Committee on Climate Change

Updating an assessment of the costs and benefits of low-regret climate change adaptation options in the residential buildings sector

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Executive summary

Purpose of this report

This report has been produced for the purpose of presenting updated cost curves for a range of building scale adaptation measures for the UK, updating previous workings developed by Davis Langdon (2011) as part of the "Research to identify potential low-regrets adaptation options to climate change in the residential buildings sector" project.

This report comprises the following sections:

- Overview of the UK residential building sector, key climate risks and adaptation measures;
- Methodology for updating the original cost curves to include indirect benefits and the explicit consideration of climate change scenarios;
- Analysis of the results including comparison with previous findings, presentation of updated cost curves for the UK residential building sector;
- Discussion of the project findings, including the analysis and definition of low regret adaptation measures; and
- Technical appendices detailing supporting datasets.

The updated cost curves presented in this report provide an indication of the cost and benefits of a range of residential adaptation measures based on assumed and derived metrics for direct and indirect benefits and costs. The cost curves and underpinning datasets have been updated to reflect current prices, including additional analysis to address limitations in the original study. This exercise has included updating the original study assumptions to include indirect benefits where these confer a significant societal value.

The updated cost curves, developed as part of this project are presented in the context of a range of climate risks: (1) water stress, (2) flooding and (3) overheating. A large proportion of the adaptation measures considered by this study, including those identified as economically 'low regret' were consistent with previous findings, thereby permitting comparative analysis. Furthermore, a number of these measures were subject to further analysis to assess effects associated with their installation and operation. The measures used are discussed in their context of their economic viability and sensitivity to different climatic and non-climatic factors.

Headline Messages

Headline messages are presented here for water stress, flooding and overheating building scale measures, detailing the key findings and economic low regret measures. The assessment considered benefits to householders and to society as a whole representing two distinct perspectives when calculating costs and benefits of adaptation measures[1].

Water Stress

In the case of water stress reduced water bill represented benefits to householders while avoided costs of increased water supply reflected benefits to society. Installation of **end-of-life water efficiency measures** including WC (dual flush WC), shower, washroom and kitchen tap water efficiency measures across all types of residential dwellings were found to be low-regret measures (using a simple criterion for economic low

1 A discount rate of 8% was used when discounting costs and benefits to households and companies. A discount rate set out in the Treasury Green Book was used when discounting societal benefits and costs (3.5% (years 1-30) and 3.0% (years 31-45)).

regret of CBR<1). In the case of discretionary retrofits, installation of low flow shower was shown to be the only low-regret measure and only when considered from a household perspective.

New build water efficiency package was shown to be low-regret in relation to the 110 L/person/day standard only (due to relatively higher installation costs of more ambitious packages).

In summary the following water stress adaptation measures were found to be economically **low regret adaptation measures** (CBR<1):

- New build water efficiency package 110 L/person/day standard – newbuild
- Dual flush WC – end-of-life upgrade
- Low flow tap (pair) – end-of-life upgrade
- Click protect kitchen tap – end-of-life upgrade
- Low flow shower – end-of-life upgrade
- Low flow shower – discretionary retrofit (from household perspective only)

Sensitivity analysis was also carried out on the results of this analysis and included consideration of worst-case and best-case scenarios[2]. In particular:

- Best case scenario reflected low costs of measures (-20% of the base estimate) and high-water savings (+10% relative to water calculator default);
- Worst case scenario reflected high costs of measures (+20% of the base estimate) and low water savings (-10% relative to water calculator default)[3].

When considering best case scenario (from a household perspective) over a 15-year time period, low-regret measures include in addition:

- New build water efficiency package 105 L/person/day standard – newbuild
- Installation of dual flush WC during discretionary retrofit

Conversely, when considering worst case scenario, the list of low-regret measures was reduced to exclude the installation of low flow shower during discretionary retrofit.

Finally, the analysis considered **wider benefits** including reduced energy bill (household perspective) and avoided carbon costs (societal perspective). Overall, the inclusion of wider benefits associated with reduced electricity costs and avoided carbon costs has produced an expanded list of low-regret adaptation measures. Additional measures include installation of low flow tap during discretionary retrofits (associated with electricity savings) and installation of low flow shower during discretionary retrofits (associated with carbon savings).

Updates to housing stock and unit cost data did not lead to changes in the list of low-regret measures for water stress. Total estimated benefits and costs of adaptation measures have increased due to updating unit cost and benefit input data to current prices. Furthermore, the inclusion of wider benefits such as reduced energy bill and avoided carbon costs in the assessment has led to a limited expansion of the low-regret measures for water stress.

The limitations of this study relate to:

[2] The assessment used sensitivity ranges reported in the Davis Langdon (2011) to ensure comparability. No details were provided in the original study with regard to the choice of best and worst value ranges.
[3] No changes to the definition of high/ low thresholds were made in comparison to the 2011 Davis Langdon study.

- Composite nature of water efficiency packages in new builds (corresponding to the 80, 90, 105 and 110 l per person per day) that prevented the analysis of individual components of the packages;
- The lack of updated long run marginal cost (LRMC) values resulted in the use of the original LRMC values (updated to current prices). As highlighted in the 2011 study, it is unclear to what extent these values accounted for climate change scenarios.
- The lack of incorporation of updated climate change scenarios within the analysis, the original study assumed a 100% application rate of technically feasible water efficiency measures as the chosen study area was already exposed to serious water stress. The original cost curves were not developed in relation to a water deficit (ML) and water savings required to combat the effects of water stress, but rather a category of water stress. It was thus not possible to scale this application rate considering climate change impacts.

Flooding

Avoided costs of repairs to buildings and contents reflected benefits to householders and wider society. Installation of **flood resistance packages** (fit & forget and manual activation[4]) across all types of residential dwellings were found to be low-regret measure (using a simple criterion for economic low regret of CBR<1) in the case of deep and shallow floods. This measure is a economic low regret measure across all adaptation stages including newbuild, on repair and discretionary retrofit, when potential flooding is greater than 1% Annual Exceedance Probability (AEP). In practice only one, relatively more cost-beneficial activation technology (manual or automatic) would be installed at a given property.

Flood resilience measures were largely shown to be low-regret in newbuild dwellings. In particular, the following flood resilience measures were found to be economically **low regret adaptation measures** (CBR<1 at ≥ 1% AEP):

- Raise floor above likely flood level, newbuild, all floods
- Chemical damp-proof course, newbuild, all floods
- Move service meters above flood level, newbuild, all floods
- Move washing machine to first floor, newbuild, all floods
- Raised, newbuild, built-under oven, newbuild, all floods
- Wall-mounted boiler, newbuild, all floods
- Move electrics above flood level, newbuild, deep floods
- New floor with treated timber joists, newbuild and on repair, all floods (societal perspective only)
- Wall-mounted boiler, on repair, all floods (societal perspective only)

Installation of a new floor with treated timber joists during discretionary retrofits (repair) and of a wall-mounted boiler are the only measures which have a CBR<1 for existing dwellings (but only from societal perspective that uses lower discount rate).

Sensitivity analysis was also carried out and included consideration of worst and best-case scenarios. In particular:

[4] These are mutually exclusive alternatives that i) require no action by the residents to deploy the device in the case of fit& forget package; or ii) need to be deployed manually in the case of manually activated measures.

- Best case scenario reflected low costs of measures (-20% of the base estimate) and high savings/societal benefits (+10% in averted loses in comparison to ABI baseline);
- Worst case scenario reflected high costs of measures (+20% of the base estimate) and low savings/ societal benefits (-25% in averted loses in comparison to ABI baseline)[5].

When considering best case scenario over 15-year time period, the list of low-regret measures was supplemented with the installation of a dense screed in new builds and on repair (all floods). Conversely, when considering the worst-case scenario (high costs / low savings), the list of low-regret measures was reduced to exclude:

- New floor with treated timber joists, newbuild and on repair, all floods
- Wall-mounted boiler, on repair, all floods

Finally, the analysis considered **wider benefits** including avoided costs of evacuation and human health impacts. Overall, the inclusion of wider benefits associated with reduced evacuation costs and intangible human health impacts has produced an expanded list of low-regret adaptation measures. Additional measures include:

- installation of dense screed in newbuild properties and on repair (flood resilience - floors)
- moving washing machine and oven above flood level on repair in the case of deep floods
- raising built-in oven on repair in deep floods and
- installing closed cell insulation in newbuild properties in the case of deep floods.

Updates to housing stock and unit cost data did not lead to changes in the list of low-regret measures for flooding. Total estimated benefits and costs of adaptation measures under the main scenario have increased due to updating unit cost and benefit input data to current prices. The inclusion of wider benefits such as avoided costs of evacuation and mental health impacts in the assessment has led to a limited expansion of the low-regret measures for flooding.

The limitations of this study relate to:

- The lack of technical effectiveness data on the impact of flood resilience measures that are aiming to minimise impact of flooding and facilitate repair, drying & cleaning and subsequent reoccupation on the instance and duration of evacuation.
- The incorporation of newly published climate change scenarios within the analysis using a scaling factor applied to the number of properties affected (25%, 75% and 150%). This approach was followed in the absence of updated Catchment Flood Management Plans (Environment Agency, 2009) that provided data on the number of current and future residential properties at risk of flooding (by dwelling type) for the 2011 study.

Overheating

Evidence from the previous study and more recent work by the CREW project[6] suggests that the potential effect of measures that can provide adequate ventilation (and which can be continuously adjusted) to respond to overheating pressures is significant. However, the quality and serviceability of ventilation systems in individual houses with respect to their capability to respond to overheating will depend on their post-construction modifications and general state of maintenance.

[5] No changes to the definition of high/ low thresholds were made in comparison to the 2011 Davis Langdon study.
[6] https://www.arcc-network.org.uk/dwelling-type-the-most-significant-factor-in-overheating-homes/

The effectiveness of the ventilation system in the UK housing stock (e.g. whether windows can be opened), how far it is from design standard, and the level at which it is maintained in general, is key to the overall ability to control overheating risk. As little information is available on the capability and state of the ventilation system, it is less certain how well the current building stock will react to overheating pressures, including changes in climate variables which affect overheating.

The evidence from computer modelling in the previous study and CREW project indicates that improvements to the ventilation system of existing homes are measures which are more effective than other measures which were considered in the CREW project[7] and the previous report. Measures which address poor ventilation may have the greatest impact but are difficult to estimate costs for as less research is available on the practical steps that would be required to improve ventilation systems as they depend on specific circumstances.

The costs for measures identified as part the CREW project have been updated in this study using the latest market prices. There is currently no scientific consensus with respect to the best indicator to use to express the benefits of overheating measures with respect to the UK's building stock, instead we adopt a simple measure of effectiveness (%) in terms of the reduction in degree hours to identify potential low regret measures[8]. Here, the improvement in effectiveness is taken as a simple the benefit of measure and is not further monetised. If a threshold of £100 per 1% improvement in effectiveness is used, and the upper rather than lower level of costs chosen to be cautious, the following measures are identified as low-regret measures.

For a detached house, low-regret measures include:

- Curtains
- Remedial cross-ventilation or room protection

For a semi-detached house, low-regret measures include:

- Curtains
- Remedial cross-ventilation or room protection
- Internal blinds
- Solar reflective walls
- Cavity wall insulation

For a Town House (mid-terrace), low-regret measures include:

- Curtains
- Remedial cross-ventilation or room protection
- Internal blinds
- Solar reflective walls and roofs
- Cavity wall insulation
- External shutters

[7] Reported in Porritt, S., Shao, L., Cropper, P. and Goodier, C., 2011. Adapting dwellings for heat waves. Sustainable Cities and Society, 1(2), pp.81-90.
[8] The previous study used a metric for benefits which assumed that air-conditioning would be used as an alternative to a measure and the method amounts to a multiplier on the effectiveness on the measure. The CREW project compared only costs and not benefits.

- External fixed shading
- Extra loft insulation

For a flat, low-regret measures include:

- Curtains
- Remedial cross-ventilation or room protection
- Internal blinds
- Solar reflective walls and roofs
- Cavity wall insulation
- External fixed shading

The main limitations of the study are:

- The impacts from overheating are not well defined because the simple metric of degree-hours is used but it is only a proxy for real impacts. Measures addressing ventilation have been assumed to fully address the requirement for ventilation (100% effective). Better understanding of potential benefits would allow a focus on the most appropriate measures for the circumstances.
- Overheating events are characterised by variety in their severity, frequency and affected geographic region, with potentially different types of effects and mitigating measures. This type of variation is not considered. Additionally, analysis of the affordability of measures is not included.
- Alternative specifications for costs and benefits could be used. For example, the costs calculated and presented for the case studies are poor reflections of the benefits that might arise from the introduction of a measures such as triple-glazing. If the occupant was already satisfied, the benefit would be zero, while in other cases, if it avoided a fatality, the benefit would be substantially higher. Upcoming research on overheating health impacts by MHCLG would enable health outcomes to be represented in terms of avoided financial and economic health costs.
- The benefits and costs of financial instruments to enable and manage costs have not been considered although an important element of feasibility for many residents. Furthermore, wider economic impacts such as effects on supply chains are not included.

The main recommendations are:

- As a result of the potential negative impacts from poor ventilation, further research is required to identify the state of ventilation systems in the housing stock, by, for example conducting survey/consultation to understand for divergence from design standards.
- Better definition of practical measures to address ventilation is required to confirm their very high effectiveness compared to other measures when ventilation is poor.
- In advance of new data being available, the table of measures and costs (Table 5.4) and reference to the CREW project is recommended to be used to establish the preference order for measures in the case of any single dwelling, excluding measures that that do not apply to specific conditions.
- With respect to tower blocks specifically, overheating measures could be considered as part of cladding or recladding work to making savings in one-off installation costs.

Contents

1. Background

The section describes the background situation in relation to the UK residential housing sector, key climate change impacts and adaptation measures which have been considered to mitigate these risks.

1.1 Overview

Residential Housing Sector

As a sector the UK residential building stock is characterised by a large ageing building stock, with approximately 1-2% of new building stock being added each year. This means that by 2050 about 70% of the building stock which exists today will still be in place[9]. Currently, residential properties account a significant proportion of greenhouse gas emissions in the UK, and many of the properties are in desperate need of repair and retrofit, both to support current government mitigation and adaptation targets for the UK[10].

In 2013, 2.9-5% of existing properties are being retrofitted annually, well below the targeted need to achieve the Government's emission reduction targets[11]. Many of these properties are exposed to a range of climate hazards including water stress, flooding and overheating and there exists the possibility to mitigate these risks and contribute to emission reduction targets through the careful implementation of adaptation measures at the building scale such as water (and energy) saving devices and domestic flood risk measures.

However, the UK residential building sector currently lacks up-to-date, accessible and actionable information relating to the performance of building scale measures to support climate change adaptation efforts, this is further complicated as there are multiple differences between the types of datasets, impact models, option appraisal techniques, socio-economic and climate change scenarios as well as decision-making techniques currently applied by different stakeholders seeking to engage in adaptation across the UK[12].

For example, climate change projections typically differ in terms of the severity of climate change impacts, their associated uncertainties, available climatic variables and their spatial and temporal resolution. Whereas option appraisal techniques employed by stakeholders engaging in adaptation differ in terms of: the number and type of criteria they consider; the economic model they follow; the level of stakeholder participation they require and facilitate, and the level of quantitative and numerical modelling required versus the level of discussion and arbitration they permit.

In the context, industry standard cost-curves have previously been developed for a range of building scale adaptation measures[13] to resolve this information deficit and have been somewhat successful, despite some criticisms being levelled against the use of cost curves for adaptation purposes[14]. However, as the underpinning science has developed, so has the need to update methods and datasets to ensure they are fit for purpose and can accommodate the range of options and approaches adopted by stakeholders engaging in adaptation. This is critical to ensure continued efforts to mainstream adaptation efforts in the UK.

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[9] https://www.waterwise.org.uk/resource/water-efficiency-strategy-for-the-uk-2017/
[10] http://www.legislation.gov.uk/ukpga/2008/27/contents
[11] Eames, et al (2013) City futures: exploring urban retrofit and sustainable transitions, Building Research & Information, 41(5), pp.504-516
[12] http://www.lse.ac.uk/GranthamInstitute/news/adapting-to-the-impacts-of-climate-change-in-the-uk/pb-ranger-adaptation-uk-2/
[13] https://www.theccc.org.uk/archive/aws2/ASC%202nd%20Report/Davis_Langdon%20_Final.pdf
[14] https://www.theccc.org.uk/archive/aws2/ASC%202nd%20Report/N%20Granger.%20Commentary_cost_curves_jul11.pdf

This study has thus focussed on developing updated cost curves for a range of adaptation measures previously considered by the UK residential building sector to address to key climate flooding, water stress and overheating, such as domestic water saving devices and flood protection, based on their direct and indirect benefits and costs. These risks are discussed in turn, outlining recommended adaptation measures applied to date.

Climate Change

Water Stress

Climate change will likely significantly impact the temporal and spatial availability of water resources, resulting in increasingly variable weather patterns which will in turn reduce certainty in rainfall and rivers flows, with more frequent floods and droughts[15]. Several high-profile studies have suggested that the UK will experience significant and more frequent drought events in the future as a direct result of climate change, population growth, increased water use and the need to protect vulnerable environments[16].

Across the UK, demand for water resources will also be challenged by population change and migration. In response to the risks posed by climate and population change, interest in water efficiency has grown significantly in recent years[17], with the recognition that it can contribute both climate adaptation and mitigation efforts. The installation of water efficient appliances and devices can reduce water and energy bills, and at a sectoral level reduce the pressure on existing water infrastructure and demand for new infrastructure to meet rising demands.

Water efficiency can contribute to reduced energy use and greenhouse gas emissions, with more efficient fixtures and fittings contributing to reduced domestic water use, thereby reducing the need to pump and treat water and wastewater and the associated energy costs. Water efficiency comprise a range of appliances and practices such as new and retrofit water saving devices, smart metering, building standards as well as leakage control. The most widely installed appliances and devices including water savings toilets, taps and showerheads. Flow tap aerators and regulators can also be installed easily with minimal disruption, comprising precision drilled holes, filters or flow aerators to regulate the flow of water. Flow regulators are not suitable for installation in electric showers as well as some power and multi-jet showers and are better suited for combi and condensing boilers with gravity fed showers. Low flows taps are better suited for installation in bathrooms but can also be fitted in kitchens and other rooms in residential properties.

The range of water efficiency appliances and practices which have been applied to curb water use is growing, with new innovations continually being developed. New innovations include smart point of use water management devices, smart rainwater butts, air flush toilets, ultra-low-flow products and improved customer engagement displays and devices[18]. In addition to new technologies, behavioural change and awareness raising is also important in ensuring water reduction targets are realised[19]. For instance, a water efficient dishwasher, once installed, is likely to generate anticipated water savings irrespective of its user, while water savings achieved through the use of dual flush WC or low flow shower will depend on the user's behaviour.

Flooding

Many urban areas in the UK are exposed to flash flooding incidents and this is anticipated to worsen due to climate change, owning to an increase in rainfall intensity and duration, pushing the capacity of existing

[15] https://nerc.ukri.org/research/partnerships/ride/lwec/report-cards/water/
[16] http://www.hwa.uk.com/site/wp-content/uploads/2017/12/SWCD6.3-Water-UK.-2016.-Water-resources-long-term-planning-framework-2015-2065-199.pdf
[17] https://www.gov.uk/government/news/environment-agency-calls-for-action-on-water-efficiency
[18] https://www.waterwise.org.uk/wp-content/uploads/2018/02/Waterwise-National-water-strategy-report.pdf
[19] https://www.waterwise.org.uk/wp-content/uploads/2018/02/Smart-Water-2007_Promoting-Behavioural-Change-in-Household-Water-Consumption.pdf

drainage networks to their limits, resulting in sewer surcharging and localised flooding. As the temperature rises, so will atmospheric water vapour capacity, with current climate models predicting more rainfall over most of England with intense, highly localised summer rainfall events increasing, especially over the South and East of England. Flooding, particularly surface-water (pluvial) flooding represents a significant threat to many urban environments[20]. Elsewhere, coastal flooding poses a significant risk to many coastal properties. Flooding not only poses a risk to human lives and livelihoods, but even small-moderate events can incur significant damage to buildings and supporting infrastructure.

Surface (pluvial) flooding typically results when excess rainfall falling on hard surfaces is unable to infiltrate because the surface is impermeable, saturated or frozen. In the case of new building developments, replacing traditionally permeable surfaces with hard standing surfaces, such as car parks and paving, can exacerbate localised flooding. During flooding events water can directly penetrate building structures due to: permeable wall and floor surface; concealed voids including party walls and cavities, airbricks and other ventilators, insufficient or damaged seals around door and window frames as well as damp-proof membranes or tanking, subfloor voids; mortar and render cracks; surface entry points as well as drainage backflow through sanitary or washing appliances[21].

Adaptation measures adopted to combat the risk of flooding include considering the citing and orientation of buildings, land use and topographic features based on their relative proximity to sources and areas of flooding[22]. Direct interventions can include adoption of a water exclusion strategy where the floor level is raised above the maximum predicted flood height. Promotion of natural attenuation and infiltration systems, such as SUDS including permeable paving, swales and retention ponds can also be considered. Additional measures can include permanent or temporary flood defences such as flood boards and grate covers, promotion of water-compatible developments including multipurpose outdoor attenuation-recreational spaces as well as water entry strategies whereby water is allowed uninhibited access in and out of buildings to support accelerated recovery.

Overheating

Climate change will result in increased temperatures, particularly during summer, across parts of England[23]. In recent years greater emphasis has been placed on the risk overheating, such as during the 2013 heatwave[24] and more recently in 2018 resulting in heat health alerts being issued by the Met Office. Certain buildings and properties are naturally more susceptible to overheating such as top floor flats and new-build detached houses[25]. Properties in built-up areas, such as cities and large towns, are more susceptible than rural properties owing to the Urban Heat Island Effect (UHIE) where ambient temperature in urban areas are normally a few degrees warmer than the surrounding environment[26]. The UHIE occurs as dark coloured hard standing surfaces, e.g. roads, pavements, roofs absorb heat during the day and then remit it at night, warming the ambient environment and preventing surrounding buildings from cooling. Additionally, air conditioning units directly discharge heat into the surrounding environment resulting in gradual warming.

Overheating poses a specific public health risk to those in ill health and the elderly, with around 2000 deaths a year attributed to heat[27]. Beyond this, overheating can lead to and exacerbate productivity issues with staff being too hot in their workplace. As the temperature rises so will the need for air conditioning, which in turn increases energy demands and greenhouse gas emissions. The UHIE (and by extension overheating) can be

[20] https://flood-warning-information.service.gov.uk/long-term-flood-risk/map
[21] https://www.ciria.org/Resources/Free_publications/flood_damaged_buildings.aspx
[22] Wilby, R.L. and Keenan, R., 2012. Adapting to flood risk under climate change. Progress in physical geography, 36(3), pp.348-378.
[23] https://www.metoffice.gov.uk/news/releases/2018/2018-uk-summer-heatwave
[24] https://www.theguardian.com/uk-news/2014/jul/16/heatwaves-questions-answers
[25] https://www.bre.co.uk/filelibrary/Briefing%20papers/116885-Overheating-Guidance-v3.pdf
[26] https://www.metoffice.gov.uk/binaries/content/assets/mohippo/pdf/8/m/mo_pup_insert_health.web.pdf
[27] https://www.theccc.org.uk/2017/08/08/hidden-problem-overheating/

reduced by decreasing anthropogenic heat emissions from buildings and transportation, reducing air-conditioning use, increasing vegetation by utilising green space, roofs and walls and increasing the albedo of hard standing surfaces, such as roofs and pavement.

Additional considerations can include the use of building materials with a high solar reflect and high infrared emittance, thus lowering surface temperatures, which in turn prevents less heat from penetrating buildings and being transferred to the ambient environment. The negative impacts of the UHIE can be mitigated through improvements in energy efficiency buildings, promotion of zero carbon buildings and implementing green spaces to support urban cooling and reduce the risk of overheating, whilst contributing health and wellbeing benefits by facilitating recreational activities.

1.2 Objectives

In recognition of the challenges facing the UK residential building sector, this project aims to enhance the residential building sector's understanding of climate change risks and adaptation options through improved data, modelling and assessment, enable more proactive planning and improved protection of the built environment, as well as strengthen institutional responses to climate change risks. This project comprises the following objectives.

a) **Review previously developed cost curve models of adaptation measures for the UK residential building sector**, considering their strengths, weaknesses, limitations as well as their coverage of different climate risks and adaptation options;

b) **Identify and compare building scale adaptation measures** based on previously developed models, their evidence of uptake and derived benefits in relation to the UK residential building sector;

c) **Collate and analyse economic and environmental data** to inform updates to the previously developed cost curve models, considering different climate change risks and using cost-effectiveness analysis to assess multi-dimensional benefits of different adaptation measures;

d) **Update the previous cost-curve models to ensure they are consistent with the latest evidence and are fit-for-purpose**, updating the underpinning datasets using current sources and published materials, as well as refining assumptions as necessary.

e) **Undertake sensitivity analysis of the updated cost curves to assess factors and rankings that influence the prioritisation of options**, accounting for non-monetary and indirect costs as well as multidimensional benefits and behavioural factors;

1.3 Scope

The scope of this project was defined in relation to the previous study completed by Davis Langdon and commissioned by the Committee on Climate Change in 2011. As part of this study, three distinct climate risks and a range of adaptation measures relevant to residential buildings were identified and subject to further analysis. These risks and associated measures comprise:

- **Water Stress** – comprising water efficiency appliances and devices;
- **Flooding** – comprising flood resistance and resilience measures; and
- **Overheating** – comprising measures to reduce thermal discomfort.

Other climate risks were identified as being highly relevant to the UK residential building sector including the impact of storms, lightening and extreme wind. However, these risks were screened out of the original study due to insufficient information being available on the impact of these risks and the effectiveness of different adaptation measures and thus were excluded from the analysis.

All of the adaptation measures considered by the original study and included in our analysis can be installed by a householder, or developer (in the case of a new build) and are commercially widely available. The original study considered the impact of climate change in a marginal way due to the lack of outputs of the UK Climate Change Risk Assessment and associated Adaptation Economics Assessment at the time of the assessment. This study, which builds upon the previous work, did not explicitly consider the impact of climate change in terms of the assessment of economic low-regret measures due to similar reasons.

As this study was undertaken before the completion of the latest CCC Research projects (see previous projects[28]), this project utilises the outputs of the UK Climate Change Risk Assessment 2017 to assess the impacts of climate change on the cumulative benefits of adaptation measures[29]. This study follows the original project's assumptions and methodology (with the exception of overheating) to permit comparative analysis, however additional sensitivity analysis has been undertaken, scaling the number of properties exposed to the impacts of climate change in attempt to resolve this discrepancy. Furthermore, wider benefits associated with water efficiency measures, flooding resistance and resilience measures are also included in the analysis.

Following completion of the latest UK Climate Change Risk Assessment research projects, the findings of this report can be updated using the number and typology of exposed properties to infer the cumulative costs and societal benefits of installing adaptation measures.

1.4 Methodology

The methodologies adopted for all three topic areas all follow themes implicit in this common basic structure.

1. Population

2. Housing stock

3. Behaviour and Use (incl. baseline definition)

4. Measures

The difficulties vary for the three topic areas – water stress, flooding and overheating - according to their intrinsic characteristics, the data available and assumptions required.

Water stress by definition will affect all populations and households in dwellings allocated in water company areas identified as areas of serious water stress which is in practice probably all or most populations and households within quite large areas. Flooding is likely to be more localised and building elevation can provide a good proxy for identifying affected dwellings and populations. Methods for valuing impacts on water stress are well established based on the avoided costs of additional supply and avoided water charges and, for flooding, on estimates from the insurance industry on avoided costs of repair related to flood depth.

In contrast, overheating is localised, and a methodology for identifying both dwellings and affected populations is required. This missing information is only some of that contributing to uncertainty in the definition of the current situation and baseline. Compared to the other topic areas, overheating does not show the same level of development in the data and metrics and the application of integrated assessment

[28] https://www.theccc.org.uk/tackling-climate-change/preparing-for-climate-change/uk-climate-change-risk-assessment-2017/research-projects/
[29] https://www.theccc.org.uk/tackling-climate-change/preparing-for-climate-change/uk-climate-change-risk-assessment-2017/

and costing methodologies. Despite this, it is possible to make simple estimates for some key variables to indicate the overall scale and the different effectiveness and costs of measures.

Some important elements of the approaches taken within the context of the themes in the three topic areas are:

For **water stress**, our methods use industry standard methodologies developed for the water sector including the use of Long-Run Marginal Costs (LRMC) of water supply and water charges. They apply to all dwellings within water companies' service areas and impacts are valued in terms of these costs, either to households (avoided water charges) or to the water company (LRMC). As regards measures, all water efficiency measures are completely additive, so all matter. Baseline uptake rate of water efficiency measures in existing homes is assumed to be 50% which is consistent with the 2011 study. The future level of uptake for existing homes is 50% and 100% for new homes (of eligible dwelling types). The level of savings is costed using LRMC of water supply (from a societal perspective) and using avoided water charges for metered properties (from a household perspective). The assessment also considers wider benefits of water efficiency measures associated with reduced electricity use and carbon emissions.

For **flooding**, our methods similarly use authorised and established methodologies for estimating the specific impacts and costs on individual properties from flooding and their mitigating measures including flood resistance and flood resilience measures. The study uses the number of current and future residential properties at risk of flooding (by dwelling type) distinguishing between shallow (up to 0.5 m) and deep (over 0.5 m) flood and different risk levels. These estimates from the Catchment Flood Management Plans (Environment Agency, 2009) were used in the 2011 study and inflated to account for new residential properties built between 2010 and 2018. Mitigating measures reduce the damage otherwise expected and so provide savings. There are fewer mitigating measures than for water stress, but, as damage is relatively more costly, the benefits of measures are much higher and uptake expected to be greater. The assessment also takes into account a range of wider benefits including avoided evacuation and human health impacts associated with flooding and temporary displacement.

For **overheating**, the existing evidence from the previous report and more recent information from the CREW project shows that the capability and state of the ventilation system is critical to the management of overheating pressures. For this reason, the representation and assessment of other measures in this previous work is conducted with respect to a clear specification of the operation of the ventilation system. For these measures, the methodology of the previous work has been followed and, in particular no new modelling of the physical response of example dwellings has been done. However new cost estimates for all measures have been developed to show the current order of preference for these measures. In addition, the comparison of possible measures addressing poor ventilation has been covered in an assessment based on a case study assessment of the city of Exeter.

Climate Change Scenarios

The original study undertaken by Davis Langdon had intended to make an explicit link between climate hazards and sector impacts as well as the adaptation measures included in this report. However, as this information was not available at the time the study was undertaken it was not included within the analysis. Instead a bespoke approach was developed for each of the three topic areas (covering water stress, flooding and overheating). Generally, climate change was implicitly considered within the underlying data as opposed to be an explicit component of the cost-effectiveness analysis or sensitivity analysis.

As part of the original study climate change tended to be incorporated implicitly within the case studies, based on previously published datasets with some limited modelling using the national UK Climate Projections (UKCP09[30]) integrated weather generator for overheating. The limitations of this approach are unfortunately carried through the analysis, which treats measures as economically low regret if "they are cost

[30] http://catalogue.ceda.ac.uk/uuid/87f43af9d02e42f483351d79b3d6162a

effective under current climate" with limited consideration of the impacts of climate change or uncertainty. Where climate change was considered, the following (deterministic) climate scenarios were used, consistent with approaches used at a sectoral level:

- 2020s – Medium emission scenario (90% 'probability' level)
- 2050s – Low (10% 'probability' level), Medium (50% 'probability' level) and High (90% 'probability' level)

To improve upon the original study, the intention was to update the original datasets and assumptions used in the Davis Langdon study to reflect recently published sources such as the updated UKCP09 projections and more recently released UKCP18 projections[31]. Unfortunately, it is not possible to repeat the original analysis in terms of the use of UKCP09 (and more recent UKCP18) projections, particularly as many of the original datasets are now (1) out of date or no longer publicly available thus more difficult to independently validate and/or (2) redundant as they did not explicitly consider the impacts of climate change. Furthermore, any additional incorporation of climate change scenarios as an explicit input to the model may have the unintended consequence of duplicating the impacts of climate change, particularly where it has been included implicitly within the original case study datasets.

The UKCP09 projections have only been subject to a couple of minor adjustments since the completion of the previous study to address under-representation of some extreme events. These minor amendments would likely have had a minimum impact on the outcomes of the original study. This is because only a small proportion of the original study used outputs from UKCP09 directly in the analysis. Secondly, the key conclusions of this study, being the identification of a series economically low regret adaptation measures can largely be derived irrespective of the prevailing climate. Climate change will impact the number of properties impacted by climate change, however as the analysis is undertaken on a per property basis, based on assumed costs and benefits of measures, any variation in the future climate would effectively scale the derived societal benefits without modifying the cost-effectiveness ratio of individual measures. Only where the updated climate change scenario would affect the unit cost and/or benefit of individual measures, conclusions on the low-regret measures could be impacted (e.g. if LRMC of water supply would increase as a result of more severe climate change projection).

Recognising these limitations, an attempt was made to explicitly connect the methods and datasets used in the original study and enhanced by this study with the output of the UK Climate Change Risk Assessment (CCRA) 2017. A range of sources and scenarios were identified from a systematic literature review of published materials referenced in CCRA 2017 and ancillary sources (Table 1.1). Using these sources, it is possible to deriving scaling factors to infer the societal benefits of adaptation measures based on a worsening climate.

For some climate risks this scaling exercise is possible within the constraints of the model. For example, the number of exposed properties to flood risk can be easily scaled using a multiplier factor. Similarly, for overheating it is possible to scale the societal benefits, acknowledging that climate change will disproportionally impact top floor flats which are more prone to heating. However, for water stress the original study assumed that the entirety of the study area was already to water stress (i.e. 100% of properties benefit from water efficiency measures). It is thus not possible to scale the results of this assessment to infer the benefits from further adaptation as all of the properties will benefit from water saving measures.

[31] https://www.metoffice.gov.uk/research/collaboration/ukcp/about

Table 1.1 Climate change risk - anticipated impact

Climate risk	Relevant variable	Med. Impact '+2°c world'	High impact '+4°c world'	Source/s
Water stress	% reduction in available public water supply	6-11% (2050s)	8-15% (2080s)	HR Wallingford (2015) Water availability[32]
Flooding	% increase exposed residential properties	40-140% (2080s)	93-230% (2080s)	Sayers (2015) Future Flood Risk[33]
Overheating	% total exposed flats % total exposed detached houses	59 – 73% (2030s) 24-29% (2030s)	80-92% (2050s) 56-61% (2050s)	Jenkins (2014) Overheating in buildings[34]

Following the identification of these climate risk trends for water stress, flooding and overheating a series of scaling factors were identified for inclusion in the sensitivity analysis. A low, medium and high impact % increase coefficient was inferred from these studies based on a review of published materials and professional judgment (rounding to the nearest 5%). It is acknowledged that these factors won't impact the identification of economic low regret measures, because they are assessed as being low-regret irrespective of the prevailing climate due to limitations in the original study's methodology. However, they can be used to infer the cumulative benefits. The results of this assessment are included in the sensitivity analysis of each component chapter.

Table 1.2 Climate change risk - anticipated impact on modelled variables

Climate risk	Modified variable	Low impact	Med. Impact	High impact
Water Stress	No. of residential properties affected within additional water stressed areas	+5%	+10%	+15%
Flooding	No. of residential properties affected by flooding	+25%	+75%	+150%
Overheating	No.(and type) of residential properties exposed to overheating	+55%	+70%	+85%

[32] https://www.theccc.org.uk/wp-content/uploads/2015/09/CCRA-2-Updated-projections-of-water-availability-for-the-UK.pdf
[33] https://www.theccc.org.uk/wp-content/uploads/2015/10/CCRA-Future-Flooding-Main-Report-Final-06Oct2015.pdf.pdf
[34] Jenkins, et al (2014) Developing a probabilistic tool for assessing the risk of overheating in buildings for future climates, Renewable Energy, 61: 7-11

1.5 Cost Curves

Cost curves provide a graphical means of comparing adaptation measures in terms of their effectiveness and costs. In the context of this study cost curves can be used to compare measures for making buildings more resilient to climate change, either by augmenting the physical attributes of structures (e.g. protection from flooding) or reducing the demand for critical resources (e.g. water, energy) upon which buildings operations are dependent, thereby reducing the impact and consequential losses attributed to climate change. Figure 1.1 provides an illustrative example of a cost curve.

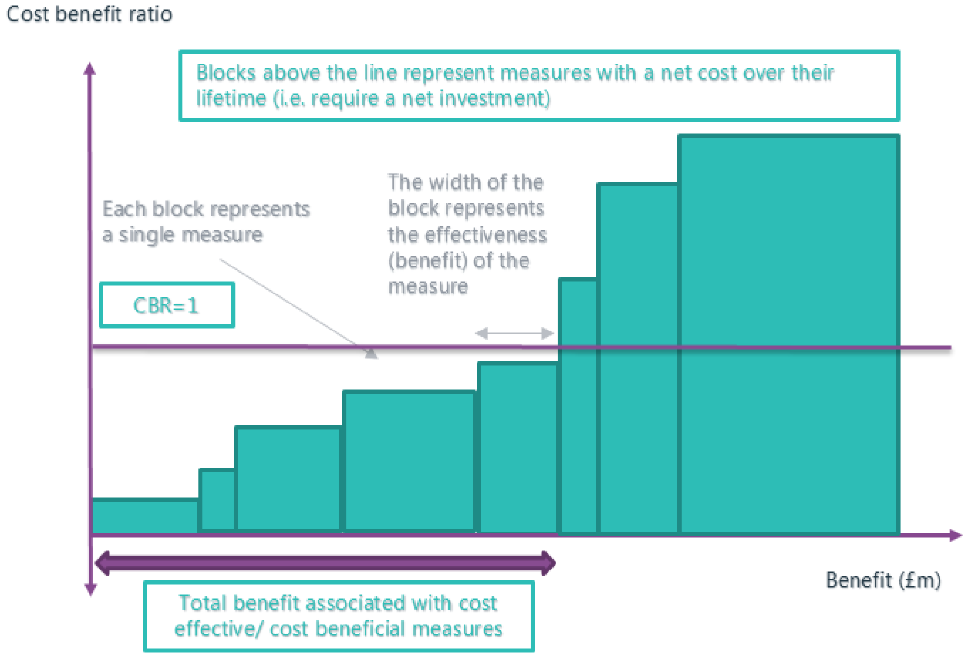

Figure 1.1 Interpretation of a standard cost curve (an illustrative example)

In this study, climate change adaptation measures with a cost benefit ratio of less than 1 (CBR<1) were considered to be low-regret.

The horizontal axis (x-axis) represents anticipated benefit expressed in million pounds sterling (present value). Different benefit metrics are appropriate for water stress, flooding and overheating which capture effects of ranging from avoided water charges to avoided physical damage from flooding.

The vertical axis (y-xis) represents the cost benefit ratio of individual adaptation measures (calculated as present value costs (£)/present value benefits (£)). All adaptation measures located below the line (CBR=1) can be considered as economically low regret as their lifetime benefits outweigh the costs. Furthermore, all adaptation measures are plotted on the cost curve in sequence moving from the left side of the curve to the right. This sequence starts with the measure that provides the highest benefit per pound and then moves on to the next most cost-beneficial adaptation measure and so on.

It should be noted that cost curves show each adaptation measure individually without taking into account any additivity or mutually exclusivity of different measures. Such potential interactions and inter-dependencies between different measures could mean that the total aggregate benefit (£m) associated with any given low-regret adaptation measure package (the simple sum of measures) is overstated. Furthermore, cost curves typically account for all technically feasible measures while in practice the actual uptake rate (e.g. number of households installing water efficiency measures) can be lower resulting in a lower total benefit at the societal level.

2. Adaptation Measures

This section details the adaptation measures which were considered to mitigate the impacts of water stress, flooding and overheating.

2.1 Water stress

The assessment considered water efficiency measures identified below in Table 2.1.

Table 2.1 Water stress adaptation measures and unit costs

Adaptation Measure		Unit costs (£ per property, one-off) – discretionary retrofit					
		<70m² semi- or terrcd	<70m² flat	70 - 110m² semi- or terrcd	70 - 110m² flat	70 -110m² dtchd	>110m² dtchd
WC water efficiency	Dual flush WC	264	264	463	463	463	662
Shower water efficiency	Low flow shower	293	293	293	293	293	516
Washroom tap water efficiency	Low flow tap (pair)	117	117	199	199	199	281
Kitchen tap water efficiency	Click lock kitchen tap	117	117	117	117	117	117
Washing machine water efficiency	Low water washing machine	571	571	571	571	571	571
Dishwasher water efficiency	Low water dishwasher	644	644	644	644	644	644
Garden water efficiency	Water butt	59	n/a	59	n/a	59	59
Rainwater system	Low volume, gravity RW system	1172	n/a	1172	n/a	1172	1172
Greywater system	Short retention GW system	2639	2639	2939	2939	2939	2939
		Unit costs (£ per property, one-off)– end of life					
		<70m² semi- or terrcd	<70m² flat	70 - 110m² semi- or terrcd	70 - 110m² flat	70 -110m² dtchd	>110m² dtchd
WC water efficiency	Dual flush WC	0	0	0	0	0	0
Shower water efficiency	Low flow shower	0	0	0	0	0	0
Washroom tap water efficiency	Low flow tap (pair)	0	0	0	0	0	0

Kitchen tap water efficiency	Click lock kitchen tap	0	0	0	0	0	0
Washing machine water efficiency	Low water washing machine	124	124	124	124	124	124
Dishwasher water efficiency	Low water dishwasher	174	174	174	174	174	174
Garden water efficiency	Water butt	0	0	0	0	0	0
Rainwater system	Low volume, gravity RW system	0	0	0	0	0	0
Greywater system	Short retention GW system	0	0	0	0	0	0
		Unit costs (£ per property, one-off) - newbuild					
		<70m² semi- or terrcd	<70m² flat	70 - 110m² semi- or terrcd	70 - 110m² flat	70 -110m² dtchd	>110m² dtchd
Washing machine water efficiency	Low water washing machine	112	112	112	112	112	112
Dishwasher water efficiency	Low water dishwasher	157	157	157	157	157	157
Garden water efficiency	Water butt	53	n/a	53	n/a	53	53
Rainwater system	Low volume, gravity RW system	1055	n/a	1055	n/a	1055	1055
Greywater system	Short retention GW system	2375	2375	2645	2645	2645	2645
New build water efficiency package							
110 L/person/day standard	all	0	0	0	0	0	0
105 L/person/day standard	flat, semi & trcd, dtchd	281	281	281	281	338	338
90 L/person/day standard	flat, semi & trcd, dtchd	4502	2181	4502	2181	4924	4924
80 L/person/day standard	flat, semi & trcd, dtchd	5852	2405	5852	2405	6274	6274

Source: Davis Langdon (2011). Research to identify potential low-regrets adaptation options to climate change in the residential buildings sector. London: Adaptation sub-committee, Committee on Climate Change inflated to current prices.

2.2 Flooding

The assessment considered flood resilience measures identified below in Table 2.2.

Table 2.2 Flooding adaptation measures and unit costs

Category	Adaptation Measure	Unit costs (£ per property, one-off) – discretionary retrofit				
		Three-Bedroom Semi-Detached House	Four-Bedroom Detached House	Two-Bedroom Ground Floor Flat	Two-Bedroom Terrace House	Three-Bedroom Bungalow
Flood resilience - floors	Install dense screed	821	997	721	633	1,184
	Replace chipboard flooring with treated timber floorboards	1,143	1,378	997	879	1,641
	Install a new floor with treated timber joists	4,244	5,129	3,763	3,324	5,944
	Install a solid concrete floor	10,845	12,779	9,848	8,910	14,655
	Raise the floor above likely flood level	37,869	42,675	36,344	33,062	52,406
Flood resilience - walls	Use closed cell cavity insulation to prevent water wicking in walls.	821	956	780	727	1,049
	Use water resistant plaster	7,972	8,998	7,709	7,328	9,614
	Install a chemical damp-proof course	7,673	9,262	6,753	5,962	10,868
	Install water resistant doors and windows	12,275	15,042	12,791	9,508	17,598
Flood resilience - interiors	Install a wall-mounted boiler	1,172	1,172	1,172	1,172	1,172
	Move washing machine to first floor	703	703	N/A	703	N/A
	Specify a raised, built-under oven	762	821	762	762	879
	Move electrics above flood level	938	1,055	821	821	1,290
	Move service meters above flood level	1,759	1,759	1,759	1,759	1,759
	Specify plastic kitchen / bathroom units	3,986	9,262	6,753	5,962	10,868
Category	**Adaptation Measure**	**Unit costs (£ per property, one-off)– on repair (end of life)**				
		Three-Bedroom Semi-Detached House	Four-Bedroom Detached House	Two-Bedroom Ground Floor Flat	Two-Bedroom Terrace House	Three-Bedroom Bungalow
Flood resilience - floors	Install dense screed	135	170	123	106	199
	Replace chipboard flooring with treated timber floorboards	592	709	516	457	850
	Install a new floor with treated timber joists	610	733	539	475	856

Category	Adaptation Measure	Unit costs (£ per property, one-off) – discretionary retrofit				
	Install a solid concrete floor	7,210	8,383	6,624	6,061	9,567
	Raise the floor above likely flood level	14,069	15,007	13,424	12,896	21,514
Flood resilience - walls	Use closed cell cavity insulation to prevent water wicking in walls.	317	410	299	276	451
	Use water resistant plaster	3,429	3,928	3,371	3,195	4,221
	Install a chemical damp-proof course	4,039	4,865	3,529	3,113	5,780
	Install water resistant doors and windows	5,475	6,601	5,944	4,350	7,779
Flood resilience - interiors	Install a wall-mounted boiler	176	176	176	176	176
	Move washing machine to first floor	234	234	N/A	234	N/A
	Specify a raised, built-under oven	234	234	234	234	234
	Move electrics above flood level	352	440	293	293	586
	Move service meters above flood level	586	586	586	586	586
	Specify plastic kitchen / bathroom units	1,934	4,865	3,529	3,113	5,780
Category	**Adaptation Measure**	**Unit costs (£ per property, one-off)- newbuild**				
		Three-Bedroom Semi-Detached House	Four-Bedroom Detached House	Two-Bedroom Ground Floor Flat	Two-Bedroom Terrace House	Three-Bedroom Bungalow
Flood resilience - floors	Install dense screed	121	153	111	95	179
	Replace chipboard flooring with treated timber floorboards	533	638	464	412	765
	Install a new floor with treated timber joists	549	659	485	427	770
	Install a solid concrete floor	6,489	7,544	5,962	5,455	8,610
	Raise the floor above likely flood level	N/A	N/A	N/A	N/A	N/A
Flood resilience - walls	Use closed cell cavity insulation to prevent water wicking in walls.	285	369	269	248	406
	Use water resistant plaster	3,086	3,535	3,034	2,875	3,799
	Install a chemical damp-proof course	N/A	N/A	N/A	N/A	N/A
	Install water resistant doors and windows	4,928	5,941	5,350	3,915	7,001

Category	Adaptation Measure	Unit costs (£ per property, one-off) – discretionary retrofit				
Flood resilience - interiors	Install a wall-mounted boiler	0	0	0	0	0
	Move washing machine to first floor	0	0	0	0	0
	Specify a raised, built-under oven	0	0	0	0	0
	Move electrics above flood level	0	0	0	0	0
	Move service meters above flood level	0	0	0	0	0
	Specify plastic kitchen / bathroom units	1,741	4,379	3,176	2,801	5,202

Source: Davis Langdon (2011). Research to identify potential low-regrets adaptation options to climate change in the residential buildings sector. London: Adaptation sub-committee, Committee on Climate Change inflated to current prices.

The assessment also considered flood resistance measures identified below.

Category	Adaptation Measure	Unit costs (£ per property, one-off)					
		<70m² semi- or terrcd	<70m² flat	70 -110m² semi- or terrcd	70 -110m² flat	70 -110m² dtchd	>110m² dtchd
Flood resistance	Flood resistance package (fit &forget) Demountable door guards; Manual airbrick covers; Sewerage bungs/ toilet pan seals; Repointing of external walls up to 1m above ground level with water resistant mortar						
	Discretionary	£1,685	£1,903	£1,059	£1,145	£2,813	£3,115
	Repair	£1,421	£1,639	£795	£882	£2,549	£2,851
	New Build	£1,231	£1,341	£786	£868	£2,014	£2,178
Flood resistance	Flood resistance package (manual activation) Demountable door guards; Smart airbricks; Non-return valve on main sewer pipe; Repointing of external walls up to 1m above ground level with water resistant mortar						
	Discretionary	£1,228	£1,504	£601	£722	£2,387	£2,672
	Repair	£1,228	£1,504	£601	£722	£2,387	£2,672
	New Build	£1,047	£1,220	£601	£722	£1,871	£2,027

Source: Davis Langdon (2011). Research to identify potential low-regrets adaptation options to climate change in the residential buildings sector. London: Adaptation sub-committee, Committee on Climate Change inflated to current prices.

2.3 Overheating

The assessment considered overheating measures identified below and compared for a flat (the type of dwelling most likely to be at risk of overheating). A comprehensive list of measures and groups is provided in Appendix F, including measures for which only qualitative assessment is possible.

The assessment considered overheating measures identified below in Table 2.3. Further of the cost calculation and use of unit costs is explained in section 5.

Table 2.3 Overheating adaptation measures and cost per dwelling

No	Measures	Cost (£) per dwelling		Note
		Low	High	
Flat		*The example block of flats was constructed in the 1960s and has uninsulated cavity walls. The ground floor is uninsulated solid concrete and the roof is a cold roof design, with 50mm of insulation and an ashphalt covering. Some modernisation work has been carried out, including the replacement of the single-glazed windows with uncoated uPVC double-glazing. The living room and main bedroom are both at the rear of the block and the layout of the ground, mid and top floor flats is identical.*		
B2.2	Curtains	-	70	*Use of existing fitted curtains, which are closed during day*
B2.1	Internal Blinds	228	1,437	*Internal solar reflective blinds to each window, which are closed during day*
B2.4	External Shutters	1,386	4,310	*External solar reflective shutters to each window that provide a total block to solar radiation, which are closed during day*
B2.5	Low e triple glazing	7,303	9,900	*Low e triple glazing Low e triple glazing involves replacing the existing glazing with high performance low emissivity triple glazing. The inner and outer panes are coated to reflect solar radiation. They are an expensive option at an estimated cost of £6,100 for a 2-bed flat, but they also have the benefit of reducing winter heating energy use.*
B2.3	External fixed shading	532	2,228	*Fixed overhang shading to a horizontal depth of 1.0m above south, east and west facing windows*
B1.5	Upgrade flat roof	2,634	3,500	*Assumes costs shared by 8 flats. new highly insulated roof will have little impact for ground floor flats, but a larger impact on both overheating and winter heating costs for top floor flats*
A2.2	Solar reflective roof	373	479	*Coating the roof tiles with a high performance solar reflective paint*
A2.3	Solar reflective walls	746	958	*Coating the external walls with a high performance solar reflective paint*
B1.1	External wall insulation	8,873	10,297	*60mm phenolic foam to the external wall faces, 20mm render layer*
B1.4	Internal wall insulation	5,051	5,747	*60mm phenolic foam to the internal faces of external walls, dry lined with plasterboard*
B1.2	Cavity wall insulation	239	330	*Glass wool insulation*
B3.1	Remedial cross-ventilation/room protection	-	2,434	*Replacement of two windows*
Town House (mid terrace)		*The example terraced houses are typical of ones constructed towards the end of the 19th century. They have solid brick walls and a suspended timber ground floor. Some modernisation work has been carried out, including the addition of 100mm of loft insulation and the replacement of the single-glazed windows with uncoated uPVC double-glazing. The rear extensions, housing the kitchens and bathrooms, were added during the 20th century and have uninsulated brick/block cavity walls and solid concrete ground floors. The living rooms are at the front of the houses and the main bedrooms at the rear*		
B2.2	Curtains	-	70	*Use of existing fitted curtains, which are closed during day*

B2.1	Internal Blinds	228	1,916	*internal solar reflective blinds to each window, which are closed during day*
B2.4	External Shutters	1,386	3,951	*external solar reflective shutters to each window that provide a total block to solar radiation, which are closed during day*
B2.5	Low e triple glazing	7,200	9,900	*Low e triple glazing Low e triple glazing involves replacing the existing glazing with high performance low emissivity triple glazing. The inner and outer panes are coated to reflect solar radiation. They are an expensive (estimated cost £5,100 for a 3-bed terraced house), but they also have the benefit of reducing winter heating energy use.*
B2.3	External fixed shading	589	2,468	*fixed overhang shading to a horizontal depth of 1.0m above south, east and west facing windows (2.0m awnings to east and west ground floor windows except for front windows - due to proximity to pavement/road)*
B1.6	Extra loft insulation	180	230	*topping up the existing loft insulation*
A2.2	Solar reflective roof	839	1,078	*coating the roof tiles with a high performance solar reflective paint*
A2.3	Solar reflective walls	1,212	1,556	*coating the external walls with a high performance solar reflective paint*
B1.1	External wall insulation	8,770	10,177	*60mm phenolic foam to the external wall faces, 20mm render layer*
B1.4	Internal wall insulation	4,992	5,627	*60mm phenolic foam to the internal faces of external walls, dry lined with plasterboard*
B3.1	Remedial cross-ventilation/room protection	-	2,400	*Replacement of two windows*
Semi-detached		*The example semi-detached house is typical of those constructed from the 1930s to the 1950s. It has uninsulated brick cavity walls and the ground floor is uninsulated solid concrete. Some modernisation work has been carried out, including the addition of 100mm of loft insulation and the replacement of the single-glazed windows with uncoated uPVC double-glazing. The living room and main bedroom are both at the front of the house.*		
B2.2	Curtains	-	93	*Use of existing fitted curtains, which are closed during day*
B2.1	Internal Blinds	304	2,634	*internal solar reflective blinds to each window, which are closed during day*
B2.4	External Shutters	1,848	5,388	*external solar reflective shutters to each window that provide a total block to solar radiation, which are closed during day*
B2.5	Low e triple glazing	11,374	13,200	*Low e triple glazing Low e triple glazing involves replacing the existing glazing with high performance low emissivity triple glazing. The inner and outer panes are coated to reflect solar radiation. They are an expensive option at an estimated cost of £9,500 for a 3-bed semi-detached house, but they also have the benefit of reducing winter heating energy use.*
B2.3	External fixed shading	1,416	5,933	*fixed overhang shading to a horizontal depth of 1.0m above south, east and west facing windows (2.0m awnings to east and west ground floor windows except for front windows - due to proximity to pavement/road)*
B1.6	Extra loft insulation	180	240	*topping up the existing loft insulation*

A2.2	Solar reflective roof	932	1,197	*coating the roof tiles with a high performance solar reflective paint*
A2.3	Solar reflective walls	1,119	1,437	*coating the external walls with a high performance solar reflective paint*
B1.1	External wall insulation	13,000	15,086	*60mm phenolic foam to the external wall faces, 20mm render layer*
B1.4	Internal wall insulation	7,400	8,381	*60mm phenolic foam to the internal faces of external walls, dry lined with plasterboard*
B1.2	Cavity wall insulation	239	475	*glass wool insulation*
B3.1	Remedial cross-ventilation/room protection	-	2,844	*Replacement of two windows*
Detached House		*The example detached house is constructed to 2006 UK Building Regulations. brick/block cavity walls with cavity insulation, dry-lined using plasterboard on dabs, loft space, windows low e coated uPVC double-glazed. main bedroom at front, living room at rear*		
B2.2	Curtains	-	140	*Use of existing fitted curtains, which are closed during day*
B2.1	Internal Blinds	456	3,113	*fitting of internal solar reflective blinds to each window, closed during day*
B2.4	External Shutters	2,772	6,824	*fitting of external solar reflective shutters to each window that provide a total block to solar radiation, closed during day*
B2.5	Low e triple glazing	15,565	19,800	*high performance low emissivity triple glazing. The inner and outer panes are coated to reflect solar radiation.*
B2.3	External fixed shading	1,888	7,911	*fixed overhang shading to a horizontal depth of 1.0m above south, east and west facing windows (2.0m awnings to east and west ground floor windows except for front windows - due to proximity to pavement/road)*
A2.2	Solar reflective roof	1,492	1,916	*coating the roof tiles with a high performance solar reflective paint*
A2.3	Solar reflective walls	2,144	2,754	*coating the external walls with a high performance solar reflective paint*
B3.1	Remedial cross-ventilation/room protection	-	2,594	*Replacement of two windows*

3. Water Stress

This section discusses the approach used to assess water efficiency measures and key emerging results in relation to low-regret adaptation measures.

3.1 Headline Messages

Adaptation measures which are shown to be low-regret for water stress, using a simple criterion for economic low regret of CBR<1, include **end-of-life water efficiency measures** including WC (dual flush WC), shower, washroom and kitchen tap water efficiency measures.

New build water efficiency package was shown to be low-regret in relation to 110 L/person/day standard only.

In the case of discretionary retrofits, installation of low flow shower was shown to be the only low-regret measure and only when considered from household perspective.

3.2 Approach

Metrics

The assessment of adaptation measures aiming to reduce water stress considered household scale water efficiency measures, alternative water supply (e.g. rainwater harvesting) and design measures for low water use[35].

The benefits used in this economic assessment of water efficiency measures included the following metrics only:

- Reduced water bill to household consumers (savings on metered bills); and
- Avoided Long-run marginal costs (LRMC)[36] (water savings x LRMC) to reflect a societal perspective.

Costs of individual measures covered equipment, material and labour costs. Maintenance costs were calculated as a percentage of the capital costs. The assessment covered existing and new residential dwellings using the residential typology employed across all hazards (overheating, flooding and water stress).

In addition, reduced water abstraction and (hot) water consumption is also associated with reduced energy use. Indicators relating to reduced energy bill (household perspective) and avoided carbon costs (societal perspective) have been considered as part of a dedicated sensitivity scenario that covers wider benefits of water efficiency measures.

[35] In the case of droughts, emergency powers can be used to restrict water supplies and/or impose temporary restrictions on water consumption including temporary use bans, requests to re-use water for watering gardens etc. However, using the costs of these measures as a benchmark to assess benefits of adaptation would not be appropriate due to the inherent nature of droughts, i.e. a rare, although increasing in frequency, civil emergency event.

[36] The aim of climate change adaptation policies in relation to water stress is to "help create a freshwater environment capable of supporting the biodiversity it contains and the ecosystem services it provides" (UK CCRA, 2017). No suitable indicator is readily available to reflect benefits of reduced water stress on freshwater ecology. However, as current water policy already establishes controls for low flows with a view to protecting the environment, the costs associated with the use of alternative water supply source(s) (LRMC) represent a suitable proxy for the benefit. The model uses LRMC values for individual water companies expressed in pence/m^3. Ofwat states that Long run marginal cost (LRMC) is the additional cost of providing an extra unit of product (water) in the long term.

Model

Scope

The 2011 study carried out the assessment for the South East of England excluding London. This assessment covers the same geographic area. The area was chosen as it is most at risk of water stress in the UK, due to being the driest and the most populous area. London has been excluded from the analysis to ensure consistency with the 2011 study. No attempts were made to extrapolate the analysis to the national scale due to significant variation in water tariffs and LRMC even within the region.

Cost curves were developed using residential housing stock data available from 2016 English Housing Survey in 19 sub-groups representing dwelling type, size and age[37]. In reusing the model, housing stock data for 2017 was used and extended to future years using the reported new build rate from the period 2012-2017, assuming no demolition or upgrade.

No updated information was available from the 2016 English Housing Survey on the distribution of existing housing stock by dwelling type (e.g. terraced house, flat) within different age brackets (pre 1919, 1919-1980 and 1980-2017). The housing stock growth rate between 2008 and 2017 was used instead to calculate the number of dwellings in the 1980-2017 age bracket and to update the distribution of existing housing stock by age brackets.

The assessment considered water efficiency measures, alternative water supply (e.g. rainwater harvesting) and design measures for low water use in new builds that are applicable at the scale of individual dwellings (see Section 2.2 for the list of measures).

Application, i.e. uptake rate per measure (as a percentage of homes by dwelling type) in the 2011 study was estimated taking into account prevailing construction types for houses and flats of different ages. In the case of water efficiency measures, the original model used assumptions on the percentage of existing (50%) and new (100%) homes to which efficiency measures are applicable. No further details were provided on how these values have been derived and no changes were made in this study to anticipated uptake rates of water efficiency measures. Changing applicability rate would not affect cost-benefit ratio of water efficiency measures, but it would have an impact on the total volume of water saved (through larger and lower number of dwellings affected) and associated benefits[38].

Measures were assumed to achieve a constant reduction in water consumption in a given dwelling type, thereby reflecting technically feasible water use reductions associated with different measures. Following further research, no adjustments were made to account for consumer behaviour that could potentially negate or reduce water savings achieved (e.g. taking longer to shower in the case of a low flow shower). This is discussed in the section below on householder behaviour.

The 2011 study used data from a range of sources such as CLG, Waterwise that provided unit costs of measures. The dataset on the costs of adaptation measures included low, medium and high unit costs. Low and high unit costs were derived as -20% and +20% below/ above the medium, i.e. best estimate. The unit

[37] The analysis of flood resilience measures was carried out per dwelling type that was a factor of i) type of home (detached, semi-detached and flats); ii) age (4 groups); iii) household size.

[38] Water company reports in some cases provide relevant information on (baseline) ownership of different types of devices and associated water consumption. These reports, however, are not standardised and rarely use consumption brackets that match the definition of water efficient devices in this appraisal. Furthermore, there is a significant variation in the ownership and baseline water consumption across devices and different water company areas. For instance, information available for Sutton East Surrey Water suggests that 95% of households own a washing machine with the average consumption of 16.7 l but no information is available on the prevalence of water efficient devices within the total ownership. In the case of South East Water, on the other hand, data available suggest that 95% of households own a washing machine, of which 61% are less than 5 years old and use 50 l per cycle or less. Having regard to the number of water companies within the study region, partial reporting on micro-component values and the use of different approaches to report this information, deriving an updated regional baseline uptake estimate for water efficiency measures would be very challenging.

costs of water efficiency measures have been inflated to current prices (2018) using Consumer Price Index (CPI).

Anticipated benefits (i.e. savings on metered bills) were estimated using household water tariff, water supply and LRMC data using information published by water companies and Ofwat. Information on current water tariffs and number of households served have been sourced from water companies[39] and their Water Resources Management Plans. No updated information was available on LRMC per water company and 2011 model data was inflated to current prices using CPI.

Costs and benefits were assessed over 15-year and 45-year period. In the case of household benefits a discount rate of 8% was used to discount private costs and benefits, i.e. savings (in line with the 2011 study). For societal benefits and costs, discount rate set out in the HMT Green Book was used in the assessment (3.5% (0-30 years) and 3% (31-45 years).

Reduced water bills and avoided costs of alternative water supply constitute only a partial representation of anticipated benefits. Indicators relating to reduced energy bill (household perspective) and avoided carbon costs (societal perspective) have been incorporated in the updated version of the adaptation cost curves as part of a dedicated sensitivity scenario. The assessment used carbon emission factors to calculate avoided carbon emissions.

Effects of Householder behaviour

There are a number of ways in which householder behaviour may impact on actual water savings of measures installed in the home. Typically these may be broken down into:

1. Misunderstanding of how to use water efficient products – e.g. dual flush toilets used sub-optimally
2. Mistrust of water saving settings leading to under use – e.g. eco setting on dishwasher not used due to fear of inadequate performance
3. Rebound effect, i.e. awareness of product efficiency leading to reduced concern about length/amount of use – e.g. householder spending longer in the shower because they know they have an efficient shower head
4. Other unintended consequences – e.g. a more efficient dishwasher fails to wash cooking pots effectively, so householder then washes by hand afterwards or instead.

There is clear evidence of type 1 impacts occurring with dual flush toilets. A review of studies carried out in the USA (Funk, 2012) concluded that dual flush toilets typically use more water than expected due to the ratio between small and large flushes being lower than predicted. Average consumption from multiple trials was seen to be 5.64 litres per flush, which was similar to figures achieved by high efficiency single flush toilets.

A UK study concluded that a similar effect occurs in the UK. However, the resulting average water usage is lower than in the US studies, averaging 4.7 litres per flush. This is consistent with the figure proposed in the cost curve analysis. It is worth noting that lower volumes still may be possible – systems are available with design volumes of 2 litres and 4 litres for small and large flushes. Actual performance below 4 litres per flush has been measured and could potentially be replicated and further reduced over time through better public awareness.

There has been some discussion and assessment of type 3 impacts, but most studies have concentrated exclusively on agricultural water usage (Collins, 2012) (McGlade, 2012) (Dumont, 2012). Broader application of the principle has been discussed theoretically, but the common thread has been one of large-scale efficiencies leading to increased available supply and hence a reduction in the cost of water, in turn leading to greater consumption. This driver is not considered relevant to domestic water usage. There is evidence of

[39] List of water companies included Southern Water, Southeast Water, Thames Water, Anglian, Affinity, Portsmouth, Sutton East Surrey and Essex Suffolk

a rebound factor (lower costs leading to greater consumption) occurring with domestic energy efficiency improvements, but this is considered to be unlikely to be replicated for domestic water saving technologies.

Several studies have attempted to measure a rebound effect in relation to efficient domestic shower heads. (Pinzger, 2016) observed a rebound effect when shower heads with a flow restrictor were fitted in place of conventional showerheads. The savings were shown to be 38% compared to a modelled saving of 45%. As shower heads with flow restrictors are commonly considered to have a lower efficacy than their unrestricted counterparts, the reduced savings were considered to be due to the extra time required to fully rinse with the less effective replacement shower. Other studies, for example (Nadel, 2012), measured the performance of aerating shower heads, with efficacies presumed to be similar to the showers they were replacing. Both studies observed no rebound effect.

The limited evidence available suggests that a rebound effect can be expected where the fitting reduces performance of the shower, but not where the performance, or the user's perception of performance, remains unchanged.

We have assumed that any policies developed to promote the use of water efficient fittings and appliances would be designed to support those fittings and appliances with equivalent performance to the previous market standard, so as to maximise public acceptance and uptake.

We have found no reports of trials or other evidence to evaluate the incidence of type 2 or type 4 impacts. We have therefore been unable to make any corrections to savings figures on the basis of these potential impacts.

On the basis of all the above, no adjustments have been made to the projected savings figures in relation to unintended householder behaviour. However, further research may identify and evaluate actual impacts in the future, which may need to be applied to the calculations where appropriate.

Results

The following water stress adaptation measures were found to be economically low regret adaptation measures (CBR<1)[40]:

- Dual flush WC – end-of-life upgrade
- Low flow tap (pair) – end-of-life upgrade
- Click protect kitchen tap – end-of-life upgrade
- Low flow shower – end-of-life upgrade
- Low flow shower – discretionary retrofit (from household perspective only)
- New build water efficiency package 110 L/person/day standard – newbuild

Summary results of the assessment are presented in the table 3.1. Results covering non low-regret measures are presented in Appendix D.

From the societal perspective low flow showers (end of life upgrade) conferred significant economic savings up to the 2030s and 2060s, £251m and £403m respectively. This trend is consistent for the household perspective with low flow showers (discretionary retrofit and end of life upgrade) conferring the most significant savings (£190m and £151m respectively), followed by duel flush WC (end of life upgrade, £24m) and low flow tap (end of life upgrade, £19m).

[40] The original model aggregated total costs / total benefits per measure across the entire applicable housing stock. In some cases measures showing as not cost-beneficial as a whole, were found to be cost-beneficial at individual combinations of dwelling types and sizes.

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Table 3.1 Residential adaptation cost curve – low-regret water efficiency measures

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year Econ saving, mid (£m)**	**15-year Econ CBR, mid**	**Cumulative 15-year Econ saving, mid (£m)**	**15-year Household saving, mid (£m)**	**15-year Household CBR, mid**	**Cumulative 15-year Household saving, mid (£m)**	**45-year Econ saving, mid (£m)**	**45-year Econ CBR, mid**	**Cumulative 45-year Econ saving, mid (£m)**	**45-year Household saving, mid (£m)**	**45-year Household CBR, mid**	**Cumulative 45-year Household saving, mid (£m)**
11	Low flow shower – end-of-life upgrade	251	0.00	251	151	0.00	151	403	0.00	403	242	0.00	242
12	Low flow tap (pair) – end-of-life upgrade	31	0.00	283	19	0.00	170	62	0.00	465	37	0.00	279
10	Dual flush WC – end-of-life upgrade	39	0.00	322	24	0.00	193	78	0.00	543	47	0.00	326
21	110 L/person/day standard – newbuild	22	0.00	344	22	0.00	215	35	0.00	578	35	0.00	361
13	Click protect kitchen tap – end-of-life upgrade	12	0.00	355	7	0.00	222	23	0.00	601	14	0.00	374
2	Low flow shower – discretionary retrofit	-	-	-	190	0.70	412	-	-	-	190	0.70	564

Notes: Results are presented from societal and household perspective over two time periods: 15 and 45 years. Each set of results includes economic or household savings in £m; associated CBR and cumulative economic (LRMC based) and financial (water bill) savings.

Graphs

Water stress adaptation cost curves are presented below. Please note that low-regret measures are those located below the CBR=1 line (and listed in the table 3.1).

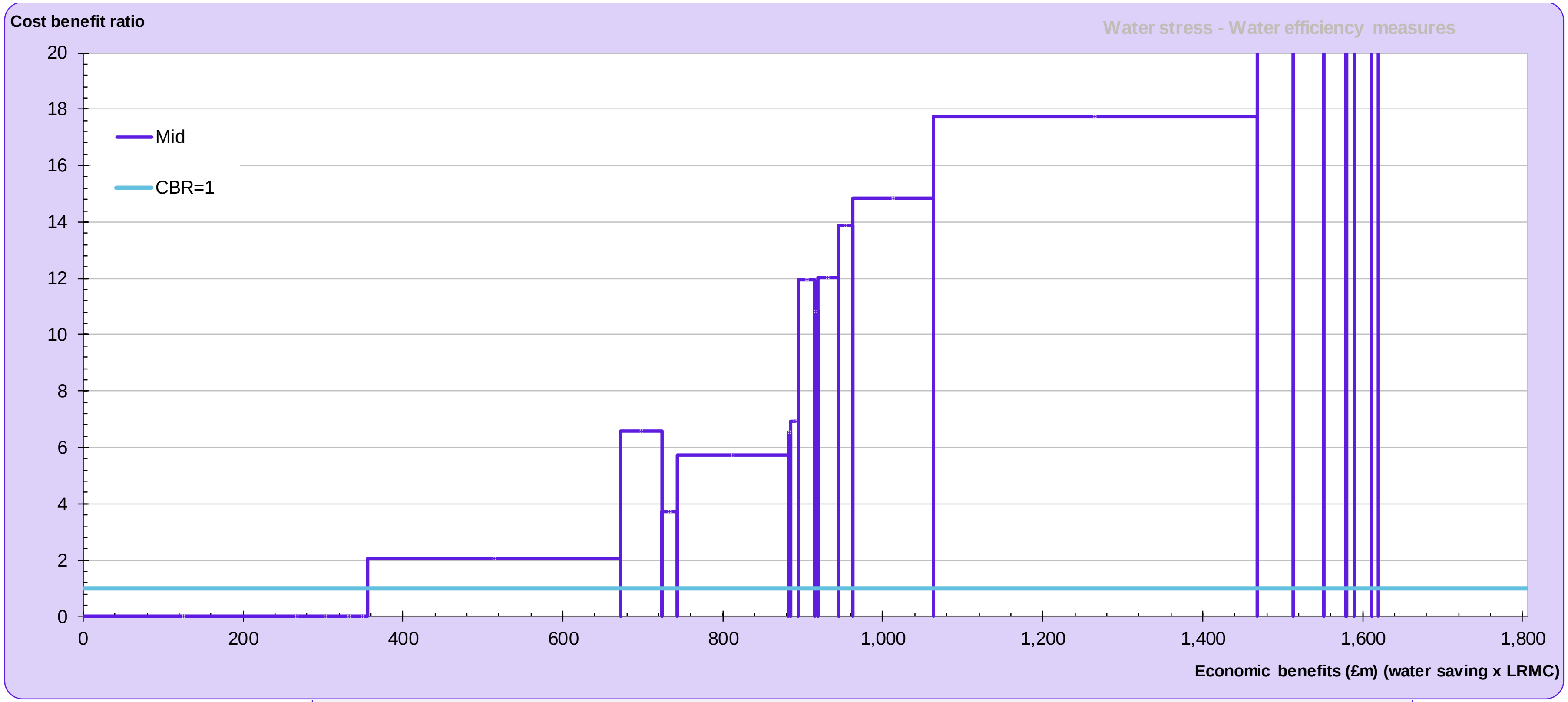

Chart type	Adaptation cost curve for ALL water efficiency measures, societal perspective	Cost benefit ratio	**y-axis units**
Sector	Residential, South East England	£m (2018)	**x-axis units**
Hazard - Adaptation	Water stress - Water efficiency measures	Year 1-30: 3.5%. Year 30+: 3%	**Discount rate**
Chart details	Headline summary with weighted average cost benefit ratios	to 2030s	**Period**

Figure 3.1 Residential adaptation cost curve - ALL water efficiency measures, to 2030s, societal perspective

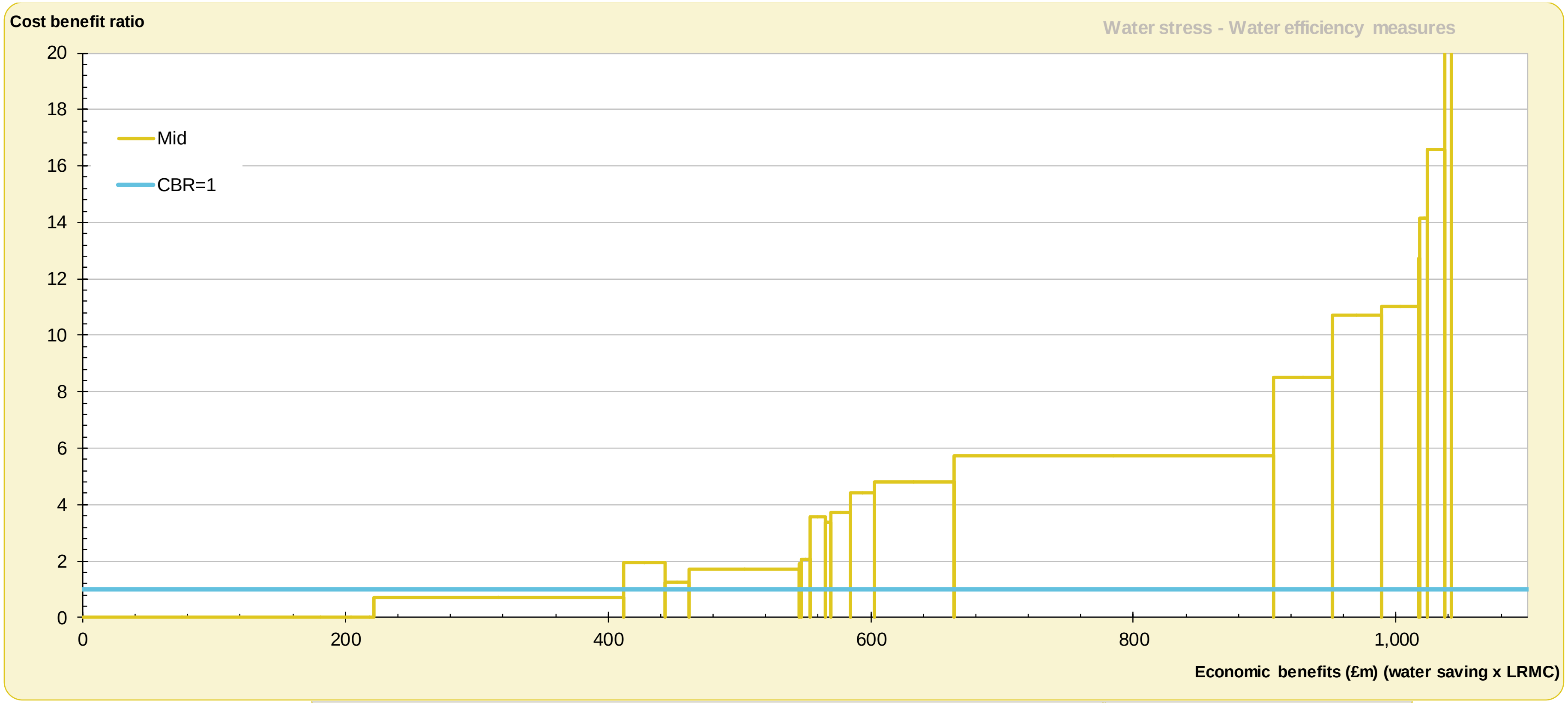

Chart type	Adaptation cost curve for ALL water efficiency measures, householder financial perspective	Cost benefit ratio (household)	**y-axis units**
Sector	Residential, South East England	£m (2018)	**x-axis units**
Hazard - Adaptation	Water stress - Water efficiency measures	8%	**Discount rate**
Chart details	Headline summary with weighted average cost benefit ratios	**to 2030s**	**Period**

Figure 3.2 Residential adaptation cost curve - ALL water efficiency measures, to 2030s, household perspective

Assessing water efficiency measures from household perspective results in one further low-regret measure (installation of low flow shower during discretionary retrofit). This is driven by a relatively higher water saving values from household perspective (water bills) in comparison to societal savings in the form of LRMCs.

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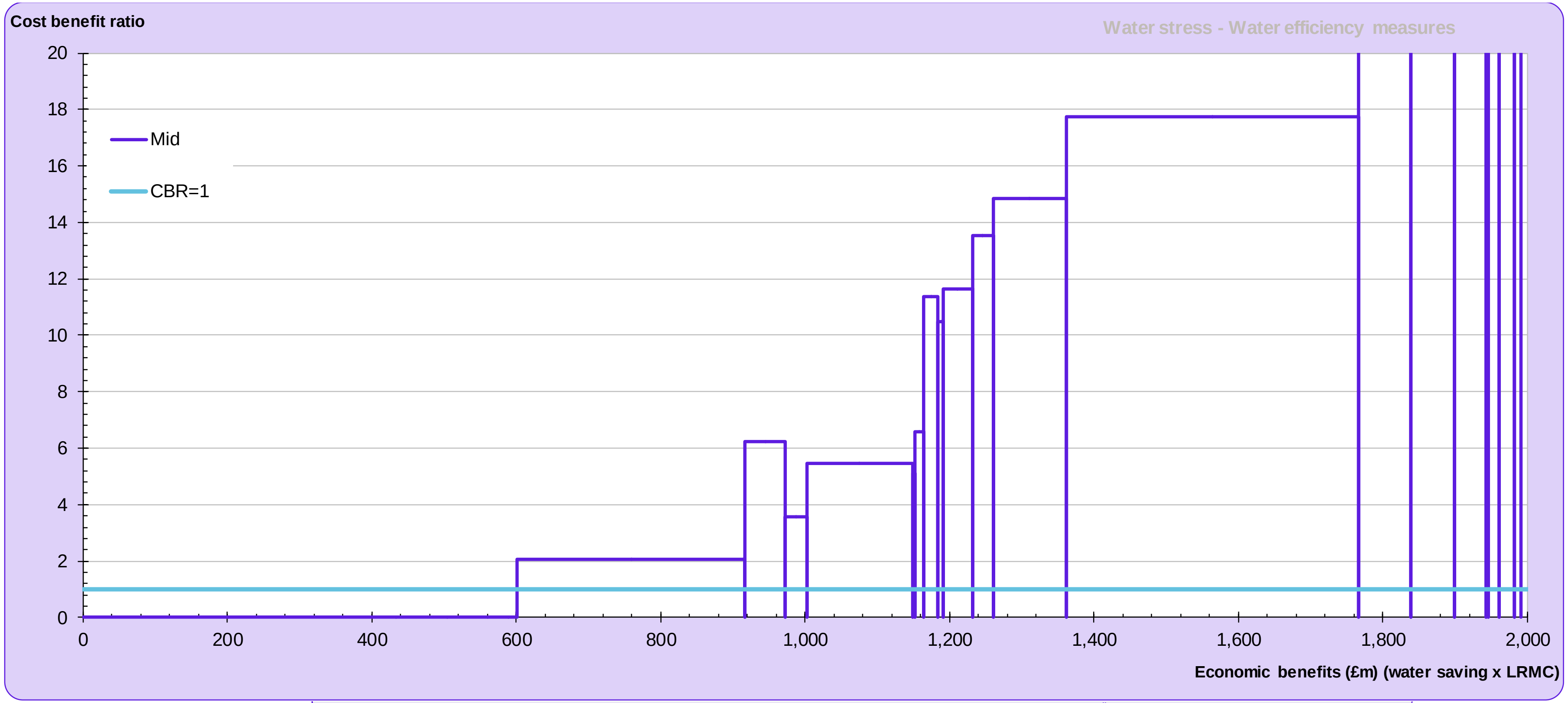

Chart type	Adaptation cost curve for ALL water efficiency measures, societal perspective	Cost benefit ratio	**y-axis units**
Sector	Residential, South East England	£m (2018)	**x-axis units**
Hazard - Adaptation	Water stress - Water efficiency measures	Year 1-30: 3.5%. Year 30+: 3%	**Discount rate**
Chart details	Headline summary with weighted average cost benefit ratios	to 2060s	**Period**

Figure 3.3 Residential adaptation cost curve - ALL water efficiency measures, to 2060s, societal perspective

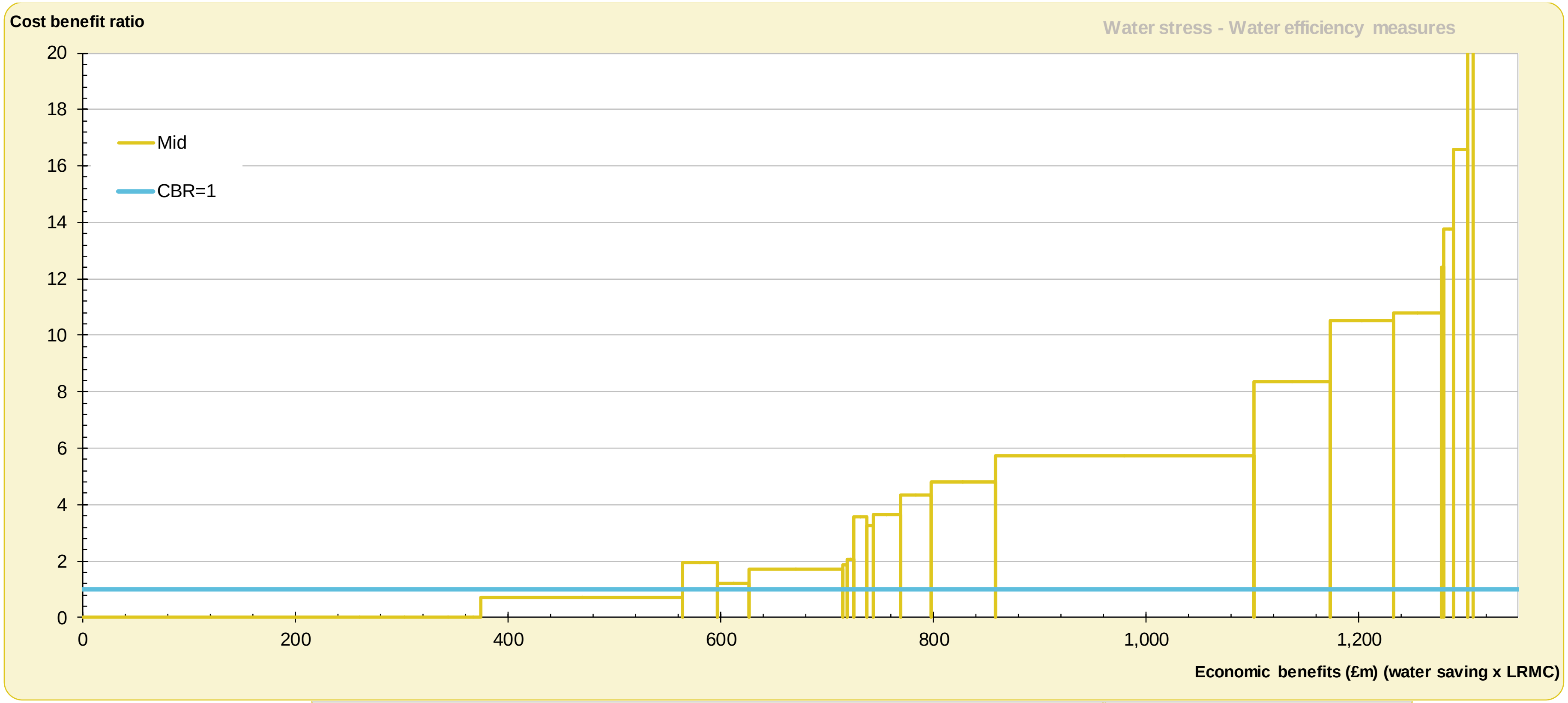

Chart type	Adaptation cost curve for ALL water efficiency measures, householder financial perspective	Cost benefit ratio	**y-axis units**
Sector	Residential, South East England	£m (2018)	**x-axis units**
Hazard - Adaptation	Water stress - Water efficiency measures	8%	**Discount rate**
Chart details	Headline summary with weighted average cost benefit ratios	**to 2060s**	**Period**

Figure 3.4 Residential adaptation cost curve - ALL water efficiency measures, to 2060s, household perspective

Sensitivity Analysis

Best- and worst-case estimates

The assessment also included consideration of the worst-case and best-case scenario. In particular:

- Best case scenario reflected low costs of measures (-20% of the base estimate) and high-water savings (+10% relative to water calculator default);
- Worst case scenario reflected high costs of measures (+20% of the base estimate) and low water savings (-10% relative to water calculator default)[41].

The results of the sensitivity scenarios are summarised in the table 3.2 and table 3.3. Full results are presented in the Appendix D.

Table 3.2 Residential adaptation cost curve – low-regret water efficiency measures (sensitivity scenario, 15 years)

ID	Measure description & application	15-year, societal CBR (best)	15-year, societal CBR (mid)	15-year, societal CBR (worst)	15-year, household CBR (best)	15-year, household CBR (mid)	15-year, household CBR (worst)
11	Low flow shower – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00
12	Low flow tap (pair) – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00
10	Dual flush WC – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00
21	110 L/person/day standard – newbuild	0.00	0.00	0.00	0.00	0.00	0.00
13	Click protect kitchen tap – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00
2	Low flow shower – discretionary retrofit	1.42	2.05	3.77	0.38	0.70	1.67
22	*105 L/person/day standard – newbuild**	*2.45*	*3.70*	*7.02*	*0.64*	*1.25*	*3.06*
1	*Dual flush WC – discretionary retrofit**	*3.98*	*5.72*	*8.19*	*0.95*	*1.71*	*3.86*

* Low regret measures attributed to sensitivity analysis

When considering best case scenario (from a household perspective) over 15-year time period, low-regret measures include in addition:

- New build water efficiency package 105 L/person/day standard – newbuild
- Installation of dual flush WC during discretionary retrofit

[41] No changes to the definition of high/ low thresholds were made in comparison to the 2011 Davis Langdon study.

Conversely, when considering worst case scenario, the list of low-regret measures excludes the installation of low flow shower during discretionary retrofit.

Table 3.3 Residential adaptation cost curve – low-regret water efficiency measures (sensitivity scenario, 45 years)

ID	Measure description & application	45-year, societal CBR (best)	45-year, societal CBR (mid)	45-year, societal CBR (worst)	45-year, household CBR (best)	45-year, household CBR (mid)	45-year, household CBR (worst)
11	Low flow shower – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00
12	Low flow tap (pair) – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00
10	Dual flush WC – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00
21	110 L/person/day standard – newbuild	0.00	0.00	0.00	0.00	0.00	0.00
13	Click protect kitchen tap – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00
2	Low flow shower – discretionary retrofit	1.36	2.05	3.77	0.38	0.70	1.67
22	*105 L/person/day standard – newbuild**	*1.99*	*3.58*	*6.80*	*0.62*	*1.22*	*2.98*
1	*Dual flush WC – discretionary retrofit**	*3.78*	*5.44*	*8.19*	*0.95*	*1.71*	*3.86*
18	*Water butt – newbuild**	*2.90*	*5.10*	*9.35*	*0.99*	*1.87*	*4.38*

* Low regret measures attributed to sensitivity analysis

When considering best case scenario (from a household perspective) over 45 year time period, low-regret measures further include the installation of water butt in newbuilds.

In the context of climate change projections, the 2011 study has been informed by water stress classification assessment that identified water companies projected to be at serious water stress under different climate change scenarios. Within this area (South East) 100% of properties were included in the cost curve analysis (baseline plus technically feasible future uptake). Therefore, it has not been possible to explicitly incorporate the recently released UKCP18 projections.

Wider benefits

The assessment considered wider benefits including reduced energy bill (household perspective) and avoided carbon costs (societal perspective). The results are summarised in the table 3.4, 3.5 and 3.6. Approach to assessing electricity and carbon savings is described in the Appendix A.

Table 3.4 Residential adaptation cost curve – estimated energy and carbon savings of water efficiency measures (wider benefits)

Measure	existing retrofit [mid]	existing replacement [mid]	new homes [mid]	Water savings (m3/per person per year)
Energy savings from reduced hot water consumption, kWh at point of use				
	kWh/year/ person	kWh/year/ person	kWh/year/ person	
Low flow shower	302.06	302.06	n/a	9.43
Low flow tap (pair)	177.27	177.27	n/a	3.67
Click protect kitchen tap	42.31	42.31	n/a	0.88
Low water washing machine	26.34	26.34	26.34	0.89
Low water dishwasher	17.53	17.53	17.53	0.33
Financial savings from reduced energy bills				
	£/year (person)	£/year (person)	£/year (person)	
Low flow shower	15.32	15.32	n/a	
Low flow tap (pair)	12.15	12.15	n/a	
Click protect kitchen tap	2.90	2.90	n/a	
Low water washing machine	5.02	5.02	5.02	
Low water dishwasher	3.34	3.34	3.34	
Carbon savings from reduced energy use				
	kg Co2/year (person)	kg Co2/year (person)	kg Co2/year (person)	
Low flow shower	77.98	77.98	n/a	
Low flow tap (pair)	45.76	45.76	n/a	
Click protect kitchen tap	10.92	10.92	n/a	
Low water washing machine	5.73	5.73	5.73	
Low water dishwasher	3.81	3.81	3.81	
Energy savings (household bills)				
	£ per m3 per year	£ per m3 per year	£ per m3 per year	
Low flow shower	162	162		
Low flow tap (pair)	331	331		
Click protect kitchen tap	331	331		
Low water washing machine	561	561	561	
Low water dishwasher	1008	1008	1008	

Measure	existing retrofit [mid]	existing replacement [mid]	new homes [mid]	Water savings (m3/per person per year)
Carbon savings*				
	£ per m3 per year	£ per m3 per year	£ per m3 per year	
Low flow shower	140	140		
Low flow tap (pair)	212	212		
Click protect kitchen tap	212	212		
Low water washing machine	109	109	109	
Low water dishwasher	196	196	196	

* Maximum value (trade prices of carbon) was used for sensitivity purposes (average over 45 year period)

Table 3.5 Residential adaptation cost curve – low-regret water efficiency measures (wider benefits) – household perspective

		Household perspective, to 2030s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year household benefits (£m)**	**15-year, household CBR**	**Cumulative 15-year household benefits (£m)**	**45-year household benefits (£m)**	**45-year, household CBR**	**Cumulative 45-year household benefits (£m)**
11	Low flow shower – end-of-life upgrade	374	0.00	374	599	0.00	599
12	Low flow tap (pair) – end-of-life upgrade	62	0.00	435	122	0.00	721
10	Dual flush WC – end-of-life upgrade	24	0.00	459	47	0.00	768
21	110 L/person/day standard – newbuild	22	0.00	481	35	0.00	802
13	Click protect kitchen tap – end-of-life upgrade	23	0.00	503	45	0.00	847
2	Low flow shower – discretionary retrofit	470	0.47	973	470	0.47	1,317
3	*Low flow tap (pair) – discretionary retrofit**	*103*	*0.97*	*1,077*	*109*	*0.97*	*1,426*

* Low regret measures attributed to sensitivity analysis

The inclusion of wider benefits associated with reduced energy bill (household perspective) resulted in a further measure being added to the low-regret water efficiency measures list. In particular, installation of low flow tap during discretionary retrofits has become a low-regret adaptation measure.

It should be noted that while measures such as installation of low water washing machine show significantly reduced cost benefit ratio (e.g. 1.23 as opposed to 10.82[42]), accounting for additional electricity savings is not sufficient for these to become low-regret measures.

[42] This is cost-benefit ratio without considering wider benefits of the measure (see Table D.1. Residential adaptation cost curve – non low-regret water efficiency measures in the Appendix D).

Table 3.6 Residential adaptation cost curve – low-regret water efficiency measures (wider benefits) – societal perspective

		Societal perspective, to 2030s			Societal perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits (£m)**	**15-year, societal CBR**	**Cumulative 15-year societal benefits (£m)**	**45-year societal benefits (£m)**	**45-year, societal CBR**	**Cumulative 45-year societal benefits (£m)**
11	Low flow shower – end-of-life upgrade	623	0.00	623	998	0.00	998
12	Low flow tap (pair) – end-of-life upgrade	103	0.00	725	204	0.00	1,202
10	Dual flush WC – end-of-life upgrade	39	0.00	765	78	0.00	1,279
21	110 L/person/day standard – newbuild	22	0.00	786	35	0.00	1,314
13	Click protect kitchen tap – end-of-life upgrade	38	0.00	824	75	0.00	1,389
2	*Low flow shower – discretionary retrofit**	*784*	*0.87*	*1,608*	*784*	*0.87*	*2,173*

* Low regret measures attributed to sensitivity analysis

When considering wider benefits from societal perspective (avoided carbon costs), the list of low-regret adaptation measures also includes installation of low flow shower during discretionary retrofits.

Measure based assessment (Equivalent Annual Costs)

Cost-benefit ratios were also derived for individual measure/ dwelling type/dwelling size combinations using Equivalent Annual Costs (EAC). The assessment considered i) capital and annual costs of different measures; ii) anticipated lifetime; iii) water savings (m^3 saved per measure); and iv) associated annual benefit values from societal and household perspectives. The results are presented in the Appendix D.

The assessment showed that in addition to low-regret water efficiency measures discussed above, a number of measures appear cost-beneficial for particular combinations of dwelling types, household sizes and intervention stages (while the measure overall is not cost-beneficial across total housing stock). For instance, installing a water efficient washing machine as part of an end-of-life upgrade is not cost-beneficial overall unless it is installed in large house with 4 people.

The summary of measures that are cost-beneficial for particular dwelling types and sizes is presented in the Table 3.7.

Table 3.7 Residential adaptation cost curve – low-regret combinations of water efficiency measures

ID	Stage	Low-regret measure	Household size	Types of dwellings/ hhld size s
Household perspective	Discretionary retrofit	Dual flush WC	2,3,4	<70m^2 semi- or terrcd, 2 people <70m^2 flat, 2 people 70 -110m^2 semi- or terrcd, 3 people/ 4 people 70 -110m^2 flat, 3 people/4 people 70 -110m^2 dtchd, 3 people/ 4 people >110m^2 dtchd, 4 people
	Discretionary retrofit	Low flow tap (pair)	2,4	<70m^2 semi- or terrcd, 2 people

				<70m^2 flat, 2 people 70 -110m^2 flat, 4 people 70 -110m^2 semi- or terrcd, 4 people 70 -110m^2 dtchd, 4 people
	Discretionary retrofit	Water butt	4	70 -110m^2 semi- or terrcd, 4 people 70 -110m^2 dtchd, 4 people >110m^2 dtchd, 4 people
	End-of-life upgrade	Low water washing machine	4	70 -110m^2 flat, 4 people 70 -110m^2 semi- or terrcd, 4 people 70 -110m^2 dtchd, 4 people >110m^2 dtchd, 4 people
	Newbuild	Low water washing machine	4	70 -110m^2 flat, 4 people 70 -110m^2 semi- or terrcd, 4 people 70 -110m^2 dtchd, 4 people >110m^2 dtchd, 4 people
	Newbuild	Water butt	4	70 -110m^2 semi- or terrcd, 4 people 70 -110m^2 dtchd, 4 people >110m^2 dtchd, 4 people
	Newbuild	105 L/person/day standard	2,3,4	70 -110m^2 semi- or terrcd, 3 people/ 4 people 70 -110m^2 dtchd, 2 people/4 people 70 -110m^2 flat, 3 people/ 4 people >110m^2 dtchd, 2 people >110m^2 dtchd, 4 people
Societal perspective	Discretionary retrofit	Low flow shower	2,3	<70m^2 flat, 2 people <70m^2 semi- or terrcd, 2 people 70 -110m^2 flat, 2 people/ 3 people 70 -110m^2 semi- or terrcd, 2 people/ 3 people 70 -110m^2 dtchd, 2 people
	Newbuild	105 L/person/day standard	3,4	70 -110m^2 flat, 3 people/ 4 people 70 -110m^2 semi- or terrcd, 3 people/4 people 70 -110m^2 dtchd, 4 people >110m^2 dtchd, 4 people

Discussion

Adaptation cost curves for water stress adaptation measures represent a conservative view on anticipated benefits as it only accounts for household water bill savings and avoided LRMC for water companies. Therefore, adaptation measures identified as low-regret water efficiency measures are cost-beneficial from household financial perspective (even without considering its beneficial environmental impact on reducing water stress). The same conclusion applies to the resulting list of low-regret measures which largely features measures applied to existing housing stock as part of the end-of-life replacements. Measures such as installation of low flow washing machines and dishwashers appear to be not cost-beneficial at any stage of housing stock (newbuild, end of life or discretionary retrofit due to relatively high costs of installation in comparison to anticipated water savings.

In addition to South East, East of England and parts of East Midlands are projected to be at serious water stress affecting operational areas of Anglian, Affinity and Essex and Suffolk Water. Volumetric water tariffs and LRMC for these water companies are comparatively lower than those in South East region leading to relative more modest benefits. However, low-regret measures identified for South East region including end-of-life upgrades to install low flow shower and taps as well as dual flush WC are associated with zero marginal unit costs in the case of end-of-life replacement. This suggests that these adaptation measures will be low-regret across all water stressed regions.

Consideration of wider benefits such as reduced energy use and electricity bill and avoided carbon emissions as part of sensitivity analysis has led to an expanded list of low-regret measures. However, use of assumptions with regard to electricity mix and anticipated electricity savings leads to some uncertainty.

The assessment is also associated with a number of limitations such as:

- The composite nature of water efficiency packages in new builds (corresponding to the 80, 90, 105 and 110 l per person per day) that prevented the analysis of individual components of the packages;
- The lack of updated long run marginal cost (LRMC) values resulted in the use of the original LRMC values (updated to current prices). As highlighted in the 2011 study, it is unclear to what extent these values accounted for climate change scenarios.
- The lack of incorporation of updated climate change scenarios within the analysis using the number of properties affected as the original analysis assumed 100% application of technically feasible water efficiency measures in the regions projected to be in serious water stress.

Conclusions

In the case of water stress, low-regret adaptation measures (with a CBR>1) included **end-of-life water efficiency measures** including WC (dual flush WC), shower, washroom and kitchen tap water efficiency measures. More specifically, economic low regret measures included installation of dual flush WC, low flow tap (pair), click protect kitchen tap and low flow shower as part of the end-of-life upgrade.

New build water efficiency package was shown to be low-regret in relation to 110 L/person/day standard only.

In the case of **discretionary retrofits** installation of low flow shower was shown to be the only low-regret measure and only when considered from household perspective.

Inclusion of wider benefits associated with reduced energy bill and avoided carbon costs resulted in an expanded list of low-regret measures due to increased levels of anticipated benefits (reduced energy bill/ carbon savings).

3.3 Updates on previous findings

Metrics

The addition of reduced energy bill and avoided carbon costs constitute the only methodological change in comparison to 2011 Davis Langdon study.

Results

Updates to housing stock and unit cost data did not lead to changes in the list of low-regret measures for water stress. Total estimated benefits and costs of adaptation measures have increased due to updating unit cost and benefit input data to current prices.

The inclusion of wider benefits such as reduced energy bill and avoided carbon costs in the assessment has led to the expansion of the low-regret measures for water stress (see Section 4.3)

4. Flooding

This section discusses the approach used to assess flood resilience and resistance measures and key emerging results in relation to low-regret adaptation measures.

4.1 Headline Messages

Adaptation measures which are low-regret for flood prevention, using a simple criterion for economic low regret of CBR<1, include installation of **flood resistance packages** (fit & forget and manual activation) across all types of residential dwellings. This measure is a economic low regret measure across all stages including newbuild, on repair and discretionary retrofit, when potential flooding is greater than 1% AEP.

Flood resilience measures were largely shown to be low-regret in newbuild dwellings. Installation of a new floor with treated timber joists during discretionary retrofits (repair) and of a wall-mounted boiler are the only measures which have a CBR<1 for existing dwellings (but only from societal perspective that uses lower discount rate).

In general terms:

- Flood resistance measures aim to prevent water entering the building and damaging it in the first place;
- Flood resilience measures aim to minimise impact of flooding and facilitate repair, drying & cleaning and subsequent reoccupation.

4.2 Approach

Metrics

The cost benefit assessment for flood resistance and flood resilience measures considered costs of implementation of different measures in residential buildings and value of avoided damages[43] (cost of repairs) as a benefit indicator. The assessment only covers measures that could be implemented by householders and developers of new homes and excludes any flood defence infrastructure and/or catchment scale flood management planning measures.

No other metric was used to consider the benefits of flood protection measures in the 2011 Davis Langdon study. The study, however, acknowledged that the valuation of damage associated with disruption and the financial impact of enforced absence from the house (e.g. the cost of hotels) could be added to the benefits if such data becomes available.

A recent evidence review carried out by FloodRe and UWE (Evidence review for property flood resilience. Phase 2 report) reported that the costs of evacuation (related to displacement from normal living space) typically forms a bulk of the indirect costs and could be quite substantial. In addition, human health benefits associated with mental stress linked to the disruption could be significant. Such wider benefits are considered in this assessment and reported in the adaptation cost curve under sensitivity scenario (Lamond et al., 2018).

[43] Unlike for other hazards, benefit assessment in the case of flooding for household and societal perspectives is the same with the difference in the results being driven by the use of different discount rates.

Model

The assessment was originally carried out for Yorkshire and Humberside region by Davis Langdon, and the same study area has been used here. It has a mix of rural and large urban areas at risk of flooding, and has suffered from flood events in the past.

The cost curves were developed using the same residential housing stock data as used for water stress and described above.

The Number of residential properties at risk of flooding constituted one of the key inputs in the development of the cost curves. The assessment used information on the current and future numbers of homes at risk of flooding at each of five risk levels referred to as Annual Exceedance Probability (AEP): 5%, 1.3%, 1%, 0.5% and 0.1% from the 2011 Davis Langdon study[44]. The number of residential properties at risk was then updated using the growth rate in residential housing from 2010-2017.

The assessment considered flood resilience and flood resistant measures that are applicable at the scale of individual dwellings (see Section 2.2 for the list of measures). Flood resilience measures were structured in terms of their applicability to floors, walls and interiors.

The 2011 study used data from the Association of British Insurers (ABI, 2009) that provided unit costs of measures and value of avoided damages for flood resilience measures. Anticipated costs and benefits (avoided damage) were calculated for different dwelling types while distinguishing between shallow (up to 5 cm) and deep (up to 1m) flooding.

The analysis also used the costs of 2 flood resistance packages (fit& forget and manual activation) distinguishing between end-of-life repair, discretionary retrofits and new builds for dwellings of different sizes.

The unit costs of flood resilience and resistance measures have been inflated to current 2018 prices using CPI.

Application, i.e. uptake rate per measure (as a percentage of homes by dwelling type) in the 2011 study was estimated taking into account prevailing construction types for houses and flats of different ages. No changes were made to anticipated uptake rates of measures by dwelling type and age e.g. pre-1919, 1919-1980 and post 1980.

In order to assess wider, indirect benefits of flood resilience and resistance measures, probability of evacuation, duration (in relation to flood depth) and costs of evacuation were included (see Appendix B).

In particular, the costs of evacuation include both a short-term emergency response to flooding aimed to limit loss of life and injury as well as evacuation from the property to allow flood damage to be repaired. In such cases, evacuation requires temporary or alternative accommodation for households affected and this incurs additional costs and the duration of evacuation has a major impact on total costs. A range of evacuation cost estimates are available including:

- For overview appraisals the MCM Handbook (2017) recommends using the total average cost of evacuation of £4,280 per household (based on an average evacuation of 23 weeks);
- Joseph (2014)[45] quotes an average of over £7,000 with the minimum cost of alternative accommodation of £590 and the maximum of £29,625.

The expected duration of evacuation has, therefore, significant impact on costs.

[44] The 2011 study used published Catchment Flood Management Plans (Environment Agency, 2009) as a source of data on the number of current and future residential properties at risk of flooding (by dwelling type) distinguishing between shallow (up to 0.5 m) and deep (over 0.5 m) flood and different risk levels.
[45] Joseph, R. D. 2014. Development of a comprehensive systematic quantification of the costs and benefits (CB) of property level flood risk adaptation measures in England. PhD, University of the West of England (cited in Lamond et al., 2018)

Deployment of flood resilience and resistance measures would contribute to an increased speed of reoccupation (flood resilience measures) or potentially avoid the need for evacuation and result in no displacement of people (flood resistance measures).

The FloodRe and UWE (Evidence review for property flood resilience. Phase 2 report) report indicates that it is generally assumed that flood resistance measures will result in zero displacement. In the case of flood resilience measures, there are no studies that quantify the increased speed of reoccupation. Anecdotal evidence suggests that successful full-scale resilience adoption allows reoccupation of the affected property within 24 hours, thus obviating the need to relocate (occupants can often stay upstairs while any repairs are carried out to address specific residual problems).

The period of evacuation time is also strongly associated with intangible health impacts. The FloodRe and UWE report suggests that studies show that stress and mental health issues are related to length of evacuation. Therefore, implementation of flood resilience and resistance measures can help in reducing time for repair and recovery after flooding and positively affect mental health.

A range of unit values associated with intangible human health costs are available including:

- MCM Handbook (2017) recommends using the average value of £232 per household per year to account for the potential value of avoiding intangible health impacts associated with floods.
- Owusu (2014)[46] assessed intangible human health benefits at £795 per household per year; and
- Joseph (2014)[47] reports a value of £653 per household per year (see Appendix B).

The assessment has been expanded to include avoided costs of evacuation and mental health benefits as a dedicated sensitivity scenario.

Results

The following flood resilience and resistance measures were found to be economically low regret adaptation measures (CBR<1 at ≥ 1% AEP):

- Raise floor above likely flood level, newbuild, all floods
- Chemical damp-proof course, newbuild, all floods
- Move service meters above flood level, newbuild, all floods
- Move washing machine to first floor, newbuild, all floods
- Move electrics above flood level, newbuild, deep floods
- Raised, newbuild, built-under oven, newbuild, all floods
- Wall-mounted boiler, newbuild, all floods
- Flood resistance package, manual activation, all floods - newbuild, on repair and discretionary retrofit
- Flood resistance package, fit & forget, all floods- newbuild, on repair and discretionary retrofit
- New floor with treated timber joists, newbuild, all floods (societal perspective only)
- New floor with treated timber joists, on repair, all floods (societal perspective only)

[46] Owusu, S. 2014. Public attitudes towards flooding and property level flood protection (PLFP) uptake. PhD, Heriot-Watt University (cited in Lamond et al., 2018)
[47] Joseph, R. D. 2014. Development of a comprehensive systematic quantification of the costs and benefits (CB) of property level flood risk adaptation measures in England. PhD, University of the West of England (cited in Lamond et al., 2018)

- Wall-mounted boiler, on repair, all floods (societal perspective only)

Summary results of the assessment are presented in the table 4.1. Results covering non low-regret measures are presented in the Appendix E.

From the societal perspective flood resistance packages (manual activation and fit& forget, discretionary retrofit conferred significant economic savings up to the 2030s. These were £6.7m and £10.2m for deep and shallow floods respectively.

Low-regret flood resilience measures (while relatively more cost-beneficial) were associated with lower benefits in absolute terms. Raising the floor above likely flood level in newbuilds conferred the benefits of £0.07m.

Cumulative societal benefits associated with low-regret measures were £38m and £45m over a 15-year and 45-year time period respectively.

Table 4.1 Residential adaptation cost curve – low-regret flood resistance and resilience measures

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, societal CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, societal CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
73	Raise floor above likely flood level, newbuild, shallow floods	0.07	0.00	0.07	0.07	0.00	0.07	0.18	0.00	0.18	0.18	0.00	0.18
90	Raise floor above likely flood level, newbuild, deep floods	0.07	0.00	0.14	0.07	0.00	0.14	0.19	0.00	0.37	0.19	0.00	0.37
76	Chemical damp-proof course, newbuild, shallow floods	0.00	0.00	0.15	0.00	0.00	0.15	0.01	0.00	0.38	0.01	0.00	0.38
99	Move service meters above flood level, newbuild, deep floods	0.00	0.00	0.15	0.00	0.00	0.15	0.01	0.00	0.39	0.01	0.00	0.39
93	Chemical damp-proof course, newbuild, deep floods	0.00	0.00	0.15	0.00	0.00	0.15	0.01	0.00	0.39	0.01	0.00	0.39
79	Move washing machine to first	0.00	0.00	0.15	0.00	0.00	0.15	0.00	0.00	0.40	0.00	0.00	0.40

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, societal CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, societal CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
	floor, newbuild, shallow floods												
82	Move service meters above flood level, newbuild, shallow floods	0.00	0.00	0.16	0.00	0.00	0.16	0.00	0.00	0.40	0.00	0.00	0.40
98	Move electrics above flood level, newbuild, deep floods	0.00	0.00	0.16	0.00	0.00	0.16	0.00	0.00	0.41	0.00	0.00	0.41
96	Move washing machine to first floor, newbuild, deep floods	0.00	0.00	0.16	0.00	0.00	0.16	0.00	0.00	0.41	0.00	0.00	0.41
80	Raised, newbuild, built-under oven, newbuild, shallow floods	0.00	0.00	0.16	0.00	0.00	0.16	0.00	0.00	0.41	0.00	0.00	0.41
97	Raised, newbuild, built-under oven, newbuild, deep floods	0.00	0.00	0.16	0.00	0.00	0.16	0.00	0.00	0.41	0.00	0.00	0.41
78	Wall-mounted boiler, newbuild, shallow floods	0.00	0.00	0.16	0.00	0.00	0.16	0.00	0.00	0.42	0.00	0.00	0.42

ID	Measure description & application	Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
		15-year societal benefits @ ≥ 1% AEP (£m)	15-year, societal CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, household CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, societal CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, household CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
95	Wall-mounted boiler, newbuild, deep floods	0.00	0.00	0.16	0.00	0.00	0.16	0.00	0.00	0.42	0.00	0.00	0.42
34	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, deep floods	6.69	0.24	6.85	6.69	0.39	6.85	7.03	0.24	7.45	7.03	0.39	7.45
17	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, shallow floods	10.22	0.25	17.07	10.22	0.41	17.07	10.75	0.25	18.20	10.75	0.41	18.20
102	Flood resistance package, newbuild, manual activation, newbuild, deep floods	0.07	0.27	17.15	0.07	0.44	17.15	0.19	0.26	18.39	0.19	0.33	18.39
85	Flood resistance package, newbuild, manual activation,	0.07	0.29	17.22	0.07	0.46	17.22	0.18	0.27	18.56	0.18	0.35	18.56

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, societal CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, societal CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
	newbuild, shallow floods												
101	Flood resistance package, newbuild, fit & forget, newbuild, deep floods	0.07	0.31	17.29	0.07	0.50	17.29	0.19	0.30	18.75	0.19	0.38	18.75
33	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, deep floods	6.69	0.32	23.98	6.69	0.52	23.98	7.03	0.32	25.79	7.03	0.52	25.79
84	Flood resistance package, newbuild, fit & forget, newbuild, shallow floods	0.07	0.33	24.05	0.07	0.53	24.05	0.18	0.32	25.96	0.18	0.41	25.96
16	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, shallow floods	10.22	0.34	34.27	10.22	0.55	34.27	10.75	0.34	36.71	10.75	0.55	36.71

ID	Measure description & application	Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
		15-year societal benefits @ ≥ 1% AEP (£m)	15-year, societal CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, household CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, societal CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, household CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
68	Flood resistance package, on repair, manual activation, on repair, deep floods	0.61	0.32	34.88	0.61	0.52	34.88	1.59	0.31	38.30	1.59	0.40	38.30
51	Flood resistance package, on repair, manual activation, on repair, shallow floods	0.94	0.34	35.82	0.94	0.55	35.82	2.42	0.33	40.72	2.42	0.42	40.72
67	Flood resistance package, on repair, fit & forget, on repair, deep floods	0.61	0.37	36.43	0.61	0.60	36.43	1.59	0.35	42.31	1.59	0.45	42.31
50	Flood resistance package, on repair, fit & forget, on repair, shallow floods	0.94	0.39	37.37	0.94	0.63	37.37	2.42	0.37	44.73	2.42	0.48	44.73
88	New floor with treated timber joists, newbuild, deep floods	0.01	0.75	37.38				0.02	0.72	44.75	0.02	0.93	44.75
71	New floor with treated timber	0.01	0.75	37.39				0.02	0.72	44.77	0.02	0.93	44.77

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, societal CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, societal CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
	joists, newbuild, shallow floods												
54	New floor with treated timber joists, on repair, deep floods	0.06	0.84	37.45				0.16	0.80	44.93			
37	New floor with treated timber joists, on repair, shallow floods	0.10	0.84	37.55				0.26	0.80	45.19			
61	Wall-mounted boiler, on repair, deep floods	0.00	0.95	37.55				0.01	0.91	45.20			
44	Wall-mounted boiler, on repair, shallow floods	0.00	0.95	37.56				0.01	0.91	45.21			

Graphs

Flood resilience and resistance adaptation cost curves are presented below..

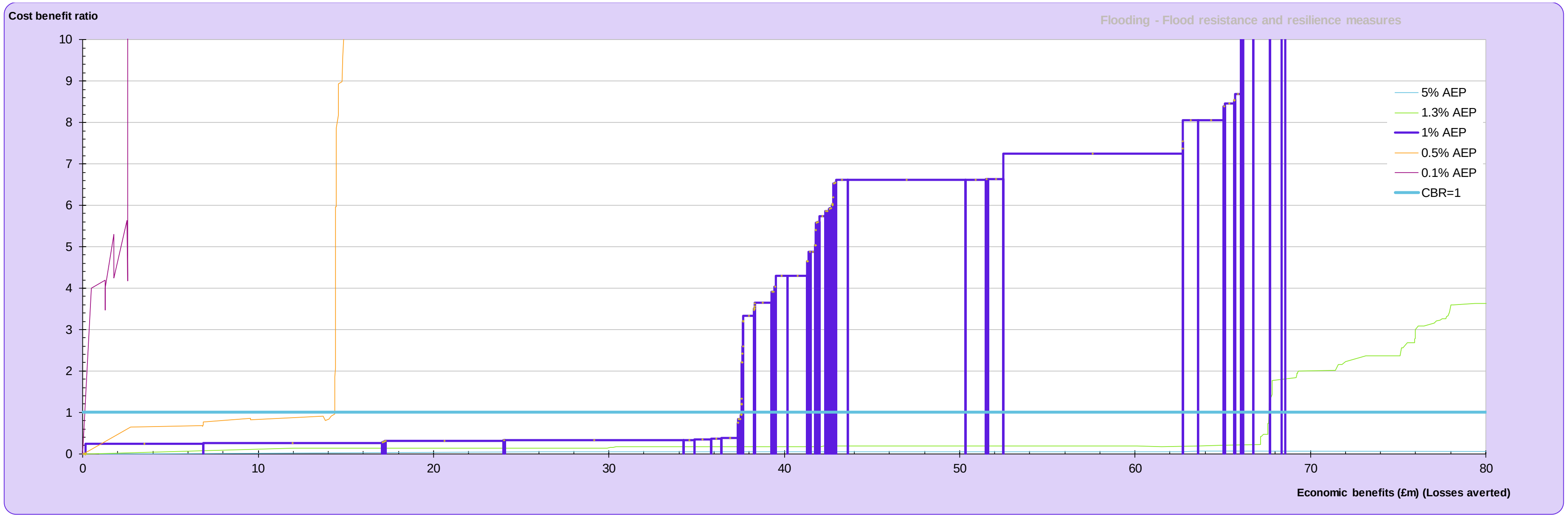

Chart type	Adaptation cost curve for retrofit measures, societal perspective	Cost benefit ratio (societal)	**y-axis units**
Sector	Residential, Aire sub-catchment, Yorkshire & Humber	£m (2018)	**x-axis units**
Hazard - Adaptation	Flooding - Flood resistance and resilience measures	Year 1-30: 3.5%. Year 30+: 3%	**Discount rate**
Chart details	Headline summary with weighted average cost benefit ratios	to 2030s	**Period**

Figure 4.1 Residential adaptation cost curve - ALL flood resistance and resilience measures, to 2030s, societal perspective

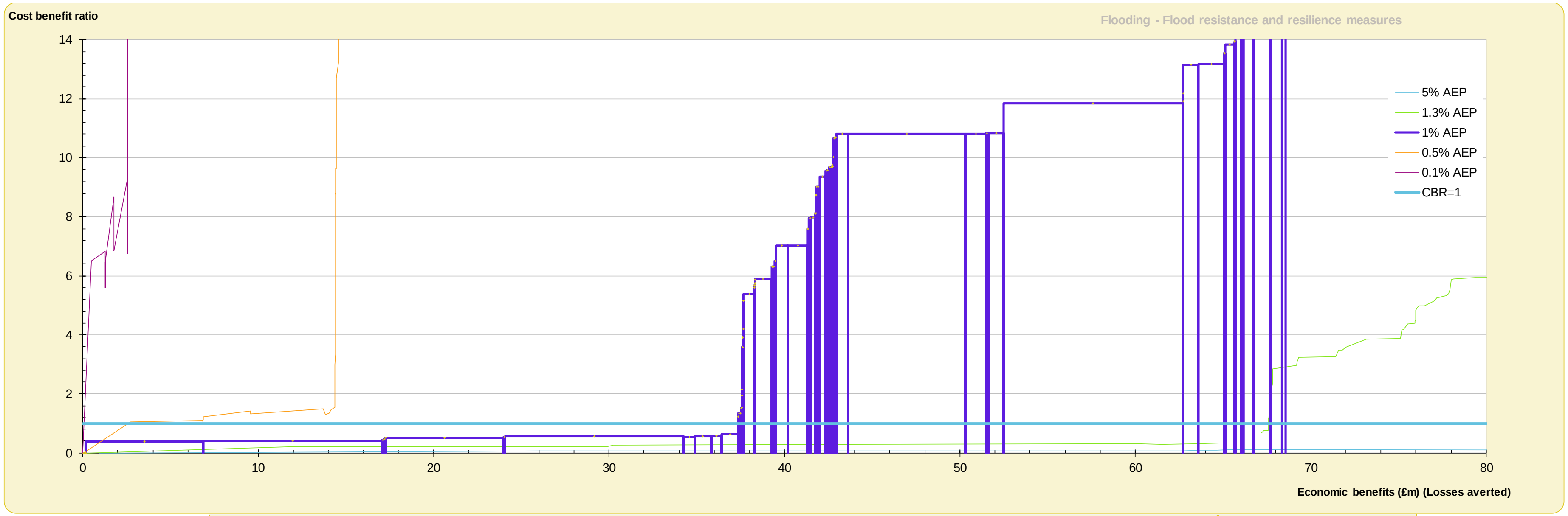

Chart type	Adaptation cost curve for retrofit measures, household perspective	Cost benefit ratio (household)	**y-axis units**
Sector	Residential, Aire sub-catchment, Yorkshire & Humber	£m (2018)	**x-axis units**
Hazard - Adaptation	Flooding - Flood resistance and resilience measures	8.0%	**Discount rate**
Chart details	Headline summary with weighted average cost benefit ratios	**to 2030s**	**Period**

Figure 4.2 Residential adaptation cost curve - ALL flood resistance and resilience measures, to 2030s, household perspective

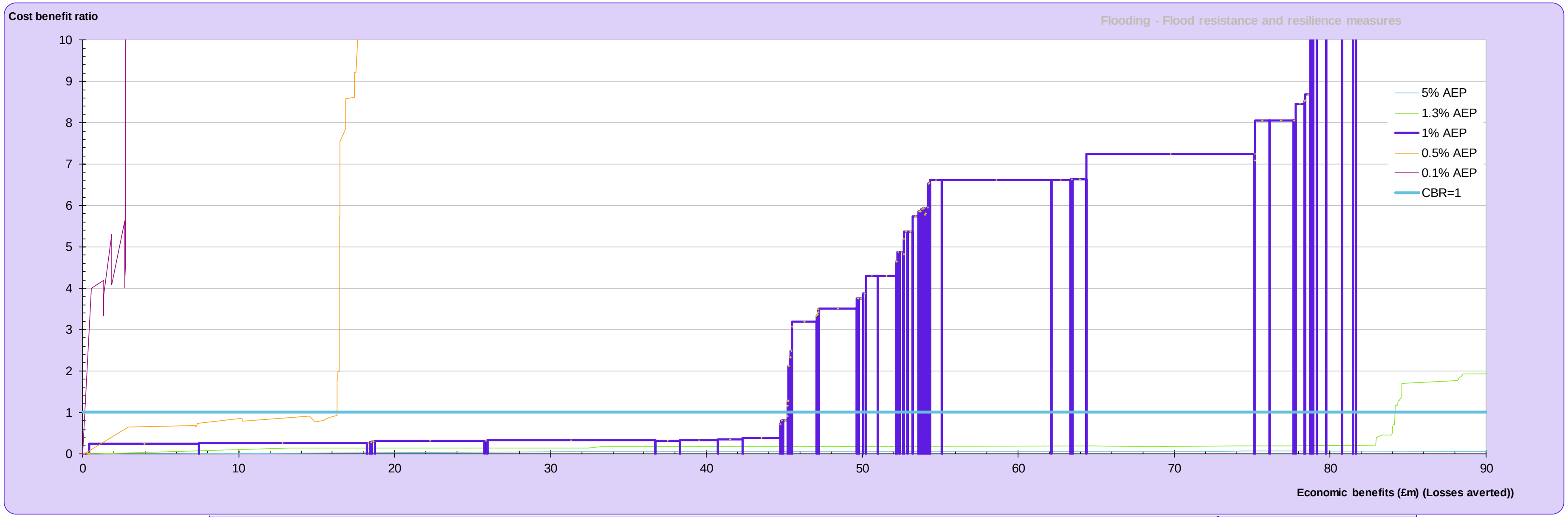

Chart type	Adaptation cost curve for retrofit measures, societal perspective	Cost benefit ratio (societal)	**y-axis units**
Sector	Residential, Aire sub-catchment, Yorkshire & Humber	£m (2018)	**x-axis units**
Hazard - Adaptation	Flooding - Flood resistance and resilience measures	Year 1-30: 3.5%. Year 30+: 3%	**Discount rate**
Chart details	Headline summary with weighted average cost benefit ratios	to 2060s	**Period**

Figure 4.3 Residential adaptation cost curve - ALL flood resistance and resilience measures, to 2060s, societal perspective

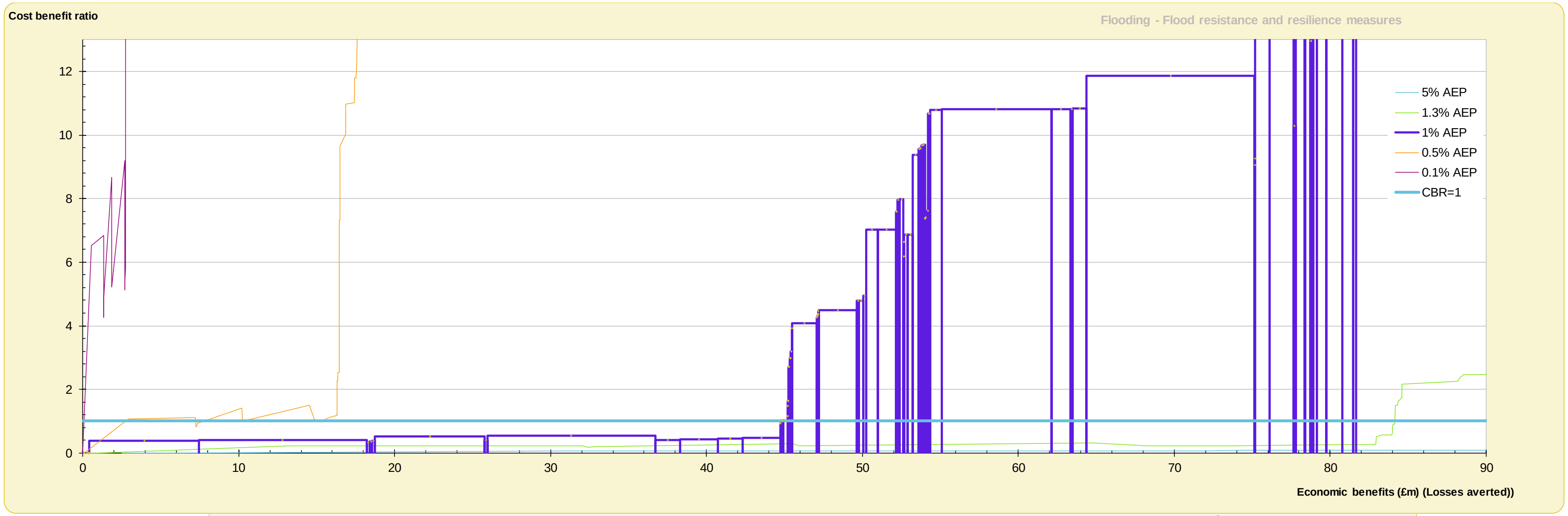

Chart type	Adaptation cost curve for retrofit measures, household perspective	Cost benefit ratio (household)	**y-axis units**
Sector	Residential, Aire sub-catchment, Yorkshire & Humber	£m (2018)	**x-axis units**
Hazard - Adaptation	Flooding - Flood resistance and resilience measures	8.0%	**Discount rate**
Chart details	Headline summary with weighted average cost benefit ratios	**to 2060s**	**Period**

Figure 4.4 Residential adaptation cost curve - ALL flood resistance and resilience measures, to 2060s, household perspective

Sensitivity Analysis

Best-case and worst-case estimates

The assessment also included consideration of the worst-case and best-case scenario. In particular:

- Best case scenario reflected low costs of measures (-20% of the base estimate) and high savings/societal benefits (+10% in averted loses in comparison to ABI baseline);
- Worst case scenario reflected high costs of measures (+20% of the base estimate) and low savings/ societal benefits (-25% in averted loses in comparison to ABI baseline)[48].

The results of the sensitivity scenarios are summarised in the table 4.2 and table 4.3.

Table 4.2 Residential adaptation cost curve – low-regret flood resistance and resilience measures (sensitivity scenario, 15 years)

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)
73	Raise floor above likely flood level, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
90	Raise floor above likely flood level, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
76	Chemical damp-proof course, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
99	Move service meters above flood level, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
93	Chemical damp-proof course, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
79	Move washing machine to first floor, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
82	Move service meters above flood level, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
98	Move electrics above flood level, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
96	Move washing machine to first floor, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00

[48] No changes to the definition of high/ low thresholds were made in comparison to the 2011 Davis Langdon study.

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)
80	Raised, newbuild, built-under oven, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
97	Raised, newbuild, built-under oven, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
78	Wall-mounted boiler, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
95	Wall-mounted boiler, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
34	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, deep floods	0.15	0.24	0.45	0.27	0.39	0.68
17	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, shallow floods	0.16	0.25	0.47	0.28	0.41	0.71
102	Flood resistance package, newbuild, manual activation, newbuild, deep floods	0.17	0.27	0.51	0.30	0.44	0.97
85	Flood resistance package, newbuild, manual activation, newbuild, shallow floods	0.18	0.29	0.54	0.32	0.46	1.03
101	Flood resistance package, newbuild, fit & forget, newbuild, deep floods	0.20	0.31	0.59	0.35	0.50	1.12
33	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, deep floods	0.20	0.32	0.60	0.36	0.52	0.90
84	Flood resistance package, newbuild, fit & forget, newbuild, shallow floods	0.21	0.33	0.62	0.37	0.53	1.19
16	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, shallow floods	0.22	0.34	0.64	0.38	0.55	0.96
68	Flood resistance package, on repair, manual activation, on repair, deep floods	0.21	0.32	0.61	0.36	0.52	1.17
51	Flood resistance package, on repair, manual activation, on repair, shallow floods	0.22	0.34	0.64	0.38	0.55	1.23

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)
67	Flood resistance package, on repair, fit & forget, on repair, deep floods	0.24	0.37	0.70	0.41	0.60	1.33
50	Flood resistance package, on repair, fit & forget, on repair, shallow floods	0.25	0.39	0.74	0.44	0.63	1.40
88	*New floor with treated timber joists, newbuild, deep floods**	*0.48*	*0.75*	*1.42*	*0.84*	*1.22*	*2.71*
71	*New floor with treated timber joists, newbuild, shallow floods**	*0.48*	*0.75*	*1.43*	*0.84*	*1.22*	*2.71*
54	*New floor with treated timber joists, on repair, deep floods**	*0.53*	*0.84*	*1.58*	*0.94*	*1.35*	*3.01*
37	*New floor with treated timber joists, on repair, shallow floods**	*0.53*	*0.84*	*1.58*	*0.94*	*1.35*	*3.01*
61	*Wall-mounted boiler, on repair, deep floods**	*0.60*	*0.95*	*1.79*	*1.06*	*1.53*	*3.41*
44	*Wall-mounted boiler, on repair, shallow floods**	*0.61*	*0.95*	*1.79*	*1.06*	*1.53*	*3.41*
86	*Dense screed, newbuild, deep floods**	*0.76*	*1.20*	*2.26*	*1.34*	*1.93*	*4.31*
69	*Dense screed, newbuild, shallow floods**	*0.77*	*1.20*	*2.27*	*1.34*	*1.94*	*4.31*
52	*Dense screed, on repair, deep floods**	*0.85*	*1.33*	*2.52*	*1.49*	*2.15*	*4.79*
35	*Dense screed, on repair, shallow floods**	*0.85*	*1.33*	*2.52*	*1.49*	*2.15*	*4.79*

* Low regret measures attributed to sensitivity analysis

When considering best case scenario over 15 year time period, low-regret measures include dense screed installation in new builds and on repair for all floods. Conversely, when considering worst case scenario (high costs / low savings), the list of low-regret measures is reduced to exclude:

- New floor with treated timber joists, newbuild, all floods
- New floor with treated timber joists, on repair, all floods

- Wall-mounted boiler, on repair, all floods

Table 4.3 Residential adaptation cost curve – low-regret flood resistance and resilience measures (sensitivity scenario, 45 years)

ID	Measure description & application	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
73	Raise floor above likely flood level, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
90	Raise floor above likely flood level, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
76	Chemical damp-proof course, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
99	Move service meters above flood level, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
93	Chemical damp-proof course, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
79	Move washing machine to first floor, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
82	Move service meters above flood level, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
98	Move electrics above flood level, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
96	Move washing machine to first floor, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
80	Raised, newbuild, built-under oven, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
97	Raised, newbuild, built-under oven, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00
78	Wall-mounted boiler, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00
95	Wall-mounted boiler, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00

ID	Measure description & application	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
34	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, deep floods	0.15	0.24	0.45	0.27	0.39	0.68
17	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, shallow floods	0.16	0.25	0.47	0.28	0.41	0.71
102	Flood resistance package, newbuild, manual activation, newbuild, deep floods	0.16	0.26	0.49	0.23	0.33	0.57
85	Flood resistance package, newbuild, manual activation, newbuild, shallow floods	0.17	0.27	0.52	0.24	0.35	0.61
101	Flood resistance package, newbuild, fit & forget, newbuild, deep floods	0.19	0.30	0.56	0.26	0.38	0.66
33	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, deep floods	0.20	0.32	0.60	0.36	0.52	0.90
84	Flood resistance package, newbuild, fit & forget, newbuild, shallow floods	0.20	0.32	0.60	0.28	0.41	0.71
16	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, shallow floods	0.22	0.34	0.64	0.38	0.55	0.96
68	Flood resistance package, on repair, manual activation, on repair, deep floods	0.20	0.31	0.59	0.28	0.40	0.69
51	Flood resistance package, on repair, manual activation, on repair, shallow floods	0.21	0.33	0.62	0.29	0.42	0.73
67	Flood resistance package, on repair, fit & forget, on repair, deep floods	0.23	0.35	0.67	0.31	0.45	0.79
50	Flood resistance package, on repair, fit & forget, on repair, shallow floods	0.24	0.37	0.71	0.33	0.48	0.83
88	New floor with treated timber joists, newbuild, deep floods	0.46	0.72	1.37	0.64	0.93	1.61
71	New floor with treated timber joists, newbuild, shallow floods	0.46	0.72	1.37	0.64	0.93	1.61

ID	Measure description & application	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
54	New floor with treated timber joists, on repair, deep floods	0.51	0.80	1.52	0.71	1.03	1.79
37	New floor with treated timber joists, on repair, shallow floods	0.51	0.80	1.53	0.71	1.03	1.79
61	Wall-mounted boiler, on repair, deep floods	0.58	0.91	1.72	0.81	1.16	2.02
44	Wall-mounted boiler, on repair, shallow floods	0.58	0.91	1.73	0.81	1.16	2.02
86	Dense screed, newbuild, deep floods	0.73	1.15	2.18	1.02	1.47	2.55
69	Dense screed, newbuild, shallow floods	0.73	1.15	2.18	1.02	1.47	2.56
52	Dense screed, on repair, deep floods	0.81	1.28	2.42	1.13	1.63	2.84
35	Dense screed, on repair, shallow floods	0.81	1.28	2.42	1.13	1.64	2.84

Wider benefits

The assessment considered wider benefits including avoided costs of evacuation and human health impacts (input unit values used are summarised in the Appendix B). The results are summarised in the table 4.4.

Table 4.4 Residential adaptation cost curve – low-regret flood resistance and resilience measures (wider benefits)

		Household perspective, to 2030s			**Household perspective, to 2060s**		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
73	Raise floor above likely flood level, newbuild, shallow floods	0.07	0.00	0.07	0.22	0.00	0.22
90	Raise floor above likely flood level,	0.08	0.00	0.16	0.24	0.00	0.46

		Household perspective, to 2030s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
	newbuild, deep floods						
76	Chemical damp-proof course, newbuild, shallow floods	0.00	0.00	0.16	0.01	0.00	0.47
99	Move service meters above flood level, newbuild, deep floods	0.00	0.00	0.16	0.01	0.00	0.48
93	Chemical damp-proof course, newbuild, deep floods	0.00	0.00	0.17	0.01	0.00	0.50
79	Move washing machine to first floor, newbuild, shallow floods	0.00	0.00	0.17	0.01	0.00	0.50
82	Move service meters above flood level, newbuild, shallow floods	0.00	0.00	0.17	0.00	0.00	0.50
98	Move electrics above flood level, newbuild, deep floods	0.00	0.00	0.17	0.01	0.00	0.51
96	Move washing machine to first floor, newbuild, deep floods	0.00	0.00	0.17	0.01	0.00	0.52
80	Raised, newbuild, built-under oven, newbuild, shallow floods	0.00	0.00	0.18	0.00	0.00	0.52
97	Raised, newbuild, built-under oven, newbuild, deep floods	0.00	0.00	0.18	0.00	0.00	0.52
78	Wall-mounted boiler, newbuild, shallow floods	0.00	0.00	0.18	0.00	0.00	0.52

		Household perspective, to 2030s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
95	Wall-mounted boiler, newbuild, deep floods	0.00	0.00	0.18	0.00	0.00	0.52
34	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, deep floods	7.36	0.33	7.54	7.74	0.33	8.26
17	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, shallow floods	11.25	0.39	18.78	11.82	0.39	20.08
102	Flood resistance package, newbuild, manual activation, newbuild, deep floods	0.08	0.37	18.86	0.24	0.28	20.32
85	Flood resistance package, newbuild, manual activation, newbuild, shallow floods	0.07	0.44	18.94	0.22	0.34	20.54
101	Flood resistance package, newbuild, fit & forget, newbuild, deep floods	0.08	0.42	19.02	0.24	0.32	20.78
33	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, deep floods	7.36	0.44	26.38	7.74	0.44	28.52
84	Flood resistance package,	0.07	0.51	26.45	0.22	0.39	28.74

		Household perspective, to 2030s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
	newbuild, fit & forget, newbuild, shallow floods						
16	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, shallow floods	11.25	0.53	37.70	11.82	0.53	40.56
68	Flood resistance package, on repair, manual activation, on repair, deep floods	0.67	0.44	38.37	1.99	0.34	42.55
51	Flood resistance package, on repair, manual activation, on repair, shallow floods	1.03	0.53	39.40	3.05	0.40	45.60
67	Flood resistance package, on repair, fit & forget, on repair, deep floods	0.67	0.50	40.08	1.99	0.38	47.59
50	Flood resistance package, on repair, fit & forget, on repair, shallow floods	1.03	0.60	41.11	3.05	0.46	50.64
88	New floor with treated timber joists, newbuild, deep floods	0.01	0.78	41.12	0.02	0.59	50.66
71	New floor with treated timber joists, newbuild, shallow floods	0.01	1.02	41.13	0.02	0.78	50.68
54	New floor with treated timber joists, on repair, deep floods	0.07	0.87	41.19	0.20	0.66	50.89

		Household perspective, to 2030s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
37	New floor with treated timber joists, on repair, shallow floods	0.11	1.13	41.31	0.33	0.86	51.22
61	Wall-mounted boiler, on repair, deep floods	0.00	0.48	41.31	0.01	0.37	51.23
44	Wall-mounted boiler, on repair, shallow floods	0.01	0.87	41.31	0.01	0.66	51.24
86	*Dense screed, newbuild, deep floods**	*0.00*	*0.40*	*41.32*	*0.00*	*0.30*	*51.25*
69	*Dense screed, newbuild, shallow floods**	*0.00*	*0.82*	*41.32*	*0.00*	*0.63*	*51.25*
52	*Dense screed, on repair, deep floods**	*0.01*	*0.44*	*41.32*	*0.02*	*0.34*	*51.27*
35	*Dense screed, on repair, shallow floods**	*0.01*	*0.91*	*41.33*	*0.03*	*0.70*	*51.30*
62	*Move washing machine to first floor, on repair, deep floods**	*0.01*	*0.74*	*41.35*	*0.04*	*0.56*	*51.34*
63	*Raised, on repair, built-under oven, on repair, deep floods**	*0.01*	*0.75*	*41.36*	*0.02*	*0.57*	*51.36*
91	*Closed cell cavity insulation, newbuild, deep floods**	*0.00*	*0.98*	*41.36*	*0.00*	*0.75*	*51.36*
64	*Move electrics above flood level, on repair, deep floods**				*0.05*	*0.88*	*53.41*
57	*Closed cell cavity insulation, on repair, deep floods**				*0.01*	*0.83*	*53.42*

* Low regret measures attributed to sensitivity analysis

Overall, the inclusion of wider benefits associated with reduced evacuation costs and intangible human health impacts has produced an expanded list of low-regret adaptation measures. Additional measures include:

- installation of dense screed in newbuild properties and on repair (flood resilience - floors)
- moving washing machine and oven above flood level on repair in the case of deep floods
- raising built-in oven on repair in deep floods and
- installing closed cell insulation in newbuild properties in the case of deep floods.

Climate change scenarios

The assessment considered the impact of incorporating recently published UKCIP18 projections in the analysis. Climate risk trends have been converted into a series of scaling factors for inclusion in the sensitivity analysis. In the case of flooding these were +25%, +75% and +150% of the number of existing residential properties affected by flooding.

The results are summarised in the table 4.5 and table 4.6.

Table 4.5 Residential adaptation cost curve – low-regret flood resistance and resilience measures (climate change scenarios, societal perspective)

		Societal perspective, to 2030s						Societal perspective, to 2060s					
	Climate change scenario	**25%**		**75%**		**150%**		**25%**		**75%**		**150%**	
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
73	Raise floor above likely flood level, newbuild, shallow floods	0.07	0.07	0.07	0.07	0.07	0.07	0.18	0.18	0.18	0.18	0.18	0.18
90	Raise floor above likely flood level, newbuild, deep floods	0.07	0.14	0.07	0.14	0.07	0.14	0.19	0.37	0.19	0.37	0.19	0.37
76	Chemical damp-proof course, newbuild, shallow floods	0.00	0.15	0.00	0.15	0.00	0.15	0.01	0.38	0.01	0.38	0.01	0.38
99	Move service meters above flood level, newbuild, deep floods	0.00	0.15	0.00	0.15	0.00	0.15	0.01	0.39	0.01	0.39	0.01	0.39
93	Chemical damp-proof course, newbuild, deep floods	0.00	0.15	0.00	0.15	0.00	0.15	0.01	0.39	0.01	0.39	0.01	0.39

		Societal perspective, to 2030s						**Societal perspective, to 2060s**					
	Climate change scenario	**25%**		**75%**		**150%**		**25%**		**75%**		**150%**	
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
79	Move washing machine to first floor, newbuild, shallow floods	0.00	0.15	0.00	0.15	0.00	0.15	0.00	0.40	0.00	0.40	0.00	0.40
82	Move service meters above flood level, newbuild, shallow floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.40	0.00	0.40	0.00	0.40
98	Move electrics above flood level, newbuild, deep floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.41	0.00	0.41	0.00	0.41
96	Move washing machine to first floor, newbuild, deep floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.41	0.00	0.41	0.00	0.41
80	Raised, newbuild, built-under oven, newbuild, shallow floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.41	0.00	0.41	0.00	0.41

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		Societal perspective, to 2030s						Societal perspective, to 2060s					
	Climate change scenario	25%		75%		150%		25%		75%		150%	
ID	Measure description & application	15-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
97	Raised, newbuild, built-under oven, newbuild, deep floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.41	0.00	0.41	0.00	0.41
78	Wall-mounted boiler, newbuild, shallow floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.42	0.00	0.42	0.00	0.42
95	Wall-mounted boiler, newbuild, deep floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.42	0.00	0.42	0.00	0.42
34	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, deep floods	8.36	8.52	11.71	11.87	16.73	16.89	8.79	9.21	12.31	12.73	17.58	18.00
17	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, shallow floods	12.78	21.30	17.89	29.76	25.56	42.44	13.43	22.64	18.81	31.53	26.87	44.87

		Societal perspective, to 2030s						Societal perspective, to 2060s					
	Climate change scenario	25%		75%		150%		25%		75%		150%	
ID	Measure description & application	15-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
102	Flood resistance package, newbuild, manual activation, newbuild, deep floods	0.07	21.38	0.07	29.83	0.07	42.52	0.19	22.83	0.19	31.72	0.19	45.06
85	Flood resistance package, newbuild, manual activation, newbuild, shallow floods	0.07	21.44	0.07	29.90	0.07	42.59	0.18	23.01	0.18	31.90	0.18	45.23
101	Flood resistance package, newbuild, fit & forget, newbuild, deep floods	0.07	21.52	0.07	29.97	0.07	42.66	0.19	23.20	0.19	32.09	0.19	45.42
33	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, deep floods	8.36	29.88	11.71	41.68	16.73	59.38	8.79	31.99	12.31	44.40	17.58	63.01

		Societal perspective, to 2030s						Societal perspective, to 2060s					
	Climate change scenario	**25%**		**75%**		**150%**		**25%**		**75%**		**150%**	
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
84	Flood resistance package, newbuild, fit & forget, newbuild, shallow floods	0.07	29.95	0.07	41.75	0.07	59.45	0.18	32.17	0.18	44.57	0.18	63.18
16	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, shallow floods	12.78	42.73	17.89	59.64	25.56	85.01	13.43	45.60	18.81	63.38	26.87	90.05
68	Flood resistance package, on repair, manual activation, on repair, deep floods	0.77	43.49	1.07	60.71	1.53	86.54	1.98	47.58	2.77	66.16	3.96	94.02
51	Flood resistance package, on repair, manual activation, on repair, shallow floods	1.17	44.67	1.64	62.35	2.34	88.89	3.03	50.61	4.24	70.40	6.06	100.08

		Societal perspective, to 2030s						**Societal perspective, to 2060s**					
	Climate change scenario	**25%**		**75%**		**150%**		**25%**		**75%**		**150%**	
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
67	Flood resistance package, on repair, fit & forget, on repair, deep floods	0.77	45.43	1.07	63.43	1.53	90.42	1.98	52.59	2.77	73.17	3.96	104.04
50	Flood resistance package, on repair, fit & forget, on repair, shallow floods	1.17	46.60	1.64	65.07	2.34	92.76	3.03	55.62	4.24	77.42	6.06	110.10
88	New floor with treated timber joists, newbuild, deep floods	0.01	46.61	0.01	65.07	0.01	92.77	0.02	55.64	0.02	77.43	0.02	110.12
71	New floor with treated timber joists, newbuild, shallow floods	0.01	46.62	0.01	65.08	0.01	92.78	0.02	55.66	0.02	77.45	0.02	110.14
54	New floor with treated timber joists, on repair, deep floods	0.08	46.70	0.11	65.19	0.16	92.93	0.20	55.86	0.28	77.74	0.40	110.54

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		Societal perspective, to 2030s						Societal perspective, to 2060s					
	Climate change scenario	25%		75%		150%		25%		75%		150%	
ID	Measure description & application	15-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
37	New floor with treated timber joists, on repair, shallow floods	0.13	46.82	0.18	65.37	0.26	93.19	0.33	56.20	0.46	78.20	0.66	111.20
61	Wall-mounted boiler, on repair, deep floods	0.00	46.83	0.00	65.38	0.01	93.20	0.01	56.20	0.01	78.21	0.02	111.22
44	Wall-mounted boiler, on repair, shallow floods	0.01	46.83	0.01	65.38	0.01	93.21	0.01	56.22	0.02	78.23	0.03	111.25

Table 4.6 Residential adaptation cost curve – low-regret flood resistance and resilience measures (climate change scenarios, household perspective)

		Household perspective, to 2030s						Household perspective, to 2060s					
	Climate change scenario	25%		75%		150%		25%		75%		150%	
ID	Measure description & application	15-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 15-year hhldbenefits @ ≥ 1% AEP (£m)	15-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)	15-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)	45-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)	45-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)	45-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)
73	Raise floor above likely flood level, newbuild, shallow floods	0.07	0.07	0.07	0.07	0.07	0.07	0.18	0.18	0.18	0.18	0.18	0.18
90	Raise floor above likely flood level, newbuild, deep floods	0.07	0.14	0.07	0.14	0.07	0.14	0.19	0.37	0.19	0.37	0.19	0.37
76	Chemical damp-proof course, newbuild, shallow floods	0.00	0.15	0.00	0.15	0.00	0.15	0.01	0.38	0.01	0.38	0.01	0.38
99	Move service meters above flood level, newbuild, deep floods	0.00	0.15	0.00	0.15	0.00	0.15	0.01	0.39	0.01	0.39	0.01	0.39
93	Chemical damp-proof course, newbuild, deep floods	0.00	0.15	0.00	0.15	0.00	0.15	0.01	0.39	0.01	0.39	0.01	0.39

		Household perspective, to 2030s						Household perspective, to 2060s					
	Climate change scenario	25%		75%		150%		25%		75%		150%	
ID	Measure description & application	15-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 15-year hhldbenefits @ ≥ 1% AEP (£m)	15-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)	15-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)	45-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)	45-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)	45-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)
79	Move washing machine to first floor, newbuild, shallow floods	0.00	0.15	0.00	0.15	0.00	0.15	0.00	0.40	0.00	0.40	0.00	0.40
82	Move service meters above flood level, newbuild, shallow floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.40	0.00	0.40	0.00	0.40
98	Move electrics above flood level, newbuild, deep floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.41	0.00	0.41	0.00	0.41
96	Move washing machine to first floor, newbuild, deep floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.41	0.00	0.41	0.00	0.41
80	Raised, newbuild, built-under oven, newbuild, shallow floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.41	0.00	0.41	0.00	0.41

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		Household perspective, to 2030s						Household perspective, to 2060s					
	Climate change scenario	**25%**		**75%**		**150%**		**25%**		**75%**		**150%**	
ID	**Measure description & application**	**15-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year hhldbenefits @ ≥ 1% AEP (£m)**	**15-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)**	**15-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)**	**45-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)**	**45-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)**	**45-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)**
97	Raised, newbuild, built-under oven, newbuild, deep floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.41	0.00	0.41	0.00	0.41
78	Wall-mounted boiler, newbuild, shallow floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.42	0.00	0.42	0.00	0.42
95	Wall-mounted boiler, newbuild, deep floods	0.00	0.16	0.00	0.16	0.00	0.16	0.00	0.42	0.00	0.42	0.00	0.42
34	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, deep floods	8.36	8.52	11.71	11.87	16.73	16.89	8.79	9.21	12.31	12.73	17.58	18.00
17	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, shallow floods	12.78	21.30	17.89	29.76	25.56	42.44	13.43	22.64	18.81	31.53	26.87	44.87

		Household perspective, to 2030s						**Household perspective, to 2060s**					
	Climate change scenario	**25%**		**75%**		**150%**		**25%**		**75%**		**150%**	
ID	**Measure description & application**	**15-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year hhldbenefits @ ≥ 1% AEP (£m)**	**15-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)**	**15-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)**	**45-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)**	**45-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)**	**45-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)**
102	Flood resistance package, newbuild, manual activation, newbuild, deep floods	0.07	21.38	0.07	29.83	0.07	42.52	0.19	22.83	0.19	31.72	0.19	45.06
85	Flood resistance package, newbuild, manual activation, newbuild, shallow floods	0.07	21.44	0.07	29.90	0.07	42.59	0.18	23.01	0.18	31.90	0.18	45.23
101	Flood resistance package, newbuild, fit & forget, newbuild, deep floods	0.07	21.52	0.07	29.97	0.07	42.66	0.19	23.20	0.19	32.09	0.19	45.42
33	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, deep floods	8.36	29.88	11.71	41.68	16.73	59.38	8.79	31.99	12.31	44.40	17.58	63.01

		Household perspective, to 2030s						Household perspective, to 2060s					
	Climate change scenario	**25%**		**75%**		**150%**		**25%**		**75%**		**150%**	
ID	**Measure description & application**	**15-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year hhldbenefits @ ≥ 1% AEP (£m)**	**15-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)**	**15-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)**	**45-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)**	**45-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)**	**45-year hhld benefits @ ≥ 1% AEP (£m)**	**Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)**
84	Flood resistance package, newbuild, fit & forget, newbuild, shallow floods	0.07	29.95	0.07	41.75	0.07	59.45	0.18	32.17	0.18	44.57	0.18	63.18
16	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, shallow floods	12.78	42.73	17.89	59.64	25.56	85.01	13.43	45.60	18.81	63.38	26.87	90.05
68	Flood resistance package, on repair, manual activation, on repair, deep floods	0.77	43.49	1.07	60.71	1.53	86.54	1.98	47.58	2.77	66.16	3.96	94.02
51	Flood resistance package, on repair, manual activation, on repair, shallow floods	1.17	44.67	1.64	62.35	2.34	88.89	3.03	50.61	4.24	70.40	6.06	100.08
67	Flood resistance package, on repair, fit & forget, on repair, deep floods	0.77	45.43	1.07	63.43	1.53	90.42	1.98	52.59	2.77	73.17	3.96	104.04

		Household perspective, to 2030s						Household perspective, to 2060s					
	Climate change scenario	25%		75%		150%		25%		75%		150%	
ID	Measure description & application	15-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 15-year hhldbenefits @ ≥ 1% AEP (£m)	15-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)	15-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 15-year hhld benefits @ ≥ 1% AEP (£m)	45-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)	45-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)	45-year hhld benefits @ ≥ 1% AEP (£m)	Cumulative 45-year hhld benefits @ ≥ 1% AEP (£m)
50	Flood resistance package, on repair, fit & forget, on repair, shallow floods	1.17	46.60	1.64	65.07	2.34	92.76	3.03	55.62	4.24	77.42	6.06	110.10
88	New floor with treated timber joists, newbuild, deep floods							0.02	55.64	0.02	77.43	0.02	110.12
71	New floor with treated timber joists, newbuild, shallow floods							0.02	55.66	0.02	77.45	0.02	110.14

Incorporation of the scaling factors does not impact the identification and the list of low-regret measures, as unit costs and benefits of measures are driven by dwelling type. However, applying flood resilience and resistance measures to a larger number of properties at risk of flooding does affect anticipated societal and household benefits in absolute terms.

In particular, cumulative societal benefits associated with low-regret measures over a 15-year time period increase from £38m to £47m, £65m and £93m under +25%, +75% and +150% climate risk scenarios respectively. Over a 45-year time period, cumulative societal benefits increase from £45m to £56m, £78m and £111m respectively under different climate change scenarios.

Discussion

The presented results for flood resilience and resistance measures represent a conservative view of anticipated benefits. The same conclusion applies to the resulting list of low-regret measures which largely features measures applied to newbuild dwellings.

Consideration of wider benefits such as avoided cost of evacuation and human health impacts as part of sensitivity analysis leads to an expanded list of low-regret measures. However, lack of quantitative evidence on anticipated impact of flood resilience measures on reduced probability and duration of evacuation leads to significant uncertainty.

The assessment is also associated with a number of limitations such as:

- The lack of technical effectiveness data on the impact of flood resilience measures that are aiming to minimise impact of flooding and facilitate repair, drying & cleaning and subsequent reoccupation on the instance and duration of evacuation.
- The incorporation of newly published climate change scenarios within the analysis using a scaling factor applied to the number of properties affected (25%, 75% and 150%). This approach was followed in the absence of updated Catchment Flood Management Plans (Environment Agency, 2009) that provided data on the number of current and future residential properties at risk of flooding (by dwelling type) for the 2011 study.

Conclusions

In the case of flooding, low-regret adaptation measures (with a CBR>1) included installation of **flood resistance packages** (fit& forget and manual activation) across all types of residential dwellings. This adaptation measure was shown to be an economically low regret intervention across all stages including newbuild, on repair and discretionary retrofit (at ≥ 1% AEP). It should be noted that while both sets of flood resistance packages (manual activation and fit& forget) are shown to be low-regret these are mutually exclusive, alternative measures.

Both alternatives have the same, absolute benefit values but different CBRs (due to different installation costs) that determine the preferred alternative. For instance, in the case of low-regret measures from societal perspective (to 2030s), installation of flood resistance package entailing manual activation is more cost-beneficial than the same measure with an automatic activation (fit& forget). Once the first measure is installed, the alternative would not be later applied to the same property. The cumulative benefits presented in the section are, therefore, overstated in absolute terms due to several measures on the cost curve being mutually exclusive (which is a common feature of the cost curves).

Flood resilience measures were shown to be low-regret in newbuild dwellings. Installation of a new floor with treated timber joists during discretionary retrofits (repair) and of a wall-mounted boiler are the only measures which have a CBR<1 for existing dwellings (but only from societal perspective that uses lower discount rate).

Low-regret measures for newbuild properties largely related to dwelling interior and included measures such as moving meters and electric goods above likely flood level. Installation of a chemical damp-proof course in newbuild was the only low-regret measure for walls. Low-regret flood resilience measures for floors only included raising the floor above likely flood level and installing a new floor with treated timber joists in newbuild houses.

Inclusion of wider benefits associated with avoided evacuation costs and mental health impacts resulted in an expanded list of low-regret measures due to increased levels of anticipated benefits (damage value avoided).

4.3 Updates on previous findings

Metrics

The addition of avoided costs of evacuation and human health benefits to the assessment constituted the only methodological change in comparison to 2011 Davis Langdon study.

Cost curves have been built for the mid cost and saving estimates[49].

Results

Updates to housing stock and unit cost data did not lead to changes in the list of low-regret measures for flooding. Total estimated benefits and costs of adaptation measures under the main scenario have increased due to updating unit cost and benefit input data to current prices.

The inclusion of wider benefits such as avoided costs of evacuation and mental health impacts in the assessment leads to the expansion of the low-regret measures for flooding (see Section 4.2).

[49] We note that the original model and 2011 study seem to have used best estimate values instead of mid estimates due to identical column label ("15-year, societal CBR @ ≥ 1% AEP") and formula picking up values from the first column out of 3 (best, mid, worst).

5. Overheating

5.1 Headline Messages

Due to the stability of the weather systems that lead to high UK temperatures, overheating events have the potential to affect relatively large regions simultaneously. Within each region, all dwellings will require the same overheating control capability at the same time and similar dwellings will require similar control measures.

If a single type of dwelling is at risk, then all dwellings of the same type (in the same region) are also at risk. Differences between individual houses with respect to their capability to respond to overheating events will depend on their post-construction modifications and general state of maintenance, the quality and serviceability of the ventilation control system which is critical for control of overheating. However, there is little information on this subject.

Local markets and supply chains may not have enough response capacity within the time frame of an overheating event. Within the overall concept of 'access to measures', measures are most importantly distinguished by the immediacy with which they can be implemented.

Time and mobility of the population will affect access to and use of an infrastructure of community refuges, and time, investment and replacement cycles in the property sector, will affect finance and access to finance for building improvements and service lines (see Table 5.1).

Table 5.1 Illustrations of measures to address overheating, with time to become effective

Measure	Time to become effective
Time to relocate to refuge	< 3 hours
Portable air conditioning	1 day to 3 weeks (mail order/local delivery)
Additional ventilation maintenance	1 week to 3 months
Installed air con	3/6 months - 3 years (local specialist/builder)
External shading - fixed louvres	3/6 months - 1 year (local specialist/builder), + 2 years additional if planning required
External shading - adjustable	3/6 months - 1 year (local specialist/builder), + 2 years additional if planning required
External shading - as part of triple glazed window units	3/6 months - 1 year (local specialist/builder), + 2 years additional if planning required
Window replacement to restore ventilation design standards	1 week to 3 months
Local realm greening (1-3 yrs)	1-3 years, assuming council involvement
Replacement roof and increased thermal mass	Up to 10 years and/or turnover rate in building stock
Rebuild whole property	Turnover rate in building stock

Local realm 'deep greening' + trees (strategic policy level)	10-30+ yrs

Previous report (DL, 2009) and more recent evidence

Readers are directed to Appendix C for the review of evidence used in this study. Since the previous report, the CREW project has provided effectiveness and cost information for overheating measures which are used in place of the results of the previous study.

A comparison of the main aspects of the analysis and the changes made in response to the review of evidence is provided in Table 5.2. This exercise has been undertaken recognising the limitations in the original study. The city of Exeter, which has the same national average of elderly people is used to assess vulnerability of population, as a proxy of an average UK city.

Table 5.2 Comparison of methodological aspects of approach taken in previous report and this study

Measure	Davis Langdon (2009)	Wood
1. Population		
Subsection	South East	Exeter, (scaled to UK totals)
Population breakdown	by number of occupants, but used mainly for technical calculations of the additional heat they would add to a dwelling	by household for all, and elderly; average UK breakdowns applied within filtered groups
2. Housing stock		
Housing Stock breakdown description	by size, period	same, + number of floors {note, filter by period yet to be applied}
3. Behaviour and Use		
Access to measures	100%	filtered for 5km square centred on City of Exeter
Implementation of measures	100%	potentially filtered for other geographically based attributes (mobility, financial resources) of population
Uptake of Measures	100% (implicit for DL in their analysis)	selected by assumption and sensitivity to generate filtered cost information
4. Measures		
Temperature threshold for overheating	28 deg C (implicit in use of DL house model)	CINSE threshold temperatures of 26C for bedrooms and 28C for other living areas
Metrics of effectiveness for measuring overheating	degree hours, and hours	Degree hours
Metrics for benefits measured	Avoided costs of air-conditioning	same, but noted as based on unlikely behavioural assumption in baseline (100% uptake of air-conditioning)
Number of measures	~7	same, plus additions

Number of measures for which effectiveness information is available	7	same 7 measures (same source)
Derivation of measures of effectiveness for additional measures		judged by Wood using a proxy from the 7 measures with metrics of effectiveness
Costs of measures	per measure	updated, similar and range of increase small compared to uncertainty in other variables

Important aspects of similarities in the analysis conducted here are that:

- In both the DL, 2009 work and the CREW project, the effectiveness of measures was assessed using a computer model of different dwelling types to represent the response of the housing stock to measures. These models were not rerun for this study, it is assumed that the assumptions underpinning the previous studies continue to represent the physical effects of measures accurately.
- The definition of the costs of measures from the CREW project is the main basis used. These are primarily based on market prices and represent financial costs, using including labour costs of installation, but not, for example, economic costs of disruption to occupants.
- The same measures were considered, subject to the need to make use of the CREW project data together with some additions.

Important differences:

- The analysis was extended to look at the need for remedial measures should buildings not be meeting acceptable standards. This is presented as a case study for Exeter which uses a geospatial analysis to identify dwellings at particular risk.
- The analysis addressed the potential issue of vulnerability of populations through consideration of the use of dwellings by the elderly in the Exeter case study.

5.2 Approach

Metrics

Measures to address overheating in residential dwellings fall into three main categories identified in the CREW project research:

- **Insulation measures** - to reduce the transfer of heat through the building fabric;
- **Solar control measures** - to prevent the absorption and transmission of solar radiation by shading or reflection; and
- **Ventilation modification measures** - to control air movements.

The main quantitative metric used for comparing insulation and solar measures for overheating is degree-hours. The effect of the physical change caused by each measure can be quantified in terms of the reduction in the time and severity of over-heating in a typical dwelling compared to a reference temperature. The single measure of degree-hours is calculated as the time the reference temperature is exceeded multiplied by difference between temperature and reference. A benefit of this measure is that this is simple to measure and model. It provides a useful range of variation for comparing insulation and solar measures installed on a typical dwelling. The costs to install and operate these measures can be easily estimated using current market prices, and the effectiveness of each measure compared in the decrease in degree-hours for each £ of cost.

Using this approach, the benefits of a measure can be quantified as the level of effectiveness in terms of the reduction in degree-hours that it achieves. In the previous work, the cost of achieving this reduction using air-conditioning was then calculated but in fact this depended only on the measure of effectiveness and was merely an alternative way of presenting the same measure of effectiveness. In this study, measures are explicitly compared in terms of their effectives. If the impacts of different degree hours on the population were better understood, then i=t would be appropriate to use a more meaningful measure of benefits.

Ventilation measures need a different metric for effectiveness. The range of difference between a ventilated and unventilated house is much larger than the effects of insulation and solar measures and might be considered to lie on a different scale. In circumstances where ventilation systems are inadequate, the only realistic measure is to reinstate appropriate ventilation and, where it applies, the effectiveness of this one measure is will make the additional contribution of any other measure immaterial as well as meet any underlying need. The proposed metric of effectiveness is the aggregate costs to address potentially high risk dwellings as a proportion of the number of dwellings. This metric is used in the Exeter case study.

Other categories of measure identified in the literature are:

- Measures in the external environmental realm not directly related to individual dwellings, such as trees and green space – these have small direct impacts and not considered further.
- Air-conditioning, which is a practical if expensive option but, because it can implicitly substitute for any other measure, provides a benchmark for comparing the others.

Model

Scope

Overheating in buildings can be accurately analysed using basic physics but in practice occurs very differently across the housing stock and affects people in potentially very different ways and with different capacities to adapt.The measures analysed in the previous work (DL, 2009) cover almost all of those currently proposed as technical solutions to overheating in buildings in the sources reviewed in the literature in this study. Work in the later CREW project in 2011 looked for and identified a similar set of measures. No breakthrough technologies were identified or changes which have a major effect on costs from the literature review (see Appendix F). These measures do not have difficult technical implementation requirements and the skills and materials are available from local construction and building maintenance suppliers.

The measures were analysed using a computer model of a building that shows the response of several different dwelling types to the different physical changes caused by each measure. The effect of the physical change is quantified in terms of the time and severity of over-heating compared to a reference temperature, combined in a single measure of degree-hours (time multiplied by difference between temperature and reference). The computer model used in the previous work (DL,2009) simulates the effects of costed measures for insulation and solar control but the ventilation system is modelled using a number of reference states with no specific cost identified for switching between them. Ad-hoc but specific evidence is that control of the ventilation system is not always possible (e.g. due to "un-openable windows") and there is a non-zero cost of repair.

Reduction in ventilation capability is leads to high temperatures inside dwellings as observed in theory and practice. The computer model shows large differences in overheating between two ventilation reference states in the estimates from the computer model. The use of natural (i.e.. unforced) ventilation to remove heat absorbed by a dwelling during the day reduces overheating by 66% on average and up to 75% in small flats (DL, 2009 (model)) as measured in terms of the reduction in degree hours experienced by occupants in a dwelling. The ad-hoc evidence that lack of ventilation may be a primary cause of overheating, particularly of very high levels of overheating, and that costs have been under-represented, made it an area of focus for this study, while the costs and effectiveness of measures for insulation and solar control as estimated in DL 2009 were largely confirmed as still applicable, though represented here using the later CREW project analysis.

Baseline

The suitability of the housing stock for current climatic conditions depends on decisions in the past. Over time, the knowledge of the environment may become sufficiently culturally and practically embedded in the population that people instinctively build appropriate dwellings for their location. Under this conception, the current building stock is by definition adequate to cope with overheating. However, influences from the past, from simple lack of knowledge to lack of maintenance and poor design and materials, means that both design standards and actual construction is likely to be less than ideal.

Examples of past influences which have been quoted as being associated with poor building performance regarding overheating are:

- Exposed (high and south facing) flats in high rise towers
- Single-sided flats with poor ventilation
- Flat roofed dwellings including community residences
- Dwellings with energy-saving designs (including "passive" houses)

If a single type of dwelling is at risk then, as they are broadly exposed to the same climate, all dwellings of the same type should also be at risk. The differences in risk between individual but otherwise similar houses with respect to their capacity to respond to external overheating will depend on modifications to the building fabric and on the general state of maintenance, in particular the quality and serviceability of the ventilation system. The baseline, representing the situation before any proposed intervention, is very likely to include dwellings with a wide and uncertain range of capability to respond to overheating challenges and so a corresponding wide range of potential vulnerability.

It is also possible that some dwellings with a pre-disposition to overheating, such as flat-roofed bungalows are also those with occupants, that are particularly vulnerable to overheating, such as the elderly. The highest risk occurs where vulnerable populations are housed in dwellings with poor performance, however identifying these situations is not trivial.

Results

Selection of measures

The documentary sources listed in Appendix C provided the basis for the identification of the list of measures in this study which fall into the broad categories shown in the schematic in Figure 5.1

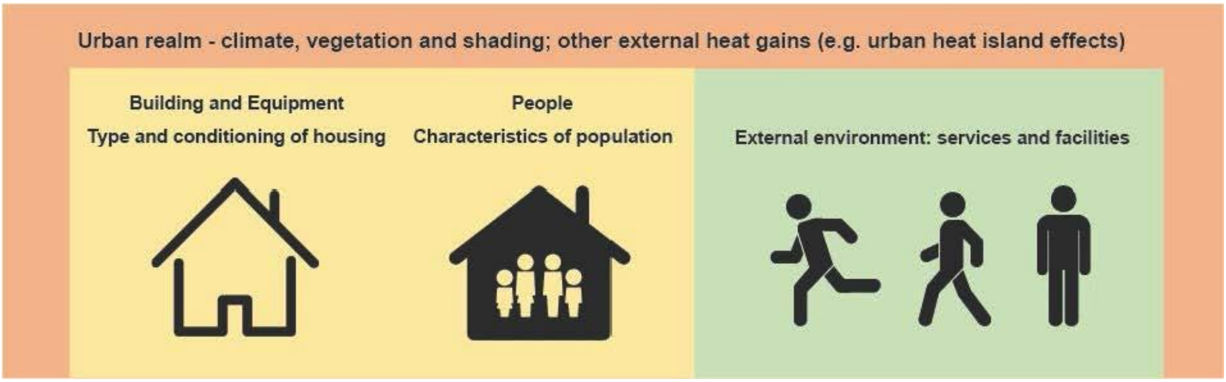

Figure 5.1 The context for analysis of overheating

With respect to this study, the previous work and the CREW project both focused on measures addressing buildings and equipment although the methodology also represented occupants with respect to their contribution to heat inputs to the dwelling. The pattern of use of the dwelling by occupants was also reflected in the measurement of effectiveness as unoccupied rooms were not included in the metric of degree hours. More generally however, how occupants use and operate their heating/cooling systems is not well known and there is limited evidence on the effects of overheating in residential buildings and on the general population.

There is academic evidence of adaptation for people, the effect being that perceived overheating reduces over time, though that does not clarify whether other (non-perceived e.g. health) effects persist (Arbuthnott et al. ,2016)[50]. The current UK standards for buildings expressed in the CIBSE Guide A: Environmental Design. Chartered Institute of Building Services Engineers (2006) acknowledge this possible adaptation.

Impacts of overheating on the elderly and vulnerable are clearer, though evidence is not usually linked to type of circumstances that might cause overheating in the residential housing sector, but to aggregate statistics, such as mortality increases for increases in average temperatures.

These factors suggest that the circumstances of people, and their inherent vulnerability greatly affect their need for overheating control. Furthermore, good ventilation is a critical requirement. These three factors are assessed in the case study for Exeter and present a low-regrets perspective beyond simply the scope of the technical aspects of the building. A range of measures and their characteristics considered by thus study are detailed in Table 5.3.

[50] Also, Åström, D. O., Forsberg, B., Edvinsson, S., & Rocklöv, J. (2013). Acute fatal effects of short-lasting extreme temperatures in Stockholm, Sweden: evidence across a century of change. Epidemiology, 24(6), 820-829, and Johnson, H., Kovats, R.S., McGregor, G., Stedman, J., Gibbs, M. and Walton, H., 2005. The impact of the 2003 heat wave on daily mortality in England and Wales and the use of rapid weekly mortality estimates.

Table 5.3 The main groups of measures and their characteristics

	Measure	Nature of benefit	Cost/scale
A1	Urban Realm - City Planning		
1	Street 'canyons'	Shading and wind control at the building/street scale	small changes in Local Authority charges
2	City ventilation air flow	Wind control at the city scale	small changes in Local Authority charges
3	Trees to reduce UHI effect and shading	Shading at dwelling level	small changes in Local Authority charges
4	Reduce waste heat from city	Reduced heat gain at city scale	changes in Local Authority charges
5	Community refuges	Provides emergency network for extreme overheating events	changes in Local Authority charges
A2	Urban Realm - Urban design		
1	Green roofs	Provide insulation and evaporative cooling	small changes in Local Authority charges
2	Solar reflective roof	Reduces solar and heat energy transmitted through roofs	quantified in Table 5.4
3	Solar reflective walls	Reduces solar and heat energy transmitted through roofs	quantified in Table 5.4
4	Orientation (for new build)	Reduces effect of solar and heat gain for the building	% increase in cost if result is fewer dwellings per site
5	Avoid single aspect flats	Reduces potential for poorly ventilated dwellings	% increase in cost if result is fewer dwellings per site
6	Do not add car parks at expense of green space	Green space benefits	% increase in cost if result is fewer dwellings per site
B1	Building & Equipment: Improvements to insulation		

1	External wall insulation	Reduces solar and heat energy transmitted through walls	quantified in Table 5.4
2	Cavity wall insulation	Reduces solar and heat energy transmitted through walls	quantified in Table 5.4
3	Thermal mass (add)	Reduces max and min internal temperatures and makes night cooling more effective	
4	Internal wall insulation	Reduces solar and heat energy transmitted through walls	quantified in Table 5.4
5	Flat roof insulation	Reduces solar and heat energy transmitted through flat roofs	quantified in Table 5.4
6	Roof Insulation	Reduces solar and heat energy transmitted through roofs	quantified in Table 5.4
B2	Building & Equipment: Improvements to solar protection		
1	Blinds	Reduces solar energy transmitted through windows	quantified in Table 5.4
2	Curtains	Reduces solar energy transmitted through windows	quantified in Table 5.4
3	External fixed shading	Reduces solar energy transmitted through windows	quantified in Table 5.4
4	External shutters	Reduces solar energy transmitted through windows	quantified in Table 5.4
5	Low emissive coated triple glazing	Reduces solar energy transmitted through windows	quantified in Table 5.4
B3	Building & Equipment: Improvements to ventilation and cooling systems		
1	Remedial cross-ventilation/room protection	Additional 'free-running' ventilation capacity, or room protection	quantified in Table 5.4
2	Chimneys	Additional 'free-running' ventilation capacity	important local effects supplementary to general ventilation
3	Fans	Mechanical ventilation	high operating costs and significant capital costs

4	Air conditioning	Mechanical cooling of ambient air	high operating costs and significant capital costs
5	Mechanical ventilation with heat recovery	Mechanical ventilation and heat transfer	high operating costs and significant capital costs
C	Health & Behaviour		
1	Access to cool shady area	Reduction in body temperature	Part of behaviour in the urban realm
2	Shade	Reduction in body temperature	General requirement for access to shade
3	Appropriate clothing	Reduction in body temperature	Existing baseline may include government information programmes
4	Drink water	Reduction in body temperature	
5	Ice	Reduction in body temperature	
6	Avoid exercise	Reduction in body temperature	
7	Shower	Reduction in body temperature	
8	Switch off non-essential equipment	Control and reduce other sources of heat gain	
9	Monitor temperature	Reduction in body temperature	Availability of existing monitoring systems for monitoring
10	Monitor people	Social contract	

Source: Wood
Note: Further information on the measures is reported in Appendix F (Groups of measures and additional characteristics) and Appendix G (Table of current prices used in assessing costs of measures).

The measures are numbered for later reference. The costs of technical measures for dwellings are represented by installation and capital costs at current market prices unless noted otherwise. The measures covering insulation, solar protection and ventilation measures (B1, B2, and B3) are the main focus of the results as they make the greatest differences to the internal temperatures of a typical dwelling.

Other measures were more difficult to cost and have different types of impact. Overheating has a widespread impact on the population and potential to affect the very vulnerable. Measures may require a combination of factors to be ineffective. Community refuges (A1.5) are a measure fitting the pattern of a more general emergency response measure which directly targets vulnerable populations. The total cost of refuges is likely to be much less than the total costs for installing ventilation measures at each individual dwelling, as each refuge can provide for many occupants. While it may be infeasible or ineffective, for example due to mobility issues for users, it is one of the potentially lowest cost measures, and correspondingly a potential low-regret measure. The measure is listed under the 'urban realm' heading as the implicit need for a network of accessible refuges may mean it is implemented or overseen by the Local Authority. It also illustrates how issues of agency affect

The previous quantitative work primarily focused most on the effects of measures for insulation and reduced solar exposure. The comparisons were based on a computer-based model of a typical building under controlled climatic and solar conditions and in one or more states of ventilation. Since the time of the work by DL, 20009, modelling and analysis as part of the CREW projects has provided a new and more comprehensive source of integrated data on effectiveness and costs.

The results from the previous work were reviewed and reused where possible. This list of measures includes all those covered in the previous report (DL, 2009) and those included in the CREW work of 2011. These two sources focus predominantly on technical measures implemented through changes to the building or additional equipment. In broad terms, the results for the physical effectiveness of measures in reducing overheating were reused, while the costs of measures were researched in the current market and used to verify or update the older costs from the CREW project.

This list of measures includes all those covered in the previous report (DL, 2009) and those included in the CREW work of 2011. These two sources focus predominantly on technical measures implemented through changes to the building or additional equipment

Additional ventilation measures

In broad terms, the most significant measures are related to ventilation, as is shown quantitatively in the difference between modelling a ventilated and unventilated house. Such large ranges imply that ventilation is critical to all aspects of overheating (see further information on measure B3.1 Remedial cross-ventilation/room protection below)

Full access to and use of the design capability for ventilation in a dwelling is an assumption in the analysis in the previous work on technical measures that may not reflect conditions in the housing stock. Practically, it seems reasonable to propose that dwellings on average are operating below design performance standards through general wear and tear. However, it is difficult to compare the costs of measures which address and improve ventilation across the housing stock as the overall need for and type of measures are unknown.

New Build

The costs and benefits of overheating measures for new build are the subject of work conducted in parallel with this study by AECOM for the Ministry of Housing, Communities and Local Government. In comparison with residents, developers may accommodate measures to reduce or prevent overheating in their design as economies of scale at construction are greatest and integrated solutions for the local realm can take account all buildings on a development site. A survey by the CCC found that 45% of respondents reported that overheating had been identified as an issue after complement of new build projects. Perceived barriers to uptake were found to include the absence of regulations, lack of understanding and training, and a lack of demand. The AECOM work for MHCLG may assess this further.

Individual buildings are likely to be convertible as any other after construction, however the costs involved in this are likely to be higher than if measures were included at build stage. To avoid duplication with AECOM new build properties are not considered further as a separate category in the methodology.

Measures which can be compared quantitatively

The list of measures for which data sources allow consideration of both effectiveness and cost is shown in Table 5.4 which shows their comparative effectiveness in terms of the "Cost per % reduction". In general, the measures which are more effective in these terms have a lower value in this column.

The illustrative cost, effectiveness and cost per 1% improvement in effectiveness is shown in the Table 5.4. The effectiveness is the reported reduction in degree hours from the CREW project. The cost is the one-off cost financial cost of installing a measure. Ongoing operational costs are not included. The low and high values for cost per dwelling in Table 5.4 reflect sensitivities developed for each measure and discussed in the methodology section below.

The measures with the lowest numeric values in the two right hand columns have the best cost-effectiveness and would be preferred. They indicate the cost in £ per for a 1% improvement in the metric of degree hours, compared to the baseline.

The main metrics of effectiveness used in this study reflect the values calculated in the CREW work. The CREW metrics for effectiveness are chosen over those calculated in DL, 2009 primarily as the CREW work the cost and effectiveness for each measure are paired in the same original analysis and so will be more naturally aligned. In comparison the cost evidence for in DL, 2009 is considered less robust, and is older.

Table 5.4 Comparative cost-effectiveness of measures, in terms of Cost per 1% improvement in effectiveness

					Cost (£) per % effectiveness		
	Cost (£) per dwelling			Effectiveness	Cost (£) per 1% better effectiveness		
		Low	High	%	Low	High	
	Flat						*The block of flats was constructed in the 1960s and has uninsulated cavity walls. The ground floor is uninsulated solid concrete and the roof is a cold roof design, with 50mm of insulation and an asphalt covering. Some modernisation work has been carried out, including the replacement of the single-glazed windows with uncoated uPVC double-glazing. The living room and main bedroom are both at the rear of the block and the layout of the ground, mid and top floor flats is identical.*
B2.2	Curtains	-	70	17%	-	4	Use of existing fitted curtains, which are closed during day
B2.1	Internal Blinds	228	1,437	23%	10	62	internal solar reflective blinds to each window, which are closed during day
B2.4	External Shutters	1,386	4,310	41%	34	105	external solar reflective shutters to each window that provide a total block to solar radiation, which are closed during day
B2.5	Low e triple glazing	7,303	9,900	18%	408	553	Low e triple glazing Low e triple glazing involves replacing the existing glazing with high performance low emissivity triple glazing. The inner and outer panes are coated to reflect solar radiation. They are an expensive option at an estimated cost of £6,100 for a 2-bed flat, but they also have the benefit of reducing winter heating energy use.
B2.3	External fixed shading	532	2,228	37%	14	60	fixed overhang shading to a horizontal depth of 1.0m above south, east and west facing windows
B1.5	Upgrade flat roof	2,634	3,500	2%	1,287	1,711	Assumes costs shared by 8 flats. new highly insulated roof will have little impact for ground floor flats, but a larger impact on both overheating and winter heating costs for top floor flats

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wood.

A2.2	Solar reflective roof	373	479	20%	19	24	coating the roof tiles with a high performance solar reflective paint
A2.3	Solar reflective walls	746	958	25%	30	39	coating the external walls with a high performance solar reflective paint
B1.1	External wall insulation	8,873	10,297	1%	11,564	13,420	60mm phenolic foam to the external wall faces, 20mm render layer
B1.4	Internal wall insulation	5,051	5,747	-4%	- 1,404	-1,234	60mm phenolic foam to the internal faces of external walls, dry lined with plasterboard
B1.2	Cavity wall insulation	239	330	-4%	-86	-62	glass wool insulation
B3.1	Remedial cross-ventilation/room protection	-	2,434	100%	-	24	Replacement of two windows
	Town House (mid terrace)						*The terraced houses are typical of ones constructed towards the end of the 19th century. They have solid brick walls and a suspended timber ground floor. Some modernisation work has been carried out, including the addition of 100mm of loft insulation and the replacement of the single-glazed windows with uncoated uPVC double-glazing. The rear extensions, housing the kitchens and bathrooms, were added during the 20th century and have uninsulated brick/block cavity walls and solid concrete ground floors. The living rooms are at the front of the houses and the main bedrooms at the rear*
B2.2	Curtains	-	70	20%	-	4	Use of existing fitted curtains, which are closed during day
B2.1	Internal Blinds	228	1,916	24%	10	81	internal solar reflective blinds to each window, which are closed during day
B2.4	External Shutters	1,386	3,951	40%	34	98	external solar reflective shutters to each window that provide a total block to solar radiation, which are closed during day
B2.5	Low e triple glazing	7,200	9,900	25%	288	396	Low e triple glazing Low e triple glazing involves replacing the existing glazing with high performance low emissivity triple glazing. The inner and outer panes are coated to reflect solar radiation. They are an expensive (estimated cost £5,100 for a 3-bed terraced house), but they also have the benefit of reducing winter heating energy use.

B2.3	External fixed shading	589	2,468	25%	24	99	fixed overhang shading to a horizontal depth of 1.0m above south, east and west facing windows (2.0m awnings to east and west ground floor windows except for front windows - due to proximity to pavement/road)
B1.6	Extra loft insulation	180	230	5%	37	47	topping up the existing loft insulation
A2.2	Solar reflective roof	839	1,078	32%	26	33	coating the roof tiles with a high performance solar reflective paint
A2.3	Solar reflective walls	1,212	1,556	44%	28	35	coating the external walls with a high performance solar reflective paint
B1.1	External wall insulation	8,770	10,177	29%	300	348	60mm phenolic foam to the external wall faces, 20mm render layer
B1.4	Internal wall insulation	4,992	5,627	9%	546	615	60mm phenolic foam to the internal faces of external walls, dry lined with plasterboard
B3.1	Remedial cross-ventilation/room protection	-	2,400	100%	-	24	Replacement of two windows
	Semi-detached						*The semi-detached house is typical of those constructed from the 1930s to the 1950s. It has uninsulated brick cavity walls and the ground floor is uninsulated solid concrete. Some modernisation work has been carried out, including the addition of 100mm of loft insulation and the replacement of the single-glazed windows with uncoated uPVC double-glazing. The living room and main bedroom are both at the front of the house.*
B2.2	Curtains	-	93	24%	-	4	Use of existing fitted curtains, which are closed during day
B2.1	Internal Blinds	304	2,634	30%	10	87	internal solar reflective blinds to each window, which are closed during day
B2.4	External Shutters	1,848	5,388	53%	35	101	external solar reflective shutters to each window that provide a total block to solar radiation, which are closed during day
B2.5	Low e triple glazing	11,374	13,200	30%	382	443	Low e triple glazing Low e triple glazing involves replacing the existing glazing with high performance low emissivity triple glazing. The inner and outer panes are coated to reflect solar radiation. They are an expensive

							option at an estimated cost of £9,500 for a 3-bed semi-detached house, but they also have the benefit of reducing winter heating energy use.
B2.3	External fixed shading	1,416	5,933	50%	28	119	fixed overhang shading to a horizontal depth of 1.0m above south, east and west facing windows (2.0m awnings to east and west ground floor windows except for front windows - due to proximity to pavement/road)
B1.6	Extra loft insulation	180	240	0%	-1,039	- 778	topping up the existing loft insulation
A2.2	Solar reflective roof	932	1,197	10%	92	118	coating the roof tiles with a high performance solar reflective paint
A2.3	Solar reflective walls	1,119	1,437	48%	23	30	coating the external walls with a high performance solar reflective paint
B1.1	External wall insulation	13,000	15,086	16%	828	961	60mm phenolic foam to the external wall faces, 20mm render layer
B1.4	Internal wall insulation	7,400	8,381	0%	32,042	36,290	60mm phenolic foam to the internal faces of external walls, dry lined with plasterboard
B1.2	Cavity wall insulation	239	475	5%	49	98	glass wool insulation
B3.1	Remedial cross-ventilation/room protection	-	2,844	100%	-	28	Replacement of two windows
	Detached House						*The detached house is constructed to 2006 UK Building Regulations. brick/block cavity walls with cavity insulation, dry-lined using plasterboard on dabs, loft space, windows low e coated uPVC double-glazed. main bedroom at front, living room at rear*
B2.2	Curtains	-	140	24%	-	6	Use of existing fitted curtains, which are closed during day
B2.1	Internal Blinds	456	3,113	30%	15	105	fitting of internal solar reflective blinds to each window, closed during day

B2.4	External Shutters	2,772	6,824	51%	54	133	fitting of external solar reflective shutters to each window that provide a total block to solar radiation, closed during day
B2.5	Low e triple glazing	15,565	19,800	31%	500	636	high performance low emissivity triple glazing. The inner and outer panes are coated to reflect solar radiation.
B2.3	External fixed shading	1,888	7,911	33%	57	239	fixed overhang shading to a horizontal depth of 1.0m above south, east and west facing windows (2.0m awnings to east and west ground floor windows except for front windows - due to proximity to pavement/road)
A2.2	Solar reflective roof	1,492	1,916	5%	330	424	coating the roof tiles with a high performance solar reflective paint
A2.3	Solar reflective walls	2,144	2,754	14%	158	203	coating the external walls with a high performance solar reflective paint
B3.1	Remedial cross-ventilation/room protection	-	2,594	100%	-	26	Replacement of two windows

Discussion

A low-regrets perspective for the technical measures which can be more easily quantified and costed is simply to select those with the lowest cost for the same level of performance.

In Table 5.4, the lowest (best) values (£4 for a 1% improvement) are for curtains and the greatest (worst) values are for Internal wall insulation. Other low values are for Internal blinds, External fixed shading, Reflective walls and roofs, and Loft insulation. The relatively low value for remedial work to ensure cross-ventilation and/or protection of a single room is affected by the choice of a notional 100% for effectiveness but is likely to remain a low-cost option under any conditions of poor ventilation.

From a wider public policy perspective, interventions such as low regrets policies, may be wide, so as to, for example, raise average quality levels in the dwelling stock, or alternatively be more narrowly-targeted on specific vulnerable groups. If mortality of the elderly is linked to overheating, for which there is some evidence (Arbuthnott, 2016), and by extension also to poor ventilation, the key affected group is relatively small but the impact on each person is high. The greatest impact that public policy might provide is to ensure these groups have access to appropriate measures. Successful implementation of a low-regrets policy (and criterion), with also the lowest costs of intervention, is likely to depend most on successful targeting. The costs of the policy and interventions are closely related to the success of the targeting. For example, if only half the target group are reached or respond, the cost of the intervention doubles.

It would be relatively simple to identify and target the elderly from public institutional records. Promoting or offering air-conditioning to this group, with age as a criteria for participation in further intervention support, would be possible. Other measures with lower costs and fewer environmental impacts are also possible. The need for any measure depends on the current condition of the relevant dwellings, and so the cost cannot be estimated other than with crude assumptions for upper limits (covering all rather than just the poorer quality dwellings of a particular type). In addition, the characteristics of the vulnerable groups are relevant to their access to measures. Issues of mobility and reach may particularly affect use of the ventilation system.

Overheating also causes effects which are less potentially significant but affect a wider population. The main health effect is mortality in the elderly which is covered above. Literature sources also identify effects on economic productivity. There is also evidence of adaptation which would reduce impacts potentially only for some groups. There is no established methodology but it is the subject of current work by AECOM for MCDLG.

Methodology for assessing effects on building performance by considering individual measures

The measures with costing methodologies below are those which are predominantly applied to a dwelling and are focused on reducing the number of degree-hours of overheating in a residential building.

The following points apply to more than one measure and are introduced first:

- The number of windows in a dwelling affects the costs of a number of measures. The estimates in the CREW work are based on measures applied to the total number of windows per dwelling, whereas DL, 2009 takes into account estimates only for the number of SE- to W-facing windows, which reduces the costs by half. The effect of the number of windows on costs is included in the discussion.
- Presentation of inflation. Results are presented in current prices, with adjustments for inflation.
- Measures such as blinds and curtains have a wide range of costs because of their many different types. The cost level used to represent the measure is selected from the lower end of the price range as this represents a functional perspective consistent with the low-regrets approach.

Internal Blinds (Measure B2.1)

Internal blinds provide shading which reduces solar gains during the day and so reduce internal temperatures.

DL, 2009 does not provide costs for internal blinds. The CREW model has values which range from £1,200 to £2,600 depending on dwelling type, (Porritt et al., 2011). For the number of windows assumed per dwelling, this indicates a cost per window blind of £200-400 depending on whether south facing or all windows are included. The representation in the CREW model is of venetian blinds which are effective but not the lowest cost.

Current retail prices for DIY roller blinds are £25-125/m^2, which for the standard 3m^2 window used in this study gives indicates prices from £75 to £375 per window blind. There would be additional installation costs per fitting, proportionately greater for lower cost blinds.

Costs represented as: Original CREW cost estimate including inflation. The estimate includes installation costs.

Cost sensitivities: A lower sensitivity based on current market price for lowest cost of blind (£25.21/m^2) and DIY installation.

Curtains (Measure B2.2)

Curtains perform a similar function to blinds and have similar costs. The effectiveness of curtains is lower than internal blinds as the material absorbs more solar energy than internal blinds (CREW). In the computer modelling in the CREW analysis, the difference between blinds and curtains is represented as a difference in the transmission of solar radiation. The CREW modelling considers measures in bundles which would allow for the fact that their combined effectiveness will be less than the sum of the two.

Market prices for curtains begins at a lower price point than blinds with a range from £23 per window but also have a wide range of higher costs reflecting the variety of product types.

Both DL, 2009 and CREW assume curtains are available without additional cost. This is consistent with the assumption that curtains are maintained as a working system which is already part of the house. How well they would meet the standards for curtains required to reduce overheating in practice is unknown. Curtains, which are regularly used at night, are more likely to be available and working than blinds, and the costs of installation assumed to be less.

The cost to recover any lost level of functionality is represented as the cost of replacement curtains, priced at the lower market price (reflecting a functional need) and understood as a one-off remedial cost for restoring original operation. A lower cost for remedial work where curtains does not need to be replaced is estimated at zero.

Costs represented as: Cost of replacement low cost machine-made curtains where these are required to meet functional need. No allowance for installation costs which are assumed negligible in comparison to costs of curtains.

Cost sensitivity: Remedial work which does not require replacement curtains and estimated to be undertaken for negligible financial cost.

External Fixed shading (Measure B2.3)

External fixed shading is assumed to be provided by solar shading panels that are attached to and project 1.2m outwards from the perimeter of a building.

CREW estimates a price of £315 per metre for lengths of fixed solar shading panels (£377 per metre with adjustment for inflation), but does not estimate the costs per dwelling.

Market prices quoted currently for fixed solar shading panels are between £180 and £320 per metre. These are quoted as capital costs and implying they include installation costs.

These costs per dwelling are estimated here. The cost for a specific building depends on the length of the perimeter which is also related to the number of dwellings. For flats of 70m^2 floor area, with a square footprint and arranged 10 per storey in two parallel groups of five, the perimeter is approximately 120 metres long, and the south-facing perimeter approximately 30m. The costs based on a price of £377 per metre, if shared equally between the ten flats on a single storey, would be £1,114 per dwelling. With the possibility that shading is only required every two stories, the cost is halved to £557 per dwelling.

The estimates are highest for a single dwelling where costs are not shared. For a detached house with a footprint of 110m^2 and fixed external shading on one storey only on the South side, the estimate is £3,955 per dwelling.

Costs represented as: Share of costs of solar shading panels installed on buildings based on the CREW price, adjusted for inflation.

Cost sensitivity: Lower, using cost estimate for lower specification shading panel of £180 per metre rather than the CREW estimate of £377 per metre. Upper, assuming that shading is required on two sides of the building rather than one.

External Shutters (Measure B2.4)

External shutters work on the principle of reducing solar gains by blocking sunlight from windows during daytime hours. They are more effective than other forms of solar protection but have a higher cost.

The estimates based on Wood research for current market prices for metal and wood shutters are consistently 30% below the cost estimated in CREW, after adjusting for inflation, and assuming shutters are installed on all windows in a dwelling, not just those which are south-facing. Market price estimates are consistently 30% below CREW across the four dwelling types (Detached, semi-detached, terraced and flat) which suggests that CREW prices include an uplift which would cover installation.

The range of current market prices for a 3m^2 window (1.4 metre by 2.2metre) varied from £130/m^2 for a basic manual belt operation up to £175/m^2 for electric operation. In comparison, the costs from CREW (after adjusting for inflation) vary from £189/m^2 to £239/m^2.

The CREW estimates are used as they include installation costs.

Cost represented as: Original CREW cost estimate including inflation.

Cost sensitivity: Lower, to reflect both DIY installation and only on half the total number of windows.

Low e triple glazing (Measure B2.5)

The replacement of windows by low emissivity coated triple glazed windows reflects a greater proportion of the solar radiation reaching the window. The performance of the measure is comparable to closing curtains or blinds during daytime hours.

The current market prices for Low e triple glazing are quoted as between £400/m^2 and £550/m^2. After adjusting for inflation the CREW estimates, assuming all windows in a dwelling are replaced, range between £339/m^2 and 474/m^2, with only the value for the terraced house being below the market price range of £400-550/m^2.

Cost represented as: Original CREW cost estimate including inflation, with estimate for terraced house replaced with current market prices.

Cost sensitivity: Upper, to reflect upper end of current range of quoted prices

Solar reflective roofs and walls (Measures A2.2 and A2.3)

External walls and roofs of dwellings which are coated in solar reflective paint reduce solar energy absorption.

The effectiveness of the measure in the CREW work was greater in properties with solid external walls and less effective in properties with insulated cavity walls such as modern detached homes. Similarly the effectiveness on coated roofs was greater on poorly insulated roofs than on houses with pitched roofs with loft insulation.

The costs of the measure are directly related to the area that needs to be covered. The costs of paint are significant as it is priced at £5-6/litre and each litre covers 1 square metre. For a dwelling with a roof area of 110m^2, the cost of materials is £660. Two days of labour cost for painting and decorating of approximately £180 (at £11.19/hour) making a total, before other costs, of £840 for this example dwelling.

This estimate can be compared with the CREW estimate (after inflation) of £1,077 to paint a reflective roof on a terraced house. The exact cost will depend on the size of the individual building but these estimates for a terraced house, and because costs are pro-rata to area to be painted which is accurately as part of the modelling, implies that CREW estimates for reflective roof and wall coatings on other dwelling types remain valid.

As the CREW costs are above the estimate based on market prices by approximately 20%, a lower sensitivity is defined reflecting the lower total including labour and equipment charges only.

Cost represented as: Original CREW cost estimate including inflation.

Cost sensitivity: Lower, to reflect only labour and equipment charges at current market prices.

Cavity wall insulation (Measure B1.2)

Insulation decreases heat transfer through the building fabric. Replacing the air-space between cavity walls can be done with additional glass wool, polystyrene beads or polyurethane.

The CREW model priced the measure, after inflation, at a fixed £249 per dwelling type. Also the measure was only applied to flats and semi-detached properties because detached dwellings are assumed to already have some form of insulation and terraced houses are assumed to have solid brick walls. For this reason there is no measure of the effectiveness for these two types. Cavity wall insulation in flats is reported by CREW as causing a very small decrease in effectiveness (-ve value) and this is likely to reflect a modelling result in which the necessarily smaller quantity of heat that was absorbed by the building is retained and eventually released slowly back through the walls rather than via a separate more efficient mechanism such as ventilation. It reflects the selection of modelling conditions and does not indicate that additional heat is transferred inside the dwelling. Subject to this comment, the value is retained for consistency.

Estimates of current costs are available for all dwelling types from the Energy saving trust and are £330 for a flat and £475 for a semi-detached house, substantially greater than the CREW estimates.

Cost represented as: Current cost estimates for a flat and a semi-detached house.

Cost sensitivities: A sensitivity with lower cost, to reflect original CREW cost estimate after including inflation.

Upgrade flat roof (Measure B1.5)

Improved insulation to reduce heat transfer through a flat roof can be accomplished by applying felt, plywood and polystyrene insulation. The measure was costed in the CREW work, after inflation, at £2,634 for a flat, which corresponds to a market price of £37.6/m^2 for a 70m^2 roof. It assumes costs are shared between 8 flats.

Current market prices show a wide range. A survey of quotations for a garage roof indicated a price of £22.70/m^2 when a smaller supplier is used to 26.70/m^2 when a larger company is used while a reported set of three quotes for the same job averaged £45/m^2. An alternative supplier quotes £50-60/m^2 for a felt roof and £85/m^2 for an EDM (rubber) roof.

The CREW model price appears low compared to the current market, though this is partially the result of economies of scale across 8 flats, and the cost estimate has been replaced with a market value, though the lower of the range for a felt roof to reflect any potential economies.

Cost represented as: Current market price of £50/m^2.

Cost sensitivities: A sensitivity with lower cost, to reflect the original CREW cost estimate after including inflation.

External wall insulation (Measure B1.1)

Use of phenolic foam is the primary method of insulating external and internal walls. External insulation performs better in the CREW model than internal insulation because the outer brickwork is not exposed to solar radiation and the brickwork is able to provide some radiant cooling. The cost of the external insulation is implied to be £112-137/m^2 in the CREW work based on the cost for a semi-detached house. The range reflects the difference between gross (including windows) and net wall areas.

The current market price for fitting external insulation to a typical semi-detached house as estimated by the Energy Saving Trust is £100/m^2 which equates to a cost of £13,000 per dwelling. A variety of other sources also suggest that the costs in CREW for external insulation are high. TheGreenAge estimates £8,000 to £10,000 for a typical semi-detached house which corresponds to a range of £60-75/m^2. It is possible that the difference between the earlier CREW estimates and the current market has resulted from efficiency improvements in delivery of energy savings measures.

The cost of the materials is the smaller proportion of the total in the range 15.67 - 30.89. The main part of the work is labour for custom design and fitting to individual dwellings, and hence will never be very cost-effective.

Cost represented as: Based on current market price of £100/m^2 and a new reference cost for a semi-detached property of £13,000. Estimates for other dwelling types were based on scaling their CREW estimates by the ratio of the CREW estimate for a semi-detached property to £13,000.

Cost sensitivities: A sensitivity with higher cost, to reflect the higher original CREW cost estimate (adjusted for inflation).

Internal Wall insulation (Measure B1.4)

The same approach as used above for external wall insulation is used for internal wall insulation.

The current market price for fitting internal wall installation is £7400 for a semi-detached property. The value from the CREW work, after adjusting for inflation is £8,380, some 13% higher. The values for the CREW work for the other dwelling types were scaled to be consistent with the £7,400 estimate for the semi-detached.

Cost represented as: Cost for fitting internal wall insulation to a semi-detached property at current market price of £7,400 and estimates for other dwelling types scaled down proportionately.

Cost sensitivities: A sensitivity with higher cost, to reflect the higher original CREW cost estimate (adjusted for inflation).

Extra roof insulation (Measure B1.6)

Roof insulation is proposed as measure only for Semi-detached and Terraced houses. Detached houses are assumed to have already installed and flats may not have access to a loft.

Cost represented as: Cost for installing roof insulation at current market prices.

Cost sensitivities: A sensitivity with lower cost, to reflect the lower original CREW cost estimate (adjusted for inflation).

Ventilation remediation Internal wall insulation (Measure B3.1)

The importance of the ventilation system for controlling overheating is probably clear to most people from personal experience and is also apparent in the need to set up a range of parameters for the ventilation conditions used in the computer modelling when comparing other measures.

The CREW model as well as the DL, 20009 model do not consider measures relating to maintaining the ventilation system in a dwelling but assume it is in full operation. There is, for example, no concept of a different level of cost for a different level of ventilation capability.

However, there is ad-hoc and qualitative evidence of poor ventilation affecting comfort leading to potential health impacts as well as the established evidence that buildings rapidly overheat without appropriate ventilation. As a result, the situations where there is risk of overheating are also those at risk of extreme overheating, with corresponding level of significant impacts, including increase in mortality.

The level of benefits from avoiding these potentially significant impacts is correspondingly high which suggests that measures which need not have the lowest costs may still, for this reason, be low-regret. However, the lack of information as to the state of ventilation systems has contributed to the lack of specification of any measures.

Quantitative evidence of the importance of ventilation to control overheating is provided by assessment of the physical effectiveness of measures in DL, 2009. The DL, 2009 data is used to illustrate his point as the CREW data does not allow the same simple comparisons of the effects of different ventilation conditions. The effectiveness of the seven measures modelled in (DL, 2009) is shown in Table 5.4 which quantifies their physical effects in terms of degree-hours. The percentages show how many degree-hours of overheating would be avoided by adopting the measure and is expressed as a proportion of the number of degree-hours in the baseline.

Table 5.5 Effectiveness of measures (number of degree hours of overheating avoided per year)

Original Code	Measure	Reduction in number of overheating degree hours	as % of baseline	Maximum % (1)
Flat				
DL_D1	Baseline	3,223	100%	100%
DL_D2	high thermal mass + night cooling by natural ventilation	2,116	66%	75%
DL_D3	window film	723	22%	18%
DL_D4	reduced internal gains	560	17%	18%

DL_D5	high thermal mass + night cooling by natural ventilation + solar shading + reduced internal gains	2,611	81%	88%
DL_D6	high roof albedo	203	19%	5%
Town House				
DL_A1	Baseline	1,758	100%	100%
DL_A2	high thermal mass + night cooling by natural ventilation	1,139	65%	80%
DL_A3	window overhangs	247	14%	3%
DL_A4	reduced internal gains	196	11%	5%
DL_A5	high thermal mass + night cooling by natural ventilation + solar shading + reduced internal gains	1,317	75%	85%
DL_A6	high roof albedo	37	2%	11%
Semi-detached				
DL_C1	Baseline	1,196	100%	100%
DL_C2	high thermal mass + night cooling by natural ventilation	771	64%	71%
DL_C3	internal curtains	134	11%	10%
DL_C4	reduced internal gains	132	11%	15%
DL_C5	high thermal mass + night cooling by natural ventilation + solar shading + reduced internal gains + high roof albedo	846	71%	78%
DL_C6	whole house ventilation + high thermal mass + no window opening	4,620	-143% (2)	-155%
DL_C7	whole house ventilation + high thermal mass + WITH window opening	644	37%	66%
Detached House				
DL_B1	Baseline	1,052	100%	100%
DL_B2	high thermal mass + night cooling by natural ventilation	629	60%	63%
DL_B3	external louvres	355	34%	33%
DL_B4	reduced internal gains	86	8%	8%
DL_B5	high thermal mass + night cooling by natural ventilation + solar shading + reduced internal gains + high roof albedo	802	76%	79%

DL_B6	whole house ventilation + high thermal mass + no window opening	8,822	-738%	-801%

Notes: (1) Maximum is for a single bedroom, single occupant household
(2) Negative values indicate that overheating rises (in this case from closing the windows).
Source: DL, 2009

The effectiveness of ventilation is shown most clearly in the difference between a 37% reduction and a -143% increase (total 180%) of the baseline between measures which differ only in whether "window opening" is used in a semi-detached house (measures DL_C6 and DL_C7). For a flat, the data source does not allow an identical comparison, but a similar measure (DL_D2) which allows for ventilation at night, shows a 66% improvement over the baseline. In comparison, other measures are much less effective. For example, together solar shading and better improving heat performance from domestic electrical equipment (called 'reduced internal gains') show just a 15% additional improvement (from 66% to 81%) in the same flat. The effect of lack of adequate ventilation is shown in an extreme case for a detached house (DL_B6) where the effectiveness is shown as a 738% worsening of building performance due to 'no window opening'.

To represent a possible measure to address poor ventilation, a replacement of two windows with triple glazed units is used. Furthermore the effectiveness of the measure is set to be 100% as a simple reference point to clarify subsequent comparison. Two windows per dwelling are assumed replaced because:

- two windows is the standard number for a room, and so would allow one room to be adapted if nothing else;
- in an alternative installation, such as at the ends of a corridor, two windows would implicitly allow a through draft;
- with replacement of two windows, either an upper floor (e.g. bedroom) or main living room could be adapted to be cooler, and occupants might use it as a refuge.

This measure reflects an additional program of ventilation improvement over and above the ongoing replacement programme that already is in place as part of standard building maintenance and improvement work.

Cost represented as: Based on the costs to replace 2 windows in a property.

Cost sensitivities: A sensitivity with lower cost, to reflect replacement with windows that remediate ventilation problems but are not also an upgrade to low e triple glazed units

Community refuges (Measure A1.5)

The benefits of community refuges are that they provide a form of protection for vulnerable people in a locality.

The costs are potentially low if existing facilities can be used, are available, are suitable for protection, and potential users can move to them at time of overheating with low costs. The assumptions here are that existing community centres fulfil these requirements but might need additional air-conditioning equipment. No estimates of the mobility of users or their costs of transport or dislocation are included.

The average size of a community centre is approximately four times that of a detached house and the estimates of air conditioning costs are based on this multiple.

These costs would be spread over the number of users or potential users. The case study uses the pattern of community centres in Exeter for comparison. There are 28 centres and an estimated 9,655 dwellings occupied by the elderly.

Cost represented as: Capital and operating costs of air-conditioning equipment installed in existing community centres.

Cost sensitivities: No cost sensitivities are proposed as the effect of non-price aspects of the measure are potentially more significant.

Methodology for assessing low regrets perspectives focused on vulnerability by considering a case study of Exeter

In this section, the effects and adoption of measures to assess vulnerability is estimated for:

- Vulnerable populations, assessed as those in the living in the most exposed dwellings;
- The (less vulnerable) general population, living in a standard UK house.

The simplification adopted that exposed dwellings house the most vulnerable means that estimates are worst-case, allowing for vulnerable populations to be preferentially living in exposed dwellings, such as top floor flats but not including preferential living in more protected dwellings such as ground floor flats. The analysis below is carried out with reference to the City of Exeter. It uses attributes for individual buildings taken from Ordnance Survey Master map data.

The buildings with characteristics of the size, suitability for the elderly, and exposure to overheating are identified and the costs of measures estimated for them. Flats in high-rise buildings are typically smaller and would be expected to have a high preponderance of the elderly.

The housing stock considered includes dwellings within a 5km square centred on Exeter. It represents a sample of the UK housing stock and attributes are taken from Ordnance Survey Master Map Address Point data. Aggregate estimates are multiplication of the effects of measures for an individual dwelling by the number of dwellings.

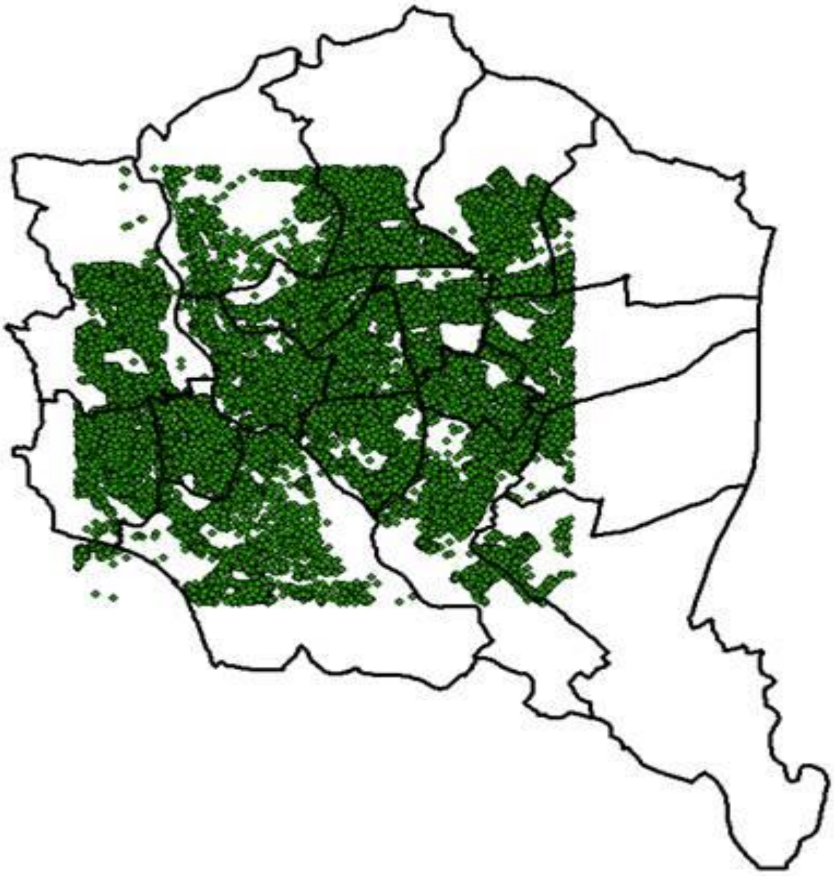

Figure 5.2 Identification of 5kn square with buildings, compared to the extent of Exeter Council

The dwelling types which were quantified separately were as follows:

- More suitable buildings for the elderly, using a criteria of number of storeys and floor area;
- The dwellings which are top floor flats;
- The dwellings which are in the top three floors of flats (an example worst case based on industry hearsay);
- Bungalows, assumed to be important subcategory for the vulnerable; and
- Single household 2 floor terraced or semi-detached, the main UK building type, used by 50% of the population.

The criteria of suitability for use by the elderly specifically is based on the following filter:

- Smaller than 100m^2
- Some dwellings with 3rd floors are excluded, by applying the criteria:
  - In single dwelling households, an elderly couple would potentially downsize away from a larger 3 storey house.
  - In buildings with multiple floors, those of four floors and above would have lifts.

Measures used in Scenarios

The aim of the case study is to assess the impact of access to measures. Three measures are considered:

- B3.1 Remedial cross-ventilation/room protection – this measure is selected due to the importance of ventilation
- B3.4 Air conditioning – this measure provides a comparison.
- A1.5 Community refuges – this measure shows the possibility of low-regrets solutions which are not applied for every dwelling.

The costs are expressed as annualised costs, reflecting ongoing and continuous provision of the measure.

The assumption for effectiveness is that each of the measures below on its own would sufficiently address an overheating challenge, primarily because it would provide additional ventilation, which is key to controlling overheating. This allows the measures below to be treated as alternatives.

Table 5.6 Estimates of the number of buildings and aggregate costs to apply measures to buildings

				Air conditioning as the benchmark measure		**Measures other than air conditioning**			
				Use air conditioning to compensate for poor ventilation - flat [HIGH CASE]	Use air conditioning to compensate for poor ventilation - not flat [LOW CASE]	Replace two windows with triple glazed units	Replace two windows with standard double glazed sashes lifetime 10 years	Replace two windows with standard double glazed sashes lifetime 20 years	Make community refuges available
Cost of measure per dwelling per year									
Unit costs	£/pa			248.18	125.23	59.12	74.67	37.33	1.60
Number of dwellings and costs of measures									
	Number of dwellings			Aggregate cost [£k], for 100% uptake in these dwelling types					
number of dwellings - total	n	42819	100%	10,627	5,362	2,531	3,197	1,599	69
more suitable dwellings for elderly	n	19017	44%	4,720	2,381	1,124	1,420	710	30
are top floor flats	n	2508	6%	622	314	148	187	94	4
are in top three floors of flats	n	7523	18%	1,867	942	445	562	281	12
bungalows	n	595	1%	148	75	35	44	22	1
number of dwellings - two floor single household - total	n	26865	63%	6,667	3,364	1,588	2,006	1,003	43

Specific sectors of housing stock									
	Number of dwellings			Aggregate cost [£k], if applied at 100% uptake, just for proportion of dwellings housing elderly					
Number of dwellings required for elderly	n	9655	23%	2,396	1,209	571	721	360	15

Note, for a simple estimate, multiply these results by 644 for results for the UK, by 536 for England, by 86 for the South East.

There are 42,819 dwellings in Exeter. The elderly currently live in around 23% of them (9,655 out of 42,819). If, for each of these homes two windows were replaced with triple glazed units, the annual cost for each would be £128.4 calculated using the methodology for Remedial cross-ventilation/room protection (Measure B3.1) and identified in the row of unit costs. The annual cost collectively would be £1,240k (see bottom row). This is below the comparative costs of 1,924k for using air-conditioning in flats, which is where the elderly are often living and close to the costs if they were living in detached houses, which have the lowest air-conditioning costs.

A policy objective which focused on ensuring that housing stock was suitable for the elderly as regards overheating would target the housing stock they might live in, not just the dwelling they currently live in. There are 19,017 buildings suitable for the elderly of which they occupy 9,655. The costs of converting all 19,017 dwellings where they might live would be double the cost of converting the 9,655 where they do live.

Focus on more specific sections of the housing stock which are more likely to overheat or on the types of vulnerable populations allows the consideration of a more targeted application of measures with potentially lower costs. The costs for simple measures for the large section of the housing stock identified under 'number of dwellings - two floor single household – total' in Table 5.6 illustrates the costs if converting a large number of standard dwellings was a policy objective.

Further aspects of scenarios are that:

- The number of residents in Care homes in England and Wales according to the UK Census 2011 is 290,000, (3.5% of the UK total) and while all these buildings potentially require attention, there may be fair degree of similarity in the status of systems and in measures applicable and similarity of costs. As with other buildings their ventilation standard is unknown. Any additional costs specific to care homes are not included, though the elderly in care homes are implicitly included in the population estimates.
- Patterns of ownership (landlord-tenant) are likely to affect the implementation, particularly the rate of uptake.
- The public sector is necessarily concerned with facilities that it manages, where it is ultimately responsible for building adequacy, these include council-owned care homes.

The vulnerability of populations and the costs of protecting them from overheating will depend on the following factors:

- Distribution of population in dwellings - the size of the overlap in the match between the vulnerable population and dwellings which overheat. The range of aggregate costs for the scenarios above illustrate the effect of applying measures to different numbers of dwellings, but their occupancy by the vulnerable is assumed. A worst case can be identified assuming the elderly are housed in the most inappropriate dwellings. This is shown in the table above by the costs to implement measures in 'all top floor flats' with a further assumption that the elderly occupy them. Without further information it is impossible to be more precise on these ranges.

- Representation of aspect - Dwellings on the south and west facing aspects of a building are more exposed to the solar radiation and would heat up more than others. If only those making up half the building needed measures, then the estimates in the table above could also be halved.
- Vulnerable groups – Consideration of the very old (over 80) rather than the elderly (>65) would factor the results by 28% on a pro-rata basis. The other vulnerable group, the very young, would be housed in types of household not represented by the same building stock and simple estimates are not available by scaling.
- Climate change - The proportion of total properties exposed to overheating is expected to increase by between 55% (low case) and 85% (high case) due to the effects of climate change. attributed to an increase in average and extreme temperatures (during heatwaves) among other factors. This would lead to a corresponding increase in costs incurred for measures to control overheating. This value is derived from Jenkins et al, (2014).

Limitations of the Study

The impacts from overheating are not well defined because the simple metric of degree-hours is used but it is only a proxy for real impacts. Measures addressing ventilation have been assumed to fully address the requirement for ventilation (100% effective). Better understanding of potential benefits would allow a focus on the most appropriate measures for the circumstances.

Overheating events are characterised by variety in their severity, frequency and affected geographic region, with potentially different types of effects and mitigating measures. This type of variation is not considered.

Analysis of the affordability of measures is not conducted.

Alternative specifications for costs and benefits could be used. For example, the costs calculated and presented for the case studies are poor reflections of the benefits that might actually arise from the introduction of a measures such as triple-glazing. If the occupant was already satisfied, the benefit would be zero, while in other cases, if it avoided a fatality, the benefit would be substantially higher. Upcoming research on overheating health impacts for MHCLG would enable health outcomes to be represented in terms of avoided real financial and economic health costs.

Wider economic impacts such as effects on supply chains are not included.

The benefits and costs of financial instruments to enable and manage costs have not been considered although an important element of feasibility for many residents.

Conclusions

The standards that housing stock should preferably meet have been defined in government guidance such as CIBSE Guide A but it is unclear how well the current housing stock meet these criteria and the possible causes of any difference between recommended and actual levels.

The comparison of technical measures shows the lowest (best) values (£4 for a 1% improvement) are for curtains and the greatest (worst) values are for Internal wall insulation. Other low values are for Internal blinds, External fixed shading, Reflective walls and roofs, and Loft insulation and external fixed shading. The ordering of these measures follows the recommendations The relatively low value for remedial work to ensure cross-ventilation and/or protection of a single room is affected by the choice of a notional 100% for effectiveness, see below), but is likely to remain a low cost option under any conditions of poor ventilation.

For any of the housing stock, the dominance of ventilation as an effective control system makes measures affecting it of prime importance, particularly as all houses will require the same basic capability, at least to meet the same climate and local conditions. The conditions affecting ventilation performance include noise, security and housing stock condition as well as affordability and the mobility of residents.

It is very possible that improvements to the ventilation system are measures which are more effective than any of the different types of measures considered more commonly in the literature to date. The limited information on how often poor ventilation occurs across the country, and hence on the scale of requirement for different measures.

In analysis, issues of lack of data affect the baseline, which needs to include and represent the individual preferences of individuals and their potential to use air-conditioning as a possible alternative for controlling overheating[51]. The preferences of the population are covered in more recent government guidance (CIBSE Technical Memorandum 52) which presents research that shows the temperature that occupants will find uncomfortable changes with the outdoor conditions. This complexity, while potentially better representing the impacts on occupants, is less relevant to the technical comparison of measures here as it does not change their relative performance.

Without knowledge of the state of the capability of the ventilation system, it is impossible to know how well the current building stock will react to background increases in the baseline and how far away it is from being able to cope effectively with future temperature increases.

There are important subsidiary issues related to targeting action (whether public or private) including identifying the buildings to apply measures to and how to identify and prioritise affected populations.

In general, the work on updating the costs of measures has confirmed the assessment of the individual technical measures in the previous study.

The main recommendations are:

- Because of the potential high negative impacts from poor ventilation, further research is required to identify the state of ventilation systems in the housing stock, by, for example conducting survey/consultation to understand for divergence from design standards.
- Better definition of practical measures to address ventilation is required to confirm their very high effectiveness compared to other measures when ventilation is poor.
- In advance of new data being available, the table of measures and costs in the above based on and with reference to the CREW project is recommended to be used to establish the preference order for measures in the case of any single building, excluding measures that that do not apply to specific conditions.

On tower blocks, overheating measures could be considered as part of cladding or recladding work as costs may be substantially less.

5.3 Updates on previous findings

Metrics

This analysis drew on the work from the CREW project which was published subsequent to the work in the previous study and covers assessment of the effectiveness of measures and their costs.

The metrics for effectiveness were based on degree-hours and the estimated values were retained in this study as they depend on a building model and set of measures which remain largely relevant and unchanged. The metrics for costs of measures were compared against current market prices and updated.

[51] Used as a comparator as there is a proven supply chain and active market in air-conditioning units

Results

Updates to data on costs did not change the order for selecting measures to treat a building which is overheating, and the more effective and lower cost measures remain the same.

In comparison with the previous study, the effect of ventilation capability was considered, as well as wider policy objectives than focus on vulnerable populations. This provides initial quantitative estimates for the costs of measures for specific targeted populations, based on a case study for Exeter.

6. Cross-cutting issues

6.1 Limitations

In the context of this study, many of the limitations levelled against the original study have been addressed through for example the inclusion of indirect benefits as well as other updates to the original assumptions and methods used.

While limitations for each topic have been addressed under their headings, there are the following cross-cutting issues which can be highlighted as relevant both in the original and this study:

- *The measure of benefits* – benefits have been represented and monetised in a variety of ways, which means that trade-offs between preventing flooding and preventing overheating cannot realistically be established.
- *Independence of measures* - many of the measures are not independent, there may be interactions between them and their effectiveness may depend on the order they were implemented. In many practical cases only a few measures are applicable and are often not easy substituted.
- *Individual preferences* – information in relation to individual preferences affect existing and future level of uptake is generally poor with, for example, few surveys of individuals that capture likely behavioural responses.
- *Effectiveness of measures* – measures may not achieve technical standards and may be impaired by lack of maintenance or knowledge and other aspects related to effective use.
- *Baseline information* – also important because it provides the so-called 'do-nothing alternative'- is often relatively difficult to determine.

Unfortunately, only a partial representation of the impact on climate change on the economically viability of different adaptation measures could be achieved within the constraints of the previous modelling framework. To ensure coherence and comparison with the original study results a similar methodological framework was used, including additional elements to assess the wider benefits of adaptation measures.

6.2 Defining Low Regret Measures

Structured comparisons of costs and benefits (including cost curves) have been used in policy analysis generally to add clarity to choices between individual technical measures and the approach has been used in environmental policy analysis. Cost-benefit analysis (CBA), which compares costs with benefits, is preferred for ranking of options. However, cost-effectiveness analysis (CEA) provides an alternative approach in cases where benefits cannot be monetised and compared directly with costs. Using a CEA approach, options are compared in terms of equivalent outcomes (such as number of lives saved) but a value is not put on these outcomes. CEA is more commonly and easily used when the aim is to identify the contribution of options towards a pre-defined target (as this does not need to be expressed in monetary terms).

Cost curves which show the relative advantages of measures can be constructed to communicate and rank options from most to least cost-beneficial (using CBA) or cost-effective (using CEA). In some cases, such as when alternative measures can all be implemented and meet other criteria (such as not depending on each other) their cumulative contribution can be shown as the sum of the measures on a cost curve (CCC, 2008). Despite these advantages, the complexity required to express limitations means that abatement cost curves often omit risk or uncertainty and, while sensitivity analysis is possible, it is not always undertaken (Watkiss et al, 2015).

The use of cost curves, whether based on CBA or CEA, has been relatively limited and specific to circumstances. Notable studies include previous work by Davis Langdon and Boyd (2006) which used multiple climate change scenarios to assess the cost-effectiveness of alternative water demand and supply options in South-East England. While cost curves have been extensively used in a mitigation context, largely because they permit options to be compared graphically using a single common and globally comparable metric (i.e. $/t$CO_2$), the same is not true of adaptation (Watkiss et al, 2015). Adaptation efforts tend to be more focussed on a specific local, regional or national situation and, as such, they may use and rely on a variety of different metrics and indicators.

As an example, adaptation to sea level rise includes actions relating to protecting people, reducing erosion and conserving ecosystems. A holistic and universally accepted adaptation metric in this instance does not currently (nor is likely to ever) exist. Furthermore, adaptation benefits are both location, technology and time-dependent with corresponding changes in unit effectiveness over time. Furthermore, cost curves focus on the comparison of measures discrete entities in a linear and sequential order which is at odds with the adaptation literature which is increasingly focussed on the promotion of adaptation portfolios and the recognition of interdependencies to manage uncertainties (IPCC, 2012).

The original Davis Langdon study adopted a narrow definition in relation to the identification of economic low regret measures, focussed on monetary aspects which can be easily identified, and which have a cost-benefit ratio less than one (equivalent to having a net present value greater than zero).

In adopting this definition, the results of analysis can be inadvertently skewed due to limitations and uncertainty in the underpinning assumptions. For example, if the metrics assigned to a measure's benefits are exaggerated, then measures yielding a positive NPV could be incorrectly assessed as being 'low regret'. Similarly, the identification of low regret measures is highly sensitive to the choice of discount rate; any measure with up-front costs can produce a negative NPV if the assumed discount rate is sufficiently large enough.

ASC (2011) states that standard appraisal techniques such as CBA, CEA and multi-criteria analysis (MCA) can be used to identify low-regret adaptation options and, while broadly correct, this statement needs to be crucially caveated. Application of the method alone does not ensure options are low-regret, rather the use of multiple scenarios in combination with standard appraisal techniques permits the identification of low-regret measures. Following this logic, the original analysis conducted by Davis Langdon is partial because the use of multiple scenarios to assess the sensitivity of measures is applied in a limited manner. As such the robustness of measures is not adequately assessed or communicated.

The current working definition of low regret measures as defined by various international research, policy and practice groups has tended towards 'low cost' options which perform adequately or exhibit robustness under a range of future climate change scenarios, whilst minimizing trade-offs[52]. More nuanced definitions have emphasised the importance of managing trade-offs more effectively, thereby encouraging the use of multiple metrics to assess performance as well as rigorously assessing sensitivity to uncertainties. Furthermore, more recently other concepts such as 'win-win' solutions, specifically climate resilient options yielding additional co-benefits, have begun to emerge within mainstream adaptation discourse.

The following aspects of low regret measures were identified following internal discussions between the project team to assist in the development of a new definition of low regret applicable to adaptation measures for the UK residential sector. This list is by no means exhaustive, and may be further refined in the future, but it is intended to provide a starting point for developing a more robust definition of low regret measures. Due to data limitations many of these aspects would need to be assessed qualitatively as opposed

[52] https://climate-adapt.eea.europa.eu/knowledge/tools/uncertainty-guidance/topic2

to quantitatively, while some may be disregarded if they are deemed to be too abstract for practical implementation.

Table 6.1 Aspects of low regret options

Low regret	Data type
Cost Effectiveness/ Cost benefit	Quantitative
Political Will	Qualitative
Technical Feasibility	Quantitative
Climate Sensitivity	Quantitative/Qualitative
Technology Readiness Level	Quantitative/Qualitative
Consumer Uptake	Quantitative
Behavioural Efficiency	Quantitative/Qualitative
Retrofit Potential	Qualitative
Geographical Transferability	Quantitative/Qualitative

Following the identification and agreement of these aspects of low regret measures, it is necessary to develop a framework through which these aspects can be integrated and applied. Various low (no) regret and robustness frameworks have been developed previously, the most famous of these being Minimax Regret which is focussed on minimizing the worst-case regret (or the difference between the perceived best and worst outcomes), more recently developed approaches including Robust Decision Making (RDM). Low (no) regret solutions are generally viewed as being characteristically robust due to their internal characteristics and not because they have necessarily been designed with an optimal future in mind (Fankhauser & Soare, 2013). These options can be designed and implemented, avoiding the needs to quantify what the future might look like and what impact it will have, instead they place much greater attention on the immediate social and economic benefits provided, delivering co-benefits and enhancing local resilience (Watkiss & Hunt, 2014).

The advantage of low regret measures is that they can be relatively low cost for example fixing leaky pipes or implementing resource recovery technologies, they also come with the added advantage of being able to show immediately visible benefits. As a result, they are generally considered to exhibit best-practice however they can also result in maladaptation if they are poorly conceived or implemented. For example, enhanced irrigation technologies when poorly deployed can increase water use and worsen drought conditions. Furthermore, these types of options are not always immune to black swan style events because future forecasting is rarely undertaken. In the context of adaptation, the ultimate goal is to identify solutions which can deliver immediate co-benefits, which are robust in the short term but are also resilient to acute shocks as well as long term trends, where these could have significant and cumulative negative impacts. The following definition of low regret measures has been proposed for the UK residential building scale based on the above points:

> *"Low regret measures are defined here as tangible assets or actions which exhibit robustness across a range of futures, which consider monetary and non-monetary costs and benefits proportionally in their evaluation and which can be easily adapted with minimal disruption in the future if priorities change."*

The previous study adopted a narrow definition of low regret measures, the focus on cost-effectiveness only provides a clear ranking of measures, how this remains only a partial representation. As part of this project, an attempt has been made to extend the analysis to incorporate other benefits and provide a more realistic representation of low regret measures. Unfortunately, the limitations imposed but the original study and cost-curve methodology does not permit further advancements to be made. Instead, the authors would recommend moving the analysis of such-low regret measures beyond a focus on cost-effectiveness and the cost curve methodology to consider other aspects which contribute to household to broader societal benefits, which incorporate climate scenarios explicitly within the analysis.

7. Case Studies

7.1 Water Stress

In the context of water stress, the study identified several low regret measures consistent with previous findings including dual flush WCs, low flow taps, click protect kitchen taps and low flower showers, representing discretionary retrofits. These results are consistent with current evidence of industry uptake. Currently about of 30% of domestic water use can be attributed to toilet flushing. Dual flush toilets can yield significant water savings, they provide a split flush button, permitting greater control over the amount of water used, most dual flush toilets use between 4-6 litres compared to 9-13 litres per flush for conventional toilets.

Figure 7.1 Water displacement device. Source: Northumbria Water

Although significant water savings could be achieved, the results of this analysis indicate that based on consumer benefits alone, discretionary retrofit of many water efficiency measures could not be justified based on a limited economic centric definition of low regret measures. Despite this, there are several commercially available low-cost measures which achieve some level of water reduction and could be deemed low regret. With respect to toilets, options include installing cistern displacement (or volume adjustments) devices[53], cistern dams which effectively partition the cistern, delayed inlet valves which prevent water inlet during flushing and other low-cost solutions such as leakage detection tablets[54].

7.2 Flooding

In the context of flooding, flood resilience measures were shown to be largely low regret for new buildings for certain flooding events. These measures comprise a number of discrete activities designed to minimise the direct damage caused by flooding as well as accelerate drying and recovery following an event. These measures included raising the floor above likely flood level, installing wall mounted boilers and moving electrics above floor level. In addition to these considered measures, a number of other flood mitigation measures are commercially available, these include doorway covers, air brick protection, drain covers, sewage anti-overflow systems and automatic flood doors.

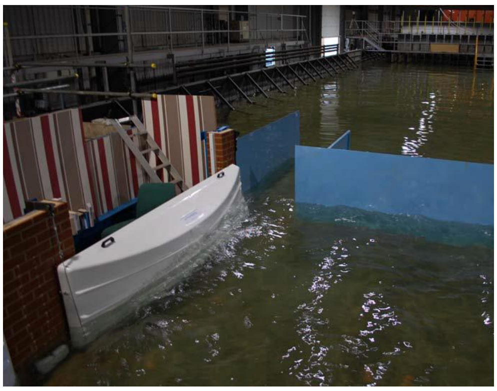

Figure 7.2 HR Wallingford Test Site: Source: Environment Agency

In addition to these commercial offerings, sandbag barriers and other fixed and demountable barriers can be erected to prevent flood water penetrating structures or direct it away from vulnerable areas. Many of these flood barriers have been designed and tested against PAS 1188 and received the BSI kitemark accreditation. PAS details a range of requirements for flood protection, including specifications for the designation, testing, production, installation documentation and allowable leakage

53 https://www.anglianwater.co.uk/_assets/media/How-to-fit-cistern-displacement-device.pdf
54 https://nwl.watersavingkit.com/product/cistern-displacement-device/

rates under a range of test conditions, see for example HR Wallingford's flooding test site where a number of these products have been tested.

A combination of rigorous testing and product testing a produced a range robust temporary and permanent flood defences measures which can be mobilised during flooding events. Additionally, a range of consumer grade pumps are commercially available to evacuate flood waters during incidents. These pumps are available as submersible units, which can be operated when an electric supply is available and placed directly in the flow. Conversely, fuel engine pumps, which are typically powered using a petrol enable them to be used in isolated locations and when utilities fail.

7.3 Overheating

In the context of overheating, low regret measures were largely identified as measures which facilitated ventilation and increased shading in properties. Recent events have highlighted the significant risk overheating poses to vulnerable people living in residential properties, particularly top floor flats. There are fewer commercial offerings with respect to overheating, and most of the measures which have proven to be effective relate to the design and orientation of buildings as well as behavioural aspects. Solar shading is very effective at minimising the amount of sunlight entering a property, however these need to be carefully designed with respect to the orientation of the opening. For example, openings on the south side of buildings should be protected using balcony shading, while openings on the east and west of buildings should be protected using vertical shading.

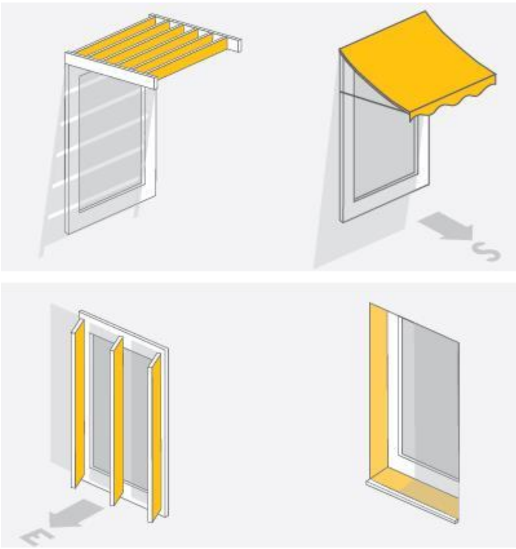

Figure 7.3 Building orientation shading. Source: NHBC Overheating Guide NF44

Natural ventilation remains one of the most effective measures in combatting overheating, however in the context of building design it is also needs to be considered along with other factors such as noise, air pollution and security. When opening of windows is not possible due to a combination of these factors and others, other options may need to be pursued. Mechanical ventilation is one option and has been applied in a number of newer buildings, it permits fresh air to enter internal areas where external permeability is designed to be intentionally low. These building scale measures and others can also be supplemented with consumer appliances such as desk-top fans and behavioural changes (e.g. drinking water throughout the day) to reduce the risk of overheating. Mechanical ventilation is common on kitchens and bathrooms, and can be used to improve air movement, remove odours and excess moisture as well as facilitating temperature control.

In additional to enhanced ventilation, green roofs can be incorporated within developments to enhance biodiversity, improve rainwater attenuation and the reduce the impacts of UHIE. Green roofs contribute to urban cooling by shading surfaces and facilitating evapotranspiration. Additionally, cool roofs and pavements can be installed in urban areas, made of highly reflect materials, these surfaces reduce the amount of solar energy that is absorbed by surfaces. Cool roofs in particular can reduce the top-flood or a non air condition building by 1-2°c.[55]

Figure 7.4 Cool roof – Bermuda. Source: Wikipedia. 2018

[55] http://www.wsp-pb.com/Globaln/UK/Whitepapers/WSP-PB-Overheating-FINAL.pdf

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Appendix A
Water Stress Input Data

Table A.1 Key assumptions and variables

Variables	Value
Percentage of EXISTING homes to which efficiency measures are applicable	50%
Percentage of NEW homes to which efficiency measures are applicable	100%
Percentage of EXISTING homes with a water meter (included in household cost curves)	60%
Percentage of NEW homes with a water meter (included in household cost curves)	100%
Baseline household water use, daily per capita consumption (l/person)	146
Hourly rate, plumber (£/h)	35

Table A.2 Long run marginal costs

Company	LRMC, South East only (pence/m3)	Number of households served
Southern		
Kent Medway	118.3	199,935
Kent Thanet	106.9	93,886
Sussex Hastings	55.6	53,541
Sussex Coast	38.5	250,542
Sussex North	31.4	114,510
Hampshire South	29.9	377,253
Thames	67.0	888,139
Folkestone & Dover	81.2	69,851
Mid Kent	134.0	250,000
Portsmouth	4.3	288,665

Company	LRMC, South East only (pence/m3)	Number of households served
South East		
Northern	51.3	375,000
Southern	141.1	229,000
Sutton & East Surrey	54.2	145,247
max	141.1	
min	4.3	
weighted average	66.10	
median	55.6	

Table A.3 Water charges

Company	Charges (pence/ m3)
Southern	136.5
Thames	129.5
Folkestone & Dover (now Affinity W)	104.37
Mid Kent:	
Standard	108.2
Low user	141.8
Portsmouth[5]	63
South East:	
Eastbourne	171.66
Mid Southern	130.07
Mid-Sussex	171.66
West Kent	171.66
Sutton & East Surrey:	
Southern Area	138.08
Volumetric charge, water, max	171.7
Volumetric charge, water, weighted average	131.1
Volumetric charge, water, min	63.0
Volumetric charge, sewerage	
Southern	239

Company	Charges (pence/ m3)
Thames	82.61
Volumetric charge, sewerage, max	239
Volumetric charge, sewerage, weighted average	193.9
Volumetric charge, sewerage, min	82.61
Volumetric charge, total, max	410.66
Volumetric charge, total, weighted average	**325.0**
Volumetric charge, total, min	212.11

Energy and carbon savings - methodology statement

Energy use of hot water provisions was calculated as follows:

- Typical temperature rises were calculated for each intervention, using weighted averages of different temperature settings where applicable.
- These were multiplied by the volume of hot water saved and by the specific heat capacity of water to give the energy saved at point of use.
- Gas water heating costs and CO_2 emissions were calculated using our long term projected factors of 4.51 p/kWh and 0.183 kg CO_2/kWh and an average water heating boiler efficiency of 69.85%.

Electric water heating costs and CO_2 emissions were calculated using our long term projected factors of 19.06 p/kWh (standard rate), 10.08 p/kWh (average time of use tariff) and 0.217 kg CO_2/kWh and assuming 100% conversion efficiency.

Tank and pipe losses were ignored as primarily fixed losses rather than consumption related.

Washing machine and dishwasher savings were presumed to be provided by electric heating only at a standard tariff.

All other interventions were assumed to be provided by a weighted average of gas and time-of-use tariff electricity, based on the current split between electric and gas water heating in UK housing (82.9% vs 10.2%). Other heating fuels were ignored due to their unknown, but presumed small, future contribution to the fuel mix.

Appendix B
Flooding Input Data

Table B.1 Probability of evacuation and duration in relation to flood depth

Maximum depth in house (cm)	% who evacuated	Mean duration of evacuation in weeks	No of days
0	23%	11	77
1-10	41%	12	84
10-20	55%	18	126
20-30	59%	18	126
30-60	69%	21	147
60-100	76%	23	161
100+	87%	33	231

Source: MCM (2017). Probability of evacuation and duration in relation to flood depth. Source: MCM Handbook Tables (2017)

Table B.2 Probability of evacuation and duration in relation to shallow and deep floods

	Share of households affected	Weeks	Days
Shallow flood (average)	32%	11.5	80.5
Deep flow (average)	69%	23	158
Average (shallow& deep)	59%	19	136

Table B.3 Cost of evacuation

Source	Cost item	£ per hh	Duration (average, days)	£ per hh/day
MCM Handbook (2017)	Total average displacement costs	4,364	154	28
Joseph (2014)	Average	7,424	154	48
Joseph (2014)	Minimum	626	77	8
Joseph (2014)	Maximum	31,420	231	136

Table B.4 Intangible (human health costs) of floods

Indicator	£ per hh per year	Source	£ per hh per day
Intangible human health costs	237	MCM, 2017	0.65
Intangible human health costs	843	Owusu (2014)	2.31
Intangible human health costs	693	Joseph (2014)	1.90

Table B.5 Baseline costs per household (adjusting for the share of affected households)

Element	Min	Mid	Max
Costs of evacuation Shallow	200	730	3,656
Costs of evacuation Deep	709	3,102	21,742
Intangible (human health costs) of floods – shallow	76	76	76
Intangible (human health costs) of floods - deep	479	479	479
Total cost – shallow	276	806	3,732
Total cost- deep	1,188	3,581	22,222

Table B.6 Adaptation measures -effectiveness

Residual probability of disruption costs	Flood resistance			Flood resilience		
	Min	**Mid**	**Max**	**Min**	**Mid**	**Max**
Shallow	0%	0%	0%	0%	23%	23%
Deep	0%	0%	0%	0%	50%	75%

Table B.7 Benefits of reduced disruption

Element	Flood resistance			Flood resilience		
	Min	**Mid**	**Max**	**Min**	**Mid**	**Max**
Shallow	276	806	3,732	276	620	2,873
Deep	1,188	3,581	22,222	1,188	1,791	5,555

Appendix C
Overheating Evidence Base

Table C.1 Evidence Matrix - Overheating

Reference	General Comment	Impacts	Measures	Building Types	Construction Materials
1. **AECOM. (2012) Investigation into overheating in homes: literature review. Department for Communities and Local Government.**	very relevant and useful literature review, highlights many further studies. Slightly dated	"it is not possible to say with any certainty what level of indoor temperature presents a risk to health" pg.21 Focused on mortality/morbidity Heat-related morbidity reflected in hospital admissions, GP consultations, ambulance calls and health service communication. Pg.20 Evidence of high outdoor temps increasing falls from windows, other accidents even suicide. Pg.20 Epidemiological vs. Physiological studies to identify health impact pg.25 – direct observation vs. laboratory test on individuals. Need for periods of rest, Productivity, "temperatures that limit the ability to perform daily activities (physical work)." pg. 26	Air conditioning repeatedly shown to be protective Edinburgh - Insulation in houses helped reduce levels of solar gain London - Super insulation increased overheating solar gains retained in interior pg. 35 Policy Instruments - Building Regulations 2010 does not require overheating to be limited Urban Realm: Street 'canyons', city ventilation air flow, trees reduce UHI effect and shading, traffic reduction result in open windows, reduce waste heat from city, green roofs, reflective roof material pg. 85 Building: Cavity wall insulation, chimneys, external fixed shading, external shutters, External wall insulation, Glazing areas, internal wall insulation, low emissive coated triple glazing, internal wall insulation, orientation (new build design), glazed areas on facades, thermal mass access, solar reflected roof and walls, avoid single aspect flats, do not add car parks at expense of green space pg. 87/88 Equipment: fans, curtains, blinds, air conditioning +RE, cross ventilation, plants and trees, MVHR operation pg. 87/88 Behaviour: window open, night ventilation, clothes, curtain/blind	"little direct epidemiological evidence about housing characteristics as independent risk factors" pg. 21 "residents of nursing homes may be particularly at risk" pg.21 Paris 2003 study showed large variation in risk relating to specific characteristic, increased mortality in top-floor flats, older dwellings, those without good insulation. Provide odds ratio to quantify risk from characteristic- pg.23 South UK most at risk, but in London "built form and other dwelling characteristics" have greater impact than location pg.35 Bedrooms perform badly, particularly in newly built flats pg. 35 Occupier house patterns, elderly spend more time in house, thermal heat	concrete ground floors significant cooling effect pg.36 High insulation and air tightness standards of newly built and retrofit houses lead to overheating pg.37 Natural ventilation may become double edged sword, in future incoming air will be higher temperature pg.37

				use, thoughtful placement of people, access to cool shady area, switch of non-essential equipment pg. 88 Health: Drink water, shade, avoid exercise, monitor temp, ice, monitor people, shower pg 89	gains pg. 35 Dwelling built in 1960s and small top floor flats considerably prone because low solar thermal protection pg.36 detached houses highest cooling load but more recent study showed least efficient cooling loads per floor space area pg. 36	
2.	**Arbuthnott, K., Hajat, S., Heaviside, C. and Vardoulakis, S. (2016) Changes in population susceptibility to heat and cold over time: assessing adaptation to climate change. Environmental Health, 15(1), 73-93.**	focused on heatwaves and severe cold spells little material on building overheating / indoor temps and impacts	Reduced vulnerability to heat in those born in Southern Italy compared to Northern suggests physiological and behavioural adaptions to heat could be important. Pg 90	"use of cooling systems or HHWS" pg90	"while comparing results across cities or regions may implicitly include adaptation to temperature over time, it cannot give an estimate of how quickly or by how much community vulnerability can change." pg90	focused on heatwaves and severe cold spells little material on building overheating / indoor temps and impacts
3.	**ASC. (2014) Managing climate risks to well-being and the economy. Adaptation Sub Committee progress report 2014.**	covers a range of climate change impacts related to health, infrastructure and business section on flooding risk	"people aged over 75, who are more vulnerable to heat, has increased by 0.8 million to 4.1 million over the last 20 years" pg. 127 Morality is most common metric but limited. Does not address life years lost, economic cost or burden of disease pg. 130 Older people particularly at risk	Urban greenspace helps mitigate urban heat effect - pg. 127 cost effective measures to retrofit-external shading and reducing internal heat gains Also political tool to raise awareness Passive cooling designed into new buildings, introduce new standards - has not been introduced as the costs and benefits have not been quantified definition of overheating needs to be standardised for building regulation standards to be adopted for overheating Air conditioning instead of passive	"Types of hospital ward that are vulnerable to overheating currently make up 90% of the total stock. Up to 20% of homes could already be overheating, even in a cool summer. Flats, which are generally more at risk of overheating than houses, now make up 40% of new dwellings compared to 15% in 1996." pg. 127 Care Quality Commission should set standards for max. temperature in	Increasing standards for energy efficiency could exacerbate from air tightness, Pg. 146

				cooling measures would cost additional £2billion on existing homes, £400million new homes over 15years AC exacerbates urban heat island effect and could create social inequalities. pg. 144 Ventilation good but depends on outdoor temperature in future and air pollution External shading, shutters, wall insulation are a "win-win" pg.145 reducing internal heat gain from pipes and appliances, curtains, tinted windows and painting roofs white cost-beneficial but uptake low	hospitals internal temperatures in homes were 21% above overheating threshold Generally living rooms more overheated than bedrooms, Purpose built, top flats, uninsulated loft conversions performed worse of all dwelling groups- single aspect and reduced air flow, heat absorption from surrounding buildings, small size, inadequate external insulation, improper ventilation in communal areas, inability to open windows in flats. pg. 140	
4.	**Beizaee, A., Lomas, K. and Firth, S. (2013) National survey of summertime temperatures and overheating risk in English homes. Building and Environment, 65, 1-17.**	Statistics heavy modelling of temperatures in different types of homes across different regions in the UK				
5.	**DCLG. (2012b) Investigation into overheating in homes: Analysis of gaps and recommendations. Department for Communities and Local Government, London**	Identifies the gaps from the Literature review (Ref 1 in list) Identifies 2 gaps in knowledge: substantial gaps in knowledge and potential activities to inform decision making	"It is relevant also to note that most heat-attributable health events are not readily identifiable as heat-related from the clinical circumstances. The attribution of heat-related is purely statistical based on the observation that a	Behaviour of residents is important to understand how many measures are utilised	n/a	n/a

			greater frequency of adverse events occur on days of high temperature" pg. 11 Comfort Pg. 20 - most work on comfort focused on productivity in non-Domestic			
6.	**Good Homes Alliance. (2014) Preventing overheating: Investigating and reporting on the scale of overheating in England, including common causes and an overview of remediation techniques.**	covers measures to address overheating and features of buildings which create overheating, separated by building types. No mention on impact of overheating	n/a	All buildings: reduce external heat gains, less glazing or with solar film, shading on south, west and east , internal/external blinds. Reduce internal heat gains less dense dwelling. Cooling ventilation, windows Behaviour: un-openable windows, shutting blind/curtains, reduce appliance use Converted flats: insulating roofs, replace un-openable windows, extraction ventilation in kitchen and bathroom, conversion allows sufficient ventilation/cross air flow New flats: replace un-openable windows, opaque panels/solar film on windows, ventilation system, open corridor windows	details the types of dwellings most at risk by age and property type. pg24 Small flats of particular problem because: overcrowded, older properties converted, new flats high insultation under ventilated. Heat gains quicker and air tight	For Pre-1919 buildings: Un-insulated roofs, Large areas of glazed wall/roof/conservatory, windows painted shut, single glaze, un-openable glazing. Conversion of building purpose, division of space, unventilated uninsulated lofts. Hot water systems. In urban areas, noise pollution and surrounding surface hard and heat absorbent Post2000 Purpose built flat: south facing, single aspect flat off central corridor. Well insulated, airtight, large glazed area, un-openable windows/restricted. communal heating pipes running through flat/corridor, poor ventilation system/faulty, urban location densely populated and noise
7.	**Hamilton, I., Milner, J., Chalabi, Z., Das, P., Jones, B., Shrubsole, C., Davies, M. and**	Assess public health impacts due to indoor air quality and temperature to meet 2030 targets	Primary outcome Quality Adjusted Life years (QALYs) Links indoor winter temperature (cold) to	n/a	n/a	n/a

	Wilkinson, P. (2015) Health effects of home energy efficiency interventions in England: a modelling study. BMJ Open, 5(4), e007298.		mental health using an exposure response relationship			
8.	**Khare, S., Hajat, S., Kovats, S., Lefevre, C., Bruine de Bruin, W., Dessai, S. and Bone, A. (2016) Heat protection behaviour in the UK: results of an online survey after the 2013 heatwave. BMC Public Health, 15(1), 878.**	Focused on heatwaves, covers a range of socio-economic groups and protective measures.	Men less likely to take up measures than women. High income reported higher uptake of measures than low income	Installed and portable AC, curtains dark/light, Shutters, Loft/wall conversion		
9.	**Lomas, K. J., & Porritt, S. M. (2017). Overheating in buildings: lessons from research.**	Good literature review of existing academic studies on overheating		Mechanical ventilation systems not installed and do not always perform well (Brown & Gorgolewski, 2015; McLeod & Swainson, 2016) external shading devices, shutters, green roofs are resisted by house buyers - no buyer incentive trickle vents - noise concerns (Baborska-Narożny et al) passive and hybrid ventilation (Thomas) Con-current operation fan and AC, ceiling fans in Care homes (Gupta et al.)	Urban buildings small ceiling, security concerns lead to no night time ventilation. internal heat gains from hot water circulation. Urban environment higher ambient temperature (GHA 2014) Elderly more susceptible to overheating (PHE 2015) retrofitted low rise social dwelling (Vellei et al.) Care homes (Gupta et al.) flats in Leeds (Baborska-Narożny et al) modern well insulated homes more at risk (McGill et al. and Morgan et al. - Scotland houses)	thermally lightweight materials cannot ameliorate large temperature swings(NHBC 2012) feature that might increase overheating "such as top floor or not, high window-to-floor area ratio, south-facing glazing. However, there was 'no discernible relationship between the incidence [of overheating] and the potential factors" compare different construction types of buildings (Birchmore et al.)

10. McLeod, R. S., Hopfe, C. J., Kwan A.S.K. (2013) An investigation into future performance and overheating risks in Passivhaus dwellings. Building and Environment, 70, 189-209.	investigating if Passivhaus dwellings will impact resident thermal comfort	Thermal comfort models used to predict comfort impact. Overheating defined at point above which occupants experience discomfort. Elderly can report comfort at high temps which are in fact unhealthy for them High temps increase cardiovascular strain and trauma above 25C. Mortality increases and there is an increase in strokes. Dehydration in young and old. Pg.8 Heat stress determines heat related mortality. CIBSR guide notes sleep may be impaired above 24C - Poor health, reduced productivity	Solar transmission major variant determining overheating, external shading is very effective Design optimisation in relation to Specific Peak Heating Load opposed to Specific Heat Demand In urban context, ventilation through opening windows limited.	Passivhaus standard dwellings, zero carbon rating. Social housing UK has greater occupant density leading to larger internal gains Social housing includes safety standards which limit window opening angles	investigating if Passivhaus dwellings will impact resident thermal comfort
11. Vardoulakis, S., Dimitroulopoulou, C., Thornes, J., Lai, K. M., Taylor, J., Myers, I., ... & Davies, M. (2015). Impact of climate change on the domestic indoor environment and associated health risks in the UK. *Environment international*, *85*, 299-313.	Considers effect on a range of categories; indoor temp, indoor air qual., allergens and infections and flood damage water contamination from climate change	Elderly, people with existing medical conditions (mental disorders, neurological or cardiovascular disease), overweight, people with reduced mobility most at risk during heatwaves pg. 2 "Older people, socioeconomically deprived populations, isolated individuals, as well as the very young and people with pre-existing medical conditions have all been	Occupant behaviour: ventilation (windows), shading, other cooling fan), clothing, fans. AC can reduce thermal discomfort and health risks but increased energy consumption and costs. Strategic placement when planting trees, construct cool paving, green roofs, paint external walls light colour, shutters, awnings, double glazing with low emissive coating, low e-triple glazing, internal heat management, wall insulation (internal/external), roof/loft insulation, replace carpets with wooden floor/tiles, reduce lighting/electrical gains, increase	Southern England most at risk, natural ventilation not enough mechanical cooling may be needed in hot weather. Urban Heat Island effect increases ambient temperatures, UHI greater at night and can stop buildings cooling down. Small top floor flats most at risk, roof has poor thermal insulation leading to overheating of flat. Also impacts loft conversions. Ground floor flats relatively cooler	Floor lever, orientation and shading are factors contributing to overheating. High airtightness and super insulated dwellings lead to overheating. Airtightness affected by year of construction, type of wall and floor, season of year, extent of drying of timbre in first year of occupancy Heavy construction material (concrete and stone) react slower to external temperature

			reported to be at higher risk of heat-related mortality/morbidity." Links to underlying medical condition but also access to control measure (cannot afford)	natural ventilation, ceiling fans, opening windows, AC		
12.	**Kolokotroni, M., Davies, M., Croxford, B., Bhuiyan, S., & Mavrogianni, A. (2010). A validated methodology for the prediction of heating and cooling energy demand for buildings within the Urban Heat Island: Case-study of London. *Solar Energy*, *84*(12), 2246-2255.**	Models Urban Heat Island in London. Focused on outdoor temperatures	Rise in external ambient temperatures: - Reduces comfort in buildings without AC. - Energy consumption increase for AC. - Health heat related mortality	n/a	n/a	n/a
13.	**Lomas, K. J., & Giridharan, R. (2012). Thermal comfort standards, measured internal temperatures and thermal resilience to climate change of free-running buildings: A case-study of hospital wards. *Building and Environment*, *55*, 57-72.**	Thermal comfort focused on hospital ward with hybrid ventilation system. But results can be repeated for other building types No values/costs	Thermal comfort challenge for hospital considering patients/occupants of different needs	Mechanical ventilation and AC should be avoided consider when applying new measures will result in refurbishment time and reduced operation of the building natural and hybrid ventilation predominates healthcare pg.5 Fans can be install with minimal disruption, small energy demand pg. 14	Monitoring of hospitals (9 buildings, 111 spaces) - 93% of spaces free-running i.e. not air conditioned or mechanically cooled, norm in UK	n/a
14.	**Lomas, K. J., & Kane, T. (2013). Summertime temperatures and thermal comfort in UK homes. *Building***	Not values or costs not so useful	Thermal comfort measured in home in Leicester. External temperature	In practice individuals adapt to changing temperatures by adapting clothing, drinks, activity, opening windows - adaptive thermal comfort criteria more	deaths due to heatwave actually less in hotter regions. P.g. 4 Homes different to offices, homes have much	

	***Research & Information*, *41*(3), 259-280.**		above 19C increase heat related deaths.	appropriate for assessing internal conditions p.g. 8	larger surface area to volume, less occupant dense. Homes also more poorly insulated,	
15.	**NHBC. (2012) Overheating in new homes, A review of the evidence. National House Building Council (NHBC) Foundation, Milton Keynes.**	Good - comprehensive overview but lacks values/costs Present case studies of overheating, there are cases when thermal gains occur most of year, independent of external temperature. Pg.	Overheating criteria set at limit of thermal comfort not threshold for long-term temperature that can cause serious health problems to vulnerable groups Night time temperature particularly risk, reduces ability to recover from daytime temp and interruption to sleep For most people overheating is issue of thermal comfort but, for some, can have significant health impacts. pg. 9 Heat stroke pg. 11 Children less able to thermoregulate pg. 12 Elderly - physical/physiological and social reasons more at risk pg. 12 Medication and drugs can affect bodies ability to regulate heat pg. 12 future work needed on mental health and heat. also types of housing inhabited by those most at risk pg.14	reducing south facing glazing and installation of light shelves for solar shading, reducing internal gains, additional thermal mass, user based ventilation (windows) p.g. 22 Ventilation is effective however, required volumes of air to remove heat are very large. pg. 23	new and refurbish houses, small dwellings, single sided properties, with no cross ventilation Zero carbon standards - airtightness hot water systems (combination/storage system), electrical appliances, heating systems pg.16 micro-environments are the boundary layer of air around buildings which is drawn into building through vents. heat of building externally increase temp of this boundary layer pg. 17/18 In adequate roof insulation problem in older properties pg. 19 Airtightness requirements in new builds pg.19	Modern building material have U-values in region of $0.4W/m^2K$ pg. 16 Solar gains through glass, g-value solar energy filtering into building compared with total energy. Single sheet g = 0.87 pg. 17 Zinc roofs particularly overheating prone pg. 19 Thermal mass is the building interior material gaining energy and releasing it over long period of time. pg. 22
16.	**ZCH. (2015a) Assessing overheating risk,**	Review of tools/methodologies to predict overheating risk		Describes the different protocols to assess overheating, building regulation etc		

	Evidence review - Methodologies. Zero Carbon Hub, London.	by tools/methodologies the report refers to Standard Assessment Procedures not particularly useful				
17.	**ZCH. (2015b) Drivers of change - Overheating in homes, Evidence review. Zero Carbon Hub, London.**	Useful overview of overheat problem but only small brochure	Demographic change; larger and aging population, obese population growing --> all more at risk pg. 5 Working from home increasing trend, overheating could impact work capacity		occupancy profile changing, one person dwelling 28% in 2014 but only 12% in 1961 7.6 million people lived alone in 2014, 4 million >65y/o Urbanisation - Urban heat island effect modern building have central corridor with single aspect apartments on either side, higher risk. older population, more care homes and their design airtightness of modern and low energy homes	Large windows increase solar gains - need for treated glass
18.	**Fernandez, N., Wang, W., Alvine, K. J., & Katipamula, S. (2015). *Energy savings potential of radiative cooling technologies* (No. PNNL-24904). Pacific Northwest National Lab.(PNNL), Richland, WA (United States).**	American study on technologies for building cooling, specifically the energy saving (could be linked to energy prices and compared with AC costs) focused on very novel technologies/materials engineering paper but gives good amount of data to identify costs (not prices)	n/a	Radiative cooling measures - transfer of heat energy from building to cooler external atmosphere Selective emittance vs. Photonic radiative cooling device Market analysis in section 6 pg. 59	Modelling conducted on office building	Regular windows on building
19.	**Peacock, A. D., Jenkins, D. P., & Kane, D. (2010). Investigating**	Investigating the potential of overheating in UK	Modelling of indoor temperatures based on domestic building	US highest risk of heat related death in 2nd floor room w/o AC pg.2	Reference of study calculating uptake of AC in London to 18% - pg. 2	use of electrical appliance can impact internal gains pg. 3

	the potential of overheating in UK dwellings as a consequence of extant climate change. *Energy policy*, *38*(7), 3277-3288.	dwellings as a consequence of extant climate change.	variants, bedroom temp is key to overheating. Building construction and geography had big impact on results.	Night temp impairs sleep quality, leading to reduced productivity, diminished attentiveness and impaired judgement pg.2 - references on temperature and sleep	Energy efficiency of AC units, reduction in AC cost (Twenga 2008) Pg. 2 Discrepancy between studies identifying thermo neutral temperatures and temperatures set using AC units, with people choosing lower temps when AC unit installed pg.2	"Our mental state at home and the range of adaptive behaviour possible is distinct to that in the office and therefore perceptions of comfort are likely to be quite different pg. 10 Low thermal mass buildings most prone pg.10
20.	**Hajat, S., Vardoulakis, S., Heaviside, C., & Eggen, B. (2014). Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. *J Epidemiol Community Health*, *68*(7), 641-648.**	Time series analysis on temperature and mortality, heat related deaths increase 257% by 2050, driven by population growth and ageing. Protection increasingly necessary				
21.	**Bennett, J. E., Blangiardo, M., Fecht, D., Elliott, P., & Ezzati, M. (2014). Vulnerability to the mortality effects of warm temperature in the districts of England and Wales. *Nature Climate Change*, *4*(4), 269.**	spatial analysis of small areas in England and Wales most venerable districts in London and S/SE England 1C warmer temperature leading to 10% increase in chance of cardiorespiratory death	Cardiorespiratory effects but only for those over 75 years			
22.	**Janković, V. (2013). A historical review of urban climatology and the atmospheres of the industrialized**	Outline of historical and contemporary studies of urban weather and climate in Europe and NA.				

	world. *Wiley Interdisciplinary Reviews: Climate Change*, *4*(6), 539-553.	Interesting but not very relevant				
23.	**Watkiss, P., Hunt, A., Blyth, W., & Dyszynski, J. (2015). The use of new economic decision support tools for adaptation assessment: A review of methods and applications, towards guidance on applicability. *Climatic Change*, *132*(3), 401-416.**	Review and assessment of Cost-benefit analysis and Cost-effectiveness analysis, uncertainty framework and others (real option analysis, robust decision making and portfolio analysis. Relevant to methodology, no mention of overheating				
24.	**WSP (2015) Overheating In Homes**	Good Whitepaper report conducts questionnaire (1000 respondents) to identify how Londoners feel about overheating, 22 in-depth interviews Identify 5 measures to reduce overheating (more related to building regulations)	Heat impacts sleep, concerns that productivity will diminish pg. 5 Older population most at risk, combine with aging population. Elderly also inside house during hottest periods. Pg. 5 Very hot temperatures can kill, 2000 deaths in 2003 heatwave. Young, elderly and those with pre-existing illnesses experience greatest risk - dehydration pg. 6 Financial impact of people not wanting to live in properties with risk of overheating should be considered pg. 6	As overheating becomes more prevalent, demand for inefficient, dangerous and unattractive retrofit cooling systems pg. 9 Most common coping mechanism to open window (72%), but could reduce as density of cities increase - noise, higher external temps pg.11 one fifth avoided use of equipment such as washing machine and oven to manage tempers pg. 11 8% already installed cooling systems, risk from larger number of inefficient systems being fitted pg. 11 Measures pg.21: - ventilation and mechanical ventilation (but issue of noise and energy) - minimise solar gains in building design (new builds) - shading and shutters	Increase demand and likelihood of flats being built in future (dense) pg. 5 Flats have more restricted air flow compared to houses pg. 5 3 primary sources of overheating: External Temp, Solar Gain, Internal Heat gains. Additional consideration UHI pg. 8 Interviews with London residents in New build flats pg.12: - showering and cooking caused uncomfortable temps - Time of day also a factor, midday uncomfortable - night time temperatures affecting sleep	Flats have glazing/windows covering greater area as possible but usually just one side pg. 5 Glazing on buildings particularly orientated S,SW increase solar gains and small windows not choice by architects pg. 21 Heavy materials (concrete/stone) able to store heat and maintain temp within property. pg.21

			increase peak energy demand, and energy demand generally --> CO_2 emissions pg.9 survey results: 83% suffered in 2015, 11% uncomfortably hot at least once; 54% would say impact their decision to buy a home; 8% of people suffering have taken action installed measure. pg. 11	- cooling systems well designed and integrated into new builds more energy efficient than retrofits - reduce thermal gains (LED lights) Reducing UHI effect: - increase green space by 10%, restrict temp rise by 4C - electrification of city, - green roofs - cool roofs and pavements (painted white to reflect heat) - plant trees for shading - Education and behaviour	- Residents now have increased concern to assess overheating in properties if they had to buy new flat/house New buildings designed to accommodate cooling system even if not fitted pg. 26	
25.	**Conlan, N., & Harvie-Clark, J. (2017) METHODS OF CONTROLLING NOISE LEVELS AND OVERHEATING IN RESIDENTIAL BUILDINGS.**	Case studies of practical passive methods improving air ventilations but also enhanced sound insulation. Includes balconies, novel arrangement of lights/windows more feasible for new builds	Overheating problem across UK but most prone in London due to higher ambient temperatures.	The London Plan Policy 5.9 list hierarchy of 6 cooling measures pg. 1 first 3 address design of building fabric, bottom 3 relate so servicing building. - Façade design; shape of façade reduce noise, balcony with solid parapet and absorptive soffit - Attenuate vents; 2 examples - windows with enhance acoustic performance; no examples - Mechanical ventilation; 2 examples - mechanical ventilation w/ cooling; 1 example	n/a	n/a

Appendix D
Water Stress – non low-regret measures

wood.

Table D.1 Residential adaptation cost curve – non low-regret water efficiency measures

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year stock Econ saving, mid (£m)**	**15-year stock Econ CBR, mid**	**Cumulative 15-year stock Econ saving, mid (£m)**	**15-year stock Hhld saving, mid (£m)**	**15-year stock Hhld CBR, mid**	**Cumulative 15-year stock Hhld saving, mid (£m)**	**45-year stock Econ saving, mid (£m)**	**45-year stock Econ CBR, mid**	**Cumulative 45-year stock Econ saving, mid (£m)**	**45-year stock Hhld saving, mid (£m)**	**45-year stock Hhld CBR, mid**	**Cumulative 45-year stock Hhld saving, mid (£m)**
2	Low flow shower – discretionary retrofit	316	2.05	672				316	2.05	917			
3	Low flow tap (pair) – discretionary retrofit	53	6.56	724	32	1.96	443	55	6.24	973	33	1.96	597
22	105 L/person/day standard – newbuild	18	3.70	743	18	1.25	462	30	3.58	1,002	30	1.22	627
1	Dual flush WC – discretionary retrofit	140	5.72	883	84	1.71	546	147	5.44	1,149	88	1.71	715
18	Water butt – newbuild	2	6.53	884	2	1.92	547	4	5.10	1,153	4	1.87	719
7	Water butt – discretionary retrofit	11	6.91	895	6	2.06	554	11	6.57	1,164	7	2.06	726
4	Click protect kitchen tap – discretionary retrofit	20	11.94	915	12	3.56	566	21	11.36	1,184	12	3.56	738
16	Low water washing machine – newbuild	4	10.82	918	4	3.36	569	6	10.48	1,191	6	3.27	744
14	Low water washing machine – end-of-life upgrade	26	12.02	944	15	3.73	585	41	11.65	1,232	25	3.64	769

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year stock Econ saving, mid (£m)**	**15-year stock Econ CBR, mid**	**Cumulative 15-year stock Econ saving, mid (£m)**	**15-year stock Hhld saving, mid (£m)**	**15-year stock Hhld CBR, mid**	**Cumulative 15-year stock Hhld saving, mid (£m)**	**45-year stock Econ saving, mid (£m)**	**45-year stock Econ CBR, mid**	**Cumulative 45-year stock Econ saving, mid (£m)**	**45-year stock Hhld saving, mid (£m)**	**45-year stock Hhld CBR, mid**	**Cumulative 45-year stock Hhld saving, mid (£m)**
19	Low volume, gravity RW system – newbuild	18	13.89	962	18	4.43	603	29	13.53	1,261	29	4.34	797
8	Low volume, gravity RW system – discretionary retrofit	101	14.86	1,063	61	4.79	663	101	14.86	1,361	61	4.79	858
9	Short retention GW system – discretionary retrofit	406	17.75	1,469	243	5.72	907	406	17.75	1,767	243	5.72	1,101
20	Short retention GW system – newbuild	45	26.71	1,513	45	8.52	951	72	26.01	1,839	72	8.35	1,173
24	80 L/person/day standard – newbuild	37	33.62	1,551	37	10.73	989	60	32.74	1,899	60	10.50	1,233
23	90 L/person/day standard – newbuild	28	34.48	1,579	28	11.00	1,017	45	33.59	1,944	45	10.78	1,278
17	Low water dishwasher – newbuild	1	41.01	1,580	1	12.72	1,018	2	39.72	1,946	2	12.41	1,280
15	Low water dishwasher – end-of-life upgrade	10	45.56	1,590	6	14.14	1,024	15	44.14	1,961	9	13.78	1,290
5	Low water washing machine – discretionary retrofit	22	52.66	1,612	13	16.59	1,037	22	52.66	1,983	13	16.59	1,303

ID	Measure description & application	Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
		15-year stock Econ saving, mid (£m)	15-year stock Econ CBR, mid	Cumulative 15-year stock Econ saving, mid (£m)	15-year stock Hhld saving, mid (£m)	15-year stock Hhld CBR, mid	Cumulative 15-year stock Hhld saving, mid (£m)	45-year stock Econ saving, mid (£m)	45-year stock Econ CBR, mid	Cumulative 45-year stock Econ saving, mid (£m)	45-year stock Hhld saving, mid (£m)	45-year stock Hhld CBR, mid	Cumulative 45-year stock Hhld saving, mid (£m)
6	Low water dishwasher – discretionary retrofit	8	160.25	1,620	5	50.49	1,042	8	160.25	1,991	5	50.49	1,307

Table D.2 Residential adaptation cost curve –water efficiency measures – sensitivity analysis results (all)

ID	Measure description & application	15-year, societal CBR (best)	15-year, societal CBR (mid)	15-year, societal CBR (worst)	15-year, household CBR (best)	15-year, household CBR (mid)	15-year, household CBR (worst)	45-year, societal CBR (best)	45-year, societal CBR (mid)	45-year, societal CBR (worst)	45-year, household CBR (best)	45-year, household CBR (mid)	45-year, household CBR (worst)
11	Low flow shower – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Low flow tap (pair) – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Dual flush WC – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	110 L/person/day standard – newbuild	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ID	Measure description & application	15-year, societal CBR (best)	15-year, societal CBR (mid)	15-year, societal CBR (worst)	15-year, household CBR (best)	15-year, household CBR (mid)	15-year, household CBR (worst)	45-year, societal CBR (best)	45-year, societal CBR (mid)	45-year, societal CBR (worst)	45-year, household CBR (best)	45-year, household CBR (mid)	45-year, household CBR (worst)
13	Click protect kitchen tap – end-of-life upgrade	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Low flow shower – discretionary retrofit	1.42	2.05	3.77	0.38	0.70	1.67	1.36	2.05	3.77	0.38	0.70	1.67
3	Low flow tap (pair) – discretionary retrofit	4.86	6.56	8.95	1.16	1.96	4.22	4.62	6.24	8.95	1.16	1.96	4.22
22	105 L/person/day standard – newbuild	2.45	3.70	7.02	0.64	1.25	3.06	1.99	3.58	6.80	0.62	1.22	2.98
1	Dual flush WC – discretionary retrofit	3.98	5.72	8.19	0.95	1.71	3.86	3.78	5.44	8.19	0.95	1.71	3.86
18	Water butt – newbuild	4.32	6.53	9.67	1.02	1.92	4.49	2.90	5.10	9.35	0.99	1.87	4.38
7	Water butt – discretionary retrofit	4.57	6.91	10.24	1.09	2.06	4.83	4.35	6.57	10.24	1.09	2.06	4.83
4	Click protect kitchen tap – discretionary retrofit	8.88	11.94	16.21	2.12	3.56	7.65	8.45	11.36	16.21	2.12	3.56	7.65
16	Low water washing machine – newbuild	5.77	10.82	19.39	1.64	3.36	8.01	5.59	10.48	18.80	1.60	3.27	7.81

ID	Measure description & application	15-year, societal CBR (best)	15-year, societal CBR (mid)	15-year, societal CBR (worst)	15-year, household CBR (best)	15-year, household CBR (mid)	15-year, household CBR (worst)	45-year, societal CBR (best)	45-year, societal CBR (mid)	45-year, societal CBR (worst)	45-year, household CBR (best)	45-year, household CBR (mid)	45-year, household CBR (worst)
14	Low water washing machine – end-of-life upgrade	6.42	12.02	21.55	1.82	3.73	8.90	6.21	11.65	20.89	1.78	3.64	8.68
19	Low volume, gravity RW system – newbuild	7.21	13.89	29.53	1.88	4.43	12.10	5.84	13.53	28.87	1.84	4.34	11.88
8	Low volume, gravity RW system – discretionary retrofit	7.63	14.86	31.71	2.02	4.79	13.12	7.26	14.86	31.71	2.02	4.79	13.12
9	Short retention GW system – discretionary retrofit	9.11	17.75	37.89	2.42	5.72	15.67	8.67	17.75	37.89	2.42	5.72	15.67
20	Short retention GW system – newbuild	13.86	26.71	56.77	3.62	8.52	23.27	11.23	26.01	55.51	3.53	8.35	22.84
24	80 L/person/day standard – newbuild	17.44	33.62	71.45	4.56	10.73	29.28	14.14	32.74	69.86	4.45	10.50	28.74
23	90 L/person/day standard – newbuild	17.89	34.48	73.29	4.68	11.00	30.04	14.50	33.59	71.66	4.56	10.78	29.48
17	Low water dishwasher – newbuild	21.89	41.01	73.50	6.22	12.72	30.35	21.18	39.72	71.24	6.06	12.41	29.59
15	Low water dishwasher – end-of-life upgrade	24.32	45.56	81.67	6.91	14.14	33.73	23.53	44.14	79.15	6.74	13.78	32.88

ID	Measure description & application	15-year, societal CBR (best)	15-year, societal CBR (mid)	15-year, societal CBR (worst)	15-year, household CBR (best)	15-year, household CBR (mid)	15-year, household CBR (worst)	45-year, societal CBR (best)	45-year, societal CBR (mid)	45-year, societal CBR (worst)	45-year, household CBR (best)	45-year, household CBR (mid)	45-year, household CBR (worst)
5	Low water washing machine – discretionary retrofit	28.11	52.66	94.39	8.11	16.59	39.58	28.11	52.66	94.39	8.11	16.59	39.58
6	Low water dishwasher – discretionary retrofit	85.52	160.25	287.23	24.67	50.49	120.45	85.52	160.25	287.23	24.67	50.49	120.45

Table D.3 Residential adaptation cost curve –water efficiency measures – low-regret combinations of water efficiency measures by dwelling type and size (EAC based)

Measure	Dwelling type / size	Application summary	One-off costs (£)	Annual costs (£/year)	Lifetime (years)	EAC, societal	EAC, hhld	Annual water savings per household (m^3/year)	Annual societal benefit, mid (£)	Annual HHld saving, mid (£)	CBR - societal	15-year stock Econ CBR, mid	CBR-hhld	15-year stock Hhld CBR, mid
Dual flush WC	<70m² semi- or terrcd	Retrofit, <70m², 2 people	264	0	20	£9.23	£21.10	8.34	5.51	27.09	1.68	3.33	0.78	0.99
Dual flush WC	<70m² flat	Retrofit, <70m², 2 people	264	0	20	£9.23	£21.10	8.34	5.51	27.09	1.68	3.33	0.78	0.99
Dual flush WC	70 -110m² semi- or terrcd	Retrofit, 70 -110m², 3 people	463	0	20	£16.20	£37.03	12.51	8.27	40.64	1.96	3.89	0.91	1.16
Dual flush WC	70 -110m² semi- or terrcd	Retrofit, 70 -110m², 4 people	463	0	20	£16.20	£37.03	16.67	11.02	54.19	1.47	2.92	0.68	0.87

Dual flush WC	70 -110m² flat	Retrofit, 70 -110m², 3 people	463	0	20	£16.20	£37.03	12.51	8.27	40.64	1.96	3.89	0.91	1.16
Dual flush WC	70 -110m² flat	Retrofit, 70 -110m², 4 people	463	0	20	£16.20	£37.03	16.67	11.02	54.19	1.47	2.92	0.68	0.87
Dual flush WC	70 -110m² dtchd	Retrofit, 70 -110m², 3 people	463	0	20	£16.20	£37.03	12.51	8.27	40.64	1.96	3.89	0.91	1.16
Dual flush WC	70 -110m² dtchd	Retrofit, 70 -110m², 4 people	463	0	20	£16.20	£37.03	16.67	11.02	54.19	1.47	2.92	0.68	0.87
Dual flush WC	>110m² dtchd	Retrofit, >110m², 4 people	662	0	20	£23.17	£52.97	16.67	11.02	54.19	2.10	4.17	0.98	1.24
Low flow shower	<70m² semi- or terrcd	Retrofit, <70m², 1 person	293	0	15	£10.26	£23.45	9.43	6.24	30.66	1.65	3.26	0.76	1.12
Low flow shower	<70m² semi- or terrcd	Retrofit, <70m², 2 people	293	0	15	£10.26	£23.45	18.87	12.47	61.32	0.82	1.63	0.38	0.56
Low flow shower	<70m² flat	Retrofit, <70m², 1 person	293	0	15	£10.26	£23.45	9.43	6.24	30.66	1.65	3.26	0.76	1.12
Low flow shower	<70m² flat	Retrofit, <70m², 2 people	293	0	15	£10.26	£23.45	18.87	12.47	61.32	0.82	1.63	0.38	0.56
Low flow shower	70 -110m² semi- or terrcd	Retrofit, 70 -110m², 1 person	293	0	15	£10.26	£23.45	9.43	6.24	30.66	1.65	3.26	0.76	1.12
Low flow shower	70 -110m² semi- or terrcd	Retrofit, 70 -110m², 2 people	293	0	15	£10.26	£23.45	18.87	12.47	61.32	0.82	1.63	0.38	0.56
Low flow shower	70 -110m² semi- or terrcd	Retrofit, 70 -110m², 3 people	293	0	15	£10.26	£23.45	28.30	18.71	91.99	0.55	1.09	0.25	0.37

Low flow shower	70 -110m² semi- or terrcd	Retrofit, 70 -110m², 4 people	293	0	15	£10.26	£23.45	37.74	24.94	122.65	0.41	0.82	0.19	0.28
Low flow shower	70 -110m² flat	Retrofit, 70 -110m², 1 person	293	0	15	£10.26	£23.45	9.43	6.24	30.66	1.65	3.26	0.76	1.12
Low flow shower	70 -110m² flat	Retrofit, 70 -110m², 2 people	293	0	15	£10.26	£23.45	18.87	12.47	61.32	0.82	1.63	0.38	0.56
Low flow shower	70 -110m² flat	Retrofit, 70 -110m², 3 people	293	0	15	£10.26	£23.45	28.30	18.71	91.99	0.55	1.09	0.25	0.37
Low flow shower	70 -110m² flat	Retrofit, 70 -110m², 4 people	293	0	15	£10.26	£23.45	37.74	24.94	122.65	0.41	0.82	0.19	0.28
Low flow shower	70 -110m² dtchd	Retrofit, 70 -110m², 1 person	293	0	15	£10.26	£23.45	9.43	6.24	30.66	1.65	3.26	0.76	1.12
Low flow shower	70 -110m² dtchd	Retrofit, 70 -110m², 2 people	293	0	15	£10.26	£23.45	18.87	12.47	61.32	0.82	1.63	0.38	0.56
Low flow shower	70 -110m² dtchd	Retrofit, 70 -110m², 3 people	293	0	15	£10.26	£23.45	28.30	18.71	91.99	0.55	1.09	0.25	0.37
Low flow shower	70 -110m² dtchd	Retrofit, 70 -110m², 4 people	293	0	15	£10.26	£23.45	37.74	24.94	122.65	0.41	0.82	0.19	0.28
Low flow shower	>110m² dtchd	Retrofit, >110m², 2 people	516	0	15	£18.05	£41.25	18.87	12.47	61.32	1.45	2.87	0.67	0.98
Low flow shower	>110m² dtchd	Retrofit, >110m², 3 people	516	0	15	£18.05	£41.25	28.30	18.71	91.99	0.96	1.91	0.45	0.65
Low flow shower	>110m² dtchd	Retrofit, >110m², 4 people	516	0	15	£18.05	£41.25	37.74	24.94	122.65	0.72	1.44	0.34	0.49
Low flow tap (pair)	<70m² semi- or terrcd	Retrofit, <70m², 2 people	117	0	20	£4.10	£9.38	3.15	2.08	10.23	1.97	3.91	0.92	1.17

Low flow tap (pair)	<70m² flat	Retrofit, <70m², 2 people	117	0	20	£4.10	£9.38	3.15	2.08	10.23	1.97	3.91	0.92	1.17
Low flow tap (pair)	70 -110m² semi- or terrcd	Retrofit, 70 -110m², 4 people	199	0	20	£6.97	£15.93	6.30	4.16	20.47	1.67	3.32	0.78	0.99
Low flow tap (pair)	70 -110m² flat	Retrofit, 70 -110m², 4 people	199	0	20	£6.97	£15.93	6.30	4.16	20.47	1.67	3.32	0.78	0.99
Low flow tap (pair)	70 -110m² dtchd	Retrofit, 70 -110m², 4 people	199	0	20	£6.97	£15.93	6.30	4.16	20.47	1.67	3.32	0.78	0.99
Water butt	70 -110m² semi- or terrcd	Retrofit, 70 -110m², 4 people	59	0	20	£2.05	£4.69	1.46	0.97	4.74	2.13	4.22	0.99	1.26
Water butt	70 -110m² dtchd	Retrofit, 70 -110m², 4 people	59	0	20	£2.05	£4.69	1.46	0.97	4.74	2.13	4.22	0.99	1.26
Water butt	>110m² dtchd	Retrofit, >110m², 4 people	59	0	20	£2.05	£4.69	1.46	0.97	4.74	2.13	4.22	0.99	1.26
Dual flush WC	<70m² semi- or terrcd	Replacement, <70m², 1 person	0	0	20	£0.00	£0.00	1.97	1.29	6.39	0.00	0.00	0.00	0.00
Dual flush WC	<70m² semi- or terrcd	Replacement, <70m², 2 people	0	0	20	£0.00	£0.00	3.93	2.59	12.78	0.00	0.00	0.00	0.00
Dual flush WC	<70m² flat	Replacement, <70m², 1 person	0	0	20	£0.00	£0.00	1.97	1.29	6.39	0.00	0.00	0.00	0.00
Dual flush WC	<70m² flat	Replacement, <70m², 2 people	0	0	20	£0.00	£0.00	3.93	2.59	12.78	0.00	0.00	0.00	0.00

Dual flush WC	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 1 person	0	0	20	£0.00	£0.00	1.97	1.29	6.39	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 2 people	0	0	20	£0.00	£0.00	3.93	2.59	12.780987	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 3 people	0	0	20	£0.00	£0.00	5.90	3.89	19.17	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 4 people	0	0	20	£0.00	£0.00	7.87	5.19	25.56	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² flat	Replacement, 70 - 110m², 1 person	0	0	20	£0.00	£0.00	1.97	1.29	6.39	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² flat	Replacement, 70 - 110m², 2 people	0	0	20	£0.00	£0.00	3.93	2.59	12.78	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² flat	Replacement, 70 - 110m², 3 people	0	0	20	£0.00	£0.00	5.90	3.89	19.17	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² flat	Replacement, 70 - 110m², 4 people	0	0	20	£0.00	£0.00	7.87	5.19	25.56	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² dtchd	Replacement, 70 - 110m², 1 person	0	0	20	£0.00	£0.00	1.97	1.29	6.39	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² dtchd	Replacement, 70 - 110m², 2 people	0	0	20	£0.00	£0.00	3.93	2.59	12.78	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² dtchd	Replacement, 70 - 110m², 3 people	0	0	20	£0.00	£0.00	5.90	3.89	19.17	0.00	0.00	0.00	0.00
Dual flush WC	70 -110m² dtchd	Replacement, 70 - 110m², 4 people	0	0	20	£0.00	£0.00	7.87	5.19	25.56	0.00	0.00	0.00	0.00

Dual flush WC	>110m² dtchd	Replacement, >110m², 2 people	0	0	20	£0.00	£0.00	3.93	2.59	12.78	0.00	0.00	0.00	0.00
Dual flush WC	>110m² dtchd	Replacement, >110m², 3 people	0	0	20	£0.00	£0.00	5.90	3.89	19.17	0.00	0.00	0.00	0.00
Dual flush WC	>110m² dtchd	Replacement, >110m², 4 people	0	0	20	£0.00	£0.00	7.87	5.19	25.56	0.00	0.00	0.00	0.00
Low flow shower	<70m² semi- or terrcd	Replacement, <70m², 1 person	0	0	15	£0.00	£0.01	9.43	6.23	30.66	0.00	0.00	0.00	0.00
Low flow shower	<70m² semi- or terrcd	Replacement, <70m², 2 people	0	0	15	£0.00	£0.01	18.87	12.47	61.32	0.00	0.00	0.00	0.00
Low flow shower	<70m² flat	Replacement, <70m², 1 person	0	0	15	£0.00	£0.01	9.43	6.23	30.66	0.00	0.00	0.00	0.00
Low flow shower	<70m² flat	Replacement, <70m², 2 people	0	0	15	£0.00	£0.01	18.87	12.47	61.32	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 1 person	0	0	15	£0.00	£0.01	9.43	6.23	30.66	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 2 people	0	0	15	£0.00	£0.01	18.87	12.47	61.32	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 3 people	0	0	15	£0.00	£0.01	28.30	18.70	91.98	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 4 people	0	0	15	£0.00	£0.01	37.74	24.94	122.64	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² flat	Replacement, 70 - 110m², 1 person	0	0	15	£0.00	£0.01	9.43	6.23	30.66	0.00	0.00	0.00	0.00

Low flow shower	70 -110m² flat	Replacement, 70 - 110m², 2 people	0	0	15	£0.00	£0.01	18.87	12.47	61.32	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² flat	Replacement, 70 - 110m², 3 people	0	0	15	£0.00	£0.01	28.30	18.70	91.98	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² flat	Replacement, 70 - 110m², 4 people	0	0	15	£0.00	£0.01	37.74	24.94	122.64	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² dtchd	Replacement, 70 - 110m², 1 person	0	0	15	£0.00	£0.01	9.43	6.24	30.66	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² dtchd	Replacement, 70 - 110m², 2 people	0	0	15	£0.00	£0.01	18.87	12.47	61.32	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² dtchd	Replacement, 70 - 110m², 3 people	0	0	15	£0.00	£0.01	28.30	18.71	91.99	0.00	0.00	0.00	0.00
Low flow shower	70 -110m² dtchd	Replacement, 70 - 110m², 4 people	0	0	15	£0.00	£0.01	37.74	24.94	122.65	0.00	0.00	0.00	0.00
Low flow shower	>110m² dtchd	Replacement, >110m², 2 people	0	0	15	£0.00	£0.01	18.87	12.47	61.32	0.00	0.00	0.00	0.00
Low flow shower	>110m² dtchd	Replacement, >110m², 3 people	0	0	15	£0.00	£0.01	28.30	18.71	91.99	0.00	0.00	0.00	0.00
Low flow shower	>110m² dtchd	Replacement, >110m², 4 people	0	0	15	£0.00	£0.01	37.74	24.94	122.65	0.00	0.00	0.00	0.00
Low flow tap (pair)	<70m² semi- or terrcd	Replacement, <70m², 1 person	0	0	20	£0.00	£0.00	1.57	1.04	5.12	0.00	0.00	0.00	0.00
Low flow tap (pair)	<70m² semi- or terrcd	Replacement, <70m², 2 people	0	0	20	£0.00	£0.00	3.15	2.08	10.23	0.00	0.00	0.00	0.00

Low flow tap (pair)	<70m² flat	Replacement, <70m², 1 person	0	0	20	£0.00	£0.00	1.57	1.04	5.12	0.00	0.00	0.00	0.00
Low flow tap (pair)	<70m² flat	Replacement, <70m², 2 people	0	0	20	£0.00	£0.00	3.15	2.08	10.23	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 1 person	0	0	20	£0.00	£0.00	1.57	1.04	5.12	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 2 people	0	0	20	£0.00	£0.00	3.15	2.08	10.23	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 3 people	0	0	20	£0.00	£0.00	4.72	3.12	15.35	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 4 people	0	0	20	£0.00	£0.00	6.30	4.16	20.47	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² flat	Replacement, 70 - 110m², 1 person	0	0	20	£0.00	£0.00	1.57	1.04	5.12	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² flat	Replacement, 70 - 110m², 2 people	0	0	20	£0.00	£0.00	3.15	2.08	10.23	0.00	0.00	0.00	0.00

Low flow tap (pair)	70 -110m² flat	Replacement, 70 - 110m², 3 people	0	0	20	£0.00	£0.00	4.72	3.12	15.35	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² flat	Replacement, 70 - 110m², 4 people	0	0	20	£0.00	£0.00	6.30	4.16	20.47	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² dtchd	Replacement, 70 - 110m², 1 person	0	0	20	£0.00	£0.00	1.57	1.04	5.12	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² dtchd	Replacement, 70 - 110m², 2 people	0	0	20	£0.00	£0.00	3.15	2.08	10.23	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² dtchd	Replacement, 70 - 110m², 3 people	0	0	20	£0.00	£0.00	4.72	3.12	15.35	0.00	0.00	0.00	0.00
Low flow tap (pair)	70 -110m² dtchd	Replacement, 70 - 110m², 4 people	0	0	20	£0.00	£0.00	6.30	4.16	20.47	0.00	0.00	0.00	0.00
Low flow tap (pair)	>110m² dtchd	Replacement, >110m², 2 people	0	0	20	£0.00	£0.00	3.15	2.08	10.23	0.00	0.00	0.00	0.00
Low flow tap (pair)	>110m² dtchd	Replacement, >110m², 3 people	0	0	20	£0.00	£0.00	4.72	3.12	15.35	0.00	0.00	0.00	0.00

Low flow tap (pair)	>110m² dtchd	Replacement, >110m², 4 people	0	0	20	£0.00	£0.00	6.30	4.16	20.47	0.00	0.00	0.00	0.00
Click protect kitchen tap	<70m² semi- or terrcd	Replacement, <70m², 1 person	0	0	20	£0.00	£0.00	0.58	0.39	1.90	0.00	0.00	0.00	0.00
Click protect kitchen tap	<70m² semi- or terrcd	Replacement, <70m², 2 people	0	0	20	£0.00	£0.00	1.17	0.77	3.80	0.00	0.00	0.00	0.00
Click protect kitchen tap	<70m² flat	Replacement, <70m², 1 person	0	0	20	£0.00	£0.00	0.58	0.39	1.90	0.00	0.00	0.00	0.00
Click protect kitchen tap	<70m² flat	Replacement, <70m², 2 people	0	0	20	£0.00	£0.00	1.17	0.77	3.80	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 1 person	0	0	20	£0.00	£0.00	0.58	0.39	1.90	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 2 people	0	0	20	£0.00	£0.00	1.17	0.77	3.80	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 3 people	0	0	20	£0.00	£0.00	1.75	1.16	5.70	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 4 people	0	0	20	£0.00	£0.00	2.34	1.55	7.60	0.00	0.00	0.00	0.00

Click protect kitchen tap	70 -110m² flat	Replacement, 70 - 110m², 1 person	0	0	20	£0.00	£0.00	0.58	0.39	1.90	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² flat	Replacement, 70 - 110m², 2 people	0	0	20	£0.00	£0.00	1.17	0.77	3.80	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² flat	Replacement, 70 - 110m², 3 people	0	0	20	£0.00	£0.00	1.75	1.16	5.70	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² flat	Replacement, 70 - 110m², 4 people	0	0	20	£0.00	£0.00	2.34	1.55	7.60	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² dtchd	Replacement, 70 - 110m², 1 person	0	0	20	£0.00	£0.00	0.58	0.39	1.90	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² dtchd	Replacement, 70 - 110m², 2 people	0	0	20	£0.00	£0.00	1.17	0.77	3.80	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² dtchd	Replacement, 70 - 110m², 3 people	0	0	20	£0.00	£0.00	1.75	1.16	5.70	0.00	0.00	0.00	0.00
Click protect kitchen tap	70 -110m² dtchd	Replacement, 70 - 110m², 4 people	0	0	20	£0.00	£0.00	2.34	1.55	7.60	0.00	0.00	0.00	0.00

Click protect kitchen tap	>110m² dtchd	Replacement, >110m², 2 people	0	0	20	£0.00	£0.00	1.17	0.77	3.80	0.00	0.00	0.00	0.00
Click protect kitchen tap	>110m² dtchd	Replacement, >110m², 3 people	0	0	20	£0.00	£0.00	1.75	1.16	5.70	0.00	0.00	0.00	0.00
Click protect kitchen tap	>110m² dtchd	Replacement, >110m², 4 people	0	0	20	£0.00	£0.00	2.34	1.55	7.60	0.00	0.00	0.00	0.00
Low water washing machine	70 -110m² semi- or terrcd	Replacement, 70 - 110m², 4 people	124	0	10	£4.35	£9.93	3.58	2.36	11.62	1.84	5.31	0.85	1.65
Low water washing machine	70 -110m² flat	Replacement, 70 - 110m², 4 people	124	0	10	£4.35	£9.93	3.58	2.36	11.62	1.84	5.31	0.85	1.65
Low water washing machine	70 -110m² dtchd	Replacement, 70 - 110m², 4 people	124	0	10	£4.35	£9.93	3.58	2.36	11.62	1.84	5.31	0.85	1.65
Low water washing machine	>110m² dtchd	Replacement, >110m², 4 people	124	0	10	£4.35	£9.93	3.58	2.36	11.62	1.84	5.31	0.85	1.65
Low water washing machine	70 -110m² semi- or terrcd	New, 70 -110m², 4 people (4)	112	0	10	£3.91	£8.94	3.6	2.36	11.62	1.65	4.78	0.77	1.48
Low water washing machine	70 -110m² flat	New, 70 -110m², 4 people (4)	112	0	10	£3.91	£8.94	3.6	2.36	11.62	1.65	4.78	0.77	1.48

Low water washing machine	70 -110m² dtchd	New, 70 -110m², 4 people (4)	112	0	10	£3.91	£8.94	3.6	2.36	11.62	1.65	4.78	0.77	1.48
Low water washing machine	>110m² dtchd	New, >110m², 4 people (4)	112	0	10	£3.91	£8.94	3.6	2.36	11.62	1.65	4.78	0.77	1.48
Water butt	70 -110m² semi- or terrcd	New, 70 -110m², 4 people (4)	53	0	20	£1.85	£4.22	1.5	0.97	4.74	1.91	3.99	0.89	1.17
Water butt	70 -110m² dtchd	New, 70 -110m², 4 people (4)	53	0	20	£1.85	£4.22	1.5	0.97	4.74	1.91	3.99	0.89	1.17
Water butt	>110m² dtchd	New, >110m², 4 people (4)	53	0	20	£1.85	£4.22	1.5	0.97	4.74	1.91	3.99	0.89	1.17
110 L/person/day standard	<70m² semi- or terrcd	New, <70m², 1 person (1)	0	0	15	£0.00	£0.01	3.7	2.41	11.86	0.00	0.00	0.00	0.00
110 L/person/day standard	<70m² semi- or terrcd	New, <70m², 2 people (2)	0	0	15	£0.00	£0.01	7.3	4.83	23.72	0.00	0.00	0.00	0.00
110 L/person/day standard	<70m² flat	New, <70m², 1 person (1)	0	0	15	£0.00	£0.01	3.7	2.41	11.86	0.00	0.00	0.00	0.00
110 L/person/day standard	<70m² flat	New, <70m², 2 people (2)	0	0	15	£0.00	£0.01	7.3	4.83	23.72	0.00	0.00	0.00	0.00
110 L/person/day standard	70 -110m² semi- or terrcd	New, 70 -110m², 1 person (1)	0	0	15	£0.00	£0.01	3.7	2.41	11.86	0.00	0.00	0.00	0.00

110 L/person/day standard	70 -110m² semi- or terrcd	New, 70 -110m², 2 people (2)	0	0	15	£0.00	£0.01	7.3	4.83	23.72	0.00	0.00	0.00	0.00
110 L/person/day standard	70 -110m² semi- or terrcd	New, 70 -110m², 3 people (3)	0	0	15	£0.00	£0.01	11.0	7.24	35.59	0.00	0.00	0.00	0.00
110 L/person/day standard	70 -110m² semi- or terrcd	New, 70 -110m², 4 people (4)	0	0	15	£0.00	£0.01	14.6	9.65	47.45	0.00	0.00	0.00	0.00
110 L/person/day standard	70 -110m² flat	New, 70 -110m², 1 person (1)	0	0	15	£0.00	£0.01	3.7	2.41	11.86	0.00	0.00	0.00	0.00
110 L/person/day standard	70 -110m² flat	New, 70 -110m², 2 people (2)	0	0	15	£0.00	£0.01	7.3	4.83	23.72	0.00	0.00	0.00	0.00
110 L/person/day standard	70 -110m² flat	New, 70 -110m², 3 people (3)	0	0	15	£0.00	£0.01	11.0	7.24	35.59	0.00	0.00	0.00	0.00
110 L/person/day standard	70 -110m² flat	New, 70 -110m², 4 people (4)	0	0	15	£0.00	£0.01	14.6	9.65	47.45	0.00	0.00	0.00	0.00
110 L/person/day standard	70 -110m² dtchd	New, 70 -110m², 1 person (1)	0	0	15	£0.00	£0.01	3.7	2.41	11.86	0.00	0.00	0.00	0.00
110 L/person/day standard	70 -110m² dtchd	New, 70 -110m², 2 people (2)	0	0	15	£0.00	£0.01	7.3	4.83	23.72	0.00	0.00	0.00	0.00
110 L/person/day standard	70 -110m² dtchd	New, 70 -110m², 3 people (3)	0	0	15	£0.00	£0.01	11.0	7.24	35.59	0.00	0.00	0.00	0.00

110 L/person/day standard	70 -110m² dtchd	New, 70 -110m², 4 people (4)	0	0	15	£0.00	£0.01	14.6	9.65	47.45	0.00	0.00	0.00	0.00
110 L/person/day standard	>110m² dtchd	New, >110m², 2 people (2)	0	0	15	£0.00	£0.01	7.3	4.83	23.72	0.00	0.00	0.00	0.00
110 L/person/day standard	>110m² dtchd	New, >110m², 3 people (3)	0	0	15	£0.00	£0.01	11.0	7.24	35.59	0.00	0.00	0.00	0.00
110 L/person/day standard	>110m² dtchd	New, >110m², 4 people (4)	0	0	15	£0.00	£0.01	14.6	9.65	47.45	0.00	0.00	0.00	0.00
105 L/person/day standard	70 -110m² semi- or terrcd	New, 70 -110m², 3 people (3)	281	0	15	£9.85	£22.51	16.4	10.86	53.38	0.91	1.89	0.42	0.64
105 L/person/day standard	70 -110m² semi- or terrcd	New, 70 -110m², 4 people (4)	281	0	15	£9.85	£22.51	21.9	14.48	71.17	0.68	1.42	0.32	0.48
105 L/person/day standard	70 -110m² flat	New, 70 -110m², 3 people (3)	281	0	15	£9.85	£22.51	16.4	10.86	53.38	0.91	1.89	0.42	0.64
105 L/person/day standard	70 -110m² flat	New, 70 -110m², 4 people (4)	281	0	15	£9.85	£22.51	21.9	14.48	71.17	0.68	1.42	0.32	0.48
105 L/person/day standard	70 -110m² dtchd	New, 70 -110m², 2 people (2)	338	0	15	£11.82	£27.01	11.0	7.24	35.59	1.63	3.40	0.76	1.15
105 L/person/day standard	70 -110m² dtchd	New, 70 -110m², 4 people (4)	338	0	15	£11.82	£27.01	21.9	14.48	71.17	0.82	1.70	0.38	0.57

105 L/person/day standard	>110m² dtchd	New, >110m², 2 people (2)	338	0	15	£11.82	£27.01	11.0	7.24	35.59	1.63	3.40	0.76	1.15
105 L/person/day standard	>110m² dtchd	New, >110m², 4 people (4)	338	0	15	£11.82	£27.01	21.9	14.48	71.17	0.82	1.70	0.38	0.57

Notes: i) LRMCs are 66.10 pence/m3 and weighted average water charges are 325 pence/m3; ii) values in red – CBR<1 (CBR >1 in the original model), i.e. EAC CBR is better than PV cost/PV benefit based calculation.

Appendix E
Flooding –non low regret measures

Table E.2 Residential adaptation cost curve – non low-regret flood resistance and resilience measures

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	Measure description & application	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, societal CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, household CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, societal CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, household CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
88	New floor with treated timber joists, newbuild, deep floods				0.01	1.22	37.38						
71	New floor with treated timber joists, newbuild, shallow floods				0.01	1.22	37.39						
54	New floor with treated timber joists, on repair, deep floods				0.06	1.35	37.45				0.2	1.03	44.9
37	New floor with treated timber joists, on repair, shallow floods				0.10	1.35	37.55				0.3	1.03	45.2
61	Wall-mounted boiler, on repair, deep floods				0.00	1.53	37.55				0.0	1.16	45.2
44	Wall-mounted boiler, on repair, shallow floods				0.00	1.53	37.56				0.0	1.16	45.2
86	Dense screed, newbuild, deep floods	0.00	1.20	37.56	0.00	1.93	37.56	0.00	1.15	45.21	0.0	1.47	45.2
69	Dense screed, newbuild, shallow floods	0.00	1.20	37.56	0.00	1.94	37.56	0.00	1.15	45.22	0.0	1.47	45.2

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, societal CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, societal CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
52	Dense screed, on repair, deep floods	0.01	1.33	37.57	0.01	2.15	37.57	0.02	1.28	45.23	0.0	1.63	45.2
35	Dense screed, on repair, shallow floods	0.01	1.33	37.58	0.01	2.15	37.58	0.03	1.28	45.26	0.0	1.64	45.3
62	Move washing machine to first floor, on repair, deep floods	0.01	2.21	37.59	0.01	3.57	37.59	0.03	2.12	45.29	0.0	2.71	45.3
45	Move washing machine to first floor, on repair, shallow floods	0.02	2.21	37.61	0.02	3.57	37.61	0.1	2.13	45.3	0.1	2.72	45.3
63	Raised, on repair, built-under oven, on repair, deep floods	0.01	2.42	37.62	0.01	3.91	37.62	0.0	2.33	45.4	0.0	2.97	45.4
46	Raised, on repair, built-under oven, on repair, shallow floods	0.01	2.43	37.63	0.01	3.92	37.63	0.0	2.33	45.4	0.0	2.98	45.4
65	Move service meters above flood level, on repair, deep floods	0.03	2.60	37.66	0.03	4.20	37.66	0.1	2.50	45.5	0.1	3.19	45.5
91	Closed cell cavity insulation, newbuild, deep floods	0.00	3.20	37.66	0.00	5.16	37.66	0.0	3.07	45.5	0.0	3.93	45.5

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	Measure description & application	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, societal CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, household CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, societal CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, household CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
74	Closed cell cavity insulation, newbuild, shallow floods	0.00	3.20	37.66	0.00	5.17	37.66	0.0	3.07	45.5	0.0	3.93	45.5
56	Raise floor above likely flood level, on repair, deep floods	0.61	3.33	38.28	0.61	5.37	38.28	1.6	3.19	47.1	1.6	4.08	47.1
64	Move electrics above flood level, on repair, deep floods	0.02	3.47	38.29	0.02	5.60	38.29	0.0	3.33	47.1	0.0	4.26	47.1
92	Water resistant plaster, newbuild, deep floods	0.01	3.51	38.30	0.01	5.67	38.30	0.0	3.37	47.1	0.0	4.31	47.1
75	Water resistant plaster, newbuild, shallow floods	0.01	3.52	38.31	0.01	5.68	38.31	0.0	3.38	47.1	0.0	4.32	47.1
57	Closed cell cavity insulation, on repair, deep floods	0.00	3.55	38.31	0.00	5.74	38.31	0.0	3.41	47.2	0.0	4.36	47.2
40	Closed cell cavity insulation, on repair, shallow floods	0.01	3.56	38.32	0.01	5.74	38.32	0.0	3.42	47.2	0.0	4.37	47.2
94	Water resistant doors and windows, newbuild, deep floods	0.01	3.63	38.33	0.01	5.86	38.33	0.0	3.49	47.2	0.0	4.46	47.2

ID	Measure description & application	Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
		15-year societal benefits @ ≥ 1% AEP (£m)	15-year, societal CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, household CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, societal CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, household CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
39	Raise floor above likely flood level, on repair, shallow floods	0.94	3.65	39.26	0.94	5.90	39.26	2.4	3.51	49.6	2.4	4.49	49.6
58	Water resistant plaster, on repair, deep floods	0.06	3.90	39.33	0.06	6.30	39.33	0.2	3.75	49.8	0.2	4.79	49.8
41	Water resistant plaster, on repair, shallow floods	0.11	3.91	39.43	0.11	6.31	39.43	0.3	3.75	50.1	0.3	4.80	50.1
60	Water resistant doors and windows, on repair, deep floods	0.08	4.04	39.51	0.08	6.52	39.51	0.2	3.87	50.3	0.2	4.95	50.3
20	New floor with treated timber joists, discretionary retrofit, deep floods	0.68	4.30	40.19	0.68	7.02	40.19	0.7	4.30	51.0	0.7	7.02	51.0
3	New floor with treated timber joists, discretionary retrofit, shallow floods	1.12	4.30	41.31	1.12	7.03	41.31	1.2	4.30	52.2	1.2	7.03	52.2
27	Wall-mounted boiler, discretionary retrofit, deep floods	0.03	4.64	41.34	0.03	7.58	41.34	0.0	4.64	52.2	0.0	7.58	52.2

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, societal CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, societal CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
10	Wall-mounted boiler, discretionary retrofit, shallow floods	0.05	4.65	41.39	0.05	7.60	41.39	0.1	4.65	52.2	0.1	7.60	52.2
28	Move washing machine to first floor, discretionary retrofit, deep floods	0.14	4.87	41.53	0.14	7.96	41.53	0.2	4.87	52.4	0.2	7.96	52.4
11	Move washing machine to first floor, discretionary retrofit, shallow floods	0.24	4.88	41.77	0.24	7.98	41.77	0.2	4.88	52.6	0.2	7.98	52.6
100	Plastic kitchen / bathroom units, newbuild, deep floods	0.01	5.03	41.78	0.01	8.12	41.78	0.0	4.83	52.7	0.0	6.17	52.7
83	Plastic kitchen / bathroom units, newbuild, shallow floods	0.01	5.03	41.79	0.01	8.12	41.79	0.0	4.83	52.7	0.0	6.18	52.7
87	Chipboard -> treated timber floorboards, newbuild, deep floods	0.00	5.41	41.79	0.00	8.73	41.79	0.0	5.19	52.7	0.0	6.64	52.7
70	Chipboard -> treated timber floorboards, newbuild, shallow floods	0.00	5.41	41.79	0.00	8.74	41.79	0.0	5.20	52.7	0.0	6.64	52.7

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	Measure description & application	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, societal CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, household CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, societal CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, household CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
66	Plastic kitchen / bathroom units, on repair, deep floods	0.08	5.59	41.87	0.08	9.02	41.87	0.2	5.36	52.9	0.2	6.86	52.9
49	Plastic kitchen / bathroom units, on repair, shallow floods	0.13	5.59	42.00	0.13	9.03	42.00	0.3	5.37	53.2	0.3	6.86	53.2
31	Move service meters above flood level, discretionary retrofit, deep floods	0.35	5.74	42.35	0.35	9.37	42.35	0.4	5.74	53.6	0.4	9.37	53.6
18	Dense screed, discretionary retrofit, deep floods	0.07	5.85	42.42	0.07	9.56	42.42	0.1	5.85	53.7	0.1	9.56	53.7
1	Dense screed, discretionary retrofit, shallow floods	0.11	5.86	42.53	0.11	9.58	42.53	0.1	5.86	53.8	0.1	9.58	53.8
29	Raised, discretionary retrofit, built-under oven, discretionary retrofit, deep floods	0.08	5.92	42.61	0.08	9.67	42.61	0.1	5.92	53.9	0.1	9.67	53.9
12	Raised, discretionary retrofit, built-under oven, discretionary retrofit, shallow floods	0.13	5.93	42.73	0.13	9.69	42.73	0.1	5.93	54.0	0.1	9.69	54.0

ID	Measure description & application	Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
		15-year societal benefits @ ≥ 1% AEP (£m)	15-year, societal CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, household CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, societal CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, household CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
53	Chipboard -> treated timber floorboards, on repair, deep floods	0.00	6.01	42.74	0.00	9.70	42.74	0.0	5.77	54.0	0.0	7.38	54.0
36	Chipboard -> treated timber floorboards, on repair, shallow floods	0.00	6.01	42.74	0.00	9.71	42.74	0.0	5.77	54.0	0.0	7.38	54.0
42	Chemical damp-proof course, on repair, shallow floods	0.05	6.04	42.79	0.05	9.76	42.79	0.1	5.80	54.1	0.1	7.42	54.1
59	Chemical damp-proof course, on repair, deep floods	0.03	6.20	42.82	0.03	10.01	42.82	0.1	5.96	54.2	0.1	7.61	54.2
23	Closed cell cavity insulation, discretionary retrofit, deep floods	0.05	6.53	42.86	0.05	10.67	42.86	0.1	6.53	54.3	0.1	10.67	54.3
6	Closed cell cavity insulation, discretionary retrofit, shallow floods	0.08	6.54	42.94	0.08	10.68	42.94	0.1	6.54	54.4	0.1	10.68	54.4
24	Water resistant plaster, discretionary retrofit, deep floods	0.70	6.61	43.64	0.70	10.80	43.64	0.7	6.61	55.1	0.7	10.80	55.1
22	Raise floor above likely flood level, discretionary retrofit, deep floods	6.69	6.62	50.33	6.69	10.81	50.33	7.0	6.62	62.1	7.0	10.81	62.1

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	Measure description & application	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, societal CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, household CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, societal CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, household CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
7	Water resistant plaster, discretionary retrofit, shallow floods	1.15	6.62	51.48	1.15	10.82	51.48	1.2	6.62	63.3	1.2	10.82	63.3
30	Move electrics above flood level, discretionary retrofit, deep floods	0.16	6.63	51.64	0.16	10.83	51.64	0.2	6.63	63.5	0.2	10.83	63.5
26	Water resistant doors and windows, discretionary retrofit, deep floods	0.85	6.63	52.49	0.85	10.83	52.49	0.9	6.63	64.4	0.9	10.83	64.4
5	Raise floor above likely flood level, discretionary retrofit, shallow floods	10.22	7.26	62.71	10.22	11.85	62.71	10.7	7.26	75.1	10.7	11.85	75.1
48	Move service meters above flood level, on repair, shallow floods	0.02	7.38	62.73	0.02	11.91	62.73	0.0	7.08	75.2	0.0	9.06	75.2
77	Water resistant doors and windows, newbuild, shallow floods	0.00	7.55	62.73	0.00	12.19	62.73	0.0	7.25	75.2	0.0	9.27	75.2
32	Plastic kitchen / bathroom units, discretionary retrofit, deep floods	0.88	8.05	63.61	0.88	13.15	63.61	0.9	8.05	76.1	0.9	13.15	76.1

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	**Measure description & application**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, societal CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year societal benefits @ ≥ 1% AEP (£m)**	**15-year, household CBR @ ≥ 1% AEP**	**Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, societal CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year societal benefits @ ≥ 1% AEP (£m)**	**45-year, household CBR @ ≥ 1% AEP**	**Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)**
15	Plastic kitchen / bathroom units, discretionary retrofit, shallow floods	1.44	8.06	65.06	1.44	13.17	65.06	1.5	8.06	77.6	1.5	13.17	77.6
43	Water resistant doors and windows, on repair, shallow floods	0.06	8.39	65.12	0.06	13.55	65.12	0.2	8.06	77.8	0.2	10.30	77.8
8	Chemical damp-proof course, discretionary retrofit, shallow floods	0.54	8.46	65.66	0.54	13.83	65.66	0.6	8.46	78.4	0.6	13.83	78.4
19	Chipboard -> treated timber floorboards, discretionary retrofit, deep floods	0.02	8.53	65.67	0.02	13.94	65.67	0.0	8.53	78.4	0.0	13.94	78.4
2	Chipboard -> treated timber floorboards, discretionary retrofit, shallow floods	0.03	8.55	65.70	0.03	13.96	65.70	0.0	8.55	78.4	0.0	13.96	78.4
25	Chemical damp-proof course, discretionary retrofit, deep floods	0.32	8.68	66.02	0.32	14.19	66.02	0.3	8.68	78.7	0.3	14.19	78.7
89	Solid concrete floor, newbuild, deep floods	0.01	10.55	66.03	0.01	17.03	66.03	0.0	10.13	78.8	0.0	12.95	78.8

		Societal perspective, to 2030s			Household perspective, to 2030s			Societal perspective, to 2060s			Household perspective, to 2060s		
ID	Measure description & application	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, societal CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	15-year societal benefits @ ≥ 1% AEP (£m)	15-year, household CBR @ ≥ 1% AEP	Cumulative 15-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, societal CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)	45-year societal benefits @ ≥ 1% AEP (£m)	45-year, household CBR @ ≥ 1% AEP	Cumulative 45-year societal benefits @ ≥ 1% AEP (£m)
72	Solid concrete floor, newbuild, shallow floods	0.01	10.56	66.03	0.01	17.05	66.03	0.0	10.14	78.8	0.0	12.96	78.8
55	Solid concrete floor, on repair, deep floods	0.05	11.72	66.09	0.05	18.93	66.09	0.1	11.25	78.9	0.1	14.39	78.9
38	Solid concrete floor, on repair, shallow floods	0.09	11.73	66.18	0.09	18.94	66.18	0.2	11.26	79.1	0.2	14.40	79.1
21	Solid concrete floor, discretionary retrofit, deep floods	0.58	12.93	66.76	0.58	21.13	66.76	0.6	12.93	79.8	0.6	21.13	79.8
4	Solid concrete floor, discretionary retrofit, shallow floods	0.95	12.95	67.71	0.95	21.16	67.71	1.0	12.95	80.8	1.0	21.16	80.8
9	Water resistant doors and windows, discretionary retrofit, shallow floods	0.66	13.80	68.37	0.66	22.55	68.37	0.7	13.80	81.5	0.7	22.55	81.5
14	Move service meters above flood level, discretionary retrofit, shallow floods	0.20	16.27	68.58	0.20	26.59	68.58	0.2	16.27	81.7	0.2	26.59	81.7

Table E.2 Residential adaptation cost curve – sensitivity analysis for flood resistance and resilience measures (full results)

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
73	Raise floor above likely flood level, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	Raise floor above likely flood level, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
76	Chemical damp-proof course, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
99	Move service meters above flood level, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
93	Chemical damp-proof course, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
79	Move washing machine to first floor, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
82	Move service meters above flood level, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98	Move electrics above flood level, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
96	Move washing machine to first floor, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	Raised, newbuild, built-under oven, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
97	Raised, newbuild, built-under oven, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
78	Wall-mounted boiler, newbuild, shallow floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
95	Wall-mounted boiler, newbuild, deep floods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, deep floods	0.15	0.24	0.45	0.15	0.24	0.45	0.27	0.39	0.68	0.27	0.39	0.68
17	Flood resistance package, discretionary retrofit, manual activation, discretionary retrofit, shallow floods	0.16	0.25	0.47	0.16	0.25	0.47	0.28	0.41	0.71	0.28	0.41	0.71
102	Flood resistance package, newbuild, manual activation,	0.17	0.27	0.51	0.16	0.26	0.49	0.30	0.44	0.97	0.23	0.33	0.57

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
	newbuild, deep floods												
85	Flood resistance package, newbuild, manual activation, newbuild, shallow floods	0.18	0.29	0.54	0.17	0.27	0.52	0.32	0.46	1.03	0.24	0.35	0.61
101	Flood resistance package, newbuild, fit & forget, newbuild, deep floods	0.20	0.31	0.59	0.19	0.30	0.56	0.35	0.50	1.12	0.26	0.38	0.66
33	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, deep floods	0.20	0.32	0.60	0.20	0.32	0.60	0.36	0.52	0.90	0.36	0.52	0.90
84	Flood resistance package, newbuild, fit & forget, newbuild, shallow floods	0.21	0.33	0.62	0.20	0.32	0.60	0.37	0.53	1.19	0.28	0.41	0.71

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
16	Flood resistance package, discretionary retrofit, fit & forget, discretionary retrofit, shallow floods	0.22	0.34	0.64	0.22	0.34	0.64	0.38	0.55	0.96	0.38	0.55	0.96
68	Flood resistance package, on repair, manual activation, on repair, deep floods	0.21	0.32	0.61	0.20	0.31	0.59	0.36	0.52	1.17	0.28	0.40	0.69
51	Flood resistance package, on repair, manual activation, on repair, shallow floods	0.22	0.34	0.64	0.21	0.33	0.62	0.38	0.55	1.23	0.29	0.42	0.73
67	Flood resistance package, on repair, fit & forget, on repair, deep floods	0.24	0.37	0.70	0.23	0.35	0.67	0.41	0.60	1.33	0.31	0.45	0.79
50	Flood resistance package, on repair, fit &	0.25	0.39	0.74	0.24	0.37	0.71	0.44	0.63	1.40	0.33	0.48	0.83

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
	forget, on repair, shallow floods												
88	New floor with treated timber joists, newbuild, deep floods	0.48	0.75	1.42	0.46	0.72	1.37	0.84	1.22	2.71	0.64	0.93	1.61
71	New floor with treated timber joists, newbuild, shallow floods	0.48	0.75	1.43	0.46	0.72	1.37	0.84	1.22	2.71	0.64	0.93	1.61
54	New floor with treated timber joists, on repair, deep floods	0.53	0.84	1.58	0.51	0.80	1.52	0.94	1.35	3.01	0.71	1.03	1.79
37	New floor with treated timber joists, on repair, shallow floods	0.53	0.84	1.58	0.51	0.80	1.53	0.94	1.35	3.01	0.71	1.03	1.79
61	Wall-mounted boiler, on repair, deep floods	0.60	0.95	1.79	0.58	0.91	1.72	1.06	1.53	3.41	0.81	1.16	2.02
44	Wall-mounted boiler, on repair, shallow floods	0.61	0.95	1.79	0.58	0.91	1.73	1.06	1.53	3.41	0.81	1.16	2.02

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
86	Dense screed, newbuild, deep floods	0.76	1.20	2.26	0.73	1.15	2.18	1.34	1.93	4.31	1.02	1.47	2.55
69	Dense screed, newbuild, shallow floods	0.77	1.20	2.27	0.73	1.15	2.18	1.34	1.94	4.31	1.02	1.47	2.56
52	Dense screed, on repair, deep floods	0.85	1.33	2.52	0.81	1.28	2.42	1.49	2.15	4.79	1.13	1.63	2.84
35	Dense screed, on repair, shallow floods	0.85	1.33	2.52	0.81	1.28	2.42	1.49	2.15	4.79	1.13	1.64	2.84
62	Move washing machine to first floor, on repair, deep floods	1.41	2.21	4.18	1.35	2.12	4.02	2.47	3.57	7.95	1.88	2.71	4.71
45	Move washing machine to first floor, on repair, shallow floods	1.41	2.21	4.18	1.35	2.13	4.03	2.47	3.57	7.96	1.88	2.72	4.72

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
63	Raised, on repair, built-under oven, on repair, deep floods	1.55	2.42	4.58	1.48	2.33	4.41	2.71	3.91	8.71	2.06	2.97	5.17
46	Raised, on repair, built-under oven, on repair, shallow floods	1.55	2.43	4.58	1.48	2.33	4.41	2.71	3.92	8.72	2.06	2.98	5.17
65	Move service meters above flood level, on repair, deep floods	1.66	2.60	4.92	1.59	2.50	4.73	2.91	4.20	9.35	2.21	3.19	5.55
91	Closed cell cavity insulation, newbuild, deep floods	2.04	3.20	6.04	1.96	3.07	5.82	3.57	5.16	11.50	2.72	3.93	6.82
74	Closed cell cavity insulation, newbuild, shallow floods	2.04	3.20	6.05	1.96	3.07	5.82	3.58	5.17	11.51	2.72	3.93	6.83
56	Raise floor above likely flood level, on repair, deep floods	2.12	3.33	6.28	2.03	3.19	6.05	3.72	5.37	11.96	2.83	4.08	7.09

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
64	Move electrics above flood level, on repair, deep floods	2.21	3.47	6.56	2.12	3.33	6.31	3.88	5.60	12.48	2.95	4.26	7.40
92	Water resistant plaster, newbuild, deep floods	2.24	3.51	6.64	2.15	3.37	6.39	3.93	5.67	12.63	2.98	4.31	7.49
75	Water resistant plaster, newbuild, shallow floods	2.24	3.52	6.64	2.15	3.38	6.40	3.93	5.68	12.64	2.99	4.32	7.50
57	Closed cell cavity insulation, on repair, deep floods	2.27	3.55	6.71	2.17	3.41	6.47	3.97	5.74	12.78	3.02	4.36	7.58
40	Closed cell cavity insulation, on repair, shallow floods	2.27	3.56	6.72	2.17	3.42	6.47	3.98	5.74	12.79	3.02	4.37	7.58
94	Water resistant doors and windows, newbuild, deep floods	2.32	3.63	6.86	2.22	3.49	6.61	4.06	5.86	13.06	3.09	4.46	7.74
39	Raise floor above likely flood level,	2.33	3.65	6.90	2.23	3.51	6.65	4.08	5.90	13.14	3.10	4.49	7.79

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
	on repair, shallow floods												
58	Water resistant plaster, on repair, deep floods	2.49	3.90	7.37	2.39	3.75	7.10	4.36	6.30	14.03	3.32	4.79	8.32
41	Water resistant plaster, on repair, shallow floods	2.49	3.91	7.38	2.39	3.75	7.11	4.37	6.31	14.05	3.32	4.80	8.33
60	Water resistant doors and windows, on repair, deep floods	2.58	4.04	7.62	2.47	3.87	7.34	4.51	6.52	14.51	3.43	4.95	8.60
20	New floor with treated timber joists, discretionary retrofit, deep floods	2.75	4.30	8.10	2.75	4.30	8.10	4.86	7.02	12.20	4.86	7.02	12.20
3	New floor with treated timber joists, discretionary retrofit, shallow floods	2.76	4.30	8.11	2.76	4.30	8.11	4.87	7.03	12.21	4.87	7.03	12.21

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
27	Wall-mounted boiler, discretionary retrofit, deep floods	2.97	4.64	8.75	2.97	4.64	8.75	5.25	7.58	13.17	5.25	7.58	13.17
10	Wall-mounted boiler, discretionary retrofit, shallow floods	2.98	4.65	8.76	2.98	4.65	8.76	5.26	7.60	13.19	5.26	7.60	13.19
28	Move washing machine to first floor, discretionary retrofit, deep floods	3.12	4.87	9.18	3.12	4.87	9.18	5.51	7.96	13.83	5.51	7.96	13.83
11	Move washing machine to first floor, discretionary retrofit, shallow floods	3.13	4.88	9.20	3.13	4.88	9.20	5.52	7.98	13.85	5.52	7.98	13.85
100	Plastic kitchen / bathroom units, newbuild, deep floods	3.21	5.03	9.50	3.07	4.83	9.14	5.62	8.12	18.08	4.27	6.17	10.72

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
83	Plastic kitchen / bathroom units, newbuild, shallow floods	3.21	5.03	9.51	3.08	4.83	9.15	5.62	8.12	18.09	4.27	6.18	10.73
87	Chipboard -> treated timber floorboards, newbuild, deep floods	3.45	5.41	10.22	3.31	5.19	9.84	6.04	8.73	19.44	4.59	6.64	11.53
70	Chipboard -> treated timber floorboards, newbuild, shallow floods	3.45	5.41	10.23	3.31	5.20	9.85	6.05	8.74	19.46	4.60	6.64	11.54
66	Plastic kitchen / bathroom units, on repair, deep floods	3.56	5.59	10.55	3.41	5.36	10.16	6.24	9.02	20.08	4.75	6.86	11.91
49	Plastic kitchen / bathroom units, on repair, shallow floods	3.57	5.59	10.56	3.42	5.37	10.17	6.25	9.03	20.10	4.75	6.86	11.92
31	Move service meters above flood level, discretionary	3.67	5.74	10.80	3.67	5.74	10.80	6.49	9.37	16.27	6.49	9.37	16.27

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
	retrofit, deep floods												
18	Dense screed, discretionary retrofit, deep floods	3.75	5.85	11.03	3.75	5.85	11.03	6.62	9.56	16.61	6.62	9.56	16.61
1	Dense screed, discretionary retrofit, shallow floods	3.75	5.86	11.04	3.75	5.86	11.04	6.63	9.58	16.63	6.63	9.58	16.63
29	Raised, discretionary retrofit, built-under oven, discretionary retrofit, deep floods	3.79	5.92	11.15	3.79	5.92	11.15	6.70	9.67	16.80	6.70	9.67	16.80
12	Raised, discretionary retrofit, built-under oven, discretionary retrofit, shallow floods	3.80	5.93	11.17	3.80	5.93	11.17	6.70	9.69	16.82	6.70	9.69	16.82

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
53	Chipboard -> treated timber floorboards, on repair, deep floods	3.83	6.01	11.35	3.67	5.77	10.93	6.71	9.70	21.60	5.11	7.38	12.81
36	Chipboard -> treated timber floorboards, on repair, shallow floods	3.84	6.01	11.36	3.68	5.77	10.94	6.72	9.71	21.62	5.11	7.38	12.82
42	Chemical damp-proof course, on repair, shallow floods	3.86	6.04	11.42	3.69	5.80	10.99	6.75	9.76	21.73	5.13	7.42	12.88
59	Chemical damp-proof course, on repair, deep floods	3.96	6.20	11.72	3.79	5.96	11.28	6.93	10.01	22.30	5.27	7.61	13.22
23	Closed cell cavity insulation, discretionary retrofit, deep floods	4.18	6.53	12.30	4.18	6.53	12.30	7.38	10.67	18.53	7.38	10.67	18.53
6	Closed cell cavity insulation, discretionary	4.19	6.54	12.32	4.19	6.54	12.32	7.40	10.68	18.56	7.40	10.68	18.56

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
	retrofit, shallow floods												
24	Water resistant plaster, discretionary retrofit, deep floods	4.23	6.61	12.45	4.23	6.61	12.45	7.48	10.80	18.76	7.48	10.80	18.76
22	Raise floor above likely flood level, discretionary retrofit, deep floods	4.24	6.62	12.47	4.24	6.62	12.47	7.48	10.81	18.78	7.48	10.81	18.78
7	Water resistant plaster, discretionary retrofit, shallow floods	4.24	6.62	12.47	4.24	6.62	12.47	7.49	10.82	18.79	7.49	10.82	18.79
30	Move electrics above flood level, discretionary retrofit, deep floods	4.24	6.63	12.48	4.24	6.63	12.48	7.49	10.83	18.80	7.49	10.83	18.80
26	Water resistant doors and windows, discretionary	4.24	6.63	12.49	4.24	6.63	12.49	7.49	10.83	18.81	7.49	10.83	18.81

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
	retrofit, deep floods												
5	Raise floor above likely flood level, discretionary retrofit, shallow floods	4.65	7.26	13.67	4.65	7.26	13.67	8.20	11.85	20.59	8.20	11.85	20.59
48	Move service meters above flood level, on repair, shallow floods	4.71	7.38	13.94	4.51	7.08	13.42	8.24	11.91	26.53	6.27	9.06	15.73
77	Water resistant doors and windows, newbuild, shallow floods	4.82	7.55	14.27	4.62	7.25	13.74	8.44	12.19	27.15	6.42	9.27	16.10
32	Plastic kitchen / bathroom units, discretionary retrofit, deep floods	5.15	8.05	15.16	5.15	8.05	15.16	9.10	13.15	22.84	9.10	13.15	22.84
15	Plastic kitchen / bathroom units, discretionary	5.16	8.06	15.18	5.16	8.06	15.18	9.11	13.17	22.87	9.11	13.17	22.87

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
	retrofit, shallow floods												
43	Water resistant doors and windows, on repair, shallow floods	5.35	8.39	15.85	5.13	8.06	15.26	9.38	13.55	30.17	7.13	10.30	17.89
8	Chemical damp-proof course, discretionary retrofit, shallow floods	5.42	8.46	15.94	5.42	8.46	15.94	9.57	13.83	24.01	9.57	13.83	24.01
19	Chipboard -> treated timber floorboards, discretionary retrofit, deep floods	5.46	8.53	16.08	5.46	8.53	16.08	9.65	13.94	24.21	9.65	13.94	24.21
2	Chipboard -> treated timber floorboards, discretionary retrofit, shallow floods	5.47	8.55	16.10	5.47	8.55	16.10	9.66	13.96	24.25	9.66	13.96	24.25

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
25	Chemical damp-proof course, discretionary retrofit, deep floods	5.56	8.68	16.36	5.56	8.68	16.36	9.82	14.19	24.64	9.82	14.19	24.64
89	Solid concrete floor, newbuild, deep floods	6.73	10.55	19.93	6.45	10.13	19.19	11.79	17.03	37.94	8.96	12.95	22.49
72	Solid concrete floor, newbuild, shallow floods	6.74	10.56	19.95	6.46	10.14	19.21	11.80	17.05	37.97	8.97	12.96	22.51
55	Solid concrete floor, on repair, deep floods	7.48	11.72	22.15	7.17	11.25	21.32	13.10	18.93	42.15	9.96	14.39	24.99
38	Solid concrete floor, on repair, shallow floods	7.49	11.73	22.17	7.17	11.26	21.34	13.11	18.94	42.19	9.97	14.40	25.01
21	Solid concrete floor, discretionary retrofit, deep floods	8.28	12.93	24.36	8.28	12.93	24.36	14.62	21.13	36.70	14.62	21.13	36.70
4	Solid concrete floor, discretionary	8.29	12.95	24.40	8.29	12.95	24.40	14.65	21.16	36.75	14.65	21.16	36.75

ID	Measure description & application	15-year, societal CBR @ ≥ 1% AEP (best)	15-year, societal CBR @ ≥ 1% AEP (mid)	15-year, societal CBR @ ≥ 1% AEP (worst)	45-year, societal CBR @ ≥ 1% AEP (best)	45-year, societal CBR @ ≥ 1% AEP (mid)	45-year, societal CBR @ ≥ 1% AEP (worst)	15-year, household CBR @ ≥ 1% AEP (best)	15-year, household CBR @ ≥ 1% AEP (mid)	15-year, household CBR @ ≥ 1% AEP (worst)	45-year, household CBR @ ≥ 1% AEP (best)	45-year, household CBR @ ≥ 1% AEP (mid)	45-year, household CBR @ ≥ 1% AEP (worst)
	retrofit, shallow floods												
9	Water resistant doors and windows, discretionary retrofit, shallow floods	8.84	13.80	26.01	8.84	13.80	26.01	15.61	22.55	39.17	15.61	22.55	39.17
14	Move service meters above flood level, discretionary retrofit, shallow floods	10.42	16.27	30.66	10.42	16.27	30.66	18.40	26.59	46.17	18.40	26.59	46.17

Appendix F
Overheating – List of measures

Table F.3 List of measures identified as applicable to overheating

	Measure	Nature of benefit	Cost/scale	Source(Wood) : type of evidence	Source(DI, 2009) : type of evidence	Source (CREW): type of evidence	Scope of applicability community/residents	Overall assessment of barriers	Time period for development & replacement	new build conception	new build costs	Other notes
A1	Urban Realm - City Planning											
1	Street 'canyons'	Shading and wind control at the building/street scale	small changes in Local Authority charges		n/a	n/a	constraint of existing buildings mean only additions	design and construction not easily implemented	street/area/major development timescales	canyons can be designed in	design + fewer dwelling units	Street 'canyons' should be avoided ref. 1 but also doubling green space would decrease summer UHI by 0.7C (35% reduction) Met office
2	City ventilation air flow	Wind control at the city scale	small changes in Local Authority charges		n/a	n/a	effective across whole region/area	redesign of city/region not easily implemented	street/area timescales	can be designed in	design + fewer dwelling units	
3	Trees to reduce UHI effect and shading	Shading at dwelling level	small changes in Local Authority charges		n/a	n/a	effective across dwellings in an area	design and construction not easily implemented	tree growth and planting strategy timescales	can be designed in	design + fewer dwelling units; + tree maintenance (could be shared)	better than grass ref. 1
4	Reduce waste heat from city	Reduced heat gain at city scale	changes in Local Authority charges		n/a	n/a	effective across large area	difficult but other societal benefits	local authority resource planning timescales	spare heat reused for domestic heating		Potential average reduction in UHI magnitude by 0.3C (15% reduction) Met Office
5	Community refuges	Provides emergency network for extreme overheating events	changes in Local Authority charges		n/a	n/a		if existing community infrastructure				
A2	Urban Realm - Urban design											
1	Green roofs	Provide insulation and evaporative cooling	small changes in Local Authority charges	https://www.building.co.uk/focus/what-it-costs-green-roofs/3124093.article		n/a	residents of building, all if public space	difficult but other societal benefits	regular maintenance necessary	can be designed in	design + fewer dwelling units; + green roof maintenance (could be shared)	
2	Solar reflective roof	Reduces solar and heat energy transmitted through roofs	quantified in Table xx		n/a	Y- Solar reflective roof (light roofs)	residents of building, also reduce UHI effect	yes depending on agency	periodic repainting necessary	can be designed in	£400 - £1600 CREW model	
3	Solar reflective walls	Reduces solar and heat energy transmitted through roofs	quantified in Table xx		n/a	Y- Solar reflective roof (light roofs)	residents of building, also reduce UHI effect	yes depending on agency	periodic repainting necessary	can be designed in	£400 - £1600 CREW model	
4	Orientation (for new build)	Reduces effect of solar and	% increase in cost if result is			orientation considered in model		not easily implemented		new build orientation, how much can , seen as loss in		CREW model showed little impact from

		heat gain for the building	fewer dwellings per site						numbers of units (not > A/C)		orientation in detached dwelling, but big impact in flats
5	Avoid single aspect flats	Reduces potential for poorly ventilated dwellings	% increase in cost if result is fewer dwellings per site						can be designed in	design + fewer dwelling units	"London Plan" from GLA already outlines regulation on permissible single aspect dwellings
6	Do not add car parks at expense of green space	Green space benefits	% increase in cost if result is fewer dwellings per site							design + fewer car parking places	Car parking can be key deciding factor for many peoples dwelling choice
B1	Building & Equipment: Improvements to insulation										
1	External wall insulation	Reduces solar and heat energy transmitted through walls	quantified in Table xx		External wall insulation	all residents within building	yes depending on agency and cost	approx. every 20 years or at building turnover rate	can be designed in	design + building materials + extra build process	
2	Cavity wall insulation	Reduces solar and heat energy transmitted through walls	quantified in Table xx	Lining in cavity of brick wall - Detached	Cavity wall insulation - effectiveness low	all residents within building	yes depending on agency and cost	approx. every 20 years or at building turnover rate			low effectiveness, can worsen overheat by reducing heat losses. But benefits during winter months
3	Thermal mass (add)	Reduces max and min internal temperatures and makes night cooling more effective					yes depending on agency and cost	one-off installation	can be designed in, but with materials as well as design cost	design + building materials	use of materials such as Phase Changing Material (PCMs), understanding full environmental impact important
4	Internal wall insulation	Reduces solar and heat energy transmitted through walls	quantified in Table xx	n/a	Internal wall insulation	all residents	yes depending on agency and cost	approx. every 20 years	can be designed in		
5	Flat roof insulation	Reduces solar and heat energy transmitted through flat roofs	quantified in Table xx		upgrade flat roof		yes depending on agency and cost	approx. every 20 years or at building turnover rate			
6	Roof Insulation	Reduces solar and heat energy transmitted through roofs	quantified in Table xx	Roof and Loft insulation	upgrade flat roof (light roof)		yes depending on agency and cost	approx. every 20 years or at building turnover rate			
B2	Building & Equipment: Improvements to solar protection										
1	Blinds	Reduces solar energy	quantified in Table xx			benefits all but benefit must be	yes	approx. 10 years	n/a	n/a	effective measure in CREW model -

		transmitted through windows				understood of using measure during daytime					30% reduction in degree hours compared to unadapted dwelling
2	Curtains	Reduces solar energy transmitted through windows	quantified in Table xx	Internal Shading - Drapes curtains	Curtains	benefits all but benefit must be understood of using measure during daytime	easily implemented	approx. 10 years	n/a	n/a	effective measure in CREW model - 23% reduction in degree hours compared to unadapted dwelling
3	External fixed shading	Reduces solar energy transmitted through windows	quantified in Table xx		External fixed shading	all residents within building - to open windows requires accessible placement	would require application of shading, difficulty varies by property type	approx. every 10 years	can be designed in	design + building materials + extra build process	can be aesthetically unpleasant to some
4	External shutters	Reduces solar energy transmitted through windows	quantified in Table xx	External louvres	External Shutters	all residents within building - to open windows requires accessible placement		approx. every 10 years	can be designed in	design + building materials + extra build process	can be aesthetically unpleasant to some
5	Low emissive coated triple glazing	Reduces solar energy transmitted through windows	quantified in Table xx	Triple glazing	Low e triple glazing - high effectiveness		yes depending on agency and cost		can be designed in, but with materials as well as design cost	design + building materials + extra build process	good effectiveness in CREW model
B3	Building & Equipment: Improvements to ventilation and cooling systems										
1	Remedial cross-ventilation/room protection	Additional 'free-running' ventilation capacity, or room protetion	quantified in Table xx	n/a	n/a	benefits all in dwelling	difficult	n/a	can be designed in	design	
2	Chimneys	Additional 'free-running' ventilation capacity	important local effects supplementary to general ventilation	n/a	n/a	all residents within building			can be designed in	design + fewer dwelling units	limited mention as a measure, performance would be comparable to windows
3	Fans	Mechanical ventilation	high operating costs and significant capital costs	Ceiling fan			easily implemented	approx. 10 years	designed ceiling fans	design + building materials + running cost + CO2 impact	environmental and energy cost
4	Air conditioning	Mechanical cooling of ambient air	high operating costs and significant capital costs	baseline proxy	n/a	limited	difficult	approx. 10 years	can be designed in	design + building materials	energy and environmental cost
5	Mechanical ventilation with heat recovery	Mechanical ventilation and heat transfer	high operating costs and	n/a	n/a		difficult	approx. 10 years	can be designed in, but with	design + building materials	Performance depends on building thermal envelope. Not

			significant capital costs			materials as well as design cost	investigated in existing models
C	Health & Behaviour						
1	Access to cool shady area	Reduction in body temperature	Part of behaviour in the urban realm		yes/no by dwelling type; nearby access outside the dwelling; depends on mobility		
2	Shade	Reduction in body temperature	General requirement for access to shade				
3	Appropriate clothing	Reduction in body temperature	Existing baseline may include government information programmes	can be considered a baseline	easily implemented		
4	Drink water	Reduction in body temperature			yes, but water may not be cool		still requires cooling , refrigeration
5	Ice	Reduction in body temperature			yes, but depends on refrigeration capacity		local community fridges might work
6	Avoid exercise	Reduction in body temperature			possible unless physically working, e.g. with children		
7	Shower	Reduction in body temperature			depends on circumstances including mobility		
8	Switch off non-essential equipment	Control and reduce other sources of heat gain					
9	Monitor temperature	Reduction in body temperature	Availabillity of existing monitoring systems for moniroting		preventative, temp not a good guide to vulnerability		
10	Monitor people	Social contract			structured approaches required		

Appendix G
Table of Current Prices Used in Assessing Costs of Measures

Table G.1 Current prices uses in assessing costs of measures

ID

ID	Group	Measure	Comment	Unit	Price (lower)	Price (upper)	Ref. Link
1	A1	green roofs	several degree C cooling effect in summer	£/m^2	30	55	https://www.building.co.uk/focus/what-it-costs-green-roofs/3124093.article
2	B1	Cavity wall insulation	Lining in cavity of brick wall - Detached	£/dwelling	725		http://www.energysavingtrust.org.uk/home-insulation/cavity-wall
3	B1	Cavity wall insulation	Lining in cavity of brick wall - Semi-detached	£/dwelling	475		ditto
4	B1	Cavity wall insulation	Lining in cavity of brick wall - Mid terrace	£/dwelling	370		ditto
5	B1	Cavity wall insulation	Lining in cavity of brick wall - Bungalow	£/dwelling	430		ditto
6	B1	Cavity wall insulation	Lining in cavity of brick wall - Flat	£/dwelling	330		ditto
7	B1	Cavity wall insulation	Lining in cavity of brick wall - per m2 of wall	£/m^2	5	6	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/656866/BEIS_Update_of_Domestic_Cost_Assumptions_031017.pdf
8	B1	Roof and Loft insulation	Lining in roof/loft - Detached	£/dwelling	290	395	http://www.energysavingtrust.org.uk/home-insulation/roof-and-loft
9	B1	Roof and Loft insulation	Lining in cavity of roof/loft - Semi-detached	£/dwelling	240	300	ditto
10	B1	Roof and Loft insulation	Lining in cavity of roof/loft - Mid terrace	£/dwelling	230	285	ditto
11	B1	Roof and Loft insulation	Lining in cavity of roof/loft - Bungalow	£/dwelling	280	375	ditto

12	B2	Solar shading	Aluminium aerofoil - Mill finished	£/m	220		http://www.greenspec.co.uk/building-design/solar-shading/
13	B2	Solar shading	Aluminium aerofoil - Polyester power coated	£/m	270		ditto
14	B2	Solar shading	Aluminium aerofoil - PVDF	£/m	320		ditto
15	B2	Solar shading	Aluminium aerofoil - anodised Bs3987	£/m	250		ditto
16	B2	Solar shading	Aluminium slat - polyester power coated	£/m	180		ditto
17	B2	Solar shading	Aluminium louvre system - Manually adjustable crank	£/m	370		ditto
18	B2	Solar shading	Aluminium louvre system - motorised adjustment	£/m	595		ditto
19	B2	Roller Blind	semi-detached w/ single glazing	£/dwelling	500		http://www.hallmarkblinds.co.uk/assets/guide-to-low-energy-shading.pdf
20	B1	Cavity wall insulation	semi-detached w/ single glazing	£/dwelling	500		Energy Saving Trust and British Blind and Shutters Association
21	B1	Loft Insulation	semi-detached w/ single glazing	£/dwelling	300		ditto
22	B1	Single to double glazing	semi-detached w/ single glazing	£/dwelling	2500		ditto
23	B2	Internal Shading - Drapes curtains	upto 2.5m x 1.4m, machine made, April 2017	£/unit	23.25	38.25	https://www.top-designer.co.uk/assets/000/407/893/top_designer_price_list_-_WORD_Apr_2017_original.pdf
24	B2	Internal Shading - Louvered shade	Vertical Blind Slats, 100% Polyester,	£/m^2	2.17		https://www.directblinds.co.uk/vertical-blind-slats/atlantex-solar-brown-89mm-vertical-blind-slats/

25	B2	Internal Shading - Roller shade	Blackout	£/m^2	25.31	122.36	https://www.roller-blinds-direct.co.uk/product/arena_moire_blackout_natural_roller_blind
26	B2	Internal Shading - Panel shade/screen	PVC and Polyester Mesh which provide solar control	£/m^2	42		https://www.orderblinds.co.uk/buy/charcoal-weave-sunscreen-roller-blind_4930.htm
27	B2	Internal Shading - cellular shade	Cellular blind, 0.8m x 1.55m	£/unit	23		https://www.ikea.com/gb/en/products/textiles-rugs/curtains-blinds/hoppvals-cellular-blind-white-art-90290627/
28	B1	Insulated roof and fascia detail	Measure applied on social housing cost per flat	£/flat	600		LCCP_social
29	B1	Insulated render to facades	Measure applied on social housing cost per flat	£/flat	4404		LCCP_social
30	B1	External window reveals	Measure applied on social housing cost per flat	£/flat	£143		LCCP_social
31	B2	Triple glazed windows	Measure applied on social housing cost per flat	£/flat	£6,768		LCCP_social
32	B2	Increase reflectivity through light coloured painting	Measure applied on social housing cost per flat				LCCP_social
33	B3	Air Conditioning Unit	RAS wall mounted, cooling capcity 2.5kw	£/unit	585	1119	http://www.toshiba-aircon.co.uk/wp-content/uploads/2018/05/Retail_Price_List_Effective_January_2018v5.pdf
34	B3	Ceiling fan	60W, 1200mm	£/unit	73.96	0	https://www.energybulbs.co.uk/vent-axia+hi-line+plus+ceiling+sweep+fan+1200mm+-+white/1498656367?gclid=CjwKCAiAodTfBRBEEiwAa1hautScNOWN_Mkn1rFR0A4dx4smfDr5Vrtew3YMmW92HS4agRTIlw77mRoCsMoQAvD_BwE

35	B3	Low emissivity film	Low grade, Reduce Glare by up to 60%, Solar Heat Gain by 58% and 99% harmful skin damaging Ultraviolet Light (UV)	£/m^2	22.8	0	https://www.omegawindowfilms.co.uk/making-glass-energy-saving-low-e/energy-saving-low-e-light-grade-window-film.html
36	B2	Low emissivity film	Heavy grade, Reduce Glare by up to 76%, Solar Heat Gain by 73% and 99% harmful skin damaging Ultraviolet Light (UV)	£/m^2	15.49	0	https://www.omegawindowfilms.co.uk/making-glass-energy-saving-low-e/energy-saving-low-e-heavy-grade-window-film.html
37	B2	Triple glazing	4 windows, 2 bedroom flat	£/porperty	2000	0	https://www.getawindow.co.uk/window-glass/triple-glazing-cost/
38	B2	Triple glazing	5windows, 2 bed terrace	£/porperty	2500	0	https://www.getawindow.co.uk/window-glass/triple-glazing-cost/
39	B2	Triple glazing	7windows, semi-detached	£/porperty	3400	4400	https://www.getawindow.co.uk/window-glass/triple-glazing-cost/
40	B2	Triple glazing	12-15 detached	£/porperty	6000	7300	https://www.getawindow.co.uk/window-glass/triple-glazing-cost/
41	B2	Triple glazing	per square metre	£/m^2	400	550	https://www.getawindow.co.uk/window-glass/triple-glazing-cost/
42	B2	External window shading	Aluminium shutter - VAT added to value	£/m^2	319.2	471.6	http://www.securityshuttersdirect.co.uk/shutters/prices.htm
43	B2	External window shading	Affordable Lourve	£/m^2	159.2	199	https://www.diyshutters.co.uk/product/affordable-basswood/full-height
44	B3	Double glazing	Double glazed unit aluminium/uPVC	£/m^2	203	225	https://www.getawindow.co.uk/window-glass/double-glazing-cost/
45	Bu	Electricity cost	Market price	p/kWh	14.4	0	https://www.nimblefins.co.uk/average-cost-electricity-kwh-uk