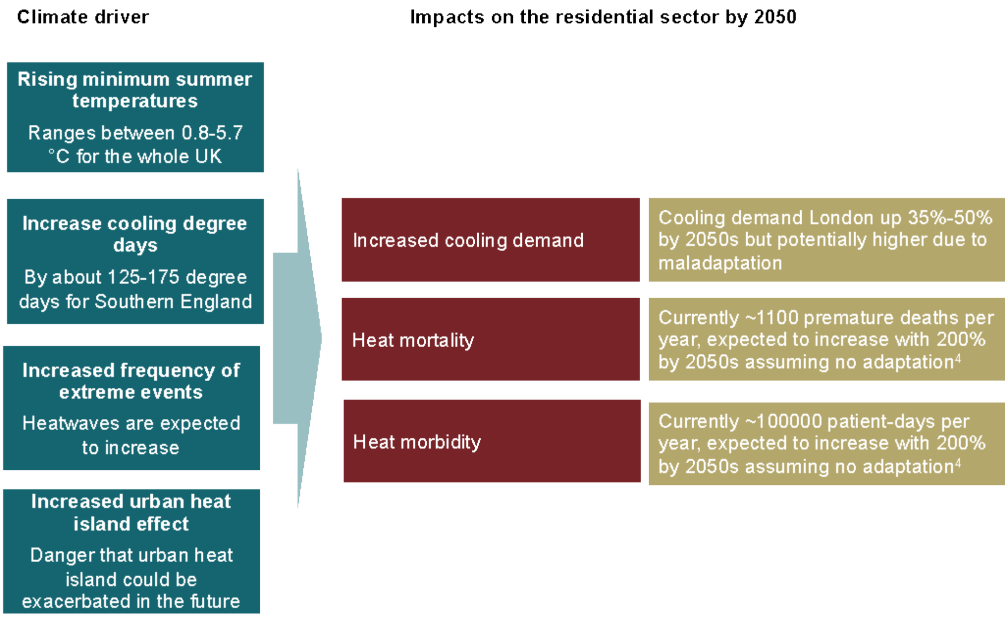
Figure 2 summarises the key climate threats the residential buildings sector could face in the future as a result of long-term temperature change and more frequent

[3] This is under the p50 medium emissions scenario.

heat waves. The impacts of these changes in climate can broadly be split into three categories:

- Increased cooling demand;
- Higher heat-related death rates and associated rise in heat-related morbidity rates; and,
- More frequent discomfort as a result of overheating (CCRA: Capon and Oakley, 2012).

Figure 2. Key climate risks and impacts on the residential sector by the 2050s

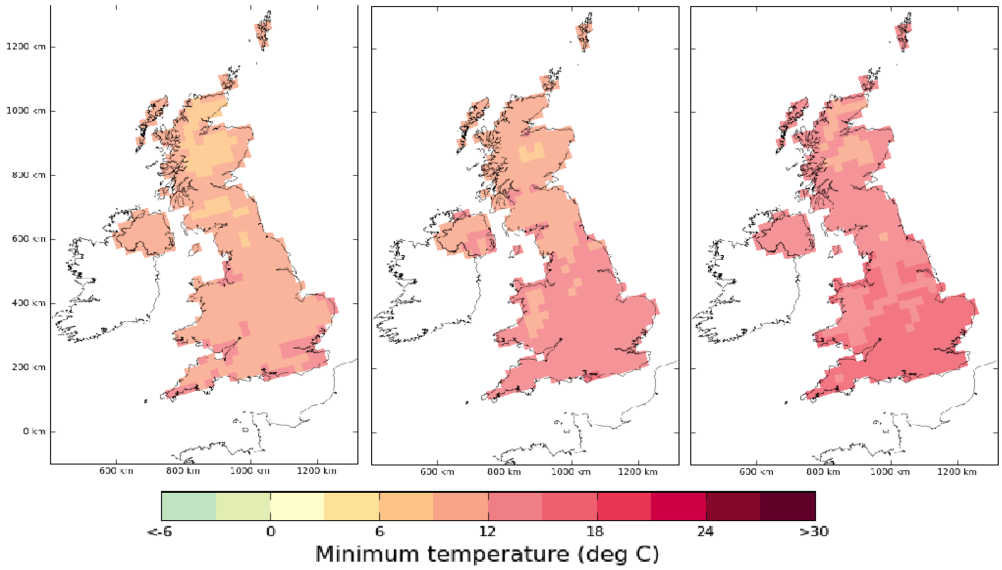


Source: CCRA: Capon and Oakley (2012); UKCP09 (based on p.10 low emissions to p90 high emissions scenario)

3.1.1 Rising temperatures

A changing climate is projected to bring a gradual increase in mean summer temperature. By the 2050s, for the central estimate p50 of the UKCP09 medium emissions scenario, the southern part of England could see temperature rises of between 2.3 ºC and 2.7ºC (Murphy et al, 2009). The projected summer minimum mean air temperature for the 2050s over the whole UK ranges from 0.8ºC in the p10 low emissions scenario to 5.7ºC in the p90 high emissions scenario (UKCP09). However, mean temperature increases will vary regionally (see **Figure 3** below).

Figure 3. Projected changes in 2050s minimum mean summer temperature (degrees Celsius) for the p10 low emissions scenario (left), p50 medium emissions scenario (middle) and p90 high emissions scenario (right).



Source: UKCP09

These projections are consistent with observed trends over the last decades. Cities in the UK have experienced increases in mean summer temperatures of between 1°C and 2°C from the 1960s to 2008 (Jenkins et al, 2009).

In addition to an increase in mean summer temperatures in future, the frequency and intensity of heat waves could increase, particularly in southern parts of England. The results of the ARCADIA project suggest that by the 2050s, one third of London's summer may exceed the Met Office heat wave temperature threshold (a day temperature of 32°C and night temperature of 18°C) (Hall et al, 2009). Currently the threshold is exceeded on average 1-2 times in the London area per year. Depending on the time in the year, and their duration, those heat waves lead to different impacts on occupants. Heat waves early in the summer (June/July) are associated with greater impacts on heat-related deaths than heat waves of comparable or hotter temperatures in the same population in subsequent months (Roaf et al, 2009).

3.1.2 Urban Heat Island

The Urban Heat Island (UHI) effect is the effect whereby the temperature at the centre of a large city can be several degrees higher than in rural areas, due to the urban environment, land coverage, built form, emissions, and the prevailing weather conditions. Future changes to the UHI are not included in the CCRA cooling demand analysis (Capon and Oakley, 2012). However, during the August 2003 heat wave, Capon and Oakley (2012) report that the UHI effect on night temperatures was up to 9ºC in London, 5-10ºC in Manchester, and 5-7ºC in Birmingham. Such localised increased temperatures would be likely to lead to a consequent increase in cooling demands. Capon and Oakley (2012) state that there is a "very real danger that the UHI could be exacerbated in the future by autonomous maladaptation in the form of widespread installation of air conditioning for comfort cooling".

3.1.3 Cooling energy demand

Cooling degree days (CDDs) refer to the day by day sum of the mean number of degrees by which the air temperature is more than a value of 22 ºC. The measure is used as an indicator for the energy demand of a cooling system (Isaac and Van Vuuren, 2009). The CCRA (Capon and Oakley, 2012) simulated a baseline average CDD of between 25 and 50 days over southern England for the period 1961 to 1990, which was projected to increase to between 125 and 175 days by the 2080s (an increase of 150% to 600%). The 2080s horizon used for this estimate is longer than the timeframe used in this report, but it is indicative of the potential scale of change. The projected increase over northern England and Scotland is smaller, at only 25 to 50 days (McColl et al, 2012).

Currently the total cooling energy demand in all buildings (including commercial) is very small compared to heating energy demand: approximately 15 TWh for cooling versus approximately 400 TWh for heating (Day et al, 2009). As cooling systems in residential buildings are still relatively low in number, the significant part of cooling energy demand is likely to remain in commercial buildings.

3.1.4 Heating energy demand

Although winter heating is outside the scope of this study, it must be considered in the broader system of greenhouse gas (GHG) emissions, particularly as the measures for reducing heating demand can be both synergistic and in conflict with measures for cooling. An increase in mean average winter temperatures is projected to lead to a decrease in heating energy demand. The projected decrease in winter energy demand per household (using a 1961-90 baseline) could be between 11% and 45% by the 2050s (range from low emissions scenario p10 to high emissions scenario p90 results). For residential buildings this is a reduction in demand for heating of between 36 and 153 TWh (Capon and Oakley, 2012). This is supported by the work of Eskeland and Mideksa (2010) who found that climate change reduced UK consumption of energy overall by 6% due to a larger reduction in heating degree days[4] compared to the increase in CDD. However, heating energy is (currently) predominantly derived from gas, while summer cooling uses electricity. Electricity is currently still associated with higher greenhouse gas emissions compared to gas. Emissions per unit of energy are expected, however, to be reduced in the future through the use of carbon capture and storage, low carbon power generation (e.g. nuclear power), and renewable energy (e.g. wind and solar energy).

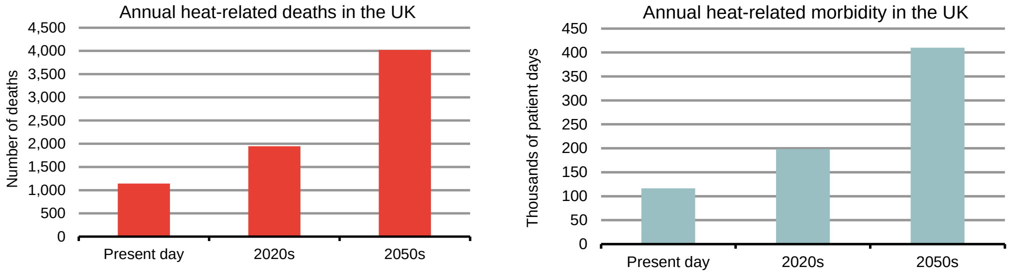
3.2 Projections of the impacts of overheating without further adaptation

3.2.1 Heat-related deaths and morbidity

The CCRA Health Sector Report (Hames and Vardoulakis, 2012) estimated future heat-related death rates. Projected heat-related deaths and illnesses for the UK are shown in Figure 4. **By the 2050s there may be approximately 4,000 heat-related deaths per year** under the p50 medium emissions scenario and the principal population projection. This is an increase of 250% against current levels. The range around the central estimates is large: under a low population, p10 low emissions scenario, there could be around 1,800 deaths; and, under a high population, p90 high emissions scenario, there could be around 10,000 deaths. These results were used to project heat-related morbidity by assuming that one heat-related death implies 102 patient days in hospital. It should be noted that the morbidity estimates are less robust than the heat-related death projections, as they are based on a limited evidence base.

[4] Heating Degree Days is the heating equivalent of CDD with a threshold of 15.5°C

Figure 4. Current and projected heat-related deaths and morbidity in the UK



Source: CCRA: Hames and Vardoulakis (2012)

Note: The figures relate to the principal population scenario and the UKCP09 p50 medium emissions climate change scenario.

The CCRA (Hames and Vardoulakis, 2012) projections in **Figure 4** indicate that the number of deaths is expected to increase at different rates across different regions. In particular, the frequency of heat-related deaths is likely to increase more in southern England than other areas of the country, as average summer temperatures are likely to rise proportionately more.

The Hames and Vardoulakis (2012) analysis also considered a scenario in which heat waves become more frequent. This indicated that there could be up to 31% more heat-related deaths per year if heat waves were to occur every second year, relative to the results described above. This is estimated by using a baseline (2003-2006) that includes proportionally more heat wave events than the central baseline scenario.

The UHI effect was not accounted for in the quantified estimates by Hames and Vardoulakis (2012); temperatures can be significantly higher in areas where this effect occurs. In addition, the analysis does not take into account the changing demographic structure of the population. The CCRA report indicates that the heat effects on health may be underestimated, as the proportion of older people is projected to increase in future. This group could be especially vulnerable to heat-related health impacts. This is explored in more detail in the ECR Health and Wellbeing report.

However, it should also be noted that the Capon and Oakley (2012) projections assume there to be no increased adoption of air conditioning units and no acclimatisation taken into account, and they do not include measures in place already such as the England Health-Health Watch system (described in more detail in the ECR Health and Wellbeing report). These factors could increase or decrease heat-related deaths and morbidity impacts contained in Hames and Vardoulakis (2012).

The CCRA projections of heat-related deaths and morbidity were monetised using figures suggested by the Interdepartmental Group on Costs and Benefits. It was estimated that heat-related death costs could increase by £84m per year and morbidity costs by £183m per year (2010 prices) from current levels by the 2050s, assuming no acclimatisation, and under the p50 medium emissions and 'principal' scenario of population growth. Cost increases due to heat-related deaths could range from £27m per year under the p10 low emissions and low population scenario to £224m per year under the p90 high emissions and high population scenario. Morbidity costs could increase from the current level by £40m per year under the p10 low emissions and low population scenario, and by £565m per year under the p90 high emissions and high population scenario.[5] **Annex 4** presents further discussion of heat-related deaths and morbidity.

3.2.2 Discomfort

Discomfort may already be an issue in some locations (CIBSE, 2005). Several studies (e.g. ARUP, 2008; Gupta and Gregg, 2012; Porritt et al, 2012) have explored the future occurrence of discomfort in residential buildings due to overheating. These found that the number of overheating hours could increase significantly in the future. For example, Gupta and Gregg (2012) found that, in Oxford, the number of hours in which indoor temperatures are above 28°C could increase from between 1 and 12 per year to between 164 and 947 per year by the 2050s (assuming a high emissions scenario p90[6]).

As with the projections for heat-related deaths and morbidity, the UHI effect, the occurrence of heat waves, and the ageing of the population are not generally considered in published work. The urban heat island effect would raise all temperatures still further, while heat waves could cause significant short-term increases in discomfort levels.

A range of different indoor temperatures has been employed in the literature to define the point at which discomfort is experienced. For example, CIBSE have defined these thresholds at 26°C for a bedroom and 28°C for a living room (CIBSE, 2005). Analysis of discomfort can depend on the assumptions. In reality, the actual temperature at which discomfort is experienced will depend on

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[5] These estimates were not presented in the CCRA report. They are based on the number of patient-days estimated for each scenario in 2050 minus the present-day level, multiplied by the per-day cost of £625 for each patient used in the CCRA.

[6] This is the only emissions scenario presented by the authors.

specific characteristics of the building and the inhabitants. Note that the elderly may experience discomfort at lower temperatures than other age groups.

While it is clear that discomfort is likely to be a major issue in the future if no adaptation action is taken, the precise scale of the challenge is uncertain. This is largely due to the subjective nature of discomfort, and the diverse characteristics of the housing stock, population and climate of the UK.

3.2.3 Energy demand for cooling – the literature

Several studies have projected energy demand for cooling from the residential sector in the future. The key papers reviewed for this project are outlined in **Table 1**.

Table 1. Key papers reviewed

Reference	Title of paper
CIBSE (2005)	*Climate change and the indoor environment: impacts and adaptation*
Collins, Natarajan and Levermore (2010)	*Climate change and future energy consumption in UK housing stock*
Day, Jones and Maidment (2009)	*Forecasting future cooling demand in London*
Gupta and Gregg (2012)	*Using UK climate change projections to adapt existing English homes for a warming climate*
Hacker, Belcher and Connell (2005)	*Beating the heat: keeping UK buildings cool in a warming climate*
Wu and Pett (2006)	*Cold Comfort for Kyoto? Carbon Implications from Increasing Residential Cooling Demand: A Scoping Report*

The results of these studies vary widely. For example, Collins et al (2010) estimated that residential energy demand for cooling could be 4.2TWh by the 2050s, while Wu and Pett (2006) calculated that residential energy demand for cooling could range between 2.1TWh and 14TWh per year by the 2050s. Mechanical cooling is currently responsible for around 15TWh per year in the UK, so these figures indicate that residential demand in the future could be equivalent to around 14% to 93% of current total current cooling demand.

Scale of the challenge

The range of results in the literature indicates that the demand for cooling from the residential sector is subject to uncertainty. This is due to the different assumptions and drivers assessed:

- **Characteristics of current and future types of cooling systems can influence energy demand**. There is a wide range of cooling systems available, each with different efficiency properties. It is difficult to predict which types will come to dominate the market, given that residential demand is currently very low. It can also be difficult to project energy efficiency, which can significantly influence total energy demand over a long period.

- **The assumed uptake rate of cooling systems is a key driver of the energy demand for cooling.** Market penetration in the residential buildings sector is currently around 3% (Giles, 2012), so it can be challenging to make appropriate inferences from past trends. The uptake rate varies from 10% to 100% by the 2050s in the literature. Studies also do not generally consider spikes in demand due to heat waves. After heat waves during the summers of 1995 and 1996, BSRIA found that, in general, uptake rates for air conditioning systems are likely to increase when two conditions are met: first, regular temperatures must exceed 35°C over three consecutive summers; and, second, a large marketing campaign must be undertaken by an air conditioning manufacturer. During summers in which these conditions held, the residential air conditioning market grew by 35% (Giles, 2012). Economic factors are also a key driver of the uptake of active cooling. Increases in employment and GDP have been shown to increase disposable income and expenditure on consumer goods such as air conditioning systems.

- **Housing stock and the type and number of occupants also influences cooling energy demand.** Energy demand can vary significantly according to occupancy rates and dwelling types. Location is perhaps the most important of these factors. Climate change is projected to affect different regions of the UK to varying degrees, so modelling at the building or city level can give different results depending on which region is analysed. Further, the UHI effect could cause a greater increase in energy demand in towns and cities than in rural areas. These assumptions demonstrate that national level modelling can be misleading, as regional variations could be significant.

Annex 3 sets out the findings of the literature review in more detail.

3.2.4 Projected cooling energy demand and emissions to the 2050s

The potential energy (electricity) demand for cooling and associated emissions to the 2050s[7] has been explored by undertaking analysis in two case study areas: the West Midlands and central London. These case study areas were selected for three particular reasons. First, they are urban areas of the UK with a relatively high density of population and residential property. Second, they are projected to experience mean summer temperatures that are higher than many other more northern areas of the UK by the 2050s as shown in **Figure 3**. Third, the areas were amenable to modelling in the time available for this analysis.

The associated impacts of cooling systems on health were not estimated for this analysis. This would require much more complex analysis than was possible in the time available for this report. It was also not possible to model impacts on a national scale due to the input data required for the model. **Annex 5** presents a detailed report on the assumptions and detail of the modelling undertaken for this report by TEAM Energy Services Ltd.

Energy demand is assumed to be driven by the size of property (floor area), efficiency of the cooling units, and cooling degree-days. All cooling is here assumed to be powered by electricity, so energy demand in this context is interchangeable with electricity demand.

Cases modelled and summary results

Seven cases combining a range of different levels of air conditioning uptake and emissions scenarios were modelled. These cases are summarised in **Table 2**. The results of the modelling suggest several key conclusions:

- **Under a medium emissions p50 scenario, energy demand for cooling could triple between 2010 and 2050** in both case study areas if uptake of air conditioning systems rises from the current (2010) uptake of 0.6% of households to around 1% of households in 2050 ('low uptake' case).

- **If 50% of households install air conditioning systems by 2050, energy demand for cooling could be 37 times greater than in a low uptake case in 2050** (assuming the same p50 medium emissions scenario).

- **The most extreme case that was modelled considered 100% of households in the case study areas installing air conditioning systems**

[7] For the purposes of modelling cooling energy demand and associated emissions, the projections were developed up to the year 2050 using climate change projections to the 2050s.

by 2050. This could result in energy demand for cooling in 2050 of more than 84 times greater than in the low uptake case.

- Improvements in the energy efficiency of air conditioning systems could mitigate these increases in energy demand for cooling to some extent. For illustration, under the low uptake case and a medium p50 emissions scenario, **energy usage could be approximately 30% lower in 2050 with efficiency improvements of 1-2% per year than if no efficiency improvements occur**.

- If the electricity grid is decarbonised in line with the Department for Energy and Climate Change (DECC) projections, the carbon content of energy is expected to fall by 93% by 2050 relative to current levels. **Despite the 3-fold rise in energy demand for cooling under the low uptake case (between 2010 and 2050), carbon dioxide emissions associated with energy demand for cooling could be around 80% lower in 2050 than in 2010 under a low uptake case as a result of decarbonisation** (and using p50 medium emissions scenario). The rate of uptake in cooling is therefore outweighed by the rate of decarbonisation.

- **In a scenario with grid decarbonisation, emissions could be seven times higher under medium air conditioning uptake (50% of households) and fifteen times higher under high uptake (100% of households) in 2050 than in 2010**. The rate of uptake of cooling by households exceeds the rate of decarbonisation.

- **In a high uptake case (i.e. the extreme case in which 100% of households have air conditioning) and a p50 medium emissions scenario, installed capacity could be over 210 times greater in 2050 than 2010 i.e. around 11.5GW in London and 7.9GW in the West Midlands**. This is equivalent to around an extra 2.4-4GW of generation capacity in London and an extra 1.6 - 2.6GW in the West Midlands by 2050[8]. To put this into context, as the ECR Power Generation and Transmission report notes, the current total installed generating capacity in Great Britain is 83.6GW and is planned to increase to 109.8GW by 2015-16 (National Grid, 2009). Such an extreme level of uptake could therefore lead to a substantial additional requirement for energy.

[8] This assumes an illustrative co-efficient of performance (COP) of 3-5. The COP is the 'instantaneous' measure of efficiency of the refrigeration system. It is the ratio of the cooling output to the electricity input. It is used in this instance to determine the peak electrical demand of cooling systems.

- When comparing the p50 medium emissions climate change scenario in 2050 with the demand under current climate in 2050 – both with low uptake of cooling – climate change means energy demand for cooling could be 56% higher in London and 72% higher in the West Midlands.

The following sections outline the assumptions that were made in the modelling process and discuss the results in more detail.

Table 2.Cases considered for each of the West Midlands and central London. Results shown for the year 2050 (shaded cells indicate the features of each scenario).

Case	Assumptions								Results					
	UKCP09 emissions scenario			Active cooling system uptake (% of households)			Heat waves	System efficiency gains (1-2% per year)	Energy demand (GWh)		CO_2 emissions (thousand tonnes)		Installed capacity (MW)	
	Current climate	Medium p50	High p50	Low (1%)	Medium (50%)	High (100%)			London	West Midlands	London	West Midlands	London	West Midlands
Base									45	13	1	0.3	111	76
A									49	14	1	0.3	122	83
B									76	25	2	0.6	122	83
C									50	16	1	0.4	122	83
F									6,288	2,045	142	46	11,455	7,851
I									78	25	2	0.6	111	76
L									2,825	932	64	21	5,727	3,925

Source: Modelling for this analysis by TEAM Energy Services Ltd (see Annex 5 for more detail)

Note: these are used as the base against which the impacts of passive measures are assessed later in this report.

Key assumptions

Annex 5 provides full details of all the assumptions underlying the analysis. Cases with different assumptions were used to reflect the uncertainty around key drivers of energy demand for cooling to 2050. Eight different types of active cooling were considered, including split units, variable refrigerant flow (VRF) systems and ground source heat pumps. Full details of the unit types considered and sales numbers are outlined in **Annex 5.** Cases differ in relation to:

- **Uptake rates of active cooling systems**: three different uptake rates were used:
  - ***Low uptake case:*** approximately 1% of households have cooling systems by 2050, based on a continuation of recent sales trends reported by BSRIA (2011). This assumes that growth in sales of less efficient units, such as portable units and split systems, will decline by 20% each year in the future. Sales of more efficient units are projected to increase by 1% or 2% per year, depending on the system type. All growth rates are based on projections made in the literature and existing sales data
  - ***High uptake case*:** 100% of households have cooling systems by 2050, based on DECC (2010)[9]. This assumes that annual sales of cooling systems follow the low uptake scenario until 2020, at which point sales build to a peak in 2035 and then the pace of growth lessens to 2050. More efficient systems are assumed to dominate the mix by the end of the period; and,
  - ***Medium uptake case*:** 50% of households have cooling systems by 2050 (this is also in line with the uptake in European countries such as Greece[10] (see **Annex 7**)). This assumes the same profile of uptake as the high uptake case but reaching 50% penetration of households by 2050. Again, more efficient systems are assumed to dominate the mix by the end of the period.
- **Heat waves**: sales of active cooling systems have historically spiked during heat waves. These are illustrated through a doubling of cooling unit sales every five years;

[9] The DECC 2050 pathways incorporate an uptake scenario in which every household in the UK has air conditioning (DECC, 2010).

[10] Annex 7 notes that in Greece, residential market penetration is 45-50% (65% in Athens) (BSRIA, 2011).

- **Climate change scenario**: the medium and high UKCP09 emissions scenarios (p50 for both) to the 2050s are illustrated;
- **System efficiency**: the Energy Efficiency Ratios (EERs) of the cooling systems modelled are based on those stated in published reports. A conservative assumption of annual improvements in the range 1% to 1.5% per year, depending on the system type;
- **Heat gains**: average heat gains are used in the model to calculate the base temperature inside homes. Data on average occupant, equipment, lighting and solar gains from CIBSE TM37 (CIBSE, 2006b) has been used; and,
- **Floor area**: this is projected by extrapolating Department of Communities and Local Government data on housing stock by assuming a linear growth rate. Total floor area is calculated by multiplying the number of dwellings by an average floor area per dwelling of 86.9m^2, in line with Housing Statistics in the European Union (2010).

Effect of active cooling demand on energy usage in the absence of climate change

Annual energy demand for cooling in London and the West Midlands is projected to increase by around 80% (27GWh for the two areas combined) between 2010 and 2050 under the current climate (i.e. in the absence of climate change) and assuming low uptake of air conditioning systems (base case). These changes are due to a continuation of current uptake trends, rather than to climate change or adaptation responses. For context, the current total energy consumption was 23,000GWh in these two regions in 2010 (DECC, 2012b).

If the occurrence of heat waves is taken into account, demand in London increases by 100% and demand in the West Midlands increases by 90% between 2010 and 2050. Any increase in the frequency or intensity of heat waves could therefore have a significant impact on the energy demand for active cooling systems.

The impact of climate change

Cases B to L take potential climate change into account, using the p50 medium and p50 high UKCP09 emissions scenarios to the 2050s.

If a p50 medium emissions climate change scenario with heat waves is assumed (case B), then even with low uptake of cooling, energy demand could be 56% higher in London and 72% higher in the West Midlands in 2050 than if no climate change occurs (case A).

Scale of the challenge

If the p50 high emissions scenario, a low uptake rate, and no heat waves are assumed (case I), energy demand could be 61% higher in London and 75% higher in the West Midlands in 2050 than if no climate change occurs (case A).

Accounting for rising average temperatures therefore notably influences the energy demand for cooling.

Uptake of air conditioning systems

Under a p50 medium emissions scenario, a medium uptake rate of active cooling is projected to result in a 36-fold increase in energy demand for cooling compared with the energy demand with a low uptake rate (case B to L in **Table 2**) in 2050.

Under a p50 high emissions climate change scenario, a 100% household uptake by 2050, and no heat waves (case F), energy demand for cooling could be 83 times higher in 2050 in London and the West Midlands than under a low uptake scenario with heat waves (case B). While these differences are partially driven by moving from a p50 medium emissions scenario to a p50 high emissions scenario, **the key driver of energy demand is the uptake rate of active cooling.**

Table 3 illustrates the magnitude of future changes in energy demand for cooling compared to current domestic electricity consumption and future changes in energy demand for heating.

Table 3. Potential future changes in energy demand for cooling and current total domestic electricity consumption (all figures are London and the West Midlands combined)

Domestic electricity consumption in 2010 (GWh)	Max increase in energy demand (GWh) 2010-2050			Decrease in energy demand for heating (GWh) 2008-2050		
	Low uptake	Medium uptake	High uptake	Low emission scenario, p10	Medium emission scenario, p50	High emission scenario, p90
23,000	69	3,700	8,300	-8,000	3,500	20,500

Source: DECC (2012a), Capon and Oakley (2012) and modelling for this report by TEAM Energy Services Ltd

Note: decreases in energy demand for heating are taken for the principal population projection.

The increase in energy demand for cooling over 2010-2050 in a low uptake scenario is very small relative to total domestic energy consumption, while in the medium and high uptake cases, changes are much more significant. Similar conclusions are reached when comparing changes in energy demand for cooling to changes in energy demand for heating. In a p50 medium emissions scenario, increases in energy demand for cooling over 2010-2050 under a medium uptake scenario for active cooling could be comparable to decreases in energy demand for heating. If high uptake of cooling systems occurs, increases in cooling energy demand could far outweigh any decreases in consumption due to reduced heating requirements by 2050.

Efficiency of air conditioning systems

The potential for improvements of 1% to 2% per year in the efficiency of air conditioning systems has been explored (case C). Under a p50 medium emissions climate change scenario and low uptake rate of cooling systems with heat waves, **efficiency improvements could result in a reduction in energy demand of 34% by 2050 for both London and the West Midlands** (comparing case C to case B).

While the impacts of energy efficiency on energy demand were not modelled for other uptake or climate change scenarios, these results illustrate that the **energy efficiency of cooling systems could partially mitigate the effects of climate change in 2050**. The magnitude of the impact will depend on the improvements in efficiency that are realised.

CO_2 emissions and decarbonisation of the electricity grid

Grid decarbonisation in the future – a movement away from fossil fuel electricity generation towards renewables and other low carbon (non-fossil fuel) sources – must be taken into consideration.

If grid decarbonisation occurs in line with Department for Energy and Climate Change (DECC) projections between 2010 and 2050, the carbon content of each unit of electricity could fall by 93% (see **Annex 5** for further discussion). If this occurs, the modelling suggests that emissions associated with the energy demand for cooling could be approximately 80% lower than 2010 levels under a p50 medium emissions scenario with low uptake rate (comparing cases A and B).

However, under a medium (50%) uptake rate of cooling (case L), annual emissions could be more than seven times higher than 2010 levels (in both case study areas). A high uptake (100%) (case F) could lead to emissions that are more than 15 times greater in London and 17 times greater in the West Midlands in the 2050s than in 2010. If no decarbonisation occurs, the increases in a medium uptake scenario could otherwise be 117 times higher in London in 2050 than 2010 and 125 times higher in the West Midlands. In a high uptake scenario, emissions could be 259 times higher in London and 289 times higher in the West Midlands.

Scale of the challenge

Total UK CO_2 emissions attributable to residential users were 149 million tonnes in 2010 (DECC, 2012b). London and the West Midlands accounted for 20% of the total UK housing stock in 2010 (see Annex 5), so the level of uptake of cooling in these areas could have a significant influence over the national level of emissions in 2050. The highest annual CO_2 emissions estimated from operating residential cooling in this analysis (case F) were 188,000 tonnes for London and the West Midlands combined, for a case with 100% uptake of cooling in 2050. Although this may seem low compared to the total level of residential emissions today, the Climate Change Act established a legally binding target to reduce the UK's greenhouse gas emissions by at least 80% below base year levels by 2050, to be achieved through action at home and abroad (DECC 2011d). Therefore, any potential rise in emissions from uptake of cooling could have implications for the action required more widely to meet UK carbon targets.

Grid decarbonisation could significantly limit the increase of or even reduce emissions, depending on the extent of uptake of active cooling systems.

Installed capacity (a proxy for peak cooling load requirement[11])

For the low uptake case, the installed capacity of cooling systems in 2050 could be more than double 2010 levels (cases I and C), though this is from the very low current level. For illustration, the extra generation capacity that would be required to service this increase in demand could in this case be around 25-40MW in London and 9-15MW in the West Midlands, assuming a coefficient of performance[12] of between 3 and 5. This is a very small requirement, considering that many power stations have a capacity of around 1GW.

Assuming a high uptake rate, the installed capacity in London could increase by 11,400MW in London and 7,800MW in the West Midlands between 2010 and 2050. These are significant increases and suggest that peak load electricity demand for cooling could be notably higher than it is today. Assuming a co-efficient of performance of between 3 and 5 by the 2050s, the additional peak cooling load required in the 2050s could be equivalent to 2.4-4GW of extra generation capacity in London and 1.6-2.6GW in the West Midlands. **The installed capacity results illustrate that significant generation capacity could be required** in certain regions of the UK to serve demand in the event of high uptake of active cooling systems.

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[11] This is the peak load requirement. Actual peak electricity demand required to deliver this cooling would require the co-efficient of performance to be estimated for London and the West Midlands.

[12] The Coefficient of Performance (COP) is the 'instantaneous' measure of efficiency of the refrigeration system. It is the ratio of the cooling output to the electricity input. It is used in this instance to determine the peak electrical demand of cooling system.

This Section has discussed the scale of the challenge of rising temperatures. The next Section considers the context for adaptation.

4 Context for adaptation

Key messages

- In 2010 there were more than 27 million residential buildings in the UK, of which two-thirds were owner-occupied, with a growing number of private renters. This is an important consideration when looking at adaptive capacity. By the 2050s, the majority of the current dwelling stock will still exist, and new builds (built post 2006) are expected to account for just 30% of the stock.

- Housing design and building is heavily regulated, yet regulation focuses on energy efficiency of buildings rather than adaptation to warmer temperatures. The Building Regulations 2010 do not currently provide for consideration of overheating risk in the retrofit of existing houses or in new builds (although there is some provision to assess risk from solar gain, but this is limited). Appendix P provides a method to assess the propensity of a house to have high internal temperature in hot weather. However, it does not assess the cooling needs and the procedure is not integral to SAP and does not affect the calculated SAP rating or CO_2 emissions. The 2015 review of SAP is anticipated to further address overheating to some extent, although that is currently uncertain.

- Adaptive capacity of the sector overall is generally considered to be low. There is a significant difference between the ability of existing stock to be adapted and designing new builds with adaptation in mind.

- Adaptive capacity of the sector is weakened by its complexity – there are many actors involved in building design and a large variety of dwelling types – and information failures, e.g. lack of awareness of householders and lack of established supply chain. There are risks of maladaptation due to new housing stock being built without adaptation consideration, the long lifetime of the housing stock, and the possibility of mitigation measures encouraging types of insulation that increase the risk of overheating

This section focuses on the context for adaptation in terms of the key characteristics of the residential housing sector, the policy framework in which actors operate, and the adaptive capacity of relevant (non-government) actors.

4.1 Key characteristics of the sector

There were more than 27 million residential buildings in the UK in 2010, the majority of which are owner occupied (65.5% or 17.9m in 2010). Private rentals accounted for 16.5% (4.5m) of dwellings, 9.5% (2.6m) of properties were rented from housing associations, and 8.5% (2.3m) of dwellings were provided by local authorities (CLG, 2012a). The proportion of owner occupied homes exceeds the UK average in Wales, where 70% of homes are owner occupied (Welsh Government, 2012). The adaptive capacity of owner-occupants is likely to be higher than that of short-term renters.

The number of UK properties that are privately rented rather than owned has been increasing. Rentals from housing associations and private enterprises increased by 264% and 124% respectively between 1991 and 2010, while the number of properties rented from local authorities decreased by 55%. The number of owner occupied dwellings has risen by 14% over this period (CLG, 2012a).

A large proportion of dwellings were built many years ago. Around 12% (2.7m) of the current dwelling stock in England was built after 1990, while 38% (8.5m) of all dwellings was built before the end of the Second World War (CLG, 2009). Older homes (i.e. pre 1940s) tend to be better adapted to the current and future climate than more recently built properties (i.e. from 1960s) due to the higher thermal mass of building materials (brick and concrete) and increased ventilation, although they may therefore be less adapted to cold winters. In Wales in 2008, 29% of dwellings were constructed before 1919 and 41% of all dwellings were constructed before the end of the Second World War.[13]

There are a range of common dwelling types in the UK. In England the most common dwelling type is the terraced house, which made up 29% of the housing stock in 2009 (CLG, 2009). In Northern Ireland terraced housing makes up around 31% of the total dwelling stock. The proportion of bungalows is more than double that in England, while the proportion of flats is less than half that in England (DSDNI, 2011c). In Scotland flats make up 33% of the housing stock, while houses and bungalows make up 67% of the housing stock (Scottish Government, 2012a). In Wales in 2008, terraced housing made up 32%, detached houses made up 27%, and semi-detached housing made up 30% of the total housing stock. Flats accounted for around 8% of all dwellings.[14] Different adaptation measures may be effective in different dwelling types.

[13] Source: Welsh Government communication.

[14] Source: Welsh Government communication.

The majority of households are located in or around urban areas. In England in 2009, 60% (13.3m) of dwellings were located in suburban areas; around 23% (4.9m) of dwellings were located in urban centres; while 18% (4.1m) of dwellings were located in villages or rural areas (CLG, 2009). In Scotland in 2010, 65% of properties were located in urban areas, 14% were located in small towns, and 21% were located in rural areas (Scottish Government, 2012b). In Wales in 2008, 80% of households were located in urban areas.[15] The high proportion of homes in urban areas may suggest that a large number of occupiers are susceptible to overheating due to the urban heat island effect[16], in addition to that due to climate change.

4.1.1 Characteristics and behaviour of occupants

Average household occupancy has been falling for decades. In England, occupancy fell from 2.8 in 1971 to 2.3 in 2008. This trend is likely to continue; the average number of people in a household is projected to fall from 2.3 in 2008 to 2.2 in 2033 (CLG, 2012e). A similar trend has occurred in Northern Ireland, where average occupancy has fallen from 2.6 in 2004-5 to 2.5 in 2010-11 (DSDNI, 2011a). Average occupancy is projected to fall to 2.2 by 2033 (NISRA, 2008). In Wales, average occupancy is projected to fall to 2 by 2031 (Welsh Government, 2010). These trends could result in greater demand for properties, in particular smaller dwelling types, such as flats. In addition, higher household occupancy tends to occur in social housing, potentially making these homes more vulnerable to overheating. Overheating risk may vary with dwelling type, so this trend could alter the effects that climate change may have on overheating risk.

The number of older household occupants is set to increase in the future. In Scotland in 2010, 28% of households contained at least one pensioner (Scottish Government, 2011). In England in 2008, 26% of household representatives were over 65. This figure could rise to 33% by 2033. This is an increase of 3.5m households. The largest increase could be seen in the South West, where overheating is typically more likely (CLG, 2012f). In Wales in 2008, 58% of households contained a pensioner.[17] The elderly may be more likely to suffer from overheating as they are more likely to be at home during the hottest hours of the day.[18] This trend therefore indicates that overheating could increase

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15 Source: Welsh Government communication.

16 This is defined as "The increased temperature of urban air compared to the rural surroundings. The temperature difference is usually larger at night than during the day and is most apparent when winds are weak" (Adaptation Sub-Committee, 2011).

17 Source: Welsh Government communication.

18 Other groups also likely to be at home during the day include young children or those who are very ill.

over and above the increase projected due to climate change. Please refer to the ECR Report on Health and Wellbeing for further information.

A significant number of households are located in deprived areas. In England in 2009, the 10% most deprived areas contained more than 10% of all households (CLG, 2009). This is equivalent to 2.2 million households. This indicates that many occupants may not be able to afford expensive adaptation measures, and so could be particularly vulnerable to overheating.

Occupants move frequently in certain areas of the UK, and renters in particular. The average length of residence in England in 2008 was 12 years for owner occupied homes. Private renters stayed in the same property for less than two years, while this figure was almost eight years for social housing (CLG, 2012g). In Scotland 71% of private renters had lived at their current address for less than three years in 2010, but 50% of owner occupiers had lived at their current address for more than 20 years (Scottish Government, 2012c). Similarly, around 37% of owner occupied householders in Wales had lived in their current property for more than 20 years in 2008.[19] Those who move frequently may have less of an incentive to adapt their properties to climate change, especially if the cost of these adaptations is not reflected in property prices.

4.1.2 Performance of the sector

The rate of house building is historically low, and has dropped further in recent years. From 2000 to 2010, net additions to the dwelling stock in England averaged 0.7% of the total stock (CLG, 2012c). In Scotland, Wales and Northern Ireland, the annual rate of new build construction averaged 0.7%, 0.6% and 1.7%[20] of the total dwelling stock respectively between 2000 and 2010 (CLG, 2012b). These figures are likely to be overestimates, as they do not include reductions in the housing stock from the demolition of existing dwellings or conversion of dwellings for other uses. By the 2050s only 30% of the total UK housing stock will have been constructed after 2006 (Arup, 2008). The low rate of house building indicates that older properties are likely to dominate the residential housing market. As described above, these properties may be less well adapted to current and future climate.

The number of households in the UK is projected to increase by 26% between 2008 and 2033. The increase could vary across regions. The projected increase is 27% for England, 25% for Wales, 28% for Northern Ireland and 21% for Scotland (CLG, 2012e). This indicates that overheating could become a more important issue in future.

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[19] Personal communication with the Welsh Government.

[20] The figure for Northern Ireland excludes 2001, for which data was not available.

Proportionally fewer privately owned properties have energy efficiency measures installed than other types of property. Just 0.2% of owner occupied properties in England and Wales are classified in the Energy Efficiency Rating Bands of A or B. The performance of privately rented or local authority owned properties is better, at 1.2% and 1.1% of dwellings in these bands, respectively. This could have implications for the impact on energy demand if the demand for mechanical cooling in homes increases.

Housing association properties perform the best, with 2.7% of dwellings in bands A and B. No properties built before 1964 have attained these bands, with the majority of such properties being built after 1990 (CLG, 2009).

Dwellings in Northern Ireland are, on average, more energy efficient than those in England. In 2009 the average Standard Assessment Procedure (SAP) was 57 in Northern Ireland and 53 in England (on a scale of 1 to 100, where 100 represents zero energy cost). In Northern Ireland, as in England, the performance of social housing is generally better than that of other tenure types (DSDNI, 2011b). In Scotland the average SAP score was 62 in 2010, exceeding that of other UK regions, with housing association and local authority dwellings outperforming other dwelling types (Scottish Government, 2011). Again this could have implications for the impact on energy if the demand for mechanical cooling increases.

4.2 The policy landscape

Any adaptation actions would need to be taken within the context of the wider policy landscape. Current policy is concerned with improving the UK's building stock through mitigation, energy efficiency schemes and reducing carbon emissions; but, to date, there has been a more limited focus on adaptation.

The Department for Communities and Local Government's Departmental Adaptation Plan update, published in May 2011, states that effective adaptation in the built environment is a priority, and explains that the department is working with other Government Departments to develop a cohesive policy framework which will incentivise designers, developers and building owners to address climate change risks. The document also sets out how the National Planning Policy Framework (NPPF, published in March 2012) will include a presumption in favour of sustainable development, and also how effective adaptation to a changing climate rests on both local action and the framework set by central Government. Many of the government's policies discussed below look to mitigate the effects of higher temperatures, but very few of them deal specifically with the risk of overheating.

This section considers the extent to which key policies could affect the ability of the sector to adapt.

4.2.1 Building Regulations in England

The Building Regulations regulate the design and construction of new developments and alterations to existing buildings in England, controlling building design, outlining technical standards for materials, ventilation systems and drainage systems. The legislative framework of the 'Building Regulations' is principally made up of The Building Regulations 2010 and The Building (Approved Inspectors etc.) Regulations 2010.

The Building Regulations are reviewed frequently. In 2006 they were revised to include some amendments requiring energy use in existing and new buildings to be measured. Part L covers requirements with respect to conservation of fuel and power, mainly through energy performance standards. The core term 'building work' was amended and extended in scope to include renovation of thermal elements and energy used by space cooling systems, as well as energy used by space heating systems. So, in order to demonstrate compliance, a builder will need to show that the building will not suffer from excessive solar gain. However, this does not deal with the risk of overheating to or comfort of occupants. For new homes, the Government has committed to introduce zero carbon standards in houses from 2016[21].

The recommended method for measuring the energy rating of residential dwellings is the Standard Assessment Procedure (SAP). It calculates the typical annual energy costs for space and water heating and lighting. SAP Appendix P provides a method for assessing the propensity of a house to have high internal temperature in hot weather, though it does not provide an assessment of cooling needs. Furthermore, the assessment is "is not integral to SAP and does not affect the calculated SAP rating or CO_2 emissions" (DECC, 2011e). While a 2013 review of the SAP will not account for overheating, a future review of SAP envisaged for 2015 is anticipated to review overheating and the assumptions around heating patterns and internal temperatures, as well as review the treatment of heating controls and different ventilation systems. Any changes made to regulations will be dependent on available evidence (DECC 2012).

Part L of the Building Regulations deals with power and fuel use rather than occupancy comfort, so the use of mechanical cooling methods are not considered in Building Regulations. Energy use for air conditioning should be accounted for within the SAP guidelines, so that systems capable of reducing

[21] Under the Government's Zero Carbon Homes Plan.

temperatures will be installed and used in hot periods, reducing overheating, as presented for consideration in a recent consultation (CLG, 2011a).

The Code for Sustainable Homes drives energy efficiency within new homes. It sets standards for energy and water use, and requires all new homes to be rated against the Code; however, the Code does not include active cooling.

4.2.2 Energy Efficiency of Homes

Carbon Emissions Reduction Target (CERT)

CERT was introduced in April 2008 primarily to reduce CO_2 emissions, and is an energy supplier obligation to make savings in CO_2 emissions from households, predominantly through the promotion of subsidised loft and cavity wall insulation.

Within three years of the introduction of CERT (by April 2011) 11% of the housing stock in Great Britain had cavity wall insulation and 16% had loft insulation (DECC, 2012). A policy impact assessment of the Green Deal projects that, if there is no replacement to CERT, the uptake of cavity wall insulation from 2013 will fall to around 5% of current rates to 30,000 installations a year (DECC, 2011a). This illustrates the importance of such a regulatory driver in adapting houses. CERT is due to expire in December 2012, when it will be replaced by a similar but broader policy in the Green Deal.

Green Deal and Energy Company Obligation

The Green Deal[22] is a financial mechanism that allows home owners, and landlords and their tenants to install energy efficiency improvements and use the savings from the installation to pay for all or some of the upfront costs through repayments on their electricity bills. The repayments should be equal to or less than the expected savings (the 'golden rule'). The Green Deal could have a significant role in improving the energy efficiency of homes and commercial buildings in the UK, with ECO benefiting the most vulnerable homes too.

ECO is a new energy supplier obligation that will integrate with the Green Deal. ECO was introduced to maintain installation rates, on the basis that if the Green Deal on its own is implemented, solid wall insulation is projected to fall dramatically, i.e. to around 15% of the rate currently seen under CERT (DECC, 2011a). For households that cannot meet the 'golden rule' obligation, the ECO subsidy is expected to meet the costs of installing the measure, as there are still

[22] http://www.decc.gov.uk/en/content/cms/tackling/green_deal/green_deal.aspx

strong policy reasons to promote energy efficiency and reduce fuel poverty. ECO will only apply to low-income and vulnerable households (DECC, 2011b).

Through secondary legislation that brings the Green Deal into operation (June 2012), the UK Government has pledged £1.3bn a year improve energy efficiency across Great Britain to help tackle climate change. An increased focus on poorer areas through support for low income and rural areas through ECO will provide additional assistance for those most in need and for properties that are harder to treat.

Although insulation is being driven by policy based on mitigation and energy efficiency, some forms of insulation can also help to reduce heat gain in the building when external temperatures increase, so in some cases, insulation can be a measure that helps protect dwellings against overheating. However, some forms of insulation can exacerbate the overheating risk. For further information on insulation and passive design measures, please refer to **section 5.1.2**.

The Market Transformation Programme (MTP)

The UK Market Transformation Programme (MTP) supports policy on sustainable products by developing an evidence base on the impacts and trends of products across their life-cycles and by providing reliable product information. The programme is a key driver of energy efficiency improvements in products and seeks to influence behavioural changes through the marketplace (ICF, 2007). The MTP covers all products under the EU Ecodesign Directive (2009/12/EC) which sets minimum environmental performance standards for energy related products, including heating ventilation and air conditioning products (AECOM, 2008). This policy may be helping to drive the current energy efficiency improvements in active cooling systems.

4.2.3 Spatial Planning

The National Planning Policy Framework (NPPF) and Planning Policy Statement on Climate Change (PPS)

The Environmental Audit Committee's climate change adaptation report identified planning as 'central' to addressing adaptation issues (CLG, 2011c). Planning policy can make a significant contribution to climate change adaptation by preventing development in inappropriate locations and providing green spaces within and between developments where necessary.

The PPS published in December 2007, set out the national policy on how spatial planning should contribute to delivering the Government's climate change programme. Planning authorities were required to have regard to the PPS in the preparation of local development documents, and the policies in the PPS were capable of being a material consideration in decisions on planning applications. The PPS enabled the planning system to support the Government's climate change objectives (including improving the adaptability of new developments) (CLG, 2011c). It is not possible to measure how much the PPS affected the implementation of other government policies, but it is clear that a facilitating PPS can significantly support adaptation to residential housing (CLG, 2011c).

The NPPF was published on 27 March 2012 and is designed to replace nearly all planning policy statements (including the PPS on planning and climate change). The NPPF sets out the Government's planning policies for England and how these are expected to be applied, and contains the government's overarching statement on the purpose of the planning system – to contribute to the achievement of sustainable development. The NPPF sets out the requirements for the planning system, including objectives, and provides a framework within which communities and local authorities can produce their own plans that reflect the needs of the area. The NPPF expects local planning authorities to adopt proactive strategies to mitigate and adapt to climate change, taking full account of flood risk, coastal change and water supply and demand considerations. In this context, the NPPF Glossary explains that climate change adaptation also includes responding to changes in rainfall and rising temperatures, although there are no explicit requirements on overheating risk. The NPPF must be taken into account in the preparation of local and neighbourhood plans, and is a material consideration in planning decisions.

The London Plan and the National Infrastructure Plan

The spacing, geometry and location of buildings to local green spaces impacts significantly on the microclimate of urban areas (Gill et al, 2007). Surface temperatures are dependent on green cover, so green infrastructure master planning can reduce the impacts of overheating in built-up areas. Influencing the built form of a city is difficult and resource intensive, but the GLA's 'London Plan' (GLA, 2011) can be used as a guide for other large cities in the UK (Kleerekoper et al, 2012).

The London Plan considers overheating as a risk and sets out adaptation strategies to manage the risk. The Plan details how major development proposals should be designed to reduce internal heat generation through energy efficient design, spatial planning, shading, insulation and green roofs. It also discusses the use of passive and mechanical ventilation systems and the use of green infrastructure, e.g. the Mayor seeks to increase greening in Central Activities Zones by at least 5% by 2030 and to increase tree cover across London by 5% in 2025 (London Assembly, 2011). Extrapolating the London Plan for other parts of the UK, so that key cities can replicate the plan, could yield significant benefits.

4.2.4 Energy efficiency of appliances

The Renewable Heat Incentive

The Renewable Heat Incentive (RHI) is set to be introduced for households in summer 2013.[23] The RHI will facilitate the deployment of heat pumps, solar thermal panels and biothermal boilers by providing a financial incentive to install renewable heating, in the form of a fixed payment per kilowatt hour of heat produced.

This is a clear economic incentive designed to encourage residents to use renewable heat. Some heat pumps are reversible and can be used as a means of active cooling. As such, increasing the use of heat pumps in residential dwellings could increase the number of mechanical cooling systems in the UK. Although cooling from heat pumps may not be eligible for the RHI as stated in the recent consultation on the RHI domestic scheme (DECC, 2012c), the RHI could still incentivise ground source heat pumps with a cooling function.

EU Regulation on fluorinated gases (F-Gas)

Efficiency in active cooling systems is also driven by the refrigerants they use. The F Gas Regulation (842/2006) covers fluorinated gases, as their global warming potential is so high. The regulations introduce minimum requirements that must be complied with, restricting certain refrigerant uses and regulating those who can install air conditioning systems. Refrigerants with high global warming potential are being phased out – use of the refrigerant R22 will be restricted from 2014 – but these tend to be the most efficient ones. Companies are therefore using refrigerants with lower warming potentials, but these tend to be more inefficient, so it can take a few years to realise the efficiency benefits.

4.2.5 Devolved Administrations

Wales

The Welsh Government leads on policy development in the built environment for Wales. The context of planning policy in Wales is largely contained within the Planning Policy Wales guidance, which is supplemented by several Technical

23 https://www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/renewable-heat-incentive-rhi

Advice Notes[24] that help embed adaptation in the planning process[25]. These standards encourage adaptation by providing guidance on best practice for local planning authorities and developers regarding construction and development. Furthermore, with Building Regulations fully devolved as of January 2012, the Welsh Government is able to set higher standards for new builds which will further enhance adaptation (Capon and Oakley, 2012).

Scotland

The Scottish Government and the Scottish Environment Protection Agency work together on sustainable construction and management through planning policy and building regulations in Scotland (Capon and Oakley, 2012).

The Scottish Government, in collaboration with its key agencies, has produced the *Planning and Climate Change: Key Agency and Scottish Government Resources and Guidance* to help local authorities' mainstream and priority climate change considerations in their planning decisions. Furthermore, through its second National Planning Framework (2009), Scotland aims to embed adaptation into development by articulating the spatial consequences of policies for climate change (Capon and Oakley, 2012).

Such planning related regulations and guidance help developers and local authorities to recognise the need for adaptation, facilitating its adoption.

Northern Ireland

In Northern Ireland, the Department of Environment leads on climate change adaptation, supported by other departments, including the Department of Finance and Personnel, which is responsible for building regulations, and the Department for Social Development, which works on residential energy efficiency (Capon and Oakley, 2012).

Under the Planning Order 1991 (Northern Ireland), the country's Department of Environment became responsible for planning. In Northern Ireland, the country's **Planning Policy Statements dictate planning and land-use policy for the whole of Northern Ireland. A number of these statements can encourage adaptation,** for instance, Northern Ireland's Warm Home scheme and policy RE2 of Planning Policy Statement 18 on Renewable Energy encourages greater application of Passive Solar Design in relation to the heating and cooling of buildings.

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[24] http://wales.gov.uk/topics/planning/policy/?lang=en

[25] Such as TAN 12 Design, TAN 15 Flood Risk and TAN 22 Sustainable Buildings.

The Northern Ireland Building Regulations apply to buildings and building work, and utilise the same compliance methodologies as identified above for England (page 38). The regulatory standards are amended in a similar timescale and to standards which harmonise with those applying in England.

4.3 Adaptive capacity

The framework for assessing the degree to which adaptation is already occurring as would be expected, is based on two key factors:

- **Adaptive capacity** (see below): Adaptive capacity is a necessary condition for the design and implementation of effective adaptation strategies, so as to reduce the likelihood and magnitude of harmful outcomes resulting from climate change (Brooks and Adger, 2005). This is assessed to provide the context for adaptation action.

- **Adaptation actions (see Section 5)**: There are many adaptation actions that individuals and organisations are already taking in some parts of the sector, and which would be expected in the future. These may be in response to an event or consequence of climate change (reactive) or as a result of government policy (planned).

This Section presents an assessment of adaptive capacity; Section 5 then considers the adaptation actions that are already being taken by some and the degree to which they are likely in the near-term (to 2020).

4.3.1 Adaptive capacity definition

For the purposes of the ECR, adaptive capacity, or the ability to adapt, is analysed using a simplified framework informed by the Performance Acceleration through Capacity Building (PACT)[26] model (Ballard et al, 2011) and the "weakest link" hypothesis[27] (Yohe and Tol, 2002; Tol and Yohe, 2006). Both PACT and

[26] This model was chosen as it was used in the CCRA, from which this project follows on, and because in a UKCIP review of adaptation tools it was ranked as the most robust (Lonsdale et al, 2010). The PACT model identifies six clear stages of development when organisations take on the challenge of climate change. These are called response levels (RLs) rather than stages, as each level is consolidated before moving to the next. RLs 2 and 3 are characteristic of 'within regime' change, RL4 is characteristic of 'niche experimentation' (or 'breakthrough projects') and RL5 is conceptualised as regime transformation. RL6 would be conceptualised at the landscape level. In this report, the RLs were used very simplistically as a comprehensive assessment of the adaptive capacity of the sector using PACT could not be undertaken. It is recommended that this be undertaken in further work.

[27] The weakest link hypothesis enables assessment of the potential contribution of various adaptation options to improving systems' coping capacities by focusing on the underlying determinants of adaptive capacity. In this report, the determinants were used to assess capacity of an actor rather than an adaptation option. This was used as it provides socioeconomic indicators by which an actor's adaptive capacity may be categorised. It enables the weakest part of an actor's capacity to be shown providing an area to focus adaptation responses.

the weakest link models introduce the idea of discrete levels of an attribute and allow identification of where an actor is now and where they would like to be, and illustrate the areas that need most development to get to the desired end point (Lonsdale *et al*, 2010).

This project defined adaptive capacity using the CCRA definition:

Adaptive capacity

"The ability of a system/organisation to design or implement effective adaptation strategies to:

- adjust to information about potential climate change (including climate variability and extremes),
- moderate potential damages,
- take advantage of opportunities, or cope with the consequences"

Source: Ballard et al, 2011 (CCRA – modified IPCC definition to support project focus on management of future risks)

Adaptive capacity refers to both the structural capacity within the overall sector, and also the capacity of different actors in the sector. The assessment of these factors allows us to explore the ability of actors to implement effective climate This project considers two factors in assessing the ability of the housing sector to adapt to climate change: **the structure of the overall sector** in general terms, and also **the organisations in the sector** – the function of key players who make critical decisions and their performance (i.e. gross margins, outputs and benefits delivered). An analysis of these two factors will describe the ability of the sector to adapt to climate change and the extent to which opportunities and risks described above are likely to be addressed. It should be noted that adaptive capacity is not only needed to optimise decisions based on climate change adaptation, but for other decisions with long term implications (Ballard et al, 2011).

The complexity of the sector weakens its adaptive capacity. There are considerable differences in the adaptive capacity of (i) existing stock vs. new builds; (ii) type of dwelling; and (iii) actor in the residential housing sector.

Structural adaptive capacity

Ballard et al, 2011 reviewed the adaptive capacity of the residential sector in England for the CCRA. Although the study focused on England, the same issues are applicable in Wales, Scotland and Northern Ireland. They **described the adaptive capacity of the sector generally as low –** due to the widespread risks that insufficient adaptation or maladaptation will occur and the extremely long decision lifetimes. The analysis of structural adaptive capacity below has been derived from Ballard et al (2011), other published studies and qualitative evidence from stakeholder and expert interviews within the sector.

(i) Sector complexity

This is a highly complex sector. Many different types of organisation are involved in decisions to adapt the built environment e.g. spatial planners, developers, construction companies, local planners, local authorities, social landlords, builders, insurance and mortgage companies, building inspectors, statutory bodies i.e. Environment Agency, water companies and the Ministry of Defence (which has a housing stock of 50,000 properties) (ARUP, 2008). There are also many different agendas that need to be taken into account (e.g. between the current needs of affordable housing, the need for developers to make profits, and desire to avoid major refurbishment costs in the future).

(ii) Dependencies

Adaptation to overheating in housing covers a range of interconnected sectors and stakeholders. Interdependencies with other sectors include power, water, health and wellbeing. The adaptive capacity of residents to respond to overheating is critically dependent on the adaptive capacity of the buildings themselves and of other actors, such as land use planners and builders. In particular, the fabric of the building is important, as is the surrounding land use (such as green and blue space). These dependencies weaken the adaptive capacity of residents whose ability to respond is limited if they are constrained by the physical surroundings they are in. This highlights the need for health and wellbeing to be considered with building design and use and regional and local planning decisions. For more information on the residents and their health and wellbeing, please refer to the ECR report on Health and Wellbeing.

There is a lack of established supply chain around retrofitting, and particularly cooling. This includes a lack of products and skilled service providers to do the retrofit (ARUP, 2008). There may be more awareness in large organisations than small ones, but the individual solutions required are less cost efficient to provide than standardised solutions. There are a few smaller "eco" architects or low carbon consultancies that could provide the bespoke solutions required. Stakeholders also referred frequently to a lack of awareness and knowledge of overheating risks and solutions, both on the part of householders and house builders/installers, although a stakeholder review carried out by AECOM (2012) found some evidence of awareness of overheating as a risk, even if there is no evidence of a response, e.g. most (16 of 20 respondents) considered overheating a problem now, and 11 of 17 respondents confirmed overheating to be a significant concern to their organisation. The evidence base for adaptation in the built environment is growing with the ARCC project[28].

(iii) Decision lifetime

The sector is characterised by very long decision lifetimes, e.g. new homes have typical design lives of 60 years, but most will last post 2100. New communities may last several hundreds of years. These timescales are far beyond the time horizon of most climate models. **Given the long life assets and low turnover, existing stock is the real challenge. However, new builds will also need to be updated in the future unless they are designed with adaptation in mind now.** In order to reduce the waste impact, materials and products can be chosen considering their longevity and building elements can be designed to be replaced or disassembled by adopting generic connections to enable easy upgrade at a later date (Simonella and Pau, 2010). For example: lifetimes for building structure are between 100-200 years; facades (glazing or cladding) are generally designed to last 25-45 years; services last 15-45 years (e.g. heating, ventilation, lighting, air conditioning); and ceilings/floors/partitions last 10-15 years. These have a shorter life cycle so can be more flexible.

(iv) Activity levels

The long timeframes involved mean that there is **limited activity** in the sector. The housing replacement rate is currently under 1% per year (ECI, 2005) therefore there are very few opportunities for adapting the housing stock. By the 2050s, only 30% total stock will have been constructed post 2006 (Sustainable Development Commission, 2007).

(v) Maladaptation

Maladaptation refers to actions or investments that enhance vulnerability to climate change impacts rather than reducing them (UKCIP, 2012). **There is significant risk of maladaptation** in the housing sector. The long lifetime of houses and only recent public awareness of climate change mean very few existing houses are designed with a changing climate in mind.

There is increasing evidence that recent new build homes, often light-weight, are built to high energy efficient standards under current/2006 Building Regulations, but are particularly vulnerable to overheating (e.g. Porritt et al, 2010, 2011, 2012; Gupta and Gregg, Mavrogianni et al, 2012.). Current retrofit initiatives have the

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28 The ARCC Coordination Network exists to enhance the cooperative development and dissemination of research between and beyond a portfolio of EPSRC-funded research projects exploring the impacts and adaptation in a changing climate within the built environment. www.arcc-cn.org.uk

aim of energy efficiency and reducing space heating, rather than adaptation. They are designed to increase air tightness and insulation levels to reduce needs for winter heating, but this can also trap summer heat inside. Stakeholders referred to examples in London where buildings have been increasingly built to minimum space requirements, and it is therefore very difficult to install adaptation measures into such small spaces, e.g. low ceiling height, small communal spaces. Other evidence for maladaptation includes modelling evidence by Shao et al, 2012 and Mavrogianni et al, 2012; monitoring evidence by Firth and Wright, 2008; stakeholder survey by AECOM 2011.

A particular area of maladaptation that must be avoided is **potential conflict between mitigation and adaptation policies and actions**. The housing sector offers opportunities to mitigate the portion of global greenhouse gas (GHG) emissions through heat losses and energy use. Although it is not the purpose of this study to consider mitigation measures, it is extremely important to consider the links between adaptation and mitigation, in order to avoid conflicts and to find synergies where possible. For example, improving the thermal mass of a building with appropriate insulation could reduce overheating risk as well as heat loss; or, increasing green infrastructure could reduce temperature as well as increase carbon sequestration.

It is important to note that the drive for mitigation retrofits provides opportunities for adaptation. It is more likely that retrofits will be carried out for mitigation than adaptation at the present time. If these retrofits were carried out with overheating in mind, then this would also enable particular interventions to be made for dwellings in respect of adaptation.

4.3.2 Organisational adaptive capacity

Table 4 below sets out a summary of the adaptive capacity of actors in the residential housing sector. The actors are key entities in the housing value chain. The data has been compiled from published reports and interviews with stakeholders.

Ballard *et al* (2011) considered adaptive capacity of new builds around two decision points: agreeing a development strategy for a locality, and assessment and implementation of a development proposal. They found that the adaptive capacity was relatively low – there was significant evidence of stakeholder responsiveness, but limited evidence of other aspects, such as efficiency of operations or examples of breakthrough projects. For a more detailed summary of the findings of their report, see **Annex 5**.

Other elements of organisational adaptive capacity for decisions around retrofitting existing stock are set out below for the following organisations within the value chain: House Builders and Developers; House Owners; Landlord/

Tenant; Vulnerable Groups; and Dwelling Type. Further detail is set out in **Annex 6**. More information, particularly on vulnerable groups, is set out within the ECR Health and Wellbeing report.

Table 4. Organisational capacity of residential housing

Actor	Resources (*economic, human, natural, technological*)	Processes (*engagement, operations*)	Organisational structure (*leadership, connection to decision making process*)	Summary
House builders and developers and professional installers	• Lack of awareness of specific risk – seen as future issue (Berkhout *et al*, 2004) • Financial constraints as cost of technologies fall on house builders, yet benefits on householders, but cannot charge premium • Technologies for cooling exist, however, not always commercially viable as too expensive • Lack of knowledge of how to incorporate technologies into design (FES, 2005) • Lack of skilled professionals at all stages – from design to development to retrofitting measures, lack of developed service provider apart from mitigation (e.g. insulation) • Lack of products to adapt to overheating • Gaps in understanding: designers design to past temperatures not future although new CIBSE DSY coming out soon	• Lack of operational consensus in the industry (Berkhout *et al*, 2004) • Decisions driven by short term financial gain • Design often driven by regulation which allows highly standardized products without design for climate risks (Berkhout *et al*, 2004)	• Limited collaboration between professionals providing expertise on different elements of the building – no established value chain • Is some collaboration and communication for technological development • Some examples of breakthrough projects (e.g. PassivHaus and other design projects) but tends to be luxury market • Some examples of retrofit projects include adaptation (e.g. TSB Retrofit for the Future)	**LOW** Different value chain for new builds and existing stock retrofits. New builds that are adapted area seen as a luxury item or non-urgent, therefore reluctance to design for this when budgets are tight. Lack of supply chain (products and service providers) for retrofits though some development around mitigation (e.g. Green Deal suppliers). Some examples of breakthrough projects.

Actor	Resources (*economic, human, natural, technological*)	Processes (*engagement, operations*)	Organisational structure (*leadership, connection to decision making process*)	Summary
House-holders (generic)	• Exposed to climate impacts yet have less control over technological choices that alter vulnerability (Berkhout *et al*, 2004) • No access to technological solutions • No economic incentive to adapt as no financial gain – potentially only a comfort gain • Adaptations are expensive: financial constraints around spending money on buildings (though constraints are less if adaptation included as part of mitigation package) • Perceived complexity of climate change reduces urgency to take action (ARUP, 2008) • Significant variation in vulnerability of householders – worse for some vulnerable groups • Lack of awareness of risks and appropriate solutions, lack of access to impartial trusted advice	• Variability in decision-making. Do not include overheating, occupants demand very different indoor temperatures during occupied periods (Pathan *et al*, 2008)	• No collaboration and huge variation between householders in types of ownership/occupancy and in use of a building • 70% owner-occupied: tend to stay in house for average 12 years (CLG, 2012g) so payback on adaptation measures unclear • Renters move on average every 2 years, so little incentive for landlords or tenants to adapt • Planning decisions can conflict with adaptation – market prevents uptake of technologies as traditional in perception of buildings (FES, 2005)	**LOW** Significant financial constraints together with lack of urgency regarding overheating risks
House-holders: Landlords/ tenants	• Approx 20% social housing (CLG, 2011b) where tenants have little capacity but landlords could do more as responsible for maintenance • Lack of financial incentive for landlord to adapt as does not enjoy benefits	• Registered social landlords have certain requirements from regulations/ local authorities	• More structure around social housing • Relationships with councils key for social housing	**LOW-MED** No incentive for landlords to take action as they do not benefit, but social housing/ Registered Social Landlords have higher adaptive capacity as run by councils and significant numbers of them

Actor	Resources (*economic, human, natural, technological*)	Processes (*engagement, operations*)	Organisational structure (*leadership, connection to decision making process*)	Summary
House-holders: Vulnerable groups	• Key vulnerable groups: e.g. elderly, socially isolated, those at home during the day, socially deprived areas (DoH, 2010), have less ability to adapt in terms of finance, access to measures, receptiveness to information etc • Difficult to reach vulnerable people and often they do not consider themselves "vulnerable"			**VERY LOW**
Dwelling type	• Significant variation between dwelling types in their ability to be adapted e.g. small purpose flats cannot fit insulation • Existing stock is mainly pre-war and has high thermal mass increasing its adaptive capacity • Age of a building indicates vulnerability e.g. modern houses (post 2006), which are built to be well insulated and airtight over heat more than older dwellings with lower air tightness and exposed thermal mass (Shao et al, 2012). Some dwelling types are particularly prone to overheating e.g. top floor 1960s flats, which have poorly insulated asphalt roofs and large glazed areas (Shao et al, 2012) • New builds can have measures built in from the start as part of the whole house design specification (Simonella and Pau, 2010) • Recent new builds with high insulation and some retrofits focusing on mitigation only lead to maladaption of existing stock if makes it to air-tight • Highly adapted new builds tend to be architect designed and luxury one off items as they are expensive • Existing stock requires difficult and expensive retrofitting	• Architectural trends are maladaptive e.g. increased use of glass • Lack of regulatory driver as does not cover building materials or design for overheating • No "one size fits all" adaptation measure for dwellings due to variation • No current process for assessing overheating risk in a dwelling and recommending individual measures	• Few examples of projects being developed for overheating, e.g. new communities	**LOW (existing stock); MEDIUM-HIGH (new builds)** Significant variation in vulnerability between new builds and existing stock, different dwelling types, and building orientation (Shao et al, 2012) There are relatively few options to drive widespread adaptation other than new construction. Significant variability between dwellings in terms of vulnerability and ability to adapt.

Building adaptive capacity

There are a number of actions required to build adaptive capacity in response to the needs identified in this section. Some actions are generic, e.g. education, training, and strengthening coordination between organisations, while others are specific to the risk of overheating in houses, e.g. lack of awareness of overheating as a risk, access to passive cooling measures, or lack of design of dwellings to address overheating risk.

5 Adaptation actions

Key messages

- Adaptation actions may be planned or autonomous. There are four main categories of adaptation action that could be taken: active cooling, passive cooling, behavioural responses, and external cooling/green infrastructure. Active cooling is expected to have a greater level of autonomous adaptation, and it is extremely effective in reducing overheating risk, so that it may have a role in protecting vulnerable groups in the long term. However, it is maladaptive (creating additional heat, pollution, GHG emissions and noise) so that alternative cooling methods, with co-benefits, should be encouraged.

- The other adaptations described here are highly effective, but have low levels of adoption. This suggests significant barriers to their uptake, such as:

  - Those at risk may not have access to information that allows them to assess their risk of overheating or the actions householders can take to alleviate impacts of heat. A lack of knowledge, skills or experience in the supply chain about what the most effective and appropriate forms of cooling system are for particular households can hinder effective adaptation.

  - Builders and developers of new properties have little incentive to incorporate design to address overheating risk in new-build residential properties, and landlords see little gain from adapting their properties.

  - Although there is increasing recognition of climate change adaptation within policy frameworks relating to residential buildings, the focus remains on climate change mitigation.

  - Short term views mean unless the effects of high temperatures are currently being experienced, people often lack the incentive to take action, or they may not consider themselves at risk.

5.1 Introduction

This section provides an overview of some of the categories of steps different actors in the sector are already taking, and would be expected to take, in order to maximise opportunities or minimise climate change risks. The categories include actions to build adaptive capacity, as well actions that reduce the particular risks of climate change. The actions range from practical, well-tested methods to more innovative adaptations and from low cost to expensive capital investment schemes.

Much of the literature on adaptation to climate change has been at a conceptual or generic level (Adger *et al*, 2007; Howden *et al*, 2007; Iglesias *et al*, 2007). This has shaped the understanding of what adaptation is, and the importance of the processes and responsibilities regarding adaptation.

For the purposes of the ECR, the adaptation actions considered are those that are already being taken, or are expected to be taken. The actions include:

- **Planned adaptation:** This tends to be (but is not exclusively) anticipatory adaptation, undertaken or directly influenced by governments or collectives as a public policy initiative. These actions tend to represent conscious responses to concerns about climate change (Parry *et al*, 2007).

- **Reactive adaptation:** This is taken as a reactive response to climatic stimuli as a matter of course (without direct intervention of a public agency) (Parry *et al*, 2007). Since farmers are continually adapting to changing conditions, whether in response to political, market, economic or social factors, a changing climate may simply be another pressure to which they must adapt.

The adaptation categories discussed in this report are mainly planned actions, which focus largely on the building itself and technical responses to overheating. However, there will be reactive adaptation too, particularly in terms of behavioural measures (including physiological acclimatisation). Both planned and reactive adaptations have the potential to be 'wrong' or lead to maladaptation in the long term or for wider society. Such consequences may need to be countered with further action, such as building adaptive capacity and by taking specific actions. Although government sets the policy landscape in which all actors operate, this section focuses on adaptations of the non-public sector.

The measures set out in this report should be viewed alongside those measures to address overheating health impacts set out in the ECR Report on Health and Wellbeing. The aim in this report is to avoid maladapted design (e.g. where energy efficiency measures have the potential to exacerbate summer heat risks, and where active cooling is the response, leading to increased energy demand). The focus is therefore to reduce cooling load as far as possible using passive design measures and then find the most efficient mechanical solution using the option that best fits other design objectives.

The identification of measures was based on identifying decisions made by organisations within the sector (e.g. householders, builders, etc.) and then determining how these may change under a changing climate. The groups of options were informed initially by assessment of key sources of literature and discussions with the expert panel. Many modelling studies exist that seek to quantify the projected effects of adaptation actions in reducing overheating risk in residential housing (AECOM, 2012). In this study, adaptation measures were generally identified from previous studies (e.g. Porritt *et al*, 2010, 2011, 2012; and Shao *et al*, 2012; ARUP 2008; ABI 2003; Shaw *et al*, 2008; Aecom-Ecofys, 2011; Gupta and Gregg, 2012; Mavrogianni, *et al* 2012). The categories of actions were then refined and verified in the stakeholder interviews to ensure that the ECR considered the key options to address overheating. These were refined and verified in the stakeholder interviews to ensure that the ECR considered the key sorts of actions to address the particular risks considered. Annex 1 sets out the stakeholders interviewed. The interviews were conducted under Chatham House Rules, so the stakeholders are not referred to individually or by name in this report.

Many of these **adaptation actions relate to building the adaptive capacity** of the residential housing sector, such as raising awareness. For the purposes of this report, building adaptive capacity is not described as a separate action in itself, but is an integral part of each adaptation option, as the greater the capacity of the individual, the more likely it is for an action to be taken.

The list of actions set out here is not exhaustive, but is intended to illustrate the key types of responses to climate change that actors in the housing sector are taking/ will take without government intervention. The categories of actions are described in detail in Annex 7. They are briefly set out below with a description of the action, a summary of the barriers and enablers, and potential outcomes[29]. Policy or legislative requirements that act to facilitate or hinder actions are also noted.

The immediate risk discussed in this report – overheating in houses and the associated potential energy demand from cooling – is at the house level. However, the adaptation strategies for overheating in residential housing will need to manage risks at three spatial scales:

- **conurbation** (part of an overarching strategy, include variety of land uses, planning, networks of open spaces);
- **neighbourhood** (development of discrete groups of dwellings with focus on spaces between buildings); and,

[29] The potential outcomes include extent of current and future adoption, timing, cost and effectiveness. Costs are relative to the sector. For example, high cost is major infrastructure investment or change in approach or strategy (e.g. hundreds of thousands or millions); low cost is the individual cost of a change to processes or operations, information provisions, or minor investment in equipment (e.g. thousands or tens of thousands).

- **building** (this includes building works, the design of building, its orientation, its surrounding, as well as behavioural changes implemented by households, such as how it is used/managed).

There are important trade-offs and conflicts to consider at each scale, particularly in terms of **adaptation policies and actions vs. mitigation**. For example, narrow streets with tall buildings can reduce heat risks but may aggravate winter gloom; insulation in winter may increase overheating in summer. Differences also exist between adaptation measures in high-density urban, suburban areas, and rural/urban fringes.

Adaptation measures for housing are not general, but are very building-type specific and require individual attention.

5.2 Evidence of actions

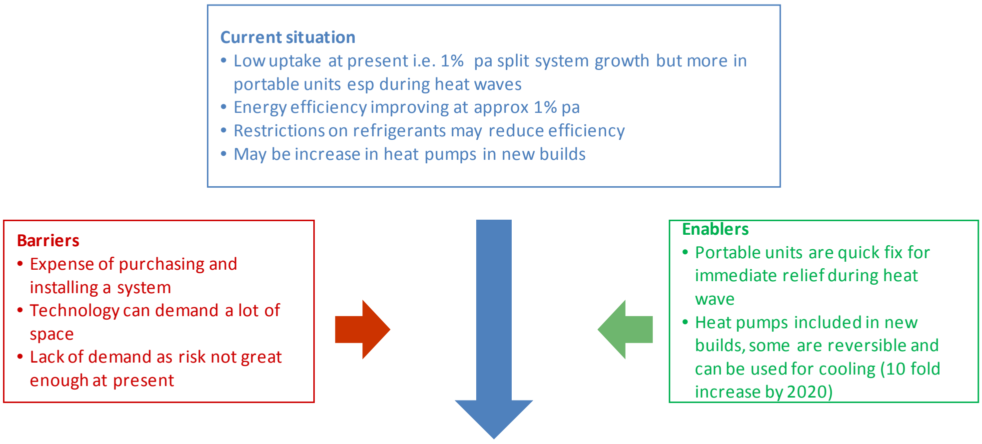
The actions described below are categorisations of a number of individual actions, which in future could be disaggregated. The four categories are:

- **active cooling** (i.e. air conditioning, other mechanical cooling systems, heat pumps);
- **passive cooling** (i.e. measures to prevent solar heat gains, measures to insulate, measures to ventilate including mechanical ventilation);
- **human behaviour** (i.e. change of clothes, living patterns, use of building and both active and passive cooling systems); and,
- **external cooling** (i.e. green infrastructure, shading, green roofs)

(i) Active cooling

An increase in summer temperature has the potential to increase energy use through widespread responsive installation of air conditioning for comfort (Collins *et al*, 2010). This is a reactive or autonomous adaptation measure, although the efficiency of cooling systems is planned. However, there are many different types of system (most common for residential are DX split system or portable units, with a growth in VRF predicted), with different energy efficiencies (e.g. portable units are much less efficient) associated. For more detail, please refer to **Annex 7**.

Figure 5. Summary of active cooling adaptation options



Outcome
- Increased use of high efficiency active cooling systems especially in new builds
- Increased use of inefficient portable air conditioning units during heat waves

Current levels of adoption	Anticipated levels of adoption	Timing	Cost	Effect (incl. co-benefits)
Low	Medium	Short (portable) - Long (whole house)	Low (portable: £300) to Medium (Heat pump: £10,000)	High (though maladaptive)

Source: Based on published evidence where cited and stakeholder views

Extent

Active cooling has an extremely low adoption rate at present (roughly 1,500 split units and 14,000 portable units in residential buildings in 2011, according to BSIRA, with 4% growth predicted in the next few years (Giles, 2012)), and growth is not forecast in the next few years, according to industry experts. Active cooling uptake is reactive, and comes in spikes, e.g., during the 2003 heat wave, B&Q reported sales of air conditioning units were 176% higher for one week than for same week in the previous year (Derby and White, 2005). BSRIA predicts that heat pumps, which can be reversible and used for cooling, will increase ten-fold in new builds by 2020 (Giles, 2012)) but their base is so small that this is not a large increase. Predicting future uptake is difficult as it depends so much on socioeconomic drivers and cultural norms, as well as individual human responses. Any predictions require assumptions about the threshold of air conditioning being taken up and when it is used. However, looking to the USA or Southern Europe for reference[30], suggests that uptake can alter rapidly

[30] E.g. According to the Residential Energy Consumption Survey, 68% US households had air conditioning in 1993 and in 2009 this had risen to 87%.
See: http://205.254.135.7/consumption/residential/reports/air_conditioning09.cfm

(Biddle, 1998) and in Greece, residential market penetration is 45-50% (65% in Athens) (BSRIA, 2011).

Barriers

For existing stock retrofits, a key barrier is the **expense of purchasing and then installing an efficient air conditioning system**. According to experts interviewed, installation costs are 100% of the capital costs; that is, if a system itself costs £5,000-£8,000, there is an additional cost of £5,000-£8,000 for installation, totalling £10,000-£16,000. A heat pump used for cooling is also expensive, at approximately £10,000. Most householders would rather spend far less and might choose a cheap portable unit (£100) or a high wall unit (£200-£400) which do not require complicated installation; however, according to manufacturers interviewed, these are considerably less efficient. Another barrier is that **technology, such as whole house ventilation and heat recovery systems, can demand a large amount of space**, which might be in short supply in existing housing stock (Inside Housing, 2011a).

For new builds, a barrier is **lack of demand**. The climate risk is not currently so pressing that buyers would request or seek built-in air conditioning. There is also **a lack of clear industry guidance** for house builders/developers about the relative efficiency and carbon performance of different cooling systems and therefore what might be most appropriate in different dwellings, or for different occupants.

Effectiveness

Active cooling is extremely effective at reducing temperatures and maintaining human comfort, as well as reducing heat-related morbidity and deaths. Studies from the US show that it can reduce death rates during heat waves significantly (Ostro et al, 2011). However, they are a cure rather than prevention and are arguably **maladaptive in terms of generating additional heat, producing air pollution, and reducing air quality internally. There are trade-offs to consider between mitigation and adaptation using active cooling, as it uses considerable energy with consequent greenhouse gas emissions.**

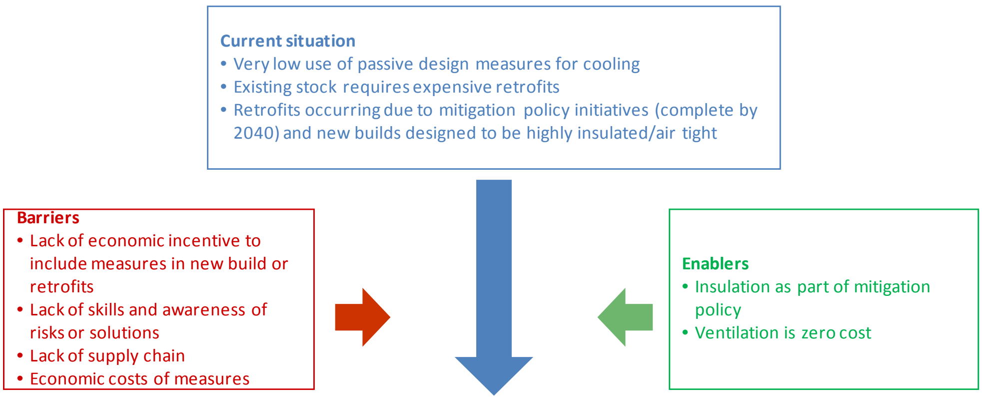
There is limited information available about the use of air conditioning in the residential sector, as there are so few monitoring in situ studies. One such study found significant variation between individuals in their use of active cooling (Pathan et al, 2008) and this has a substantial impact on the associated energy demand/emissions (Collins et al, 2010). **Energy efficiencies of active cooling systems are improving due to policy drivers such as the EU Ecodesign Directive (2009/125/EC) and high efficiency cooling systems may have a**

role to play in the future, depending how climate change manifests itself, and once preventative adaptation measures have been used (Gupta et al, 2012).

(ii) Passive cooling

There are four main ways of designing a building that allow for passive cooling. These are: **increasing thermal mass** (in the construction of new builds); **insulation** (by loft/wall insulation retrofits for existing stock); **preventing solar gains** (by shading, such as external shutters or fixed overhangs above windows), **and ventilation** (installing natural ventilation systems and "window rules", i.e. only opening windows at night or when external temperatures are lower than internal). These measures are reactive (e.g. ventilation/window rules) and are likely to require planning (e.g. thermal mass in new builds). For more detail, please refer to **Annex 7.**

Figure 6. Summary of passive cooling adaptation options



Outcome
- Limited use of passive design measures as alternative to active cooling apart from insulation
- Some maladaptation of internal wall insulation and airtight new builds

	Current levels of adoption	Anticipated levels of adoption	Timing	Cost	Effect (incl. co-benefits)
Insulation	Low-Med	High	Short-Med	Low-Med	Med (exc internal wall)
Thermal mass (new builds)	Low	Low-Med	Med	High	High
Shading	Negligible	Low	Med	Med	High
Ventilation	Low-Med	Med	Short	Zero	Med

Source: Based on published evidence where cited and stakeholder views

Extent

According to stakeholders, **the level of current adoption of passive design measures is extremely low and it is not expected to increase in the future**

unless it is included with the large scale mitigation programmes that are planned. The use of natural ventilation (opening windows) is widespread as a zero cost option, but it is being designed out in new builds. The only measure that is spreading, due to government initiatives, is insulation. For example, under the CERT scheme 16% stock in Great Britain has had loft insulation and 11% has had cavity wall insulation since 2008, although these numbers are projected to decline once CERT expires (DECC, 2012). If these rates were to continue, the majority of the housing stock could be insulated by 2040.

Barriers

There are many barriers to the autonomous uptake of passive design measures, whether in new builds or existing stock retrofits, including significant behavioural constraints.

Crucially, there is a lack of economic incentive for house builders to incorporate expensive passive measures (as they do not realise the benefit through increased house prices) and **for house owners** to invest in expensive passive measures. For passive cooling measures, the only incentive is to maintain comfort.

The weak adaptive capacity of the sector – for actors and stock – is a significant barrier. There are such differences between dwellings that there is no 'one size fits all' adaptation package that can be rolled out, making it less cost-effective than a standardised refurbishment. Adaptations need to be tailored to the house and the individual and the location. In addition, there is no substantial foundation of research data, and a lack of knowledge and awareness of overheating as a risk, of appropriate adaptation responses and their correct use.

The **lack of established supply chain/value chain for retrofits**, lack of communication between contractors, lack of training for service providers, and lack of available products, has been referred to several times by stakeholders, pointing to the few people in the sector who understand the issues involved in retrofitting. There is a lack of skills/expertise to choose and install appropriate measures (ARUP, 2008). There is a lack of technical understanding and guidance for installers/builders, e.g. designers design for past temperatures rather than future ones – although CIBSE and the GLA are currently developing Design Summer Years based on future temperatures (TM49). The lack of value chain means that even where demand does exist, householders do not know where to go to for advice or cooling solutions. This results in the search for immediate relief such as purchasing portable air conditioning units (from retailers such as B&Q or Argos).

Trade-offs can exist with other policy aims, such as space heating and planning permission, potentially leading to maladaptation, as policy measures do not take adaptation into account.

Information failure as overheating is not viewed as a significant risk and therefore there is a lack of forethought/planning for overheating. People are reactive, and will respond when there is a problem, but until hot summers begin to occur each year, they are unlikely to invest in cooling measures. People tend to err from precautionary measures where there is uncertainty and where the benefits, which remain with the house rather than the occupants, will only be realised in the future rather than immediately. This is particularly the case where house owners in England tend to move every 12 years and tenants every two years.

Effectiveness

There are many studies that have examined the effectiveness of passive design measures; a summary of these is contained in **Table 18** in **Annex 7**. A review of the relative effectiveness of individual measures is contained within **Table 19** in **Annex 7** and **Table 5** below sets out the effectiveness of individual measures on both overheating and space heating in different dwelling types. Much of the data referred to in this section comes from the CREW project[31] (CREW, 2012).

Passive design measures are relatively effective. The majority of studies show that preventing solar gains by external shading is the most effective passive measure, as illustrated in **Table 5** below. It is very important to note that these studies are based on assumptions and are there are inherent uncertainties associated with them. The studies must therefore be interpreted in light of these assumptions.

The effectiveness of an individual measure is increased significantly when in combination with other measures (CREW, 2012)**.** Different studies show passive measures can be used to reduce overheating to varying degrees, but many of the differences between studies relates to the different assumptions used in the models. A key point is that the overheating criteria with regards to health are extremely uncertain. Even if the measures cannot feasibly and economically eliminate overheating completely, the research is conclusive that passive design can go a significant way to maintaining human comfort and reducing the overheating risk well into the future.

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[31] The Community Resilience to Extreme Weather (CREW) project is a research programme, funded by the EPSRC to look at community, business and borough level resilience measures. It developed an online toolkit that can be used to assess impact of a range of passive measures in managing overheating, the associated impact on space heating energy use and the relative cost-benefits of individual and combined measures. http://www.iesd.dmu.ac.uk/crew/index.php

Scenario-building studies suggest that **effective use of passive cooling, and increasing thermal mass of new homes, has the potential to substantially delay uptake of active cooling in homes and reduce carbon emissions.** One such study found the point at which scenarios projected people would install air conditioning varied between 2021 and 2061, depending on how much thermal mass was built into the starter home (Capon and Hacker, 2009). Thermal mass in new builds is important as it reduces the range of temperatures in a house. However, if misplaced or misused, thermal mass can increase overheating, and the need for proper safe and secure night ventilation is essential for high thermal mass dwellings. In addition, as increasing thermal mass is practicable for new builds only, its scope is constrained by the fact that much of the existing stock will still be here in the 2080s.

There are some examples of maladaptation with insulation. That is, internal wall insulation can increase overheating risks slightly in some properties, so external wall insulation may be more appropriate, depending on other factors to be considered: the precise choice of insulation will be dependent on the precise circumstances. Another example of maladaptation is in some new builds where ventilation has been designed out in favour of air tight buildings, despite being a zero cost adaptation option. **Adaptation must be integrated with mitigation in the retrofit of existing dwellings and in new builds**, otherwise the building stock could end up overheating and becoming harder and more expensive to treat (Shao et al, 2012; Mavrogianni et al, 2012). It is unlikely that adaptation retrofits will occur independently of mitigation, so **the effectiveness of adaptation measures may depend on whether they can be included alongside the mitigation** that is more likely to occur (and is already occurring).

Another risk of maladaptation is that some types of insulation take much longer to dry out after a flood. Therefore, knowledge of all climate risks affecting a dwelling is crucial – as some forms of insulation, or cooling measure, may not be suitable for all dwellings. Mitigation retrofits therefore provide an opportunity for adaptation measures to be installed at the same time.

Costs are relatively moderate but can vary considerably between dwellings. The CREW toolkit uses indicative figures which suggest that it may be possible to reduce overheating by 80% at £3000 for 3 bed semi-detached and by 97% at £10,000 cost, with reduction in winter heating too (10% and 30% respectively). However, the type of dwelling has a significant impact on cost, e.g. a reduction in overheating from passive measures that costs £3,000 in a semi-detached house can cost £23,000 in a modern detached house (CREW, 2012).

The effectiveness of passive measures depends on **(i) dwelling type (**i.e. it may be harder to treat 1960s top floor flats and post-2006 modern detached houses than terraced houses (Shao et al, 2012)**, (ii) orientation, and (iii) occupancy**

(occupancy does not significantly change the relative effectiveness of the adaptation options, but does have an impact on the absolute effectiveness of particular adaptations), as has been illustrated in CREW's website graphics**. The effectiveness of measures will vary between new build and existing stock.** They can be much more effective in new builds as they are included in the design rather than being bolted on as retrofits (Simonella and Pau, 2010; Dunster, 2005).

Passive design measures could have **co-benefits**. As well as reducing overheating risk, adequate ventilation is important for air quality and human health. The NHBC (2009) has warned that a lack of adequate ventilation in air-tight new builds could result in a build-up of pollutants released by furnishings and building insulation materials, alongside humidity and condensation, and cause asthma and other respiratory diseases.

Table 5. The relative effect of individual passive measures on overheating (O/h) and heating energy use (H) from base case in different dwelling types (rounded to nearest %) in worst case scenarios. There is much uncertainty associated with any figures; for the assumptions used in this data, please refer to the CREW project website.

	End terrace		Mid terrace		Semi-detached		Mid-floor flat		Top-floor flat		Modern detached	
	O/h	**H**	**O/h**	**H**	**O/h**	**H**	**O/h**	**H**	**O/h**	**H**	**O/h**	**H**
Extra loft insulation	- 4%	- 2%	- 4%	- 3%	0	- 4%	n/a	n/a	n/a	n/a	Already included	Already included
External wall insulation	- 20%	**- 46%**	- 22%	**- 38%**	-5%	**- 40%**	- 4%	**- 47%**	+ 1%	**- 37%**	Already included	Already included
Internal wall insulation	+ 18%	**- 46%**	0	**- 38%**	+ 12%	**- 41%**	+ 6%	**- 47%**	+ 6%	**- 37%**	Already included	Already included
Shutters	**- 41%**	0	**- 48%**	0	**- 56%**	0	**- 48%**	0	**- 35%**	0	**- 55%**	0
Night ventilation	- 20%	0	- 25%	0	- 25%	0	- 22%	0	- 17%	0	- 36%	0
Window rules	- 25%	0	- 23%	0	- 8%	0	-1%	0	0	0	- 0.5%	0

Source: Stephen Porritt, pers. comm. from CREW (2012)

Key: Text in red shows increases in overheating, text in bold shows most effective measure

Note: Worst case scenarios are the scenarios used in the CREW project website where overheating risk is highest, that is, in those properties where the living room and bedroom are west facing, and where the property is daytime occupied.

(iii) *Human behaviour*

Behaviour is not a separate issue from building design, but a consequence of that design. There are many influences on behaviour (personal knowledge, social context, economic resources), as well as building design (Gething, 2010). The measures considered here include: behavioural responses (changing clothes, advising councils to put vulnerable people in less vulnerable homes); existence of and use of controls in the house (e.g. opening windows); and changing cultural norms (increasing the temperatures people expect from their homes). These measures are autonomous. For more detail, please refer to **Annex 7**.

Figure 7. Summary of human behavioural adaptation options

Current situation
- Humans adapt to environments and suffer discomfort when temperatures are greater than 'usual'.
- Reactive response to alter clothes when temperatures change – humans adapt better when have control over surroundings
- Vulnerable people often in most vulnerable dwelling types
- Cultural norms vary and can alter: look to USA and Europe as different norms

Barriers
- Lack of awareness / information of appropriate practices or need to alter practice
- New builds have controls designed out
- Cultural norms encourage irrational decisions
- Adaptation not included in social housing policy

Enablers
- Socioeconomics and marketing drive cultural norms e.g. air con seen as luxury

Outcome
- People's perception of thermal comfort can change over a long time
- Discomfort is reduced if people have control over their buildings and attire
- Less heat-related mortality and morbidity if vulnerable groups are in less vulnerable dwellings

	Current levels of adoption	Anticipated levels of adoption	Timing	Cost	Effect (incl. co-benefits)
Change cultural norms	Low	Low	Long	Low	Med-High
Change clothing	Med	High	Immediate	Zero	Med-High
Adapted placing of vulnerable	Negligible	Negligible	Med	Low	High

Source: Based on published evidence where cited and stakeholder views

Extent

Changing clothing is a very common adaptation response and will continue in the future as temperatures increase. Cultural norms do not appear to be changing to accept increased temperatures; in the future, it may be expected that norms change in the other direction – to increase expectation of cooler temperatures in buildings. There is little evidence of councils or social housing taking overheating risk into account when placing vulnerable people into dwellings, and that is not expected to increase in the future.

Barriers

There is a physiological barrier/societal barrier when people may be unable to adjust their clothing further (Roaf *et al*, 2009). **Cultural norms can encourage irrational decisions**, such as an aspiration to have air conditioning which is perceived as a luxury, and increasing use of air conditioning in cars and offices can lead to increased expectation for homes to have it. **There is a lack of adaptive capacity** in councils and social housing associations that means that adaptation is not considered in placing tenants (e.g. avoiding elderly in top floor flats).

Another barrier is lack of information or awareness of overheating as a risk, or of appropriate adaptation measures. For example, this is seen with 'window rules' (open at night, close during the day when outside temperatures are hotter than internal ones), yet people tend to do the opposite.

Another important barrier to consider is that **opening windows allows pollution inside, increases noise and raises security issues**. Many people, particularly those living by roads or railways, or in noisy urban areas, are reluctant to open windows.

Effectiveness

Human behavioural adaptation responses are "zero cost" adaptations. The IPCC has indicated that occupant behaviour or culture and consumer choice are major determinants of energy use in buildings. Many stakeholders interviewed suggested that **altering people's perception of thermal comfort could make a significant difference** – although this takes a long time, and is a slow process (Roaf et al, 2009). Cultural norms have changed over the last five decades in terms of what is meant by thermal comfort (Chappels and Stove, 2003; 2005). Acclimatisation of individuals is also important, although there is considerable uncertainty around the impact of this and it affects individuals differently. Changing behaviour requires a multi-pronged approach, and education and awareness-raising of risks, solutions and use of responses is extremely important.

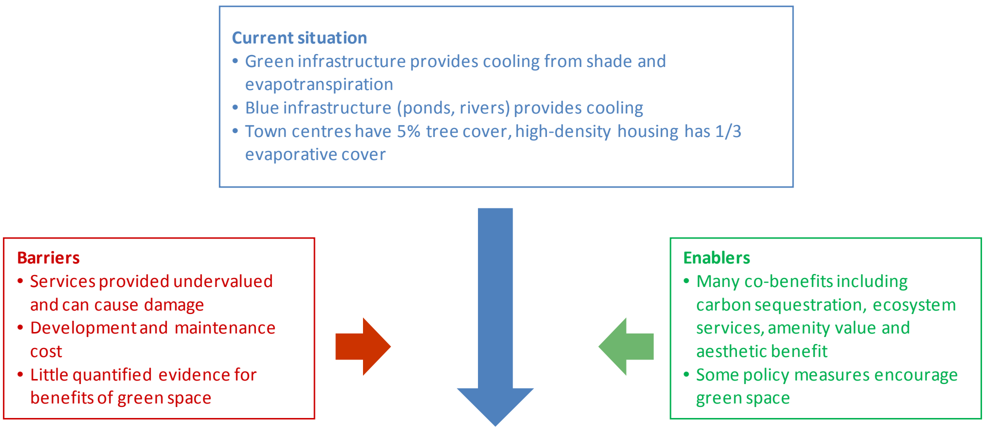
The effectiveness of adjusting clothing is relatively high, though there comes a point at which it no longer has any effect, i.e. after 28°C people may be unable to adjust their clothing further (CIBSE TM36, 2005; Roaf et al, 2009). **Discomfort is increased if control over thermal temperature is not provided, or if the controls are ineffective, inappropriate or unusable (Nicol and Humphreys, 2002).** This is very important to note for new builds, which tend to have controls designed out.

There is a significant risk of maladaptive behaviour that causes or exacerbates overheating, e.g. inability to detect overheating (e.g. cognitive impairment) or inability to take action (e.g. elderly who cannot move easily) would increase overheating risk (AECOM, 2012), as would placing vulnerable groups into vulnerable properties.

(iv) External cooling

An adaptation measure for moderating the effect of temperatures is to increase 'green infrastructure', at both conurbation and neighbourhood level, and also outside houses. This includes green roofs, trees for shading, and green spaces such as parks and gardens. These measures can be both autonomous (e.g. individuals planting trees) and planned (e.g. planning decisions to incorporate green infrastructure). For more detail, please refer to **Annex 7**.

Figure 8. Summary of external cooling adaptation options



Outcome
- Increase in green cover can keep temperatures lower in urban areas
- Green roofs have significant impact on reducing surface termpatures
- Planting reduces solar gain in housing

Current levels of adoption	Anticipated levels of adoption	Timing	Cost	Effect (incl. co-benefits)
Low-Med	Med	Med-Long	Med	Med-High

Source: Based on published evidence where cited and stakeholder views

Extent

There is some current adoption of green infrastructure (e.g. innovative pilot programmes like Green and Blue Space for adaptation for urban areas and eco-towns (GRaBS)[32]), and its value is increasingly being realised. It is likely to

[32] http://www.grabs-eu.org/

increase in adoption in the future, particularly in new developments under various policies like the Sustainable Communities Programme. Green cover varies in urban areas, being least prevalent in town centres and high density housing. Tree cover is usually low (Gill et al, 2007) but is increasing as part of policy drives like the Mayor's Climate Change Adaptation Strategy to increase tree cover by 5% by 2025 (London Assembly, 2011).

Barriers

While such an approach is often strongly advocated, **there has to date been little quantifiable evidence for the climate-related benefits of green space** (Handley, 2006). What evidence there is, is discussed below.

The services provided by green infrastructure are often little understood. For example, trees are felled for the perceived threat they pose near highways and buildings (Biddle, 1998). Trees are often blamed for causing subsidence. The cooling effect of green space can cease where significant drought occurs and trees/grass stop evapotranspiring. **There is also a cost** involved in developing and maintaining green space, e.g. sweeping leaves, cleaning water bodies, maintaining grassland etc. Green infrastructure, and large trees for shading, takes a long time to develop.

Effectiveness

Green infrastructure has the dual effect of providing (i) evaporative cooling and shading that reduces the heat vulnerability of area; and (ii) climate refuges to which people can go for respite. The maximum surface temperature is very dependent on the proportion of green cover (Gill et al, 2007). It could therefore reduce overheating in some circumstances.

The effectiveness of green cover is demonstrated by Handley and Carter (2006) who found that **adding 10% green cover would keep maximum surface temperatures in high-density residential areas (Manchester) at or below the 1961-1990 baseline up to the 2080s.** The cooling effect of green cover is also seen in the variation between high-density and low-density residential housing, as shown by Gill et al (2007) in **Table 6** below.

Table 6. Table to illustrate temperature cooling effects of green cover in high density housing (evaporating cover 31%)

Mst with no change in green cover		Mst with 10% green cover removed		Mst with 10% green cover added	
1961-90	2080	1961-90	2080	1961-90	2080
BASE: 27.9 °C	+1.7 °C to +3.7°C	n/a	+7 °C to +8.2°C	-2.2 °C	-0.7 °C to +1.2°C

Source: Gill et al, 2007

The LUCID[33] work modelled average daily min temperature in London during June/July 2006 heat wave. The results clearly show the impact of green space on the UHI (e.g. temperatures are approximately 3ºC lower in Richmond Park and Hampstead Heath than in surrounding areas). The work also showed that UHI is less important than the thermal quality of the building. For example, in London, research suggests that the number of deaths in response to rising temperatures in London increases above about 21 to 24ºC (a higher threshold than in other UK regions) (Armstrong et al, 2010; Hames and Vardoulakis, 2012). London has a greater relative risk of heat-related death than other regions above this threshold. This is partly due to London being in the warmest part of the UK, and also having poorer air quality and a greater population density than other areas (Armstrong et al, 2010; Hames and Vardoulakis, 2012).

Gill et al (2007) found that **green roofs can have a significant impact in terms of minimising surface temperatures**, keeping temperatures below the 1961-90 baseline for all time periods and emission scenarios (UKCIP02). It makes the biggest difference in areas where the building proportion is high and evaporating fraction is low (e.g. town centres, manufacturing, high-density residential). Green roofs are a low maintenance option, experiencing less thermal expansion and contraction stress, leading to a doubling of lifespan compared with standard roofs (NSF, 2010).

Planting has a substantial impact on reducing solar heat gain in buildings (Papadakis et al, 2001). Plants result in less use of air conditioning systems and in a smoother energy load profile, and proximity to a park has also been found to reduce air conditioning energy use (Ca et al, 1998).

Green infrastructure has **many co-benefits** associated. It provides cooling, but also other ecosystem services (e.g. drainage, reducing run off, soil structure, air quality, rainwater interception, storage and infiltration) and plays a role in mitigation strategies, e.g. carbon sequestration by trees. There is an aesthetic benefit to green infrastructure, as well as amenity value. There is an association between green spaces and better mental/physical health (DoH, 2011) and vulnerability of population, e.g. residential areas with higher levels of socio-economic deprivation (Pauleit et al, 2005).

When grass dies and stops evapotranspiring, **rivers and canals become the coolest areas followed by woodland.** Blue infrastructure, such as creating water bodies, ponds, lakes etc. has a very cooling effect, as well as many co-benefits, such as providing amenity value, water storage, biodiversity.

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[33] www.lucid-project.org.uk

The use of green infrastructure can be considered using case studies from abroad. For example, Stuttgart was designed for UHI management with areas protected for unimpeded air flow to improve air quality and reduce UHI (CABE, 2009). In Japan, Nagoya recently established a policy to require tree planting for all plots for new development over 300 sqm. Greenery must account for 10-20% of such a plot and in Tokyo the Metropolitan Government has identified a target to reduce the number of excessively hot summer evenings to 20 per year.

5.3 Uncertainties and limitations in the analysis

There are a number of uncertainties and limitations of the analysis of adaptation actions including:

- **Nature of the evidence:** There is some modelling evidence on the impacts of some specific options; however, there is little evidence as to the impacts of different options used in combination in real cases. There are very few monitoring studies. Therefore, the data on quantified impacts of adaptation decisions, and whether or not, and to what extent, decisions will mitigate climate risks, is based on models which are only as good as their assumptions, and are not based on real cases including human use.
- **Interaction with other measures:** The measures discussed in this section relate to overheating, but there will be other measures that occur to housing, such as for flooding, and they may interact.
- **Timeline:** Buildings have an extremely long lifetime. This project looked to 2050 and beyond, but the analysis of adaptation actions in this report is primarily based on activities occurring in the present or near future and on the experience of experts and stakeholders today.
- **Subjective assessments:** Assessing the extent of adaptation measures and their likelihood of increasing in extent in the future is subjective and based on the views and opinions of stakeholders and experts. The work is inevitably biased by the views and opinions of the stakeholders that responded to requests for interviews.
- **Comprehensiveness:** The work is not comprehensive in scope and is limited by the expertise of the particular experts and stakeholders that responded to the work. Given the diversity of the sector, some generalisations are inevitable.

5.4 Cross-sectoral links

Many of the actions discussed above are cross-sectoral, and the responses need to be cross-sectoral. For example, the physical responses to reduce heat in buildings need to be integrated with the responses to overheating impacts on health (see ECR Report on Health and Wellbeing). In addition, the location, design and building of dwellings and the proximity of dwellings to green and blue space needs to be integrated with surrounding land use planning decisions and flood risk management. The location and physical design of a dwelling must not only be adapted to overheating, but also to other potential climate risks such as flooding and water scarcity, and energy efficiency.

Figure 5 to **Figure 8** summarise key evidence on the adaptation actions explored. It should be noted that the assessments shown are intended to be a summary of the average situation in terms of levels of adoption and effectiveness – this masks the likely variation across householders.

5.5 Summary of current and anticipated adaptation

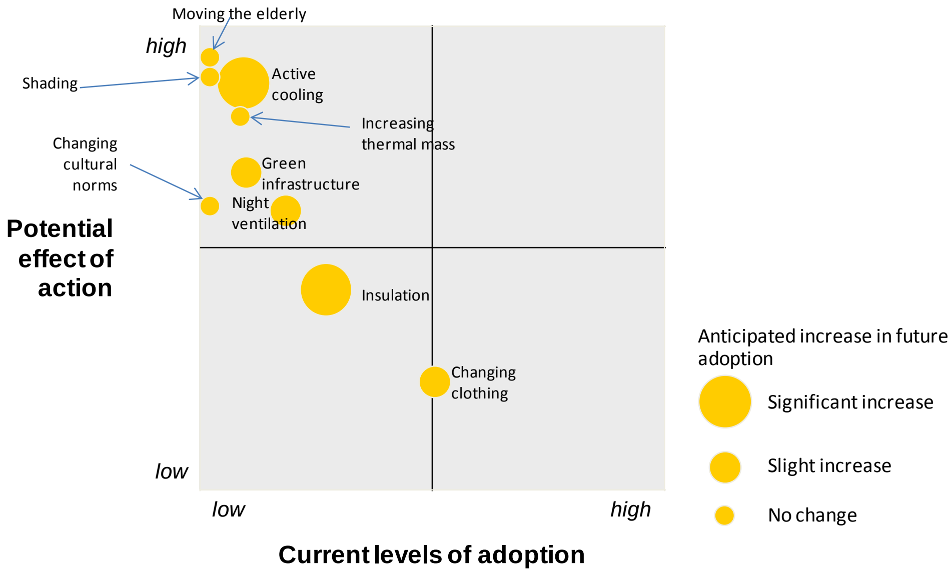
It is important to gain a general view of the current and expected degree of effective adaptation so that key barriers can be identified and addressed through intervention by government or other bodies. This is shown in **Figure 9**.

Figure 9 provides a simplified summary of the extent of adoption of the adaptation actions that are currently being taken, and those that would be expected in the future without further policy drivers, and a view about their effectiveness. The extent to which the actions are an appropriate response in particular situations would require a detailed assessment of the costs and benefits of the actions, which is beyond the scope of this report.

The approach provides a framework for summarising a substantial amount of information. The summary uses the classifications 'high', 'medium' and 'low' used within **Figure 5** to **Figure 8** above and as further explained in **Annex 7**. The assessment is based on the evidence presented in this section and discussions with the expert panel and stakeholders.

Figure 9 is intended to provide an overview of the findings set out in this report. It is illustrative only, as there is no reliable data available from large scale studies to draw on. It is intended to provide a basis for further discussions as part of future stakeholder engagement.

Figure 9. Impact of adaptation measures and the extent to which they will be used autonomously. Please note that changes are made relative to a low current starting point.



Source: Based on published evidence where cited and stakeholder views

Note: Scales are qualitative and relative to the sectors included. The **current levels of adoption** include decisions that are infrequent (e.g. shading) as well as common practice (such as changing clothing). **Effectiveness** varies from relatively limited scope (e.g. changing clothing) due to limited impact on reducing overheating, or constraints involved, to major changes in building design (e.g. increasing thermal mass). Increases in future adaptation are shown only for actions without further incentives, essentially over the next 10 years or so. The position of each measure is based on the classification used within this chapter, but could vary considerably depending on sector and company.

The yellow dots positioning the measures in **Figure 9** are scaled according to the expectation of future increase in uptake, in the absence of further intervention.

The top right corner of **Figure 9** shows those actions where adaptation is working well (i.e. actions that are generally effective and widespread). However, there are no actions where that appears to be the case. Those actions in the top left corner are effective, yet not widespread, suggesting that barriers to action exist (such as lack of awareness of overheating as a risk or cost of installing passive measures). There are many actions in this quadrant (e.g. shading, active cooling, green infrastructure). The actions in the bottom right are widespread and yet not very effective, possibly because they have non-climate drivers, or are 'easy' actions (e.g. changing clothing) or are maladaptive. Actions in the bottom left corner are neither particularly effective in addressing overheating nor widespread (such as insulation, but note that it is predicted to grow rapidly in the near to mid-term future).

Key findings of **Figure 9** are:

- Most of the adaptation actions are in the top left corner of the chart, indicating that where they are taken, the actions are expected to be effective. However, the actions are not widespread, suggesting significant barriers to action.

- Insulation and active cooling show projected increases in their future autonomous adoption. This is likely to be because active cooling is a quick fix and previous heat waves have shown significant spikes in active cooling uptake; and insulation is being driven by current government mitigation policy.

Two of the behavioural adaptation measures considered (changing cultural norms and moving the elderly out of most vulnerable dwelling types) are also in the top left, showing future low adoption (e.g. moving for the elderly can be physically difficult and they may be reluctant to move) but high effectiveness. This highlights the importance of increasing adaptive capacity: awareness-raising and improving understanding and knowledge of the risks of and solutions to overheating.

This assessment has highlighted that there are particular barriers that either prevent measures being taken, or being effective, or both. This could be due to a range of factors, which are discussed below.

5.6 Barriers to effective adaptation action

The assessment of adaptive capacity in **Section** 4 and of adaptation actions above suggests that there are particular barriers that either prevent measures being taken, or from being effective, or both. This could be due to a range of factors, which are discussed below.

Overcoming barriers would be expected to facilitate effective adaptation. It should of course be noted that whether an adaptation should be implemented in a particular case should be subject to an assessment of the relative costs and benefits.

As described in **Section** 2, barriers have been categorised in terms of market failures, policy failures, behavioural constraints and governance constraints. These are explored below.

Market failures

Information failures: this is an important category of market failure and is in several forms:

- People in areas that are likely to experience rising mean temperatures, and in particular, extreme temperatures (heat-waves) may not **have access to information that allows them to assess their risk of overheating**. This would include not only the projected temperatures, but also a lack of information about what the impacts of those temperatures might be on them.

- **Lack of information in a timely and accessible form about the actions householders can take to alleviate impacts of heat**, on themselves or others they care about.

- **Lack of knowledge, skills or experience in the supply chain about what the most effective and appropriate forms of cooling system are** for particular households. Each dwelling will have different requirements in terms of the most effective adaptation response.

Externalities (the actions of one impose a cost or benefit on another that they do not take into account in the decision making): these have been identified in two forms:

- **Builders and developers of new properties have little incentive to incorporate design to address overheating risk in new-build residential properties.** This is because the cost of doing so is typically not capitalised in the market price of the property owing to a lack of willingness to pay by residents. The costs of overheating (health and discomfort) therefore remain an external cost.

- **Landlords have little incentive to invest in appropriate cooling measures as they are not likely to realise the return from doing so**. Likewise, tenants do not have the incentive to invest because the payback period for them would be likely to exceed their tenure in the property. The external cost of health and discomfort therefore is imposed on the tenant.

Policy failures

The current Building Regulations do not appear to take the risk of overheating into account in geographical areas where it would be appropriate. There appears to be a disproportionate focus on climate change mitigation compared with adaptation.

Although there is increasing recognition of climate change adaptation within policy frameworks relating to residential buildings, the focus remains on climate change mitigation (i.e. lowering greenhouse gas emissions). This could represent a missed opportunity.

Behavioural constraints

Tenants and transient populations with short-term tenancies may not have the incentive to invest in passive cooling systems. As noted above, landlords also have little incentive to take action as they do not directly benefit, so these groups present particular barriers.

Short term views mean that, unless a heat wave or warmer temperatures are currently being experienced, or expected imminently, people may not perceive any reason to take action to prepare themselves or their properties. The perceived cost of doing so may hinder their desire to adapt.

Residents who are at a relatively higher risk of overheating may not wish to accept they are at risk. This is an issue also noted in the ECR Health and Wellbeing report.

Governance constraints

National planning policy expects local planning authorities to adopt proactive strategies to mitigate and adapt to climate change.

Governance issues around ensuring the needs of vulnerable groups are discussed in detail in the ECR Health and Wellbeing report.

This Section has explored the key categories of adaptation actions along with the barriers to effective adaptation. The next Section investigates the case for intervention.

6 Case for intervention

Key messages

- Iterative adaptation roadmaps outline a pragmatic way forward to prepare the UK for climate change. They combine actions but require iterative steps with constant review and modification to allow a flexible approach that facilitates learning over time.

- Roadmaps have been shown in this Section in response to the risk of overheating in residential housing. They should be considered illustrative only. They suggest immediate focus on 'no regrets' actions such as building adaptive capacity through enhancing knowledge, understanding and targeted areas; then over time, low cost actions such as opening windows at night and not in the day or changing clothing; and strategic actions which have long lead times such as accounting for the risk of overheating in the design of new-build properties.

- Modelling of the effect of several passive measures suggests they could reduce energy demand for cooling and associated CO_2 emissions by between 14% and 41%**.** The size of the reduction is dependent on location, the uptake rate of cooling systems, the climate change emissions scenario and the extent of adoption of passive measures.

This Section focuses on the case for intervention by drawing on the findings from previous Sections. It describes an approach through which decisions can be made in the context of uncertainty – adaptive management – and illustrates this through roadmaps. Illustrative 'what if?' scenarios are also analysed to assess the relative effectiveness of adaptation actions if barriers can be overcome. The Section concludes with recommended interventions to address barriers identified in the previous Section and facilitate effective adaptation.

6.1 Managing uncertainty: adaptive management

6.1.1 Adaptive management

The analysis in previous sections has discussed the scale of the potential impact and costs of overheating and temperature-related risks to health and well-being (this is discussed in more detail in the ECR Health and Wellbeing report). It has also explored the adaptive capacity of individuals and organisations, the adaptation actions that could be taken and their potential effectiveness, and the key barriers that may constrain adaptation actions being taken.

This section builds on the analysis by introducing the concept of 'adaptive management' in order to offer a suggested roadmap for some adaptation actions over time.

The projected nature and impacts of climate change in the UK over future decades, particularly when considering out to the 2050s and beyond, are subject to a degree of uncertainty (**Annex 2** presents more detail). Decisions affecting the resilience of agriculture to potential events or changes in weather patterns must therefore be robust.

Uncertainties are particularly problematic for planning large, high cost adaptation options with long lifetimes. As such, investments are costly to reverse and their design is dependent on what assumptions are made today about climate over its lifetime. If decisions are made without considering this uncertainty, there is a risk of over or under adaptation, wasted investments or unnecessary retrofit costs (Reeder and Ranger, 2011). Adaptation decisions must therefore be robust in the face of a fast changing and uncertain climate (Hall, 2007).

In this project, adaptive management is suggested through an illustrative roadmap as a pragmatic and effective way to allow appropriate actions to be taken (where there is a case for doing so) in the presence of uncertainty. It involves constant monitoring and reviewing of actions taken, and further small steps to be taken and iterated, consistent with a strategic direction. Adaptive management therefore allows parties to learn over time and for new information to be reflected in decision making processes. The intention is to maintain as much flexibility as possible for future options. The essence of the approach is to be clear on the direction of travel, or the vision for the desired outcomes or the management/goals, and the uncertainties about how to achieve these outcomes (Murray and Marmorek, 2004).

In the long term the direction of travel may need to change, and incremental changes may no longer be appropriate as the vulnerabilities and risks may be so sizeable that they overwhelm even robust human use systems. Transformational adaptations will then be required: those that are adopted at a much larger scale, that are truly new to a particular region or resource system, and that transform places and shift locations (Kates et al, 2012). Anticipatory transformational adaptation is extremely difficult to implement because of uncertainties about climate change risks and adaptation benefits, high costs, and institutional and individual mind-set that prefers to maintain existing resource systems and policies than create massive change. This approach allows flexibility to be incorporated into adaptation measures from the start where possible. For example, using measures that are suitable over a broad range of possible future climates or by designing the adaptation measure so it can be adjusted over time (Fankhauser et al, 1999). Flexibility is also incorporated into the overall adaptation strategy, by putting the adaptation in a sequence, and leaving options open to deal with a range of possible future scenarios.

6.2 Illustrative roadmaps

The illustrative risk-based roadmaps developed in this Section are intended to show "packages" of adaptation actions that can be implemented over time to respond to the particular risk of overheating in housing. This report has not set out detailed adaptation pathways (such as Thames Estuary 2100 Project) because it has not assessed the "known thresholds" for climate change (Reeder and Ranger, 2011) or limits to adaptation actions. Future work should analyse the thresholds of the individual climate risk and what the limits of specific actions may be in reducing a particular risk in the context (for example, the geographical area) in which actions are being considered.

The majority of the actions described in this report are to do with physical infrastructure and the fabric of a building, and so are dependent on thresholds for a particular climate change risk than operational or behavioural decisions might be. No one action will be sufficient, but the actions must be taken as a package.

The roadmaps consider a number of different risks and adaptation actions that fall within the categories discussed in Section 4; these are set out in a timeframe to illustrate how the issues could be managed adaptively. Building adaptive capacity is included within the actions, as illustrated. Some of the actions within the roadmap will continue to occur without further support, while others will require intervention by government or other stakeholders.

For housing, the roadmaps are focused on reducing climate threats using reactive and anticipatory adaptation measures such as installing passive design measures, building green infrastructure, and making behavioural changes where possible. Prioritising adaptation options in the face of uncertainty leads to focus on those actions that are:

- **No-regrets**: those actions which are worthwhile (i.e. they deliver net socio-economic benefits) whatever the extent of future climate change. These types of actions include those justified under current climate conditions (UKCIP, 2007). This may include building adaptive capacity or enhancing awareness of the overheating risk.

- **Win wins**: actions that minimise climate risks or exploit opportunities, but also have other social, environmental or economic benefits (UKCIP, 2007).

For example, actions to improve and enhance green and blue infrastructure in urban areas.

- **Low regrets/ low cost:** actions with relatively low associated costs, and relatively large associated benefits, although the benefits will primarily be realised under projected future climate change (UKCIP, 2007). These include opening windows at night and not day time, or changing clothing attire, as well as some passive design measures (e.g. shutters, light walls).

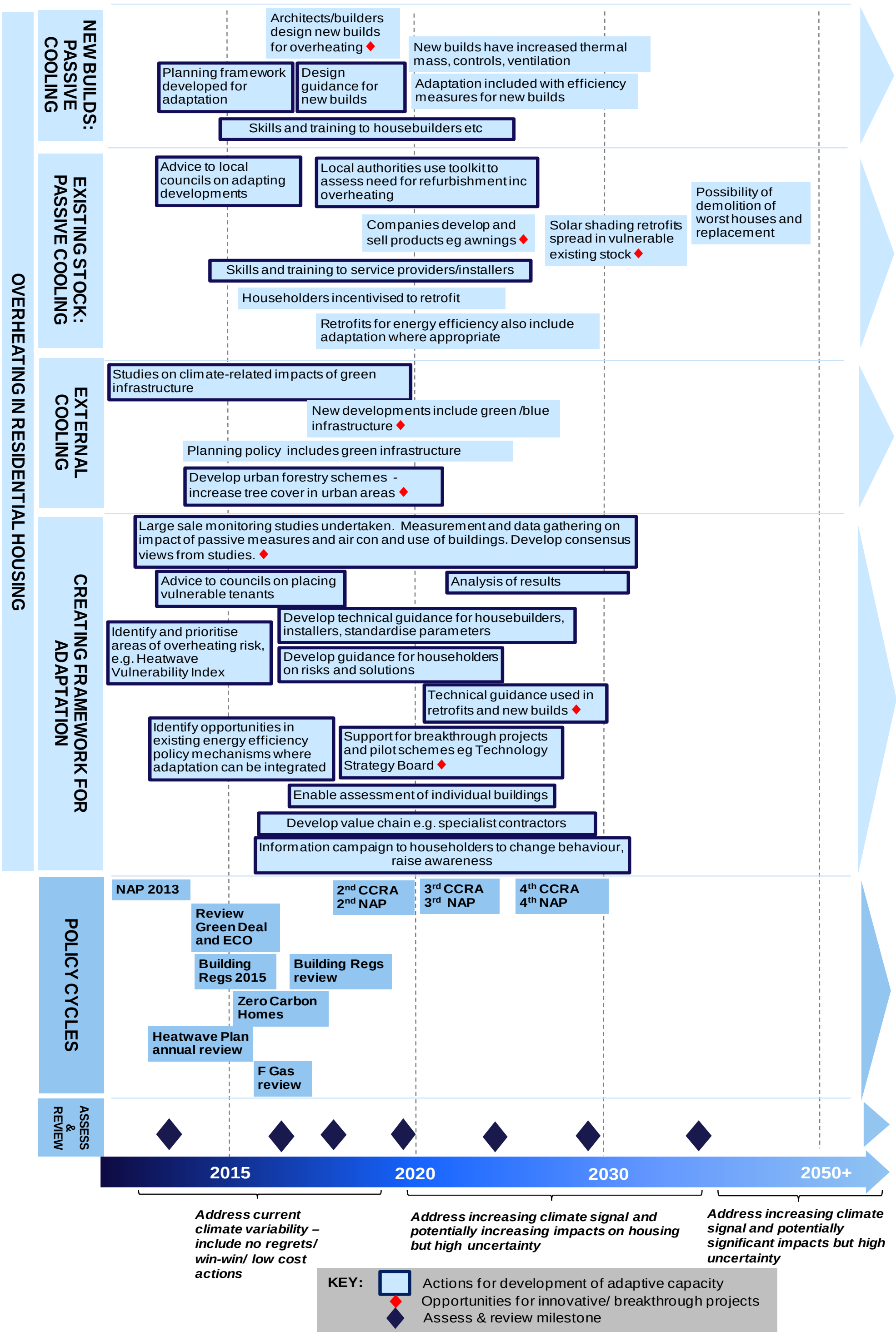
- **Strategic options with long lead-times:** these can include longer term decisions with little benefit in the short-term, but which will be important in ensuring future housing stock is suitable for future climates. These include new builds with overheating risk addressed in the design and also more transformational changes, such as demolition of existing housing stock where it is more cost-effective than retrofitting, or where retrofitting is not suitable.

The roadmap involves putting incremental adaptation options in place, rather than undertaking large-scale adaptation in one go. Actions are designed to allow for incremental change, including changing direction, as knowledge, experience and technology evolve. Delaying a specific action can be part of this, where that decision is accompanied by a commitment to continue to build adaptive capacity and monitoring and evaluating the evolving risks (UKCIP, 2007).

Adaptive management aims to ensure that actions taken will not be maladaptive if climate change progresses at a rate different from expected today, and to review any and all unintended consequences. Any action chosen should be taken with the engagement of stakeholders and drawing on available data to allow progress and emerging outcomes to be monitored and reviewed.

The roadmaps in **Figure 10** cover one particular risk, namely that of overheating in residential housing, and focuses on energy use and carbon emissions of addressing that risk. Actions to address the health impacts of overheating are contained within the ECR Health and Wellbeing report. The roadmaps put forward here are not intended to be comprehensive or exhaustive, as there are many other possible roadmaps.

Figure 10. Illustrative roadmaps



Source: Evidence and analysis in this report

Figure 10 creates a roadmap for some adaptation actions, although other actions will be happening at the same time (for example, those contained within the ECR Health and Wellbeing report).

Short term actions would focus on research and policy development in the immediate future due to the high uncertainty and are designed to provide primary information to allow subsequent decisions. These measures keep later options open, and may be repeated over time as the pathways are iterated and refined. They include **no-regrets and win-win** actions**.** These include:

- Studies on climate related impacts of green infrastructure;
- Identifying and prioritising areas of overheating risk;
- Advice to councils on adapting developments and placing vulnerable tenants; and,
- Identifying opportunities in existing energy efficiency policy mechanisms where adaptation can be integrated.

Actions in the **medium term** are those which may not require early action, or need further information before they are taken. Following research activities, development of best practice actions and implementation of research findings will occur, based on the research outcomes. These processes are iterative, allowing flexibility in decision-making. These actions may relate to significant investments that involve long decision timeframes which should therefore be considered before the risk gets significantly worse (e.g. using building materials in new builds that reduce the building's vulnerability to overheating). Other medium-term actions may not require early action but have associated costs (e.g. the decisions of owner-occupiers to invest in shading) that will only be effective as the climate risk increases. The actions include:

- Architects design new build housing to account for overheating;
- Local authorities design toolkits for refurbishments to account for overheating; and,
- New developments include appropriate green and blue infrastructure.

In the **longer term**, it is likely that more strategic responses will be required, such as changes in the structure of the sector, and longer-term investments with slower immediate results. Long-term measures include possible demolition and replacement of the most vulnerable buildings.

Figure 10 shows that some actions are likely to be innovative or breakthrough. This refers to those that are significant changes to existing practice, rather than just incremental changes to current processes or decisions. These include:

- Further retrofit and new design projects such as those run by the Technology Strategy Board;
- Architects/ builders designing new builds for overheating; and,
- Companies developing and selling cooling products.

Where incremental adaptation is no longer appropriate, and significant changes are required, transformational adaptation may be required. In initiating transformational adaptation, supportive social contexts and resources will be key enabling factors (Kates et al, 2012). Innovative transformational adaptation actions should be considered in detail in future iterations of the ECR as information and understanding develops. Early steps that should be developed include:

- Incorporating transformation adaptation into risk management; and
- Initiating research to expand the menu of innovative transformational adaptations.

Underpinning these roadmaps is the need to consider the conditions under which adaptation actions as a whole are likely to be effective. Fully mitigating the impacts of climate threats, and making the most of opportunities, requires a range of conditions to be in place, such as the policy framework and other supporting mechanisms.

6.2.1 Coordination

There are many interdependencies between the options in the pathways. Many of the options rely on capacity-building and the framework for adaptation. For example, incentivising householders to retrofit relies on householders being informed and aware of the risks and responses, and building new housing stock with increased thermal mass and ventilation depends on appropriate skills and training to be given to house builders and designers. The base must be established before the costlier options can be taken later on.

The adaptation responses in this report focus mainly on technical measures. There are many other adaptation responses to heating impacts (such as warning systems, social support etc.) that are as important, and these are assessed in the ECR Health and Wellbeing report. The actions should be considered together.

In addition, there are many dependencies on actions in other sectors that need to be considered to lead to effective adaptation. For example, new build design for overheating will also depend on design for flood protection, water and energy efficiency; development of green infrastructure will also depend on the natural environment and ecosystem services, and other needs for land use. The role of housing design needs to be closely coordinated with those involved in land use and planning.

6.2.2 Review points

The roadmaps incorporate review points, where policy and practice can be assessed and evaluated in the light of new developments, emerging information and better understanding of climate risks and research outputs. The review points are designed to coincide with policy cycles (e.g. of the NAP and CCRA), as well as with points where adaptation actions should be maturing. These frequent review points will enable pathways to be developed iteratively and with consideration of inter-dependencies and linkages between options.

Earlier review points allow analysis of short-term measures, with no-regret/win-win characteristics, and particularly those that build adaptive capacity. The review points will also allow consideration of the options in the context of developing evidence on evolving climate risks. Some options may be more or less appropriate in future time periods, depending on the level of projected change in climate risk, but also socio-economic developments. At each review point, the options must be considered as portfolios of short-term, medium-term, and long-term responses, to identify early actions to address long-term issues and ensure there is enough time for decisions with long lead-in times. There may be additional review points where major review and consultation is required (e.g. if energy consumption from active cooling spikes), or if there are repeated extreme events (such as the 2003 heatwave) or if the upper end of climate projections and uncertainty ranges are approached.

6.3 Exploring the potential effectiveness of actions

The cases discussed in **Section 3** were further developed to present 'what if' scenarios. These explore the effect of certain selected passive measures on energy demand for active cooling (air conditioning) in the residential sector.

6.3.1 Definition of 'what-if?' scenarios

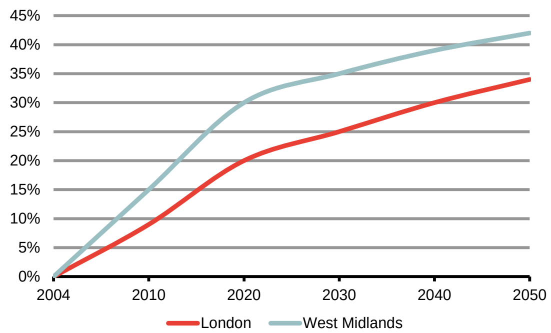
In this Section, two levels of uptake of passive measures are explored to illustrate the impacts of such measures on energy demand, CO_2 emissions and installed capacity for active cooling. **The passive measures considered are solar**

shading, increased thermal mass (through strategic insulation) and night time ventilation are. Annex 5 contains further detail.

The assumptions of uptake of passive measures in the London and the West Midlands are based on a recent report by the Energy Savings Trust (2012) which suggests that the CERT scheme has been responsible for the uptake of insulation retrofits (which increase thermal mass) in about 2.6 million homes out of a total of around 27 million (CLG, 2012a) in the UK over the last three years. Between April 2010 and April 2011 around 50,000 homes in London and 75,000 homes in the West Midlands were insulated as a result of the scheme. Following the end of the CERT Scheme in December 2012, it is expected that there will be a reduction in insulation retrofits, and for the purposes of this modelling g, a 20% annual reduction in retrofits has been assumed. The model assumes that all new homes built will incorporate passive measures, along with retrofits, and that passive measures will halve average heat gains.

The percentages of passively cooled dwellings over time for London and the West Midlands are provided in **Figure 11**. The trajectories differ over time because the current percentage of passively cooled homes in the West Midlands is higher than in London (based on the CERT figures).

Figure 11. Percentages of passively cooled dwellings in London and the West Midlands



Source: Modelling for this report by TEAM Energy Services Ltd.

The passive measure uptake conditions are (see **Annex 5** for further detail):

- **Low uptake of passive measures**: Average heat gains are halved owing to the measures. This applies to 34% of homes in London by 2050, and 42% of homes in the West Midlands.

- **High uptake of passive measures**: This assumes that the same number of homes are passively cooled as in the low uptake scenario (and with the same measures), but that occupants do not install active air conditioning systems.

Table 7 presents the 'what-if?' scenarios explored. The appropriate comparators for the cases which include the adoption of passive measures are case C (comparator for D and E), F (for G and H), I (for J and K) and L (for M and N). The cases summarised in this section are identical to their comparators in all assumptions, except that the comparators assume no uptake of passive measures.

6.3.2 Key results from the modelling

The results of the illustrative modelling exercise indicate that by 2050:

- The **adoption of the particular passive measures modelled could have significant impacts on reducing cooling energy demand and CO_2 emissions (model indicates by between 14% and 41%)**. The size of the reduction is dependent on location, the uptake rate of cooling systems, the climate change emissions scenario and the extent of adoption of passive measures.

- Relative to the case in which no passive measures are implemented:

  - With a high uptake of passive measures, CO_2 emissions could be up to 48,000 tCO_2 lower by 2050 (33%) in London and 19,000tCO_2 (41%) lower in the West Midlands, under a p50 high emissions scenario and high uptake rate of active cooling system (100%).

  - With a high uptake of passive measures, energy demand for cooling could be up to 33% lower by 2050 in London and up to 41% lower in the West Midlands, under a p50 high emissions scenario and high uptake rate of cooling system.

  - With a high uptake of passive measures, installed capacity could be up to 33% lower in London and 41% lower in the West Midlands in 2050, under a p50 high emissions scenario and a high uptake of cooling system. That is, the installed capacity that would be freed using passive measures could be 1.3GW in London and 1.1GW in the West Midlands in 2050.

Table 7. Key features of 'what-if?' scenarios with adoption of passive adaptation measures and relevant comparator cases (shaded rows, results from **Table 2**). Results for 'what-if' scenarios are shown relative to comparator cases, with percentage changes in brackets.

Case	Assumptions									Results					
	Uptake of passive measures		UKCP09 emissions scenario		Air conditioning uptake (% of households)			Heat waves	System efficiency gains (1-2% per year)	Energy demand (GWh)		CO2 emissions (thousand tonnes)		Installed Capacity (MW)	
	Low	High	Medium p50	High p50	Low (1%)	Medium (50%)	High (100%)			London	West Midlands	London	West Midlands	London	West Midlands
C										**50**	**16**	**1**	**0.4**	**122**	**83**
D										-7 (-15%)	-4 (-22%)	-0.2 (-15%)	-0.1 (-22%)	0	0
E										-8 (-16%)	-4 (23%)	-0.2 (-16%)	-0.1 (-23%)	-4 (-3%)	-3 (-4%)
F										**6,288**	**2,045**	**142**	**46**	**11,455**	**7,851**
G										-920 (-15%)	-440 (-21%)	-21 (-15%)	-10 (21%)	0	0
H										-2,105 (-33%)	-846 (-41%)	-48 (-33%)	-19 (-41%)	-3,826 (-33%)	-3,235 (-41%)
I										**78**	**25**	**2**	**0.6**	**111**	**76**
J										-11 (-14%)	-5 (-21%)	-0.3 (-14%)	-0.1 (-21%)	0	0
K										-11 (-14%)	-5 (-21%)	-0.3 (-14%)	-0.1 (-21%)	0	0
L										**2,825**	**932**	**64**	**21**	**5,727**	**3,925**
M										430 (-15%)	200 (-22%)	-10 (-15%)	-5 (-22%)	0	0
N										-940 (-33%)	-383 (-41%)	-21 (-33%)	-9 (-41%)	-1,894 (-33%)	-1,601 (-41%)

Source: Team Energy Services Ltd. Notes: Results for comparator cases are in bold, and results for passive scenarios are shown relative to these comparator cases.

6.3.3 Effect of passive measures on active cooling uptake

Low adoption of passive measures

Four 'what-if?' scenarios, or cases, were modelled to incorporate low adoption of passive adaptation measures.

The results indicate that around 15% of the increased energy demand for active cooling in London and 20% in the West Midlands in 2050 could be avoided if low adoption of passive measures occurs. The absolute size of the reductions reflects the uptake rates of air conditioning assumed under each case (around 1% for cases D and J; 100% for case G; 50% for case M).

The importance of passive measures in reducing energy demand varies by 'what-if?' scenario. For example, in London under the high uptake of cooling systems scenario, the relative benefit of passive measures would be greater, as it reduces demand by around 920GWh per year (from 6,288GWh per year) (as in case G) compared to 11GWh per year (from 78GWh per year) for a case with low uptake of air conditioning systems (case J).

The sizes of the relative reductions in CO_2 emissions that are attributable to the uptake of passive measures are identical to those for reductions in energy demand for cooling. These reductions are a sizeable proportion of emissions (14-15% in London, and 21-22% in West Midlands) in the comparator cases (cases D and J), but are very small numbers in absolute terms as they assume low uptake of active cooling.

High adoption of passive measures

A higher rate of adoption of passive measures could reduce energy demand for cooling and CO_2 emissions by between 14% and 33% in London and between 21% and 41% in the West Midlands (reflecting the greater proportion of homes in the West Midlands that take advantage of retrofitting). Greater relative (and absolute) reductions occur for those cases which assume the high rate (100%) of uptake of active cooling systems.

As with the results for the low adoption cases, the absolute size of the reduction varies significantly. For example, the range is between 8GWh and 2,105GWh per year for London. Again, this variation depends on the uptake rate of active cooling that is assumed. The same findings apply to the reductions in CO_2 emissions (CO_2 is directly proportional to energy demand).

Comparison of low and high adoption cases

There is little difference in the results for the low adoption and high adoption of passive measures cases where there is a low uptake rate of air conditioning systems. This is not surprising: if uptake of active measures is already low, the scope to impact on cooling energy and emissions is limited. However, the impacts of the passive measures on discomfort could be more notable; this is not possible to assess.

For the cases which incorporate medium or high uptake rates of active cooling measures (again using both p50 medium and p90 high emissions scenarios), reductions in cooling energy demand and CO_2 emissions due to a high uptake of passive cooling measures are twice as much as the reductions due to a low uptake of cooling systems.

This illustrates **the significant impact that changes in the adoption rate of passive measures can have on energy demand for cooling and the associated CO_2 emissions.**

6.4 Recommendations

6.4.1 Key messages

These 'what-if?' scenarios suggest that there are potential ways in which individual actions are able to mitigate at least in part the potential threats from climate change, specifically rising mean temperatures and extreme heat events.

The barriers to action noted throughout this report, however, suggest that wide-scale implementation of these actions is not likely, though they may occur in some cases.

6.4.2 Identifying the case for intervention

The case for further intervention by government or other bodies flows from the evidence presented throughout this report.

The case for intervention by government or other bodies is likely to exist where:

- **Organisations or individuals lack the adaptive capacity** to be able to adequately prepare for climate change. It is critical to **target vulnerable groups or organisations** who are often lacking in adaptive capacity and must rely on others' adaptive actions.
- There are **significant barriers or constraints** to implementing effective adaptation action. This may be because markets lack the required information to allow appropriate signals to be sent to parties to take appropriate action.
- The **UK may otherwise become 'locked'** into a path that could lead to maladaptation or removes the flexibility required to effectively manage uncertainty

Case for intervention

Importantly, **whether actions are implemented should be guided by appropriate and proportionate assessment of the costs and benefits of action** (including those that can be monetised and those than cannot) relative to the alternatives (including no further action). This must include the consideration of expected benefit of buying time and flexibility to adapt in the future.

It is important to prioritise actions on the basis of the extent to which they are no-regrets (deliver benefits irrespective of climate change), win-wins (deliver co-benefits aside from adaptation), low cost, or able to avoid lock-into actions which may otherwise lead to maladaptation. Building adaptive capacity is a top priority in the short-term.

Some emerging conclusions from the analysis undertaken in this report include:

- The impacts of overheating are not likely to be felt equally nationwide given the emissions scenarios of the UK climate projections.

- The long lifetimes of residential properties adds weight to the case for intervention in addressing overheating risk. The housing replacement rate is very low so adaptation to properties will necessarily be largely on existing stock. Therefore, new builds should have overheating risk incorporated into their design to avoid maladaptive buildings which require retrofitting in the future.

- Overheating is more likely to be an issue in some types of buildings than in others (e.g. modelling studies indicate that purpose built flats, post 2006 modern houses suffer most, but such studies must be interpreted cautiously due to the uncertainties involved). Orientation and lack of shading in flats appear to be significant issues.

- Some residents are more likely to be at risk than others, particularly those who are elderly or already have health problems.

- Extreme weather events (heat waves) may be more likely to cause an increase in heat-related death and morbidity and an increase in active cooling than gradual climate change in the short term.

This implies that a **targeted approach** to addressing the issue is likely to be justified.

The case for intervention is supported by the analysis undertaken which highlighted the following:

- Relative to the current relatively low level, energy demand for cooling could triple between 2010 and 2050 in both case study areas of London and the

West Midlands, even if uptake of air conditioning systems is low (i.e. rising from only 0.6% of households with cooling in 2010 to 1% by 2050)[34].

- Illustratively, under the same assumptions but, if 50% of households install air conditioning systems by 2050, energy demand for cooling in that year in each case study area could be 37 times greater than in a low uptake scenario in 2050. If, in an extreme case, all households in the case study areas install air conditioning systems, energy demand for cooling could be more than 84 times higher than in a low uptake scenario in 2050.

- Improvements in the energy efficiency of air conditioning systems could mitigate these increases in energy demand for cooling to some extent. Under the low uptake of cooling case, for illustration, and a medium p50 emissions scenario, **energy usage could be approximately 30% lower in 2050 with efficiency improvements of 1-2% per year than if no efficiency improvements occur.**

- **In a high uptake case (i.e. the extreme case in which 100% of households have air conditioning) and assuming the p50 medium emissions scenario, installed capacity could be over 210 times higher in 2050 than 2010 i.e. around 11.5GW in London and 7.9GW in the West Midlands**. This could be equivalent to around an extra 2.4-4GW of generation capacity by 2050 in London and 1.6 - 2.6GW in the West Midlands by 2050[35].

- Modelling of the effect of several **passive measures suggests they could reduce energy demand for cooling and associated CO_2 emissions by between 14% and 41%**. The size of the reduction is dependent on location, the uptake rate of cooling systems, the climate change emissions scenario and the extent of adoption of passive measures.

In order to overcome the barriers identified in Section 5, the following recommendations are made:

[34] This is under the p50 medium emissions scenario.

[35] This assumes an illustrative co-efficient of performance (COP) of 3-5. The COP is the 'instantaneous' measure of efficiency of the refrigeration system. It is the ratio of the cooling output to the electricity input. It is used in this instance to determine the peak electrical demand of cooling systems.

- **Build adaptive capacity of the sector by increasing the skills and knowledge of the organisations within the supply chain** so that new build properties are designed to take account of climate change risks, including overheating.

- **Build adaptive capacity of the sector by developing the supply chain for retrofits**, to ensure that builders and architects have access to equipment and information that enables them to advise on effective adaptation, and that residents have access to advice on how to adapt houses effectively. Particular focus should be on behavioural change and passive measures, which are likely to be lower cost and not maladaptive.

- **Build adaptive capacity by undertaking analysis of the impacts, costs and benefits of alternative cooling options** and the conditions under which they are effective. This must include green infrastructure options. Use this to build best practice over time.

- **Undertake ex post evaluations of interventions such as design, low-cost retrofits and green infrastructure.** Use the emerging evidence to learn and develop best practice approaches and to disseminate guidance to those at risk.

- **Address information failures** by ensuring targeted and engaging information is accessible for those at risk of overheating, along with simple guidance of appropriate actions to lower their risk.

- **Review the housing policy framework to ensure that adaptation is considered alongside mitigation in a retrofit package. Address policy imbalances** where the focus is on mitigation actions only and not adaptation.

- **Allow for flexibility in relevant building regulations at a local level so that cooling options can be better explored to prevent the need for costly retrofits.** Consideration should be given to be flexible to the types of buildings and specific locations.

- **Facilitate energy efficiency improvements** through appropriate review of the relevant policy framework to ensure it remains supportive.

- **Build adaptive capacity of residents** through ensuring greater provision of targeted education and information on behaviour change and passive measures, such as keeping curtains closed during the day, opening windows at night etc.

- **Facilitate and support the effective implementation of planning policy by local authorities to ensure decisions adequately account for adaptation** and consider efficient cooling options, where appropriate. This includes passive measures as well as green space.

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