Health impacts of net-zero housing in England

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Sign off

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About CS N0W

Commissioned by the UK Department for Energy Security and Net Zero (DESNZ), Climate Services for a Net Zero Resilient World (CS-N0W) is a 4-year, £5.5 million research programme, that uses the latest scientific knowledge to inform UK climate policy and help us meet our global decarbonisation and resilience ambitions.

CS-N0W enhances the scientific understanding of climate impacts, decarbonisation and climate action, and improves accessibility to the UK's climate data. It contributes to evidence-based climate policy in the UK and internationally, and strengthens the climate resilience of UK infrastructure, housing and communities.

The programme is delivered by a consortium of world leading research institutions from across the UK, on behalf of DESNZ. The CS-N0W consortium is led by Ricardo and includes research **partners Tyndall Centre for Climate Change Research**, including the Universities of East Anglia (UEA), Manchester (UoM) and Newcastle (NU); institutes supported by the **Natural Environment Research Council (NERC)**, including the British Antarctic Survey (BAS), British Geological Survey (BGS), National Centre for Atmospheric Science (NCAS), National Centre for Earth Observation (NCEO), National Oceanography Centre (NOC), Plymouth Marine Laboratory (PML) and UK Centre for Ecology & Hydrology (UKCEH); and **University College London (UCL)**.

Contents

Glossary

Term	Explanation
ASHP	Air Source Heat Pump.
Common mental disorder (CMD)	Term used to describe clinical depression and anxiety states.
EFUS	The Energy Follow Up Survey (EFUS) is a large interview and measurement survey of household heating patterns, thermal comfort and energy consumption over 2017 to 2019 (DESNZ 2021).
EHS	The English Housing Survey is a continuous national survey that collects information about people's housing circumstances and the condition and energy efficiency of housing in England. It comprises of two surveys: a household interview and a physical inspection of a sub sample of the properties (MHCLG and DLUHC 2013).
E-value	E is the required energy consumption by the principal heating device to maintain a one-degree Celsius temperature difference between outside and inside during steady state conditions ignoring incidental gains and ventilation heat losses. $E = \Sigma_i(U_iA_i)/\mu$, where U_i is the heat loss per square meter of surface area per degree temperature difference between inside and outside (W/m^2K) for the ith building element, A_i is its surface area, and μ the efficiency of the main heating device for the dwelling. W is Watts and K is degrees Kelvin.
HEE	Home Energy Efficiency.
Life table	A table of age-specific risks of death and survivorship for a population from which life expectancy and other measures may be calculated.

Term	Explanation
Microsimulation	Microsimulation models, model individual people and their transition in state (of health). These models are used to estimate how changes in demographic, behaviour, and policy might impact health outcomes for each individual.
NOx	Nitrogen oxides, primarily nitric oxide (NO) and nitrogen dioxide (NO2), which are harmful air pollutants formed during combustion processes.
$PM_{2.5}$	Particulate matter with a maximum aerodynamic diameter of 2.5 microns.
QALY	Quality adjusted life year (QALY) is a health measure that includes both the quality, and the quantity of life lived. It is used in cost-utility-analysis to evaluate the impact of a particular intervention. If the change in QALYs is positive, it is a health gain; otherwise, it is a health burden. The ratio of cost to QALY saved is used in cost-effectiveness analysis of interventions.
Standardised internal temperature	The standardised indoor temperature (SIT) is a measure of indoor temperature standardised to common measurement conditions. Specifically, it indicates the indoor temperature measured when the mean hourly outdoor temperature is 5°C and is based on the average of the living room and main bedroom temperature. It should be interpreted as a measure of the relative effectiveness of the heating (as measured by indoor temperature) in one dwelling compared with another.

1. Executive summary

There is an urgent need to retrofit homes in the UK to meet net-zero carbon targets and to adapt to climate change. Improved home energy efficiency can also lower heating costs for occupants. Decarbonising existing homes can have both positive and negative impacts on occupant comfort, wellbeing and physical health. It is essential that housing retrofits are evaluated in a holistic manner, accounting for health and healthcare costs, as well as energy and carbon dioxide emissions.

NBM-Health is a model that integrates the Department for Energy Security and Net Zero's (DESNZ) National Building Model (NBM) with University College London's (UCL) Health Impact of Domestic Energy Efficiency Measures (HIDEEM) model. NBM-Health provides an integrated microsimulation modelling platform to simultaneously evaluate health impacts, alongside energy demand and carbon dioxide emissions for various home energy retrofit, electrification, and overheating adaptation measures.

As part of the CS-N0W Work Package Group 7 (WPG7) project: Health Impacts of Net-Zero housing (HINZ), NBM-Health has been updated to include the latest data and evidence. This included updating health and healthcare cost data. Regional ambient air pollution data has also been integrated into the model. The empirically derived relationship between the housing characteristics and winter and summer time temperature exposures has been updated using indoor temperature data from the 2017-19 Energy Follow-Up Survey (EFUS 2017). Additional functionality has also been incorporated into the model such that the health impacts of electrification (i.e. heat pumps and electric cookers) and passive overheating adaptation (i.e. solar shading, shutters, and urban greening) measures can also be considered alongside those from building fabric measures (i.e. building fabric thermal insulation and glazing upgrades).

NBM-Health modelling has been performed over a 25-year period to 2050 for four individual building fabric retrofit, two electrification, and five overheating adaptation measures. Four scenarios with combinations of these measures have also been modelled (full fabric, full fabric+heat pumps, full fabric+heat pumps+electric hobs, full fabric+heat pumps+electric hobs+overheating adaptation). Findings suggest that applying net-zero measures to the English housing stock can have positive population health outcomes. Electrification measures, in particular, have great potential to improve health. This finding is based on the assumption that installing air source heat pumps leads to an increase in winter indoor temperatures of 1°C because of the expected move to continuous heating behaviour associated with low flow temperature heating (see limitation below). Replacing gas with electric cookers is assumed to reduce exposure to $PM_{2.5}$ from indoor sources by 25%.

The key findings from modelled scenarios over a 25-year period are as follows:

- Of all individual retrofit measures, replacing gas with electric cookers has the greatest beneficial impact on population mortality, increasing Quality Adjusted Life Years (QALYs) (i.e. life years gained) by 64 per 10,000 population. Installing electric cookers also had a positive impact on morbidity QALYs (i.e. quality of life years lived with health conditions improved) by 11 per 10,000. This results in an NHS saving of around £0.17 billion assuming installations in 14 million homes. Note: NHS costs do not include inflation over the model period of 25 years. Only health improvements due to reductions in PM2.5 exposure are included (additional benefits through reduced NOx exposures have not been considered).
- Replacing conventional heating systems (gas boilers and electric heaters) with air source heat pumps (ASHP) was estimated to increase mortality QALYs by 6-17 per 10,000. This measure is also predicted to have a morbidity benefit, increasing morbidity QALYs in the range 7-22 per 10,000 population and saving the NHS £0.3-0.9 billion. **Limitation: The modelled upper bound estimate for the impact of ASHPs on winter temperatures is based on a study which reported that homes with ASHPs had, on average, indoor temperatures that were 1°C higher than homes with gas boilers. A more recent paper attributes this higher temperature to longer durations (more continuous operation) of ASHP heating due to their lower flow temperatures, with an additional heat demand penalty. Conventional heating systems can be programmed to achieve the same temperature profile and there may be no difference in temperatures during occupied hours between different heating systems. Due to limited evidence on temperature differences specifically during heating and occupied periods, <u>the results associated with ASHP should be interpreted with caution</u>.**
- Full fabric retrofit (including wall and loft insulation, and double glazing with trickle vents) resulted in an increase of 12 mortality and 9 morbidity QALYs per 10,000 population. A saving of around £0.3 billion to the NHS.
- Of the passive overheating adaptation measures considered, the application of external shutters to windows provides the greatest benefit in terms of additional mortality QALYs

(1.8 per 10,000 population). This is based on the current climate and not on a future climate scenario.

This project has highlighted some areas for further research surrounding model assumptions where there is limited evidence on the impact of retrofit measures on exposures. Future research and model development could also include the morbidity impacts due to heat exposure in a warming climate. Other exposures and health outcomes could also be included in the model, such as the impact of noise on mental and physical health. NBM-Health, however, provides a useful tool for considering the health impacts of housing retrofit measures in policy scenarios.

2. Introduction

The Climate Change Act of the United Kingdom established a legal target for the UK to achieve an 80% reduction of its “net carbon account” relative to the 1990 baseline, which was subsequently strengthened in 2019 to net-zero carbon dioxide emissions by 2050 (Great Britain 2019). Homes in the UK are the oldest in Europe and in 2022, 20% of all UK carbon emissions were from domestic properties (DESNZ 2024; Piddington et al. 2020). There is a need to decarbonise buildings, including homes, if the UK is to meet the legally binding targets and abate the dangers of climate change (Rowe and Rankl 2024).

A common approach for reducing energy demand and carbon emissions of dwellings in the UK is to reduce uncontrolled and unintentional conductive and ventilative heat loss through the building fabric (BEIS 2021). In practice, conductive losses are reduced by improving the thermal performance of the fabric by installing insulation (floor, walls and roof/loft) and better insulated glazing systems. Many of these home energy efficiency (HEE) interventions also reduce ventilative heat loss, but there are other targeted interventions for specifically reducing uncontrolled ventilative heat loss, for example, draught proofing.

HEE improvements that are installed without supplementary ventilation can reduce overall effective ventilation rates (Oreszczyn et al. 2006b; Hong et al. 2004). This reduction in overall ventilation can reduce the energy demand for space heating during winter and also reduce exposure to pollutants from outdoors. However, this reduction in ventilation can increase occupants’ exposure to pollutants from indoor sources (e.g. particulates, mould growth, radon), which can impact on occupant health (Bone et al. 2010; Petrou et al. 2022; Davies and Oreszczyn 2012; Shrubsole et al. 2014). Similarly, improvements to the thermal performance of building fabric can reduce the energy required for winter space heating, however, if these are not combined with appropriate cooling strategies, this can also have consequences for indoor temperatures during the summer, which can impact comfort, well-being and physical health (Taylor et al. 2018). Carefully considered HEE solutions can both improve health and reduce energy consumption of dwellings (Paul Wilkinson et al. 2009; Thompson et al. 2009).

The Heat and Building Strategy describes the need to move away from burning fossil fuels for heating and cooking to facilitate a transition to net zero (BEIS and DESNZ 2021). One potential solution to this transition is the electrification of heating (hydronic heat pumps and heat networks) and cooking, although this may vary by building type and region (BEIS and DESNZ 2021). The electrification of heating could impact winter indoor temperatures and have an impact on occupant health (see Section 3.4.2). There is limited evidence of the impact of installing heat pumps on indoor temperatures, but Wickins (2014) reported that homes that had heat pumps experienced indoor temperatures that were 1°C higher on average than homes with gas heating (Dunbabin and Wickins 2012; Wickins 2014).

Recent analysis by Watson et al. (2021) suggests that homes with ASHP experience higher mean indoor temperatures due to longer durations of heating (more continuous operation due to their low flow temperature), however, it is not known if there is a difference in internal temperatures during occupied periods and/or times of heating for homes with ASHP relative to those with gas boilers. The higher indoor temperatures in homes are therefore considered to be due to occupant behaviour and not due to the ASHP technology itself. There is an urgent need for more empirical evidence from occupied homes to determine if there is a difference in indoor temperatures during occupied times and when the heating is in operation for homes with ASHP and homes with gas boilers. On the other hand, there is more evidence of the impacts of different cooking fuels on indoor concentrations of NOx and particulate matter in domestic kitchens (Amouei Torkmahalleh et al. 2017; Lachowicz et al. 2023). Meta-analysis of results from 14 Journal papers and reports suggests that retrofitting gas cookers with electric cookers can reduce $PM_{2.5}$ by 25% (median effect) – see NBM-Health model documentation for more details (Van Rooyen et al. 2025c).This reduction in exposure to $PM_{2.5}$ can reduce cardiovascular and respiratory conditions (Pope et al. 2002).

Anthropogenic carbon dioxide emissions are responsible for climate change and continued rises in the global temperature will result in hotter summers in the future (IPCC 2018, 2023). In England, the summer of 2018 and 2022 were the hottest summers on record, with temperatures expected to be typical of those during the 2050's (Lomas et al. 2021; Met Office 2025). Exposure to high temperatures can lead to higher rates of mortality in all groups of the population, but particularly in older and infirm people (Kovats and Hajat 2008; Armstrong et al. 2011). HEE interventions can alter indoor exposures to high temperatures during the summer and therefore have implications for health (Mavrogianni et al. 2012; Oikonomou et al. 2012). Furthermore, homes located in urban areas can experience higher outdoor temperatures than rural locations due to the urban heat island effect (Huang et al. 2023; Ward et al. 2016). There are various mitigation and adaptation opportunities that can reduce indoor temperatures in homes located in urban areas, these measures include urban greening, reducing façade solar absorptance and the addition of shutters/solar shading (Tillson et al. 2013; van Hooff et al. 2015; Ibbetson et al. 2021; Knight et al. 2021). Taylor et al. (2021) reported that the installation of external shutters to homes in London was estimated to reduce heat-related deaths by 38 to 73% and between 37 and 43% for homes in the West Midlands (Taylor et al. 2018).

Given the wide ranging positive and negative impacts that HEE, electrification and overheating adaptation interventions can have for occupant well-being and physical health, it is essential that policy evaluation account for and balance these impacts alongside intervention costs, energy and carbon emissions. NBM-health is an integrated model that enables operational energy consumption (and associated energy costs), carbon dioxide emissions, intervention costs, healthcare costs, and health impacts to be estimated simultaneously for a range of HEE interventions for the English housing stock.

The aim of this research is to estimate the impacts of a range of home energy efficiency interventions, net zero technologies (i.e. electrification) and adaptation measures on energy, carbon emissions, costs and health in English homes. This research uses the updated NBM-health (version 2.0).

This research aimed to answer the following questions:

How do HEE interventions, net zero technologies and overheating adaptation measures, and combinations of these, impact:

1. occupant exposure to high and low temperatures, indoor and outdoor air pollutants?
2. mortality and morbidity quality adjusted life years (QALYs)?
3. National Health Service costs (NHS costs)?

3. Methodology

Full details of the NBM-Health microsimulation model are provided within the model documentation and the assumptions log submitted as part of the CS-N0W project (Van Rooyen et al. 2025c; Van Rooyen et al. 2025b). This section of the report will briefly describe the NBM-Health model, the integration of NBM and the Health Impact of Domestic Energy Efficiency Measures (HIDEEM) model developed by UCL, and some of the key data sources and assumptions.

3.1 NBM-Health model overview

The NBM is a building retrofit policy modelling environment developed by DESNZ. Written in Python 3 (Python Software Foundation 2025) it provides a micro-simulation model of housing energy demand using the English Housing Survey (EHS) to represent the housing stock and its inhabitants. The health impact model was further developed as part of the CS-N0W programme. NBM-Health provides estimates of the health impacts and healthcare costs due to changes in indoor exposures related to changes to the thermal, ventilative and heating performance of homes in England.

A diagram of the model integration and key components is provided in Figure 1. In this figure, the green text highlights elements of the model that were updated and/or upgraded in 2024 as part of the CS-NOW programme. The NBM model is used to process the EHS stock, and a SAP-based (DECC 2012) algorithm calculates dwellings' energy performance, energy costs, and carbon dioxide emissions. Note that energy costs and carbon dioxide emissions are not reported in this report. SAP is also used to calculate several of the dwelling variables that are passed as inputs to NBM-Health. This includes dwelling fabric heat loss (W/K), permeability ($m^3/m^2/h$ @ 50pa), and the roof, wall and window conductance values (W/K). The NBM passes several other variables (i.e. dwelling type, floor area, and occupant ages and genders) from the 2017 EHS stock to the HIDEEM model. These variables are initially used to estimate occupant exposures to radon, $PM_{2.5}$ of indoor and outdoor origin, standardised indoor temperature (SIT), mould, and summer temperature (overheating). Individual occupant pre- and post-retrofit exposures are then used as inputs to the health module which uses exposure-response relationships from epidemiological research and the life table methodology to estimate changes in mortality and morbidity Quality Adjusted Life Years (QALYs) for several diseases. A healthcare cost module is also used to predict disease specific healthcare costs to the National Health Service (NHS).

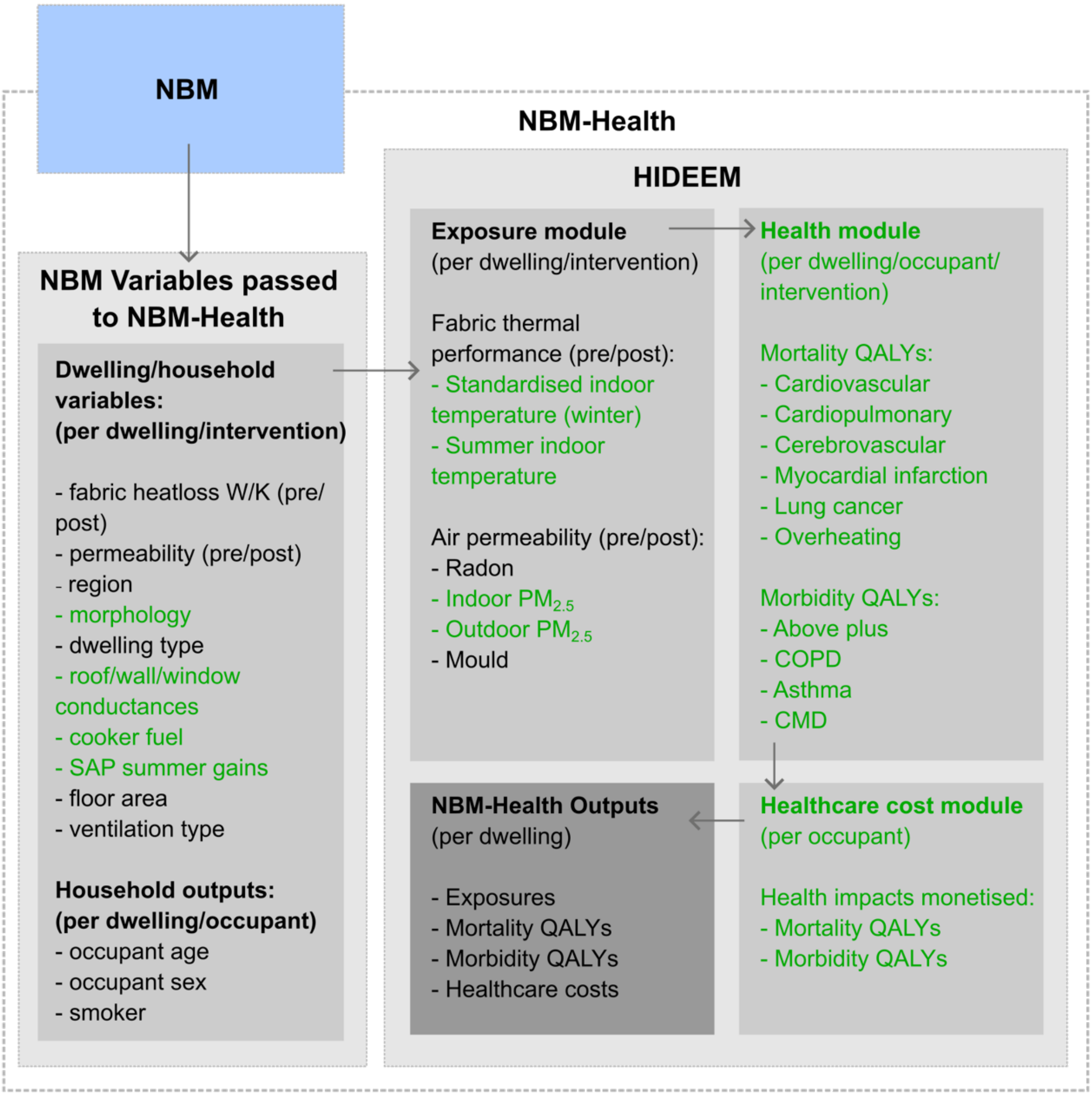

Figure 1 - Model map and workflow. Green text is used to represent components of the model that have been updated and/or upgraded as part of the CS-N0W programme.

3.2 Exposure modelling

3.2.1 Wintertime standardised indoor temperature (SIT)

The standardised indoor temperature (SIT) is defined as the indoor temperature during the heating season when outdoor temperatures are 5°C (Oreszczyn et al. 2006a). NBM-Health uses the relationship between the fabric heat loss (W/K) of homes (as calculated using SAP (DECC 2012)) and the SIT derived using empirical data. As part of the CS-N0W project, this relationship was updated using the 2017-19 Energy Follow-Up Survey (EFUS) (DESNZ 2021). Hourly day time (08:00-20:00) temperatures from the living room and night time (20:00-08:00) temperatures from the bedroom are used. A third order polynomial fit between fabric heat loss in the range 0-1200 W/K to SIT was performed and the coefficients from the fit used within NBM-Health.

3.2.2 Summertime temperature

Summertime temperature exposures are also derived using empirical data from the 2017-19 EFUS (DESNZ 2021). Similar to SIT, relationships between summertime indoor temperature and different dwelling characteristics have been derived using empirical data. Data cleaning was performed to remove anomalous data, for example, data where there were temperature spikes likely due to the monitor being placed close to a heating source or due to solar gains. Step changes in temperature measurements or data where similar readings were obtained in the living and bedroom were also removed.

Measurements were filtered to include data between 1st May 2018 and the 30th of September 2018. The daily mean dwelling indoor temperature was calculated using the mean of the living room (07:00 - 22:00) and the main bedroom (00:00-07:00 and 22:00-24:00) temperatures. Of the 750 homes in the EFUS dataset, matches based on dwelling ID were found for 545 homes in the EHS data used as input to NBM.

A set of 17 dwelling, household and SAP output variables were shortlisted based on their potential relationship with summertime temperatures. Sequential feature selection was then performed to select the top six (of 17) variables that provided the highest overall co-efficient of determination (r^2). Window, wall and roof conductance values (W/K) (SAP outputs) were forced into the sequential feature selection, such that the temperature model included components related to fabric HEE interventions. The final set of features as selected by feature selection also included: external temperature (from nearest Met Office weather station), household size and total summer solar gains (May to September) per unit area of window (W/m^2). Multiple linear regression was then performed between summer average indoor summer temperature and the six variables for each dwelling archetype (with all flat dwelling types grouped together due to low statistics). The predictor variables were assumed to be uncorrelated. The relative risk between mortality and temperature was derived from analysis of data on outdoor temperatures and mortality data from the Office of National Statistics (ONS 2023; ONS and UKHSA 2022). Due to the relative risk having been derived from external temperatures, the indoor temperature anomaly was calculated for each home, *i,* by subtracting the mean summertime temperature for all EHS dwellings within the NBM:

$$T_i^{anom} = T_i - \frac{\sum_i^n T_i}{n}$$

Here *n* is the total number of EHS homes input to the NBM. The temperature anomaly was added to the summer average external temperature (2018) from the nearest Met Office weather station to obtain the summertime temperature exposure. Finally, this summertime temperature exposure was further modified to accounting for cooling effects such as those from urban greening and surface absorptance and then used in health calculations.

3.2.3 Indoor contaminants: indoor/outdoor sourced $PM_{2.5}$ and Radon

The CONTAM modelling software has been used to estimate exposures to $PM_{2.5}$ from indoor and outdoor sources, radon and mould (NIST 2012). Exposure modelling used representative archetype dwelling forms (informed by sampling from the EHS) to represent the English housing stock (Oikonomou et al. 2012). CONTAM models for eight EHS dwelling types (detached, semi-detached, mid and end terrace houses, bungalows and high rise, low rise and converted flats) and several notional fabric air permeabilities (3, 5, 7, 10, 15, 20, 25 and 30m^3/m^2/hr at 50Pa – range from (Stephen et al. 1997)) were performed along with varying ventilation provision: window opening only, window trickle vents, extract fans, and combined use of trickle vents and extract fans. Relationships between permeabilities and $PM_{2.5}$ and radon exposures were fitted using third order polynomials, which have been used within NBM-Health.

Four distinct occupancy profiles are used in the model to account for different exposures due to the total amount of time that occupants spend in different rooms over the life course – this does not account for specific hours spent in the different rooms. These occupant profiles are provided in Table 1 and consist of a pensioner, pre-school child, working adult, and a school aged child.

Table 1 - Occupancy schedules for household occupants.

	Room		
	Living Room	**Bedroom**	**Kitchen**
Pensioner (age > 65) – at home during the day			
Proportion of time	0.45	0.45	0.1
Pre-school child (age < 5) – at home during the day			
Proportion of time	0.55	0.45	0
Working adult (age 18 – 65) - at work during the day			
Proportion of time	0.134	0.45	0.083
School aged child (age 5 – 18) - at school during the day			
Proportion of time	0.22	0.45	0

Regional factors have been applied by English region (e.g. Greater London, South East, etc…) to account for differences in local levels of radon and outdoor sourced $PM_{2.5}$. In the case of external $PM_{2.5}$, an urban/rural category is also used to account for variation of external concentrations of $PM_{2.5}$. For radon, regional factors are derived from empirical UKHSA radon data that provides arithmetic means by region (Symonds et al. 2019). For example, a factor of 1.72 is applied for the South West (the highest Radon region). In the case of external $PM_{2.5}$, regional and urban/rural population weighted mean outdoor concentrations have been derived from modelled data from Department for Environment, Food & Rural Affairs (DEFRA) for the year 2030 (DEFRA no date). The DEFRA data was modified to remove sources of $PM_{2.5}$ from road transport, rail transport, industry and domestic – replicating the scenario that these sources will be eliminated in the future. These regional values are then divided by the original outdoor concentration of 13 μg/m^3 used in the CONTAM models to provide a scaling factor.

3.2.4 Mould

A combination of CONTAM modelling of vapour pressure excess (VPX) and the SIT estimates (see Section 3.2.1) have been used to estimate mould exposure. More specifically, NBM-Health outputs the probability as a percentage that a home has a mould severity index greater than 1 (%MSI>1). External vapour pressure excess and standardised vapour pressure excess are calculated using a method described in ISO 13788 and the SIT estimate for a dwelling (ISO 13788:2012). CONTAM modelling was then used to estimate the indoor VPX by dwelling type and the permeability of the building envelope. Standardised relative humidity (SRH) is then estimated using the indoor, outdoor and standardised VPX values. A third order polynomial (as derived from Warm Front (Oreszczyn et al. 2006b)) is then used to estimate %MSI>1 using SRH as the independent variable.

3.3 Health impact modelling

NBM-Health estimates health impacts related to the interventions using life table methods applied to the individuals in the EHS data. Figure 2 shows the relationship between modelled exposures and health outcomes in NBM-Health. Mortality and morbidity related quality adjusted life years (QALYs) are calculated annually based on any changes in exposure (See Section 3.2). Health impacts are aggregated over the modelling time horizon (25 years for results in this report) and individuals in the model age as simulation years progress.

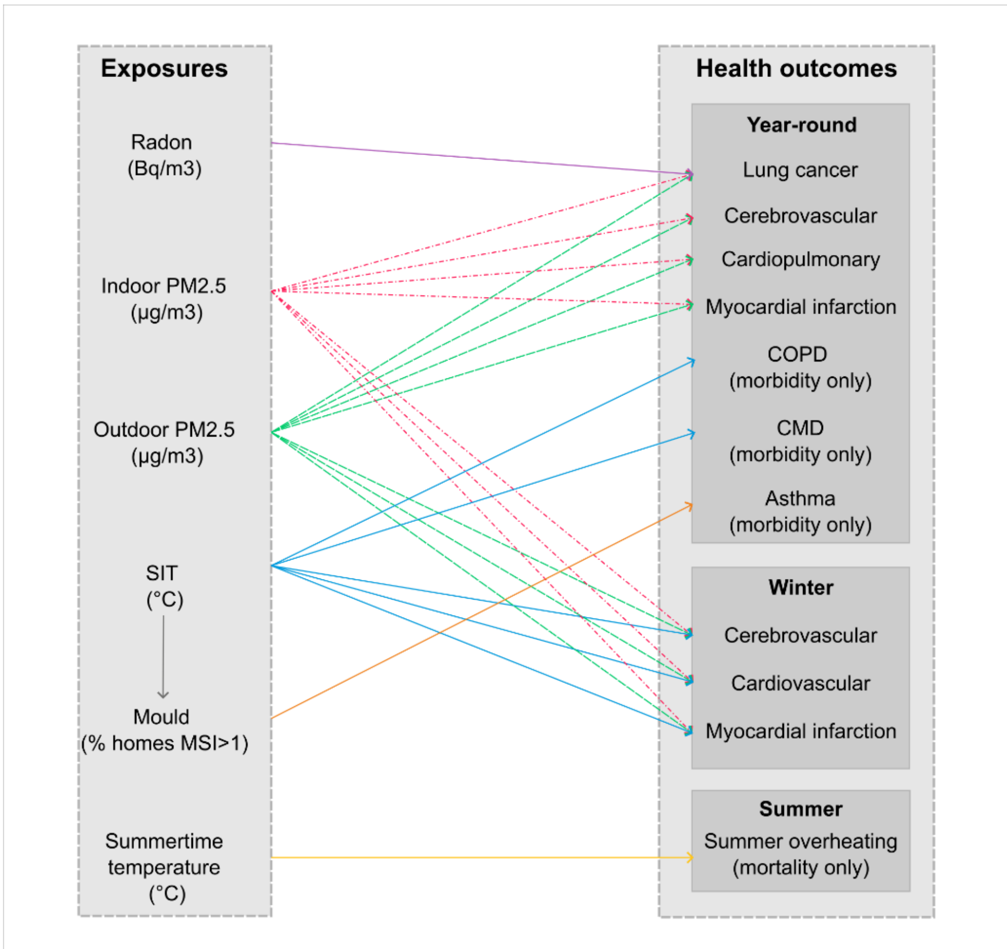

Figure 2 – Map of the relationship between modelled exposures and health outcomes in NBM-Health.

3.3.1 Mortality impacts

Mortality impacts are calculated using a modified version of the life table model, IOMLIFET (Miller and Hurley 2003). The life tables have been updated in NBM-Health to use the 2022 age-specific population and (disease-specific and all-cause) mortality data for England and Wales from the Office for National Statistics (ONS), with separate life tables for males and females (due to their differing mortality rates and life expectancy) (ONS no date). Exposure-response relationships which are used to modify mortality rates were obtained from published epidemiological studies, as shown in Table 2.

Table 2 - Mortality outcomes modelled and exposure response relationships.

Exposure	Health outcome	Exposure-response relationship	Reference
Standardised internal temperature	Winter excess cardiovascular (including excess cerebrovascular accident and myocardial infarction)	0.98 per °C	Derived from Wilkinson et al. (2001)
$PM_{2.5}$	Cardiopulmonary	1.082 per 10 µg/m^3	Pope et al. (2002)
	Lung cancer	1.059 per 10 µg/m^3	As above
Radon	Lung cancer	1.16 per 100 Bq/m^3	Darby et al. (2005)
Summertime temperature	Excess summer heat related mortality	Quadratic fits to ONS age band related mortality (18-64 and above 65 years old)	ONS (2023)

3.3.2 Morbidity impacts

Two methods have been used to estimate morbidity impacts. The first method is for diseases where mortality impacts have been estimated, used scaling factors to convert mortality QALYs to morbidity QALYs. These scaling factors are Years Lived with Disability (YLD) divided by the Years of Life Lost (YLLs) for a specific disease. These 'morbidity ratios' are obtained from the 2019 Global Burden of Disease (GBD) for England and are available by gender in 5-year age bands (IHME 2019). The second method is for diseases which do not have associated mortality outcomes. These additional impacts are (i) SIT on mental health in adults (≥16), (ii) SIT on chronic obstructive pulmonary disease (COPD) in older adults (≥45), and (iii) mould on asthma in children (<16). Exposure-response relationships for these diseases are provided in Table 3. The morbidity impacts are converted to QALYs by weighting the estimates to account for reduced quality-of-life using published utility weights (NICE 2012a, 2012b, 2013a, 2013b). Morbidity impacts due to summer temperature are not yet considered in the model.

Table 3 - Morbidity outcome modelled and exposure response relationships.

Exposure	Health outcome	Exposure-response function	
		Relative risk	Source
SIT (°C)	COPD	0.90 per °C	Estimate based on studies from UK (Osman et al. 2008) and New Zealand (Howden-Chapman et al. 2007)
	Mental health: Common Mental Disorder (CMD)	0.90 per °C	Based on Warm Front (Gilbertson et al. 2012)

Exposure	Health outcome	Exposure-response function	
		Relative risk	Source
Mould (% MSI > 1)	Asthma	1.53-1.83 per 100% (depending on harm class II (hospital admission) to IV (minor symptoms)	Based on Fisk et al. (2007)

3.3.3 Healthcare (NHS) costs

Healthcare costs are estimated by the model using an adapted version of a published method (Stafford 2015). The NHS National Cost Collection data (NHS 2022) were used for the period 2021-22 to identify total aggregate costs for selected health outcomes for England comprising: primary care, secondary care, emergency care, and community care. Social care, full primary care and public health and prevention are not included. The health care costs do not include inflation over the model horizon. Estimates of prevalence in 2021-22 (NHS 2021) for the selected disease outcomes were then used to derive the unit NHS contact costs summarised in Table 4. NHS costs remain constant over time, regardless of how a health condition may progress or evolve. Change in contacts (cases) for diseases with mortality impacts associated with them are derived using disease (and age/gender) specific incidence to death ratios from GBD 2019. Cases are derived for morbidity only diseases by multiplying the disease prevalence by the change in relative risk (due to the exposure change). The change in cases per disease are multiplied by the relevant unit costs (see Table 4) to obtain a total cost to the NHS over the model horizon. For example, an additional lung cancer case would result in an additional annual cost to the NHS of £6,254 (£156,350 over a 25-year model period).

Table 4 - Unit costs (costs per case) for selected health outcomes. Figures rounded to nearest pound.

Outcome	Unit cost (£)
Cerebrovascular	1,290
Cardiopulmonary	1,010
Myocardial infarction	750
Lung cancer	6,254

Outcome	Unit cost (£)
Cardiovascular	1,273
COPD	804
CMD	2,840
Asthma	394

3.4 Scenario modelling

The scenarios modelled using NBM-Health for this report consist of various individual measures related to building fabric retrofit (see Section 3.4.1), electrification measures that include the installation of air source heat pumps (ASHPs) and electric cookers (see Section 3.4.2), and summer overheating adaptation measures (see Section 3.4.3). In addition, several multi-measure retrofit scenarios have been modelled (all exclude draught proofing). These include the following:

i) Full fabric retrofit (FR1) – wall and loft insulation, and glazing upgrades
ii) Full fabric retrofit and an ASHP (FR2)
iii) Full fabric retrofit, electrification (ASHP and electric cookers), and extract fans in kitchen and bathroom (FR3)
iv) Full fabric retrofit, electrification, extract fans in kitchen and bathroom, and overheating adaptation measures (FR4)

Retrofit measures may simultaneously impact on multiple factors such as the fabric heat loss (W/K), permeability ($m^3/m^2/h$), SIT, summertime temperature and/or indoor $PM_{2.5}$ exposure, as described in previous sections.

For each scenario, the model only outputs results for homes deemed ‘suitable’ (due to technical feasibility - see Sections 3.4.1-3.4.4 for more details) for a retrofit and therefore where there is a change in exposure and health outcome. Post-processing of model outputs for scenarios over the 25-year model period to 2050 runs calculates:

- median exposures (pre/post intervention) and change in exposure post retrofit
- aggregated morbidity and mortality QALYs
- QALYs per 10,000 population
- aggregate NHS costs/savings

3.4.1 Fabric retrofit measures

Building fabric retrofit measures consist of wall (cavity and external) and loft insulation, and glazing upgrades. Full details of the assumptions and the suitability requirements (as specified by the NBM defaults) for these retrofits are provided in Table 5 and the NBM documentation by DESNZ (n.d.). Note that due to overlap in the suitability criteria for EWI and CWI, in the full retrofit scenarios there are homes that can be retrofitted with both measures.

Table 5 - Building fabric retrofit measures modelled in NBM-Health.

Retrofit measure	Suitability of homes for retrofit	Details of retrofit
Loft Insulation (LI)	Home must have a roof construction that is physically compatible with installing loft insulation and either have no insulation or a thickness of insulation less than 125mm.	Loft insulation of 270mm installed with a thermal conductivity of 0.035 W/mK. For homes being topped up, the total insulation will meet the above value. Assumed to reduce permeability of building envelope by 11.2% (Hong et al. 2004).
External Wall Insulation (EWI)	Installed on uninsulated walls in dwellings that have at least one of the following wall types: solid, sandstone, granite, and system build. Not applied if there is another insulated wall of same age.	Assume 50mm of expanded polystyrene foam (0.035 W/mK) installed. Assumed to reduce permeability of building envelope by 8.8% (Hong et al. 2004).
Cavity Wall Insulation (CWI)	Installed on uninsulated walls in dwellings that have at least one of the following wall types: cavity, system build or timber. Not applied if there is another insulated wall of same age.	Assume 65mm of blowing wool (0.035 W/mK) installed. Assumed to reduce permeability of building envelope by 8.8% (Hong et al. 2004).
Double glazing+trickle vents	Replace only single glazed windows in homes.	Replace with uPVC double glazing with 12mm argon filled gap (U-value = 1.4W/m^2/K) (HM Government 2023). Assumed to reduce permeability of building envelope by 12.8% (Hong et al. 2004).

3.4.2 Electrification measures

The electrification measures consist of air source heat pumps and changing gas fuelled cookers to electric cookers. Details of the assumptions and eligibility requirements (from NBM (DESNZ n.d.)) for these retrofits are provided in Table 6.

Table 6 - Electrification measures modelled in NBM-Health.

Electrification measure	Suitability of homes for measure	Details of measure
ASHP	Dwelling must not have community water or space heating. Dwelling's peak heating load must be less than 24 kW and the dwelling (peak heating load / total floor area) must be less than 0.1 kW/m^2.	ASHP with Seasonal Performance Factor of SPF4=2.8 installed to provide both domestic hot water and space heating (DESNZ n.d.). ASHP assumed to increase SIT by 1°C (Dunbabin and Wickins 2012; Wickins 2014). Note: this increase is attributed to occupant heating patterns (more continuously) and not the ASHP technology itself – see discussion in Section 2. Appendix B: ASHP Sensitivity Analysis explores the sensitivity associated with this assumption including three scenarios i) with a 0.5°C increase and caps on temperature increases above ii) 19°C and iii) 20°C.
Gas to electric cookers	Installed in any home which does not already have an electric cooker as specified by the NBM. NHS cost have been scaled to represent 14 million installations (BRE and DECC 2013).	Reduces indoor $PM_{2.5}$ exposure by 25%. 25% is the median reduction reported across studies by TNO (2023), Dennekamp et al. (2001), Gould et al. (2023), To and Yeung (2011), and Zhang et al. (2010). Refer to model documentation for more detail - Van Rooyen et al. (2025c).

3.4.3 Overheating adaptation measures

The overheating adaptation measures consist of passive installations to homes and urban greening interventions to urban spaces. Details of the assumptions and eligibility/suitability for these measures are provided in Table 7. Overheating adaptation measures can potentially have positive impacts for health (e.g. solar shading reducing indoor temperatures during the summer), but at the same time have negative impacts for energy consumption and carbon dioxide emissions (e.g. solar shading reducing beneficial solar gains during winter and increasing heating energy consumption).

A notable limitation is that NBM-Health does not have a delayed effect for urban greening measures, where in reality there will be a period of time where urban greening measures grow and mature to a point where they can have a cooling effect on surrounding urban spaces.

Table 7 – Overheating adaptation measures modelled in NBM-Health.

Adaptation measure	Suitability of homes for measure	Details of measure
Glazing coating	All windows on all homes	Solar control coating installed to windows, altering the transmittance (g-value=0.63) and solar gains (summer and winter) – Table 6b (DECC 2012).
Window overshading (external)	All windows on all homes	Overshading (solar shading) installed to windows, altering the solar gains (summer and winter) – Table 6d (DECC 2012).
Shutters	All windows on all homes	Summer solar gains are scaled to account for differing levels. Shutters assume 0.24x window solar gains – see Table P3 (DECC 2012).
Absorptance	All homes	The summertime indoor temperature is altered to account for the cooling effect from changing the absorptance of homes - painting of external walls and roofs with a low absorptance paint. Taylor et al. (2018) reported a change of −0.5°C in indoor temperatures.
Urban greening	All homes in urban locations (‘city centre' and 'other urban centre')	The summertime indoor temperature is altered to account for the cooling effect from introducing urban greening measures (Knight et al. 2021).

3.4.4 Ventilation provision and performance

Where indicated, scenarios include the impact of installing trickle vents (TV) and/or extract fans (EF) on indoor exposures to pollutants (radon, mould and $PM_{2.5}$). These scenarios model the impact of installing ventilation provision in all homes that have had any other measure installed and did not have that provision before the intervention – for example, the scenario modelling double glazing and trickle vents ('Double glazing+TV'), models the installation of double glazing to suitable homes as well as trickle vents if those homes that did not have (pre-intervention stock) trickle vents installed.

For relevant scenarios, the pre-intervention stock is modelled with a random 30% and 60% of homes having trickle vents and extract fans, respectively. NBM-Health does not model the impacts of ventilation on summertime overheating or health/healthcare costs associated with overheating.

As mentioned in Section 3.2, CONTAM was used to model the relationship between ventilative performance of dwellings and indoor concentrations of pollutants. This modelling included varying trickle vent and extract fan provision. For a more detailed description of the CONTAM modelling, refer to the NBM-Health model documentation.

Extract fans were modelled using the intermittent minimum rates as per ADF 2010 (Table 5.1a) during cooking activities, and bathroom/toilet occupation as shown in Table 8.

Table 8 – Intermittent extract ventilation rates and schedules modelled in CONTAM

Day	Room	Extract Rate	Schedule
Weekday	Kitchen	60 l/s	07:30 to 08:30 18:00 to 19:30
	Bathroom	15 l/s	07:00 to 08:00 19:30 to 20:30 21:30 to 22:00
	Toilet	6 l/s	07:00 to 08:00 19:30 to 20:30 21:30 to 22:00
Weekend	Kitchen	60 l/s	08:30 to 09:30 12:00 to 12:30 18:00 to 19:30
	Bathroom	15 l/s	08:00 to 09:00 19:30 to 20:30 21:30 to 22:00
	Toilet	6 l/s	08:00 to 09:00 19:30 to 20:30 21:30 to 22:00

Trickle ventilators were modelled to comply with the requirements of ADF 2010. The minimum background ventilation from ADF 2010 Table 5.2b for properties with permeabilities ≥5m^3/m^2/hr@50Pa was used in all instances in the modelling (Table B.13).

3.5 Summary

This section of the report has provided details of the modelling methodology employed using the NBM-Health version 2 following the significant updates made as part of the CS-N0W WPG7 project. For more details, please refer to the model documentation (Van Rooyen et al. 2025c). The next section provides results from NBM-Health for the model scenarios.

4. Results & Analysis

4.1 Number of interventions per retrofit measure

Firstly, the number of interventions across the housing stock and the number of occupants impacted per single retrofit measure are presented in Table 9. It should be noted that the number of interventions applied to the stock varies for each scenario depending on the eligibility criteria of homes. In most cases, this suitability is determined by the NBM using EHS data. For example, cavity wall insulation is only applied to homes with a previously unfilled cavity wall. The presence of overheating adaptation measures is not known, and so these are applied to the entire stock, except for urban greening. Full suitability criteria for measures are provided in Section 3.4.

Table 9 - Number of single interventions applied and impacted occupants per scenario.

Scenario	Number of interventions (unweighted)	Number of occupants impacted (unweighted)
Fabric retrofit		
Loft Insulation	5,079,777 (2,408)	12,432,387 (6,113)
External Wall Insulation	7,329,149 (3,511)	17,740,726 (8,586)
Cavity Wall Insulation	7,394,723 (3,930)	17,591,008 (9,343)
Double glazing+TV	3,489,983 (1,514)	8,067,729 (3,593)
Electrification		
Gas to electric cookers	19,658,999 (10,162)*	47,526,567 (24,792)
ASHP	19,022,978 (10,164)	44,810,871 (24,145)
Overheating adaptation		
Window coating	22,850,519 (11,963)	53,860,051 (28,341)
Solar shading	22,850,519 (11,963)	53,860,051 (28,341)
Shutters	22,850,519 (11,963)	53,860,051 (28,341)
Absorptance	22,850,519 (11,963)	53,860,051 (28,341)
Urban greening	4,314,359 (2,401)	10,012,438 (5,683)

* This is an overestimate as the 2017 EHS does not have data on the presence of gas hobs. NHS costs have been scaled to assume 14 million installations based on 2011 EFUS data (BRE and DECC 2013).

4.2 Exposure estimates

4.2.1 Individual measure scenarios

Exposures to radon, indoor and outdoor sourced $PM_{2.5}$, SIT, mould, and summertime temperature for the baseline and post-retrofit are presented in Figure 3 and Figure 4. Individual scenarios assume no additional extract fans are installed. For retrofit scenarios, the results are provided only for homes that have been retrofitted (and not unsuitable homes), hence contains a sub-sample of homes from the baseline case. Table 10 provides the median change in exposures (vs pre-retrofit) for homes that were retrofitted with a range of single measures. Appendix A: Exposures - provides absolute values for exposures for all individual and multi retrofit scenarios.

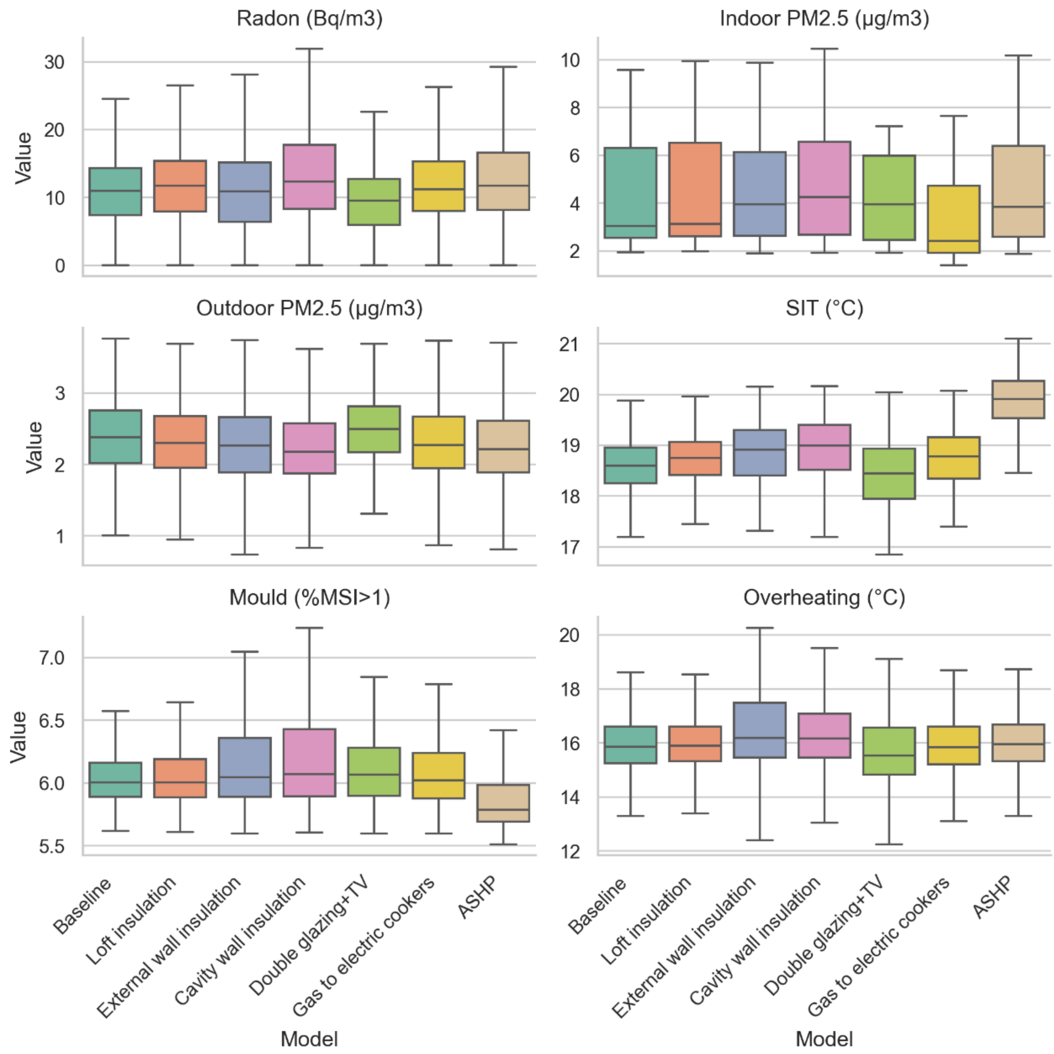

Figure 3 - Box plot of exposures across the stock for retrofit scenarios with individual measures

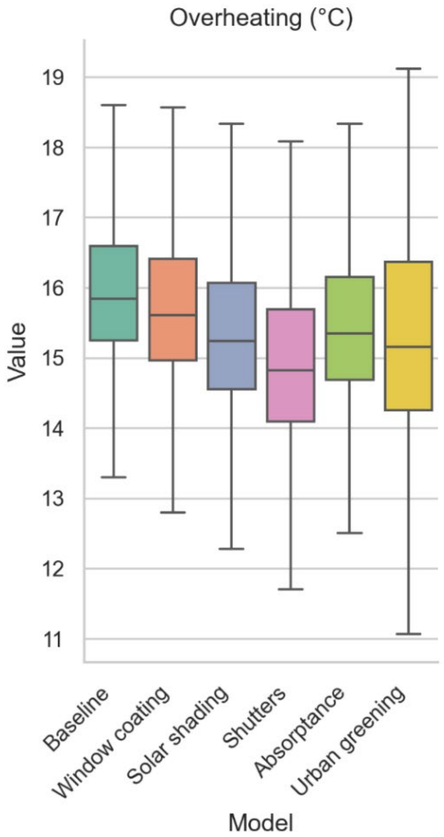

Figure 4 - Box plot of overheating exposures across the stock for individual adaptation retrofit scenarios.

Fabric retrofits that increase the airtightness of homes, such as wall and loft insulation, lead to increased exposures to radon and indoor sourced $PM_{2.5}$. Double glazing has minimal effect on radon and indoor generated $PM_{2.5}$, due to the addition of trickle vents which mitigate the increase in air tightness. All fabric retrofits (including glazing) reduce occupants' exposure to externally sourced $PM_{2.5}$. All fabric retrofits increase the SIT of homes, with EWI having the largest impact (+0.4°C), although these measures have minimal impact on MSI. NBM-Health predicts that wall insulation measures also increases mean summertime temperature exposures. This does not necessarily mean that these homes will increase exposure to overheating, indeed it may simply reflect homes having more hours at comfortable temperatures on cooler summer days.

Electric cookers, which were modelled to reduce indoor source $PM_{2.5}$ by 25%, resulted in a significant reduction in $PM_{2.5}$ exposure of 0.8 μg/m^3. ASHPs lead to an increase in SIT of 1°C, as pre-specified by the NBM-Health modelling assumption (based on best currently available evidence). Please note that there is a high degree of uncertainty associated with this assumption as mentioned in Section 2 and Table 6.

The overheating adaptation measures all reduce summertime temperature exposures by varying degrees with shutters (-1°C) and urban greening (-0.8°C) having the largest impacts.

Table 10 – Exposures for the baseline scenario and change in exposure for eligible homes that have had single interventions applied. Values in brackets are 95%CIs.

Scenario	**Radon (Bq/m^3)**	**Indoor source $PM_{2.5}$ ($\mu g/m^3$)**	**Outdoor source $PM_{2.5}$ ($\mu g/m^3$)**	**SIT (°C)**	**Percentage of homes MSI>1 (%)**	**Summertime temperature (°C)**
Baseline (all occupied homes)	11.28 (11.06, 11.49)	3.85 (3.78, 3.93)	2.24 (2.23, 2.25)	18.8 (18.79, 18.82)	6.04 (5.94, 6.15)	15.85 (15.82, 15.88)
Change in exposure post-retrofit (for retrofitted homes only)						
Fabric retrofit						
Loft Insulation	0.78 (0.34, 1.22)	0.09 (-0.08, 0.26)	-0.08 (-0.11, -0.04)	0.16 (0.12, 0.19)	0.0 (-0.12, 0.11)	0.05 (-0.02, 0.13)
External Wall Insulation	0.2 (-0.29, 0.69)	0.03 (-0.19, 0.25)	-0.02 (-0.05, 0.01)	0.38 (0.34, 0.42)	-0.09 (-0.37, 0.2)	0.34 (0.26, 0.42)
Cavity Wall Insulation	0.63 (0.05, 1.21)	0.04 (-0.17, 0.26)	-0.05 (-0.08, -0.02)	0.3 (0.27, 0.34)	-0.03 (-0.34, 0.28)	0.3 (0.23, 0.37)
Double glazing+TV	0.6 (-0.01, 1.2)	0.08 (-0.18, 0.34)	-0.06 (-0.11, -0.02)	0.12 (0.05, 0.18)	0.0 (-0.21, 0.22)	-0.09 (-0.21, 0.03)
Electrification						
Gas to electric cookers	NA	-0.8 (-0.9, -0.71)	NA	NA	NA	NA
ASHP	NA	NA	NA	1.0 (0.98, 1.02)	-0.22 (-0.37, -0.08)	NA
Overheating adaptation						
Window coating	NA	NA	NA	NA	NA	-0.24 (-0.28, -0.2)
Solar shading	NA	NA	NA	NA	NA	-0.62 (-0.66, -0.57)

Scenario	Radon (Bq/m^3)	Indoor source $PM_{2.5}$ ($\mu g/m^3$)	Outdoor source $PM_{2.5}$ ($\mu g/m^3$)	SIT (°C)	Percentage of homes MSI>1 (%)	Summertime temperature (°C)
Shutters	NA	NA	NA	NA	NA	-1.03 (-1.07, -0.98)
Absorptance	NA	NA	NA	NA	NA	-0.5 (-0.54, -0.46)
Urban greening	NA	NA	NA	NA	NA	-0.8 (-0.9, -0.7)

4.2.2 Multiple measure scenarios

Exposure changes under scenarios where multiple retrofit measures are installed are provided in Table 11 and Figure 5. It should be noted that for these scenarios, trickle vents have been installed in all homes with any fabric retrofit and not just those with a glazing upgrade (as per Table 10). Extract fans are installed in the kitchens and bathrooms in scenarios three and four, which has electrification (ASHPs and electric cookers) in addition to a full fabric retrofit.

The addition of extract fans and trickle vents in combination with other measures is beneficial in terms of reducing exposures to radon and indoor sourced $PM_{2.5}$. Scenario three (Full fabric* + Electrification + EF) provides substantial reductions, with radon exposure reduced by 1.8 Bq/m^3 and indoor sourced $PM_{2.5}$ by around 1.9 $\mu g/m^3$. In all four scenarios, exposure to outdoor sourced $PM_{2.5}$ increases slightly in the range 0.1-0.2 $\mu g/m^3$. The increased exposure to outdoor $PM_{2.5}$ is significantly lower than the reduction from indoor sourced $PM_{2.5}$ in scenario three.

SIT increases in all four scenarios with the full fabric retrofit and ASHP contributing to a 1.2°C increase in scenario three. Note that 1ºC of this increase is due to the impact of ASHP on winter indoor temperatures (see Section 2). This SIT increase coupled with the additional ventilation provided by TV and EFs results in a ~0.4% reduction in homes with an MSI>1.

Regarding summertime temperatures, fabric retrofits are predicted to increase mean internal temperatures by a small amount (~0.2-0.3°C). However, this is not an indication of increased overheating and is more than offset by the overheating adaptation measures which when combined with all other measures (scenario four) has the effect of reducing mean summertime temperature exposure by around 1.6°C.

Table 11 – Exposure changes post-retrofit (95% CIs) for homes with multiple interventions. *Includes the installation of trickle vents in all windows where another installation has taken place (not just those with glazing upgrades).

Scenario	Radon (Bq/m³)	Indoor source $PM_{2.5}$ (µg/m³)	Outdoor source $PM_{2.5}$ (µg/m³)	SIT (°C)	% homes MSI>1	Summertime temperature (°C)
FR1. Full fabric*	-0.81 (-1.15, -0.48)	0.15 (0.02, 0.29)	0.13 (0.11, 0.15)	0.38 (0.36, 0.41)	-0.17 (-0.33, -0.01)	0.28 (0.22, 0.33)
FR2. Full fabric* + ASHP	-1.6 (-1.89, -1.32)	0.11 (-0.0, 0.21)	0.19 (0.17, 0.21)	1.24 (1.22, 1.26)	-0.36 (-0.48, -0.24)	0.18 (0.14, 0.22)
FR3. Full fabric* + Electrification + EF	-1.84 (-2.11, -1.58)	-1.85 (-1.93, -1.77)	0.22 (0.21, 0.24)	1.24 (1.22, 1.26)	-0.38 (-0.49, -0.27)	0.18 (0.14, 0.22)
FR4. Full fabric* + Electrification + EF + Adaptation	-1.84 (-2.11, -1.58)	-1.9 (-1.98, -1.82)	0.22 (0.21, 0.24)	1.24 (1.22, 1.26)	-0.38 (-0.49, -0.27)	-1.59 (-1.64, -1.55)

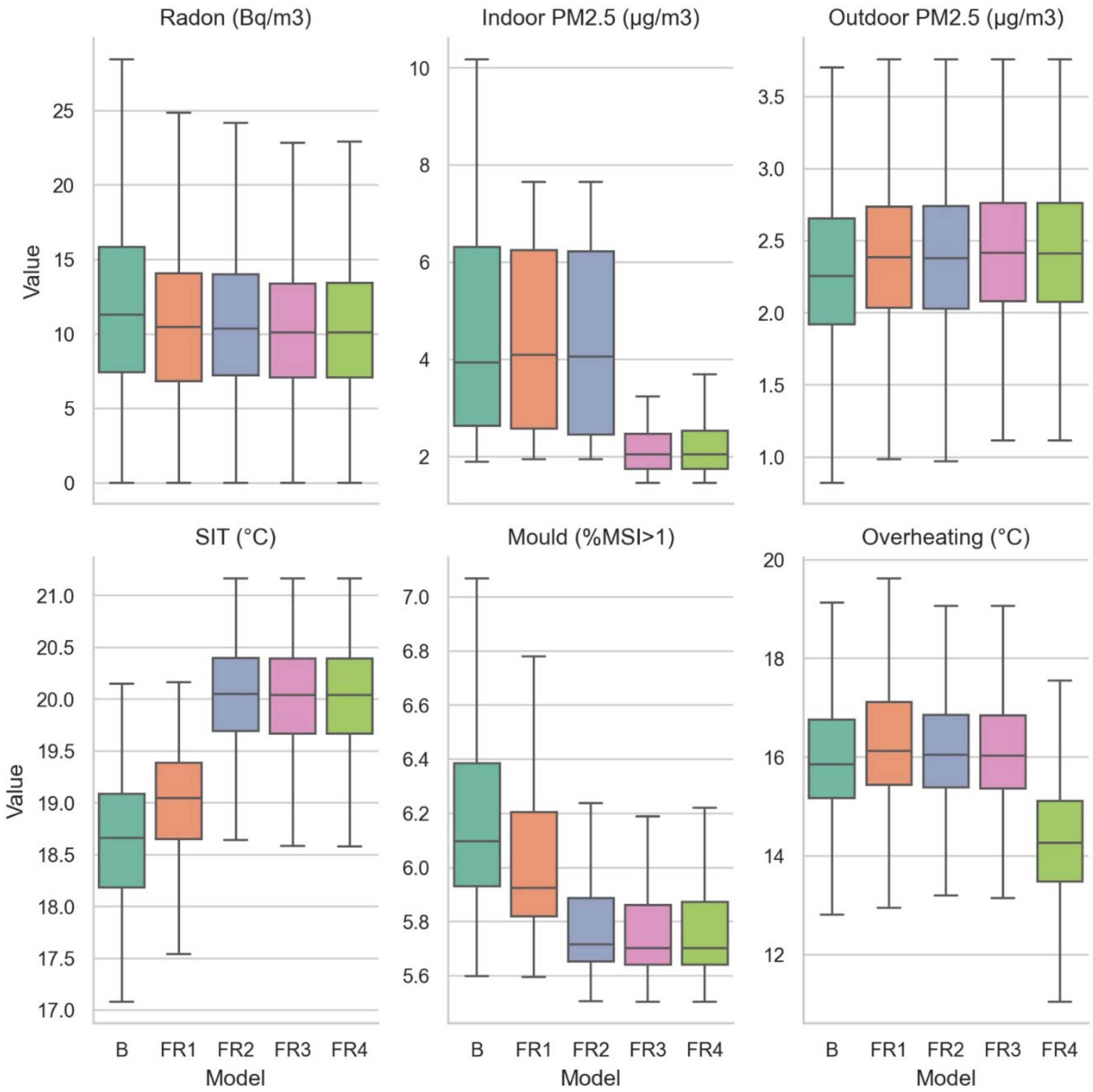

Figure 5 - Box plot of exposures across the stock for retrofit scenarios with multiple measures vs. the baseline. B = baseline, FR1 = full fabric retrofit, FR2 = full fabric retrofit + ASHP, FR3 = full fabric retrofit + electrification + EF, and FR4 = full fabric retrofit + electrification + EF + adaptation.

4.3 Mortality and morbidity QALY estimates

4.3.1 Individual measure scenarios

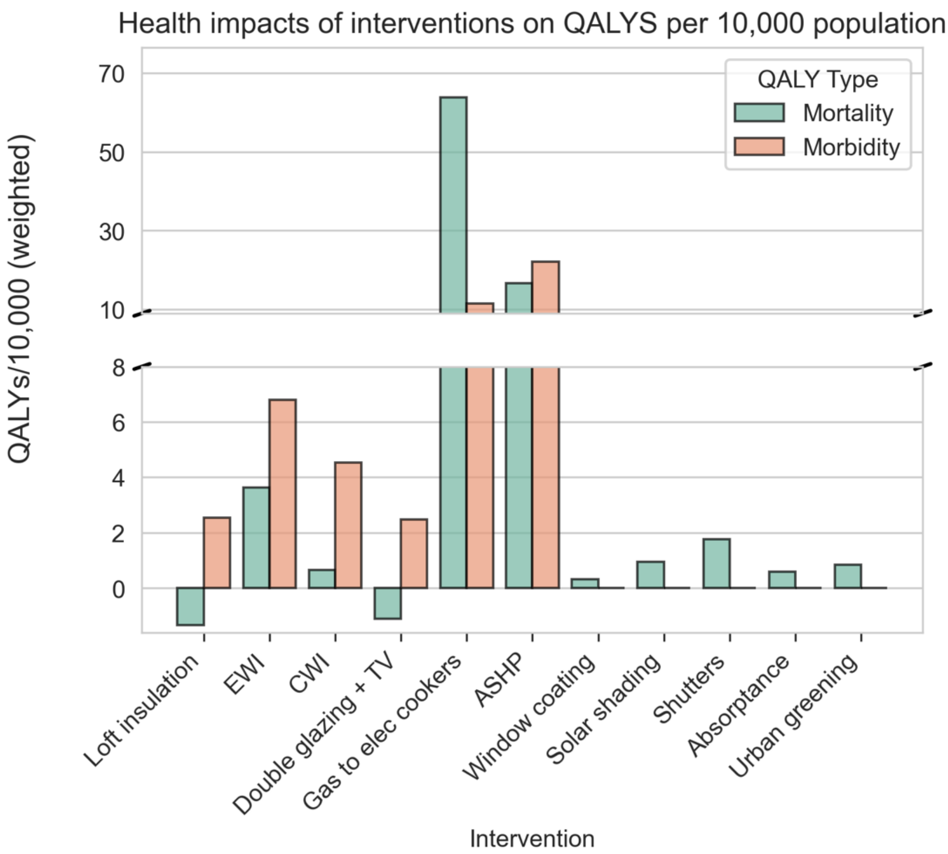

Figure 6 - Health impacts of interventions on mortality (green) and morbidity (orange) per 10,000 retrofit population over a 25-year time horizon. Positive values indicate QALYs gained (positive impact on health) and negative, QALYs lost (negative impact on health).

Mortality QALY estimates per 10,000 of impacted population due to individual retrofit measures over the 25-year modelling period are provided in Table 12 and are also plotted in Figure 6. Fabric measures have the effect of reducing QALYs (disbenefit) for cerebrovascular (CA), cardiovascular (CV), and myocardial infarction (MI) due to increased exposures to $PM_{2.5}$. Installing energy efficiency measures that reduce the effective ventilation rate of homes, without proper supplementary ventilation, can increase indoor radon concentrations resulting in a negative health impact. This can be mitigated by provision of adequate compensatory ventilation (e.g. working extract fans). These reductions in QALYs are offset in the case of the wall insulation measures with increased QALYs (benefits) due to winter excess cerebrovascular (Win CA), cardiovascular (Win CV), and myocardial infarction (Win MI). However, loft insulation and glazing measures are predicted to reduce mortality QALYs overall.

Electric cookers are predicted to provide substantial health benefits with an increase in mortality QALYs of 63.8 per 10,000 population due to significant reductions in indoor sourced $PM_{2.5}$ exposures. This measure is of particular benefit to mortality QALYs from CV disease. Since ASHPs are only assumed to impact on SIT (and indirectly mould) in NBM-Health, they provide benefit only to winter excess diseases, yet still provide a significant improvement in mortality QALYs (5.7-16.6 per 10,000 population) overall. However, limitations with the 1°C higher indoor temperature assumption used to provide the upper limit should be noted (see Section 2 and Table 6). Scenarios with alternative assumptions for temperature increases are provided in Appendix B: ASHP Sensitivity Analysis, which yield health outcomes that can vary substantially. For example, assuming a cap on health benefits for SIT increases above 19°C yields an increase of 5.7 mortality QALYs per 10,000 population (used for the lower bound).

The overheating adaptation measures all have the effect of increased QALYs (benefits) due to reduced summer excess mortality due to heat exposure. Shutters provide the greatest benefit with an increase of 1.8 QALYs per 10,000 people.

Table 12 - Mortality QALY changes per 10,000 population post-retrofit for single interventions over a 25-year time horizon.

Health conditions	**CA**	**CV**	**LC**	**MI**	**Win CA**	**Win CV**	**Win MI**	**Summer heat**	**Total**
Fabric retrofit									
Loft Insulation	-0.4	-2.1	-0.7	-0.3	0.5	1.3	0.4	0	-1.3
External Wall Insulation	-0.1	-0.5	-0.2	-0.1	1	2.9	0.9	-0.3	3.6
Cavity Wall Insulation	-0.3	-1.6	-0.5	-0.2	0.8	2.1	0.6	-0.2	0.7
Double glazing+TV	-0.4	-2.2	-0.5	-0.3	0.5	1.4	0.4	0.1	-1.1
Electrification									
Electric cookers	7.7	41	6.2	6.6	0.5	1.3	0.4	NA	63.8
ASHP	NA	NA	NA	NA	3.7	10.1	2.9	NA	16.6
Overheating adaptation									

Window coating	NA	NA	NA	NA	NA	NA	NA	0.3	0.3
Solar shading	NA	NA	NA	NA	NA	NA	NA	0.9	0.9
Shutters	NA	NA	NA	NA	NA	NA	NA	1.8	1.8
Absorptance	NA	NA	NA	NA	NA	NA	NA	0.6	0.6
Urban greening	NA	NA	NA	NA	NA	NA	NA	0.8	0.8

Changes in morbidity QALYs per 10,000 retrofit population due to single retrofit measures are shown in Table 13 and Figure 6. All individual fabric retrofit measures have a positive impact on total morbidity QALYs, in particular for common mental disorders (CMD) and asthma due to increases in SIT. ASHPs also provide substantial morbidity benefits due to increased SIT (see Appendix B: ASHP Sensitivity Analysis for alternative temperature increase scenarios). Electric cookers, on the other hand, provide increases in morbidity QALYs, primarily through reduced prevalence of CV disease due to lower $PM_{2.5}$ exposures. Impacts of overheating adaption measures on heat related morbidity have not been modelled in NBM-Health.

Table 13 - Morbidity QALYs per 10,000 retrofit population for individual intervention scenarios. Note: adaptation measures/overheating not modelled to have impact on morbidity.

Health conditions	**CA**	**CV**	**LC**	**MI**	**Win CA**	**Win CV**	**Win MI**	**Asthma**	**COPD**	**CMD**	**Total**
Fabric retrofit											
Loft Insulation	-0.1	-0.5	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	2.2	0.9	2.5
External Wall Insulation	<0.1	-0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	4.7	1.9	6.8
Cavity Wall Insulation	-0.1	-0.4	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	3.4	1.4	4.5
Double glazing+TV	-0.1	-0.5	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	2.1	0.8	2.5
Electrification											

Health conditions	CA	CV	LC	MI	Win CA	Win CV	Win MI	Asthma	COPD	CMD	Total
Electric cookers	1.3	9.9	NA	0.1	0.1	NA	NA	NA	NA	NA	11.4
ASHP	NA	NA	NA	NA	0.7	0.2	0.1	0.1	15.2	5.9	22.2

4.3.2 Multiple measure scenarios

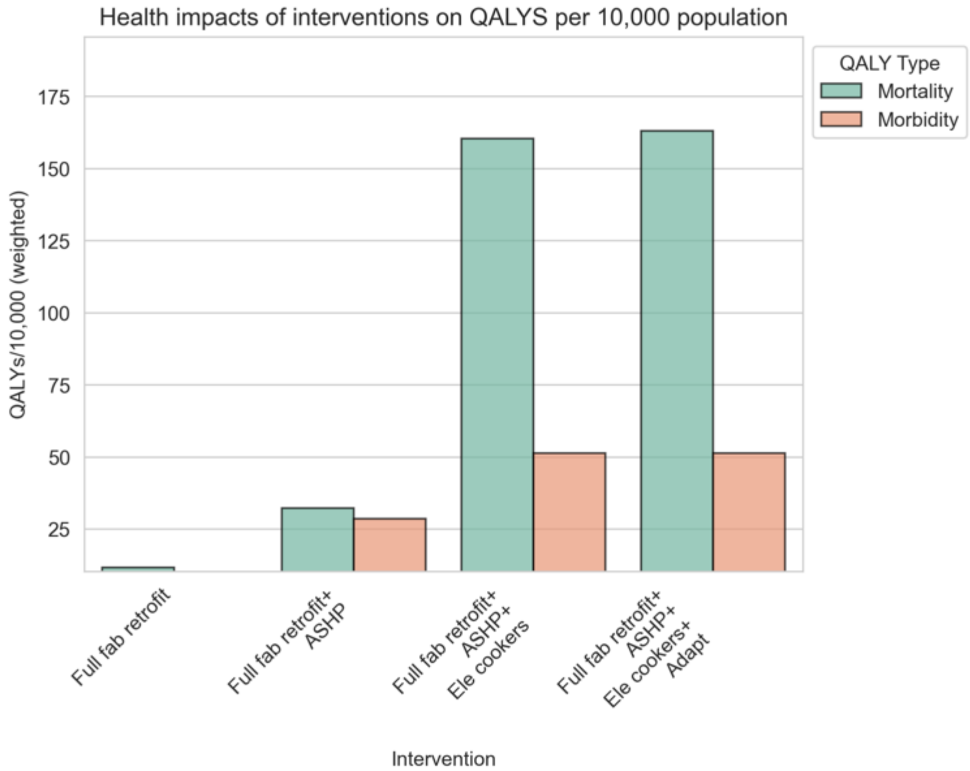

Figure 7 – Total mortality (green) and morbidity (orange) QALYs (left) and per 10,000 retrofit population (right) for multiple interventions over 25 years.

The change in mortality QALYs for the four multiple retrofit scenarios are shown in Table 14 and Figure 7. Scenario three, where electrification and extract fans are included provides the greatest increase (benefit) in mortality QALYs with 160.3 per 10,000 people. Scenario four shows the impact of adding overheating adaptations to scenario three, where this provides only around three additional QALYs per 10,000.

Table 14 – Change in mortality QALYs per 10,000 population for multiple intervention scenarios.

Health conditions	CA	CV	LC	MI	Win CA	Win CV	Win MI	Summer heat	Total
FR1. Full fabric*	0.5	2.3	2.9	0.4	1.3	3.5	1	-0.2	11.5
FR2. Full fabric* + ASHP	1.1	5.5	4.5	0.8	4.5	12.4	3.6	-0.2	32.2
FR3. Full fabric* + Electrification + EF	16.6	88	17.5	14	5.4	14.8	4.2	-0.2	160.3
FR4. Full fabric* + Electrification + EF + Adaptation	16.6	87.9	17.5	14	5.4	14.8	4.2	2.7	163.1

Changes in morbidity QALYs per 10,000 retrofit population are provided in Table 15 and Figure 7. For the full fabric retrofit scenario, the majority of the beneficial 8.5 QALYs per 10,000 are due to CMD and asthma improvements from increased SIT. The addition of ASHPs in scenario two further increases the temperature related benefits to yield a beneficial total of 28.5 morbidity QALYs per 10,000 population under the 1°C SIT increase scenario (used as an upper limit). Electrification of cookers in scenario three nearly doubles the morbidity QALY gains (to 51.3 per 10,000), primarily through the CV disease improvements from reduced indoor generated $PM_{2.5}$ noted above. Scenario four results are the same as those for scenario three due to NBM-Health not yet having the functionality to predict morbidity QALYs due to overheating.

Table 15 - Morbidity QALYs per 10,000 population for multiple intervention scenarios. Note: adaptation measures/overheating not modelled to have impact on morbidity.

Health conditions	CA	CV	LC	MI	Win CA	Win CV	Win MI	Asthma	COPD	CMD	Total
FR1. Full fabric*	0.1	0.5	<0.1	<0.1	0.2	0.1	<0.1	0.1	5.4	2.1	8.5
FR2. Full fabric* + ASHP	0.2	1.2	<0.1	<0.1	0.8	0.2	0.1	0.2	18.5	7.3	28.5

FR3. Full fabric* + Electrification + EF	2.8	21	<0.1	0.2	1	0.2	0.1	0.3	18.5	7.2	51.3
FR4. Full fabric* + Electrification + EF + Adaptation	2.8	21	<0.1	0.2	1	0.2	0.1	0.3	18.5	7.2	51.3

4.4 Healthcare costs/savings

4.4.1 Individual measure scenarios

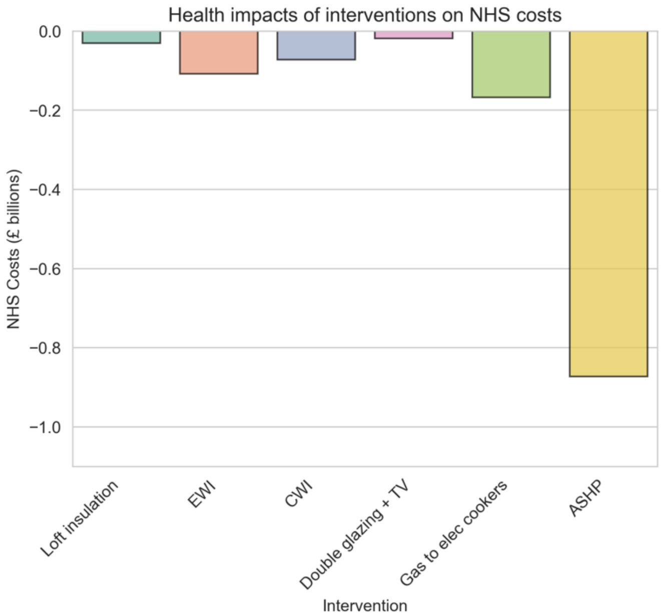

Figure 8 - NHS costs (£ billions) due to individual interventions over 25-year time horizon.

The impacts of individual retrofit measures that impact on NHS healthcare costs over the 25-year modelling period are shown in Table 16 and Figure 8. The fabric retrofit measures provide NHS savings ranging from £0.02 billion for glazing upgrades (with TV) up to £0.11 billion for EWI. Most of these savings come from reduced costs for CMD. ASHPs are predicted to provide higher NHS savings than fabric measures with a £0.28-0.87 billion saving, primarily due to savings for CMD treatment. Electrification of cookers also provides a significant NHS cost saving of around £0.17 billion assuming 14 million installations, mostly from CV disease cost savings.

Table 16 – Change in NHS costs (£ billions) for individual measures over a 25-year time horizon.

Health conditions	CA	CV	LC	MI	Win CA	Win CV	Win MI	COPD	CMD	Asthma	Total
Fabric retrofit											
Loft Insulation	0	0.003	0.001	0	0	0	0	-0.009	-0.025	0	-0.03
External Wall Insulation	0	0.001	0	0	-0.001	-0.001	0	-0.027	-0.08	-0.001	-0.109
Cavity Wall Insulation	0	0.003	0.001	0	0	-0.001	0	-0.02	-0.056	0	-0.073
Double glazing+TV	0	0.002	0.001	0	0	0	0	-0.006	-0.015	0	-0.018
Electrification											
Gas to electric cookers	-0.008	-0.140	-0.014	-0.004	-0.001	-0.001	0	0	0	0	-0.168
ASHP (1°C)	NA	NA	NA	NA	-0.005	-0.011	-0.003	-0.221	-0.629	-0.003	-0.872

4.4.2 Multiple measure scenarios

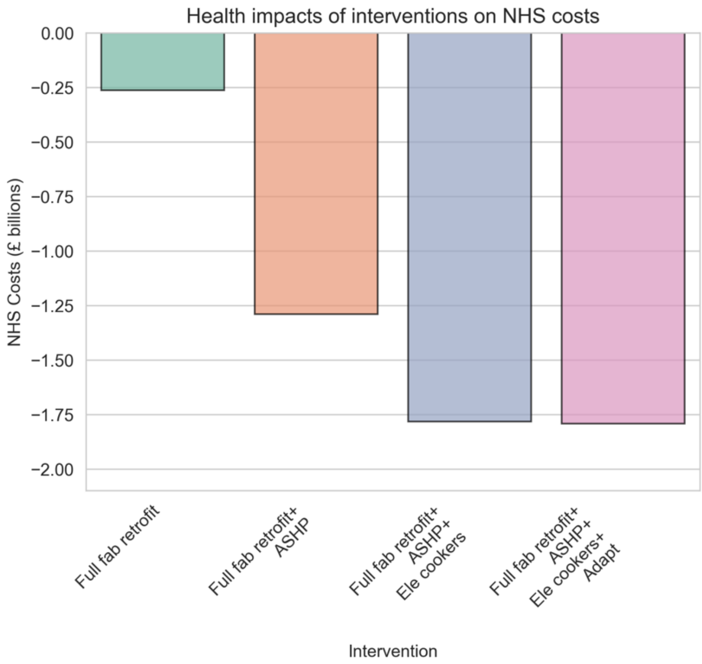

Figure 9 - NHS costs (£ billions) due to multiple intervention scenarios over 25-year time horizon.

NHS cost savings for the multiple measure scenarios are shown in Table 17 and Figure 9. Full fabric retrofit provides an NHS cost saving of around £0.26 billion. The addition of an ASHP in scenario two increases this saving to around £1.3 billion over the 25-year modelling period (assuming 1°C increase – upper limit scenario). Electrification of cookers boosts savings to around £1.8 billion. The savings from multiple measures are greater than the sum of savings from individual measures reported in Table 16. This is due to the installation of trickle vents in homes with any other retrofit measure.

Table 17 – Change in NHS costs (£ billions) for multiple measure scenarios over a 25-year time horizon.

Health conditions	**CA**	**CV**	**LC**	**MI**	**Win CA**	**Win CV**	**Win MI**	**COPD**	**CMD**	**Asthma**	**Total**
FR1. Full fabric*	0	-0.005	-0.006	0	-0.001	-0.003	-0.001	-0.062	-0.18	-0.004	-0.262
FR2. Full fabric* + ASHP	-0.001	-0.02	-0.015	-0.001	-0.008	-0.016	-0.004	-0.315	-0.901	-0.01	-1.291
FR3. Full fabric* + Electrification + EF	-0.024	-0.408	-0.055	-0.013	-0.009	-0.019	-0.004	-0.321	-0.917	-0.014	-1.785

Health conditions	CA	CV	LC	MI	Win CA	Win CV	Win MI	COPD	CMD	Asthma	Total
FR4. Full fabric* + Electrification + EF + Adaptation	-0.025	-0.411	-0.055	-0.013	-0.009	-0.019	-0.005	-0.322	-0.921	-0.015	-1.795

5. Conclusions

5.1 Summary of key findings

Results from scenarios modelled using NBM-Health indicate that implementing net-zero measures to occupied homes within the English housing stock (N~22.9 million) have the potential to yield substantial health benefits. Electrification of housing with the addition of heat pumps and electric cookers, based on the modelling assumptions used, have the potential to improve public health.

In replacing traditional heating systems (gas boilers and electric heaters) with ASHPs, our central modelling scenario assumes that winter indoor temperatures (SIT) increase by 1°C. Wickins (2014) observed that the average indoor temperatures of homes in the Energy Saving Trust (EST) heat pump field trial were 1°C higher than homes in the EST condensing boiler field trial. More recently, Watson et al. (2021) also reported an increase, but this increase was attributed to more continuous heating patterns (due to the low flow temperature of ASHPs) in homes with ASHP and is therefore considered a behavioural factor and not due to the ASHP technology itself. Similar temperature profiles could be achieved using traditional heating systems. There is a lack of evidence on the relative difference of indoor temperatures in homes with ASHP and traditional heating systems during occupied periods or when the heating is in operation, and so, there is uncertainty associated with this assumption (Watson et al. 2021). Appendix B: ASHP Sensitivity Analysis explores the sensitivity associated with the 1°C assumption and the results show that the health impacts are highly sensitive to this assumption. Due to the uncertainty associated with the 1°C assumption and that this increase could be due to behaviour rather than the ASHP technology, the results associated with ASHP should be interpreted with caution. Retrofitting traditional heating systems with ASHPs in eligible homes (N=19 million) results in a significant benefit for morbidity QALYs with an increase in the range 7-22 per 10,000 and saving the NHS £0.3-0.9 billion over a 25-year period. Note that this saving is relatively small in comparison to total NHS costs (~£180 billion per year) (Stiebahl 2024). This measure also saw an increase of 6-17 mortality QALYs per 10,000 under various assumptions (see Appendix B: ASHP Sensitivity Analysis). ASHPs also provide co-benefits by reducing CO_2 emissions; however, initial capital costs are high (Eunomia 2023). Running ASHPs on a continuous setting can also increase overall heating demand by around 8% vs traditional systems (Watson et al. 2021).

Replacing gas with electric cookers is modelled to reduce exposures to $PM_{2.5}$ from indoor sources by 25% (TNO 2023; Gould et al. 2023; Dennekamp et al. 2001; To and Yeung 2011; Zhang et al. 2010). This yields the most substantial impact on population mortality of all individual measures, increasing quality-adjusted life years (QALYs) by 64 per 10,000 for the retrofit population. Electric cookers also led to an increase of 11 morbidity QALYs per 10,000. This results in an NHS saving of £0.17 billion assuming 14 million installations (i.e. 61% of homes have gas hobs) (BRE and DECC 2013).

Fabric retrofits (including cavity and external wall and loft insulation, and double glazing with trickle vents) all lead to increases in SIT and reduced mould, but are observed to increase exposure to radon. This is due to the increased air tightness of the building envelope. Increases in exposure to $PM_{2.5}$ from indoor sources are mostly offset by the reduction in $PM_{2.5}$ from outdoor sources. This is broadly in line with previous work using the HIDEEM model (Hamilton et al. 2015; Van Rooyen et al. 2025a). Both wall insulation measures also resulted in a slight increase in mean summertime temperatures, but this does not necessarily imply increased exposure to overheating. Of the fabric retrofits, EWI was found to provide the greatest health benefit, but this intervention is likely to have a higher capital cost than other interventions (BEIS 2017). The full fabric retrofit scenario (including trickle vents in homes with any retrofit) resulted in a gain of 12 mortality and 9 morbidity QALYs per 10,000 population, alongside an NHS saving of approximately £0.3 billion.

Of the passive overheating adaptation strategies assessed, installing external shutters to windows resulted in the largest decrease (1°C) in average summertime temperatures. Urban greening (parks and gardens) and solar shading provided reductions of 0.8°C and 0.6°C, respectively. However, the impact from urban greening is likely to be overestimated due to the model including benefits from the start of the model horizon and not accounting for time lag associated with the maturing of urban greening. Modifying the solar absorptance of roofs and walls, and window coating had less substantial impacts. Therefore, shutters delivered the greatest improvement in mortality QALYs, with an increase of 1.8 per 10,000 people. This supports previous research which also suggests that shutters are one of the most effective passive overheating adaptation measures (Taylor et al. 2018; Gupta and Gregg 2013; Porritt et al. 2012). Shutters have a large potential to reduce the health impacts of heat exposure as the climate warms, since many homes do not currently have them. However, many homes in the UK have window types that might not be compatible with shutters (e.g., outward opening windows) or might limit their usefulness/impact. Overheating adaptation measures and urban greening can potentially also increase winter space heating requirements if they impact on useful wintertime solar gains (Pandit and Laband 2010).

5.2 Limitations and future work

NBM-Health relies on a number of structural and parametric modelling assumptions as highlighted in the model documentation and assumptions log (Van Rooyen et al. 2025c; Van Rooyen et al. 2025b). Unfortunately, due to the brevity of this project, it has not been possible to carry out an extensive uncertainty analysis. Comparative and sensitivity tests have been carried out on the current (v2) and previous versions of NBM-Health in addition to those presented in Appendix B: ASHP Sensitivity Analysis.

Some of the key assumptions and limitations of the model are as follows:

- Only a limited number of exposures have been considered. Other exposures, such as, volatile organic compounds (VOCs), NOx, bioaerosols, and noise and could potentially be considered. Additional health benefits related to these exposures may therefore be missed by the current version of the model.
- Health outcomes are also limited to only include those with well-established exposure-response relationships. In future, additional diseases may be considered (e.g. on dementia and Alzheimer's disease or type II diabetes) where there is emerging evidence (Mandal et al. 2023; Peters et al. 2019). Heat-related morbidity is not yet included in the model.
- There is very limited empirical data to support the key assumption that ASHPs increase SIT by 1°C. Additionally, this increased temperature has been attributed to differences in more continuous heating schedules being used rather than the ASHP technology itself. Heat pumps that replace gas boilers also have the potential to reduce air pollution exposures, although this has not been considered in this study (Defra and ICL, UKCEH, EMRC 2022). Depending on the type of installation, ASHP can also provide cooling (at an additional energy and CO_2 penalty). Future empirical studies should investigate the potential health impacts of heat pumps in more detail.
- Although there is growing evidence for the impact of changing gas to electric cookers on air pollution exposure, a uniform $PM_{2.5}$ exposure reduction factor of 25% does not account for variability within the housing stock. Future research should consider the impacts of changing gas to electric cookers in homes with varying ventilation conditions and provisions.
- The urban greening measure is only modelled to impact on summertime temperatures. This measure is also likely to reduce air pollution exposure, but increase space heating requirements.
- Only NHS healthcare costs related to health impacts are included (primary care, secondary care, emergency care, social and community care). Societal costs/benefits, for example those associated with changes in productivity (i.e. due to less sick days) are not included within the model. Healthcare costs are static and do not include inflation.

Future work and developments to the NBM-Health model should prioritise an in-depth sensitivity and uncertainty analysis. Uncertainties within the model would require large scale empirical research to further refine and validate model assumptions. Future model developments should also prioritise the investigation of the impact of HEE and net zero measures on additional exposures (e.g. NOx and noise) and health outcomes not considered as part of this study.

5.3 Summary

The NBM-Health model provides a useful tool for considering the health impacts of home energy efficiency, heating system, and overheating adaptation measures applied to the English housing stock. This project has also highlighted some uncertainties/limitations of the model and potential areas for future research. Model runs over a 25-year time horizon indicate that home energy efficiency measures and electrification (heat pumps and electric cookers) have the potential to provide health benefits, as well as the potential for reductions in CO_2 emissions. The tool can be used to support policy makers to identify optimal pathways to net-zero, whilst considering health and the associated NHS costs.

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7. Appendix A: Exposures

Exposure results from NBM-Health for the baseline and individual retrofit scenarios are provided in Table 18 and multi-retrofit scenarios in Table 19.

Table 18 – Exposures (95% CIs) for the baseline scenario and for suitable homes that have had single interventions applied.

Scenario	Radon (Bq/m^3)	Indoor source $PM_{2.5}$ (μg/m^3)	Outdoor source $PM_{2.5}$ (μg/m^3)	SIT (°C)	Percentage of homes MSI>1 (%)	Summertime temperature (°C)
Baseline	11.28 (11.06, 11.49)	3.85 (3.78, 3.93)	2.24 (2.23, 2.25)	18.8 (18.79, 18.82)	6.04 (5.94, 6.15)	15.85 (15.82, 15.88)
Loft Insulation	11.72 (11.39, 12.04)	3.12 (3.0, 3.24)	2.3 (2.27, 2.32)	18.75 (18.73, 18.77)	6.0 (5.92, 6.09)	15.9 (15.84, 15.95)
External Wall Insulation	10.84 (10.49, 11.19)	3.93 (3.78, 4.09)	2.26 (2.24, 2.28)	18.91 (18.88, 18.93)	6.04 (5.84, 6.25)	16.17 (16.12, 16.23)
Cavity Wall Insulation	12.31 (11.89, 12.73)	4.25 (4.09, 4.4)	2.18 (2.16, 2.2)	18.99 (18.97, 19.02)	6.07 (5.84, 6.29)	16.16 (16.11, 16.21)
Double glazing+TV	9.53 (9.09, 9.97)	3.94 (3.76, 4.13)	2.5 (2.47, 2.53)	18.44 (18.39, 18.48)	6.06 (5.91, 6.22)	15.53 (15.45, 15.62)
Gas to electric cookers	11.17 (10.96, 11.38)	2.41 (2.36, 2.47)	2.27 (2.26, 2.28)	18.78 (18.76, 18.79)	6.02 (5.93, 6.11)	15.83 (15.8, 15.86)
ASHP	11.71 (11.47, 11.95)	3.84 (3.76, 3.93)	2.21 (2.2, 2.23)	19.9 (19.89, 19.92)	5.79 (5.69, 5.88)	15.94 (15.91, 15.97)

Window coating	11.28 (11.06, 11.49)	3.85 (3.78, 3.93)	2.24 (2.23, 2.25)	18.8 (18.79, 18.82)	6.04 (5.94, 6.15)	15.61 (15.58, 15.64)
Solar shading	11.28 (11.06, 11.49)	3.85 (3.78, 3.93)	2.24 (2.23, 2.25)	18.8 (18.79, 18.82)	6.04 (5.94, 6.15)	15.24 (15.21, 15.27)
Shutters	11.28 (11.06, 11.49)	3.85 (3.78, 3.93)	2.24 (2.23, 2.25)	18.8 (18.79, 18.82)	6.04 (5.94, 6.15)	14.82 (14.79, 14.86)
Absorptance	11.28 (11.06, 11.49)	3.85 (3.78, 3.93)	2.24 (2.23, 2.25)	18.8 (18.79, 18.82)	6.04 (5.94, 6.15)	15.35 (15.32, 15.38)
Urban greening	9.53 (9.09, 9.97)	3.94 (3.76, 4.13)	2.5 (2.47, 2.53)	18.44 (18.39, 18.48)	6.06 (5.91, 6.22)	15.53 (15.45, 15.62)

Table 19 - Exposures (95% CIs) for multi-retrofit scenarios for suitable homes with >=1 measure installed.

Scenario	Radon (Bq/m^3)	Indoor source $PM_{2.5}$	Outdoor source $PM_{2.5}$	SIT (°C)	% homes MSI>1	Summertime temperature (°C)
Full fabric retrofit	11.28 (11.02, 11.54)	3.93 (3.84, 4.03)	2.26 (2.24, 2.27)	18.66 (18.64, 18.68)	6.1 (5.96, 6.23)	15.85 (15.82, 15.89)
Full fabric retrofit + ASHP	11.96 (11.74, 12.19)	3.95 (3.87, 4.03)	2.19 (2.18, 2.2)	18.81 (18.8, 18.83)	6.08 (5.97, 6.19)	15.86 (15.83, 15.89)
Full fabric retrofit + ASHP + Electric cookers	11.91 (11.69, 12.14)	3.89 (3.81, 3.96)	2.19 (2.18, 2.2)	18.8 (18.79, 18.82)	6.08 (5.97, 6.19)	15.85 (15.82, 15.88)

Full fabric retrofit + ASHP + Electric cookers + Adaptation measures	11.92 (11.7, 12.14)	3.94 (3.86, 4.02)	2.19 (2.18, 2.2)	18.8 (18.79, 18.82)	6.08 (5.97, 6.19)	15.85 (15.82, 15.88)

8. Appendix B: ASHP Sensitivity Analysis

In order to explore the sensitivity of the assumption that homes that have an ASHP installed experience indoor temperatures that are 1°C higher than homes with gas heating (see Section 2 and Section 3.4.2), three additional scenarios were run. Scenario 1 halved the assumption, thereby assuming that homes that had an ASHP experience indoor temperatures 0.5°C higher than homes with traditional heating systems. Scenario 2 (19°C cap) and Scenario 3 (20°C cap) assumed that homes with lower SIT would experience a greater increase in temperature after installing an ASHP than those with higher SIT. For Scenario 2, homes with SIT greater than 19°C (20°C for Scenario 3) were assumed to experience no further increase in indoor temperature after an ASHP was installed, homes with SIT between 18°C and 19°C (19°C to 20°C for Scenario 3) were assumed to have a SIT of 19°C (20°C for Scenario 3) after installing an ASHP and homes with SIT below 18°C (below 19°C for Scenario 3) were assumed to experience a temperature increase of 1°C after installing an ASHP.

Table 20 and Table 21 below show the mortality and morbidity results of the sensitivity analyses. NHS cost savings are presented in Table 22, These tables include results for the cavity wall insulation scenario as a point of reference. As expected, in Scenario 1, halving the assumed temperature impact of ASHP and approximately halved the health impacts associated with ASHP. Scenario 2 had health impacts substantially lower than Scenario 1 and our baseline scenario (1°C increase). Comparing results from Scenario 2 and 3 shows that the model is highly sensitive to the selected cap/threshold temperature.

Table 20 – Sensitivity analysis results of mortality QALY changes per 10,000 population post-retrofit of ASHP over a 25-year time horizon.

Health conditions	**CA**	**CV**	**LC**	**MI**	**Win CA**	**Win CV**	**Win MI**	**Summer heat**	**Total**
CWI	-0.3	-1.6	-0.5	-0.2	0.8	2.1	0.6	-0.2	0.7
ASHP (0.5°C)	NA	NA	NA	NA	1.9	5.1	1.5	NA	8.5
ASHP (1°C)	NA	NA	NA	NA	3.7	10.1	2.9	NA	16.6
ASHP (19°C cap)	NA	NA	NA	NA	1.3	3.5	1.0	NA	5.7
ASHP (20°C cap)	NA	NA	NA	NA	3.3	9.1	2.6	NA	15.0

Table 21 – Sensitivity analysis results of morbidity QALY changes per 10,000 population post-retrofit of ASHP over a 25-year time horizon.

Health conditions	CA	CV	LC	MI	Win CA	Win CV	Win MI	COPD	CMD	Asthma	Total
CWI	-0.1	-0.4	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	3.4	1.4	4.5
ASHP (0.5°C)	NA	NA	NA	NA	0.3	0.1	0.0	7.8	3.0	0.0	11.4
ASHP (1°C)	NA	NA	NA	NA	0.7	0.2	0.1	15.2	5.9	0.1	22.1
ASHP (19°C cap)	NA	NA	NA	NA	0.2	0.1	0.0	5.0	1.9	0.0	7.2
ASHP (20°C cap)	NA	NA	NA	NA	0.6	0.1	0.1	13.6	5.2	0.1	19.6

Table 22 - Sensitivity analysis results of NHS costs (£ billions) post-retrofit of ASHP over a 25-year time horizon.

Scenario	NHS cost (£ billions)
CWI	4.5
ASHP (0.5°C)	-0.45
ASHP (1°C)	-0.87
ASHP (19°C cap)	-0.28
ASHP (20°C cap)	-0.77

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