CARDIFF SCHOOL of ART & DESIGN

Cardiff Metropolitan University | Prifysgol Metropolitan Caerdydd

Evidence briefing

How resilient are buildings in the UK and Wales to the challenges associated with a changing climate?

Practical recommendations for risk-based adaptation

November 2022

Contents

Introduction

The urgency and likely impacts of climate change are well evidenced and publicised. Alongside projected temperature increases, extreme climate events are expected to become more frequent.

Current decarbonisation efforts are unlikely to hold global warming to 1.5˚c. We therefore need to prepare for warmer, wetter, and more extreme weather patterns.

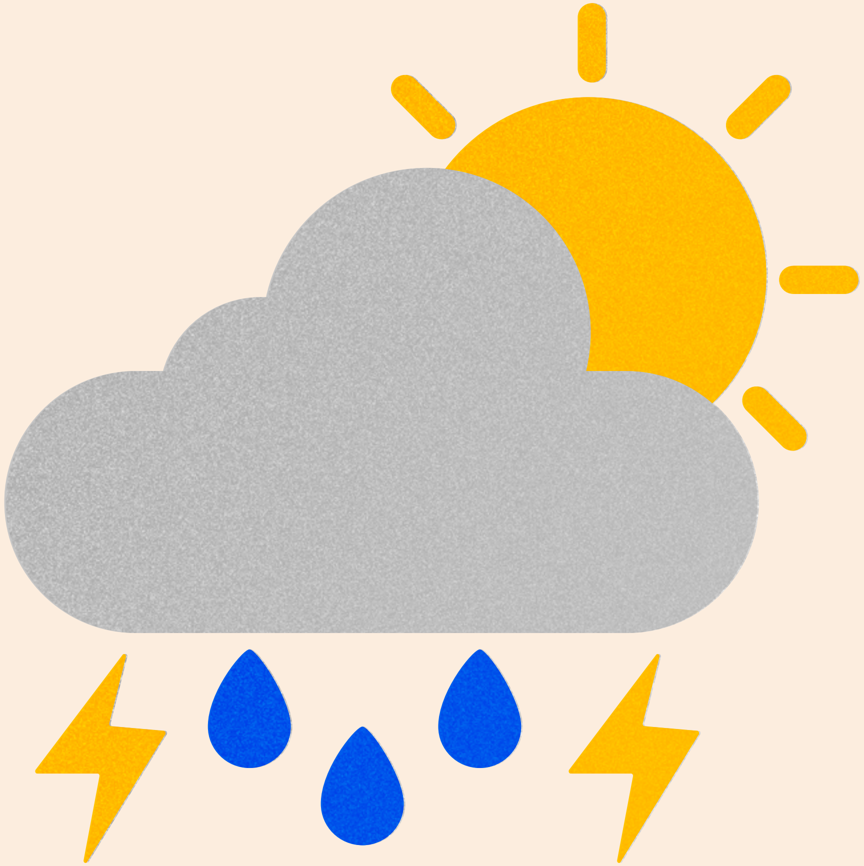
Alongside government-led programmes aimed at reducing our reliance on fossil fuels within the built environment, it is now more important than ever to look at how we can adapt our buildings to address the challenges caused by climate change.

This advice paper summarises research assessing the resilience of buildings in the UK and Wales to the challenges associated with projected climate change, and makes practical recommendations for risk-based adaptation.

It is based on

- a detailed review of the available evidence and research
- climate vulnerability modelling
- facilitated workshops with stakeholders.

Download the full research report



Recommendations

The following recommendations are addressed to the UK and Welsh Governments, building regulation and standards authorities, as well as the wider housing sector:

1. We urgently need a holistic policy approach to climate change decision-making.

We cannot continue to attempt mitigation and adaptation in isolation. **Systems thinking** (considering the connected wholes rather than separate parts) should be at the heart of UK and Welsh climate change policy design and delivery; as should **foresight** (futures thinking). This will help ensure that necessary risk-based adaptation decisions have equal footing with carbon reduction targets.

2. Embed consistent climate messaging in regulations.

Welsh building regulations and related national reference standards should address the lack of consistent messaging on the interconnectedness of climate change, building fabric and health.

3. Provide advice and tools for the construction industry.

Welsh building regulations and related national reference standards should address the shortage of advice and the tools needed by the design and construction industry, to tackle the impact of future climate conditions on the built environment.

4. Embed climate adaptation in regulations and standards.

Welsh building regulations and related national reference standards must embed climate change risk-based building fabric vulnerabilities, such as extreme wind, rain and flooding, in their guidance.

5. Legislate for overheating.

Welsh building regulations and related national reference standards must legislate for overheating, among other aspects of building safety, to help reduce the risk in existing homes undergoing retrofit, in addition to new build.

6. Update ventilation regulations to account for projected climate change.

Welsh building regulations and related national reference standards must ensure that ventilation guidelines reflect projected climate change, to help reduce the risk of inadequate air circulation in existing homes, especially those undergoing retrofit.

7. Invest in climate skills and training.

Investment in skills and training on climate mitigation and adaptation, to avoid maladaptation, is urgently needed.

8. **Merge decarbonisation and adaptation strategies for social housing.**

Social housing decarbonisation strategies should be merged with climate adaptation action plans. For example, adaptation measures implemented at the same time as energy efficiency measures, could significantly reduce the risk of overheating, mould and damp.

9. **Encourage the private sector to do the same.**

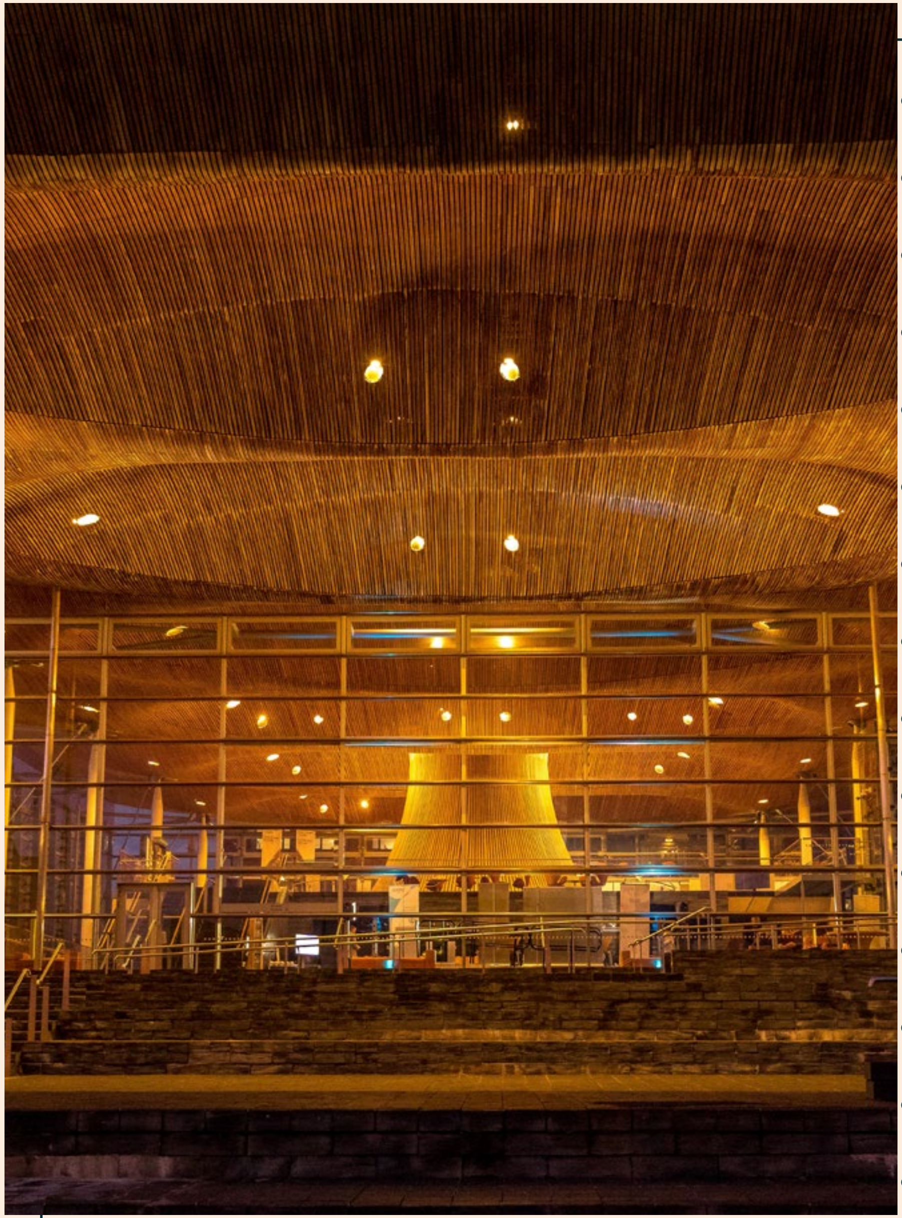
Government-backed schemes for private-sector dwellings should also merge their decarbonisation and adaptation strategies.

10. **Make climate advice accessible to everyone.**

Climate change mitigation and adaptation advice must be made accessible to everyone. If we democratise skills, knowledge and understanding of climate vulnerabilities, we give building occupants and owners agency to improve their circumstances.

11. **Promote wider understanding of climate adaptation behaviours.**

Influencing occupant behaviours has been identified as a key catalyst for boosting constructive risk-based decision making. A Welsh government led campaign or strategy that guarantees the dissemination of knowledge and understanding of climate adaptation behaviours, will ultimately improve and enhance occupants' experience of their dwelling.



Evidence review

Improving our understanding of the relationships between energy use, indoor health and comfort, and the thermal and moisture dynamics of buildings, will allow for better informed decisions. It will give us a better sense of future risks to energy efficiency, health and comfort, and allow us to better manage our homes in a changing climate.

Climate change mitigation and carbon reduction are key industry drivers

A review of recent and emerging research, and published academic literature, confirms that climate change mitigation and carbon reduction targets continue to be key industry drivers. The energy efficiency gains from retrofitting buildings have accelerated the implementation of additional insulation for the most energy inefficient of our existing housing stock.

Climate mitigation can have unintended consequences

As demonstrated by several case studies, the addition of internal wall insulation regularly diminishes the benefits of ventilation in traditional building structures (typically solid wall).

The combined impacts of climate change coupled with unsuitable energy efficiency retrofit interventions can undermine the integrity of a building's envelope, whilst failing to deliver a comfortable, healthy environment for occupants. This highlights the risk of ill-informed energy retrofits leading to unintended consequences, otherwise known as maladaptation.

Climate effects on the built environment create risks to our comfort and health

Overheating risks

Overheating is an increasing concern and will continue to be so in the future. The combined effect of internal wall insulation and increased outdoor temperatures may exacerbate overheating risks, potentially increasing the energy demand for cooling.

Any decisions to retrofit must consider known climate projections, building performance, and occupant behaviour, as occupant behaviours can either enhance or aggravate the situation further.

Moisture risks

Climate change makes moisture risks more likely. Changed precipitation patterns will affect building envelope moisture dynamics. This will also impact indoor environmental quality and occupant health.

Solar risks

Solar degradation is more likely to occur due to climate change. Changed temperatures and solar radiation intensity have the potential to affect the performance of building fabric (both solid and cavity wall construction), especially south-facing facades. This will also impact indoor environmental quality and occupant health (see overheating risks above).

Inadequate ventilation risks

Reduced ventilation (should indoor air not be regularly exchanged or extracted) not only results in the build-up of moisture that can lead to damp and mould growth, but also leads to a build-up of indoor contaminants or pollutants. These effects combine to contribute to poorer indoor environmental quality and therefore reduced health and wellbeing.

UK climate adaptation case studies

There is a paucity of UK case studies featuring climate change adaptation decision-making.

The key driver for many of the projects examining climate change impacts focus on mitigation rather than adaptation. These are principally delivered through energy efficiency measures - both building fabric improvements and the application of renewable energy technologies.

Whilst interventions to prevent overheating are the most common climate change adaptation, there are a few examples where the potential for high winds, storms and flooding have been addressed. But, so far, no published case study makes the relationships between energy efficiency, occupant health and comfort, and dwelling management explicit. Accordingly, they fall short of holistic decision-making.

Although the city-region plans purport to a holistic policy approach to the design, build and planning process, there is currently no published evidence of this.

Welsh building regulations, related national reference standards, and assessment tools

Compulsory and voluntary building regulations, standards and assessment tools clearly have a role to play in tackling the complexities of climate change.

An analysis of existing documentation in this area reveals that little reference is currently made to climate change, and there is a shortage of advice and tools to tackle the impact of future climate conditions on the built environment.

When reference is made to climate change, there is no evidence of the potential impact climate change will have on buildings in the future, and a lack of consistent messaging on the interconnectedness of climate change, building fabric and occupant health.

In conclusion, current building regulations, standards and assessment tools fail to meet the needs of the industry.

Climate vulnerability modelling

Climate vulnerability modelling, undertaken in collaboration with Professor Paul Chinowsky, Matt Huddleston and Jake Helman of the University of Colorado and Resilient Analytics, reveals that the owners and occupiers of Welsh dwellings will experience significant challenges as the climate changes.

The modelling examines vulnerabilities in indoor environmental quality and building fabric as a consequence of climate change, with three headline findings.

- The majority of Welsh dwellings will experience increased incidence of summertime overheating
- An increase in relative humidity will lead to poorer indoor environmental quality
- Our building fabrics are vulnerable to changes in solar radiation, wind and precipitation

Methodology

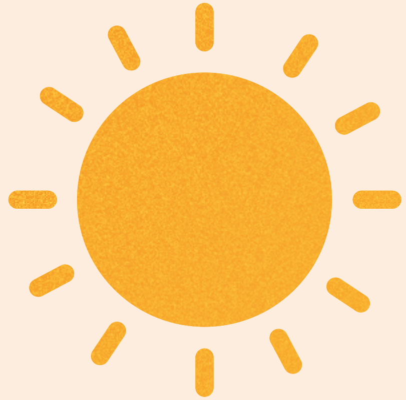
- We use UKCP18 local (2.2km) projections, under an emissions scenario of RCP 8.5 (Met Office, 2019).
- We model three time periods, named 'baseline' (1981-2000), '2030' (2021 – 2040), and '2070' (2061-2080).
- We use 12 HadGEM3-GC3.05 models (Met office, 2019), and present the results for six distinct geographical locations across Wales (**Figure 1**):
  - Cardiff
  - Brynmawr
  - Narberth
  - Wrexham
  - Shotton
  - Llangefni (**see map**).
- The relationship between outdoor temperature and indoor temperature is based on a previous study that monitored 193 free-running dwellings, without heating or cooling (Beizaee et al., 2013).
- 11 separate building classes are identified, representing the 40+ dwelling categories found across Wales according to age, construction and dwelling type (**Table 1**)
- To understand the impact of climate change on the indoor environmental quality of dwellings in Wales, we model a six-week period from **22 July – 31 August**.

Figure 1: Climate Vulnerability Assessment Results

Table 1: 11 separate building classes, representing the 40+ dwelling categories found across Wales according to age, construction and dwelling type

Building classes		Adjustment (˚C) Add to calculate internal temperature	
		Mean	Maximum
Age	Pre 1919	-1.0	-1.8
	1919-1990	0.1	0.2
	Post 1990	0.8	0.8
Building construction	Timber framed	0.0	-0.3
	Solid stone	-1.6	-2.1
	Solid and cavity brick	0.0	0.2
Dwelling type	End and mid terrace, semi detached	0.1	0.2
	Detached	-0.4	-0.4
	Flat	0.7	0.8
Insulation	Internal wall insulation	0.4	0.6
Window	Double glazing (pre 1919)	-0.4(-1.4)	-0.6(-2.4)

Summertime overheating risk



Our model shows that cooling strategies to reduce indoor air temperature will increasingly be required.

Climate change will increase both indoor and outdoor temperatures in each of our six study areas (**Figure 2**)

We model increased incidences of summertime overheating in a majority of dwellings across Wales, as identified by the number of hours exceeding the CIBSE TM59 overheating threshold of 26°C (**Figure 3**).

Figure 2: Change in daily temperatures averaged over the study period for six locations throughout Wales for 2030 and 2070

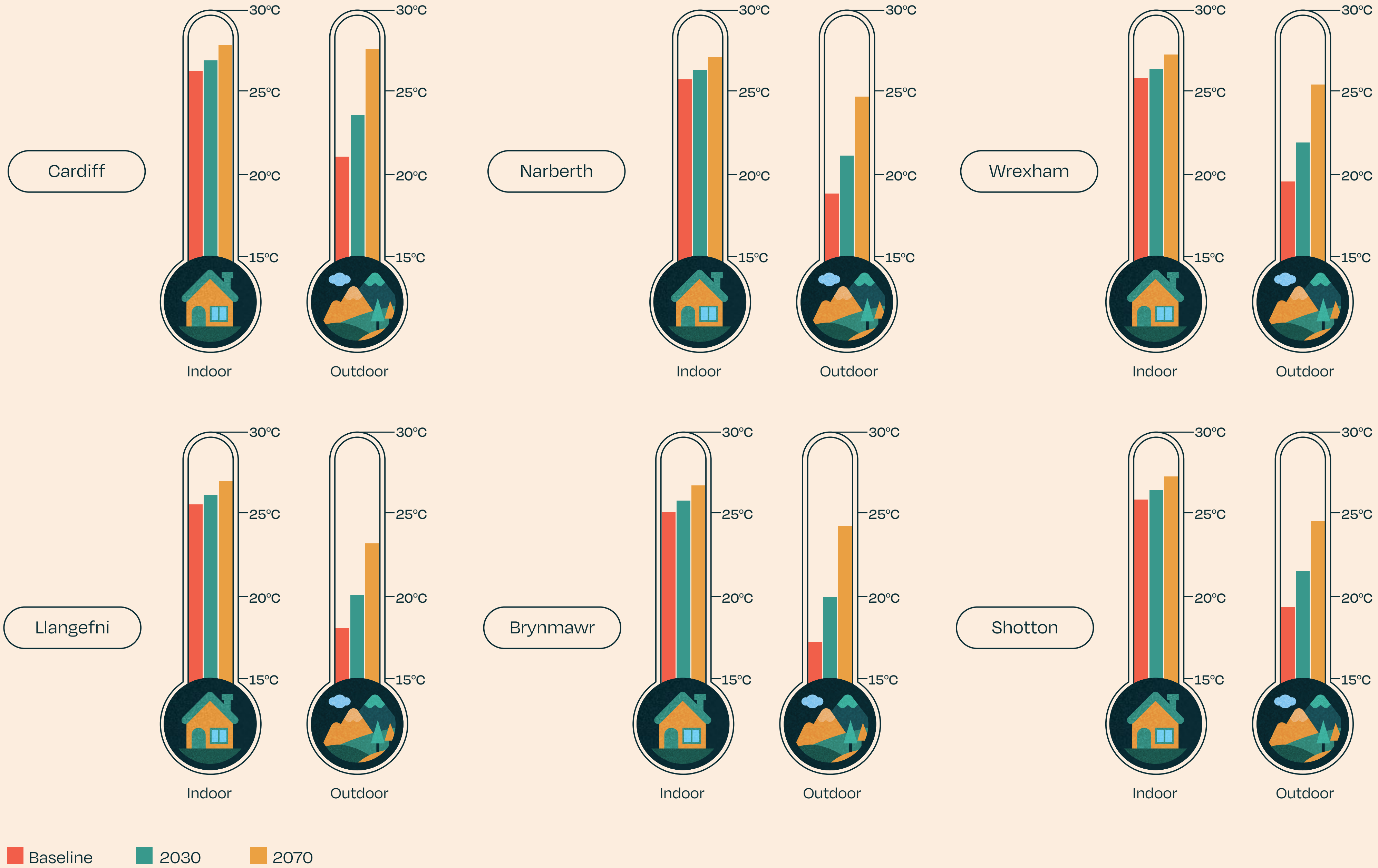
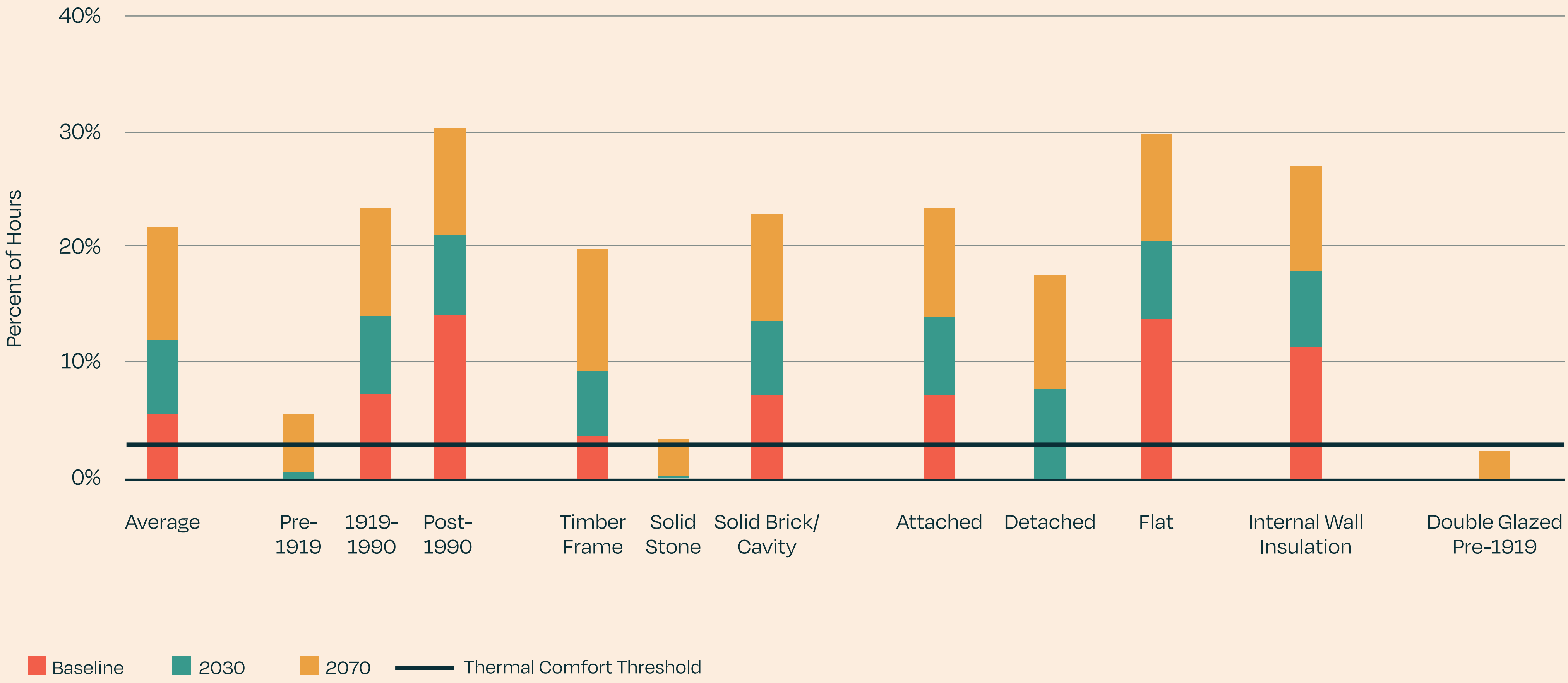


Figure 3: Percent of hours in the study period over 26°C threshold for thermal comfort. Values shown for the average building and eleven building classes. 3% of occupied hours threshold shown for reference.



The best performing dwellings are pre 1919 dwellings and dwellings with solid stone walls. The poorest performing dwellings are post 1990 dwellings, flats, and properties with internal wall insulation.

Summertime moisture risk

Our modelling shows that ventilation strategies to improve the extraction of moisture-laden air, whilst diluting the concentration of pollutants that are present indoors, are required if dwellings in Wales are to avoid increased incidences of condensation, damp, and mould growth, as well as adverse impacts from other allergens, particles and pollutants.

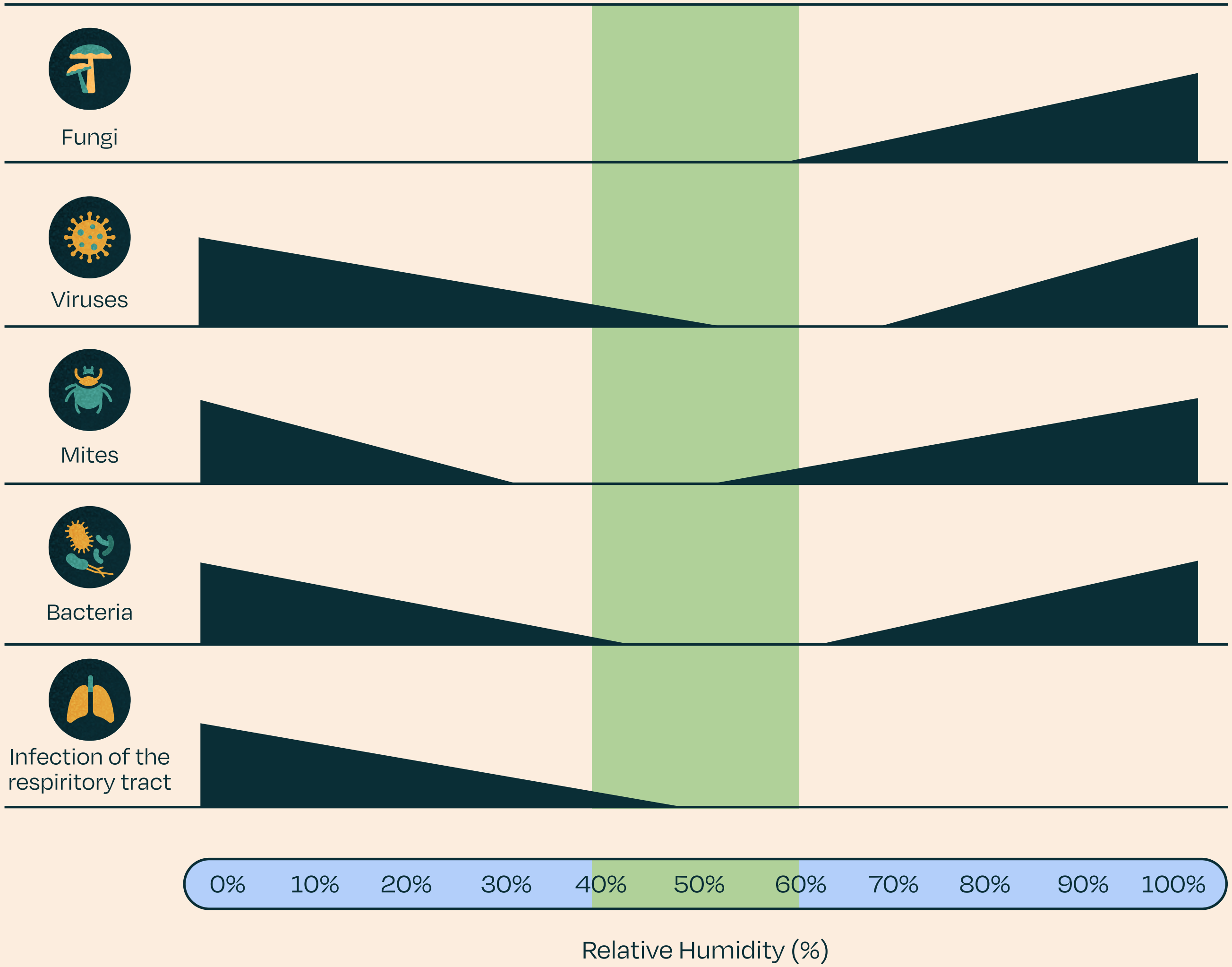
There is an optimal range of between 40-60% relative humidity for human health and comfort. Anything beyond 60% is deemed too moist (Figure 4).

Our modelling demonstrates the potential for poorer indoor environmental quality across Wales due to an increase in relative humidity.

All study locations will experience increases in relative humidity regardless of dwelling typology (**Figure 5**).

Relative humidity will be highest in pre-1919 dwellings and dwellings with solid stone walls (e.g. **Figure 6**).

Figure 4: The Schofield-/Sterling Chart



The Sterling Chart illustrates how relative humidity affects health and wellbeing and shows that the optimal air humidity level for humans is between 40 to 60% RH. This optimal humidity zone minimises risks to human health from biological contaminants and pathogens.

Figure 5: Indoor daily maximum relative humidity averaged over the study period for six locations throughout Wales for baseline, 2030 and 2070

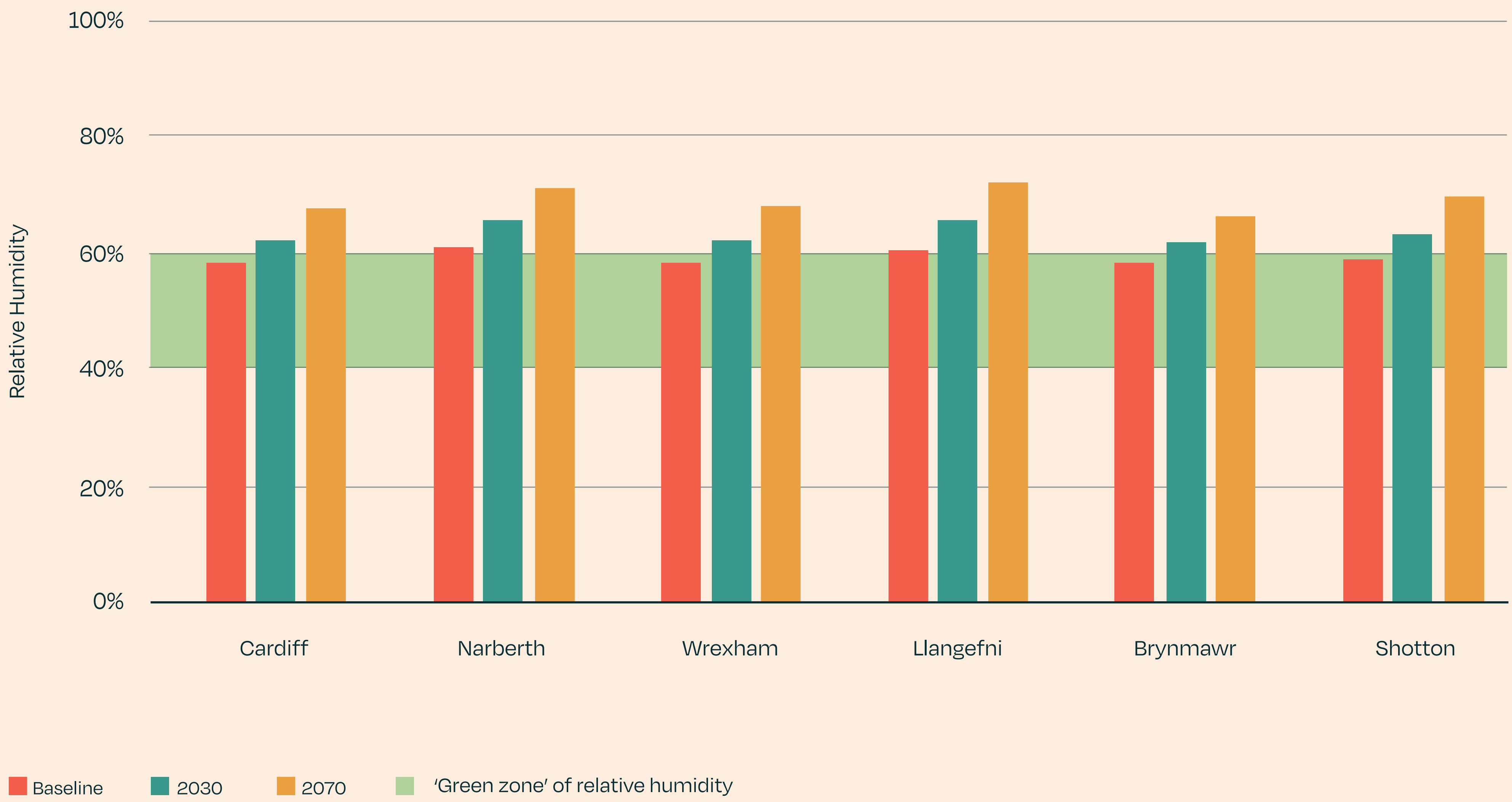
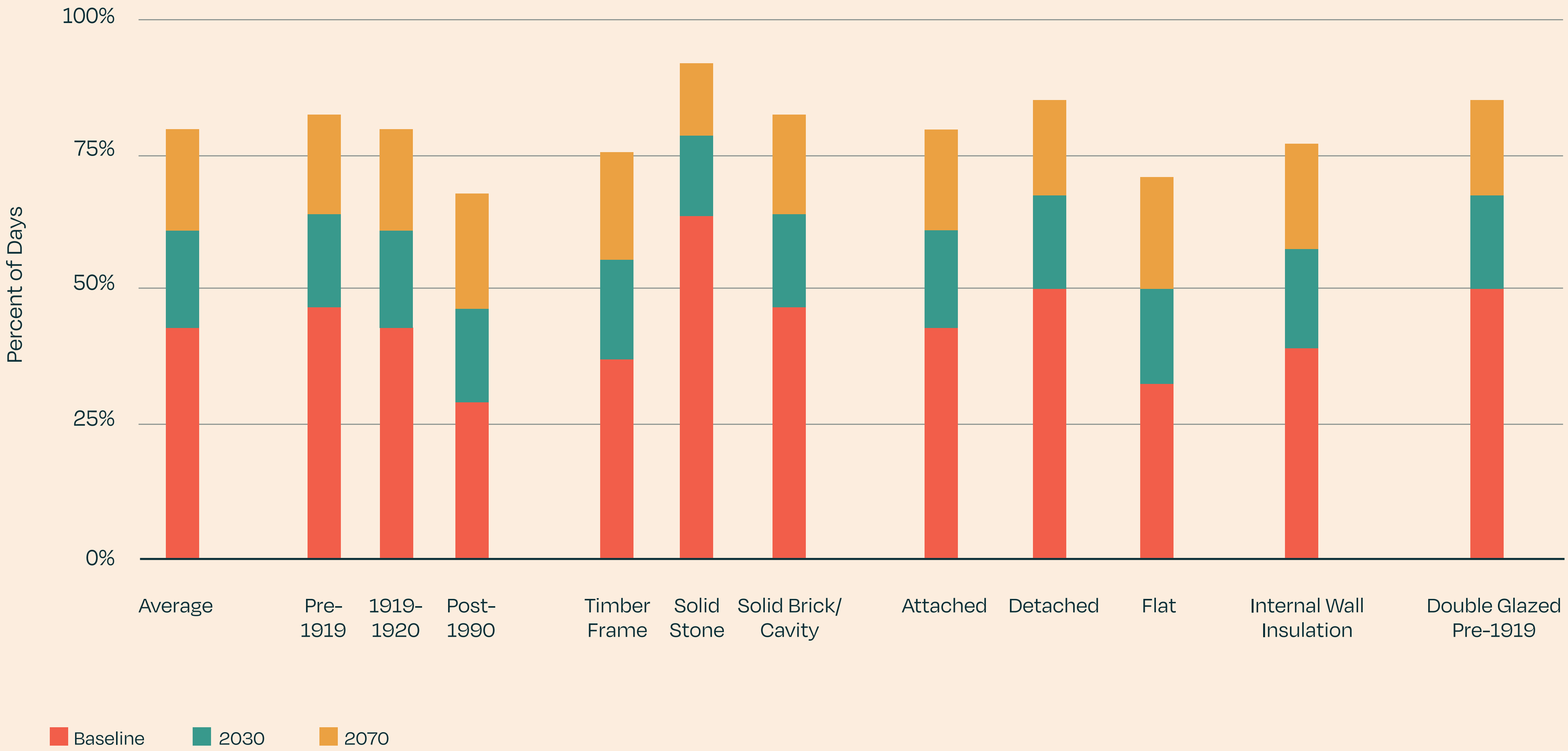


Figure 6: Percent of days in the study period with indoor daily maximum relative humidity above the 60% relative humidity threshold in Cardiff



Building fabric vulnerabilities

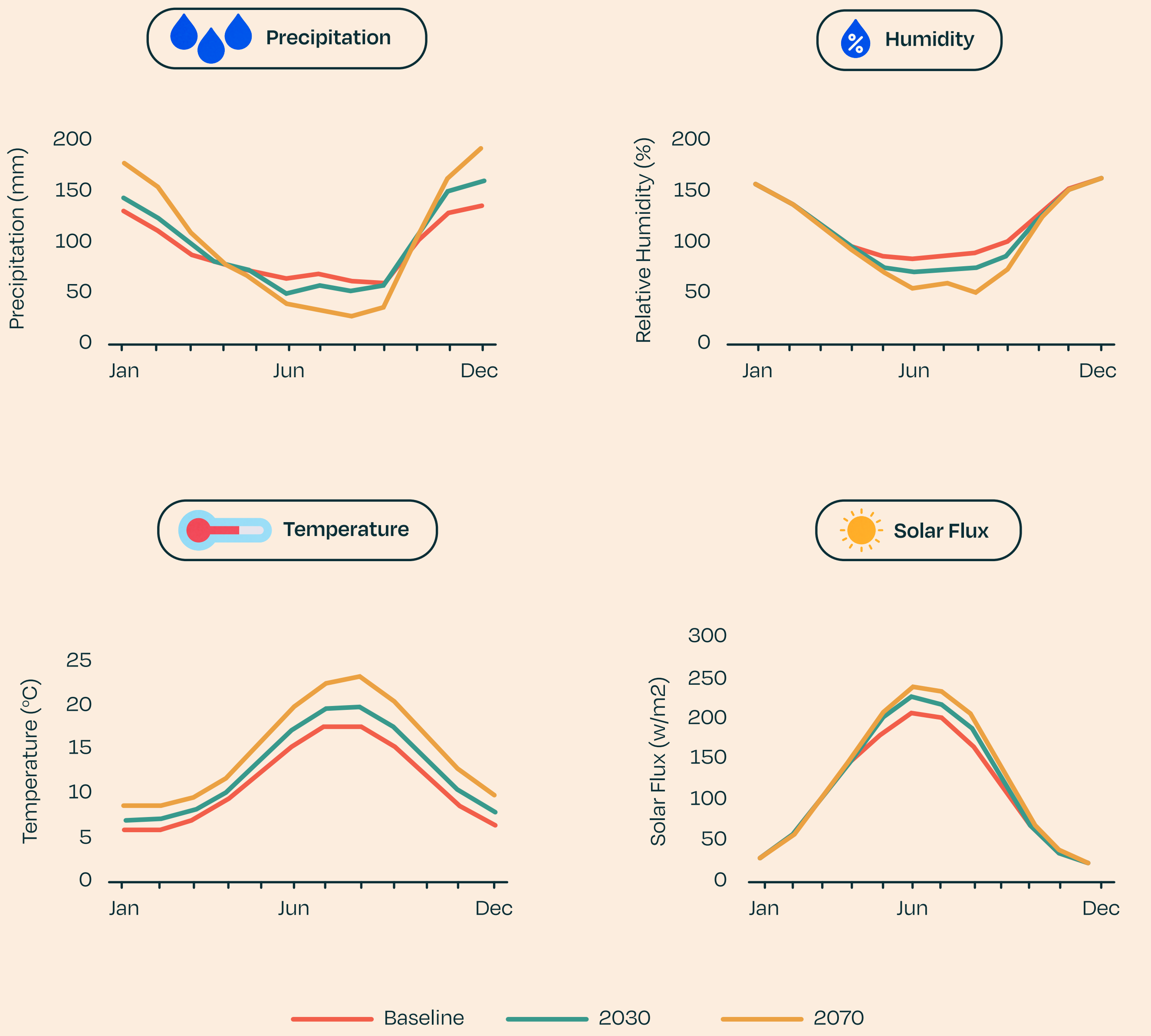
Building fabric vulnerabilities were calculated using service life data (BSI, 2008). Adjusted service lives and associated costs are quantified by applying discrete climate variables to individual building materials and components.

Changes in service life and resulting increases in baseline costs, predicted to be between 0-7%, are material dependent, and it's important to recognise that not every building material or component will be impacted by every climate variable. Building orientation will also make a difference.

Window and door frames are most vulnerable since climate variables that impact their degradation rate show trends of increasing into 2030 and 2070.

In addition to projected incremental climate impacts, extreme events, including concentrated downpours, and associated events such as flooding, must be recognised in repair and maintenance planning.

Figure 7: Modelling Cardiff's building fabric vulnerabilities



Synopsis of Building fabric degradation results for Cardiff													
Material or component	**Solar flux**	**Relative humidity**	**Precipitation**	**Forecast level of deterioration**	**Baseline service life**	**Adjusted service life**				**Change from baseline**			
						Solar flux	**Relative humidity**	**Precipitation**	**Average**	**Solar flux**	**Relative humidity**	**Precipitation**	**Average**
2030													
Roof tiles [clay or slate or concrete]	High	Low	High	Moderate	30	28.1	31.1	29.7	29.6	6.7%	-3.6%	1.1%	1.4%
Walls [brick or stone]		Low	High	Moderate	70		72.6	69.3	70.9		-3.6%	1.1%	-1.2%
Render and mortar [lime or cement]	High	Low	High	Moderate	50	46.9	51.8	49.5	49.4	6.7%	-3.6%	1.1%	1.4%
Masonry Paint	High	Low	High	Moderate	20	18.8	20.7	19.8	19.8	6.7%	-3.6%	1.1%	1.4%
Windows and door frames [timber or PVC]	High	-	High	Severe	20	18.8		19.8	19.3	6.7%		1.1%	3.9%
2070													
Roof tiles [clay or slate or concrete]	High	Low	High	Moderate	30	28.1	31.3	29.4	29.6	6.7%	-4.3%	2.1%	1.5%
Walls [brick or stone]	-	Low	High	Moderate	70		73.1	68.5	70.8		-4.3%	2.1%	-1.1%
Render and mortar [lime or cement]	High	Low	High	Moderate	50	46.9	52.2	49.0	49.4	6.7%	4.3%	2.1%	1.5%
Masonry Paint	High	Low	High	Moderate	20	18.8	20.9	19.6	19.7	6.7%	4.3%	2.1%	1.5%
Windows and door frames [timber or PVC]	High		High	Severe	20	18.8		19.6	19.2	6.7%		2.1%	4.4%

Adaptation priorities

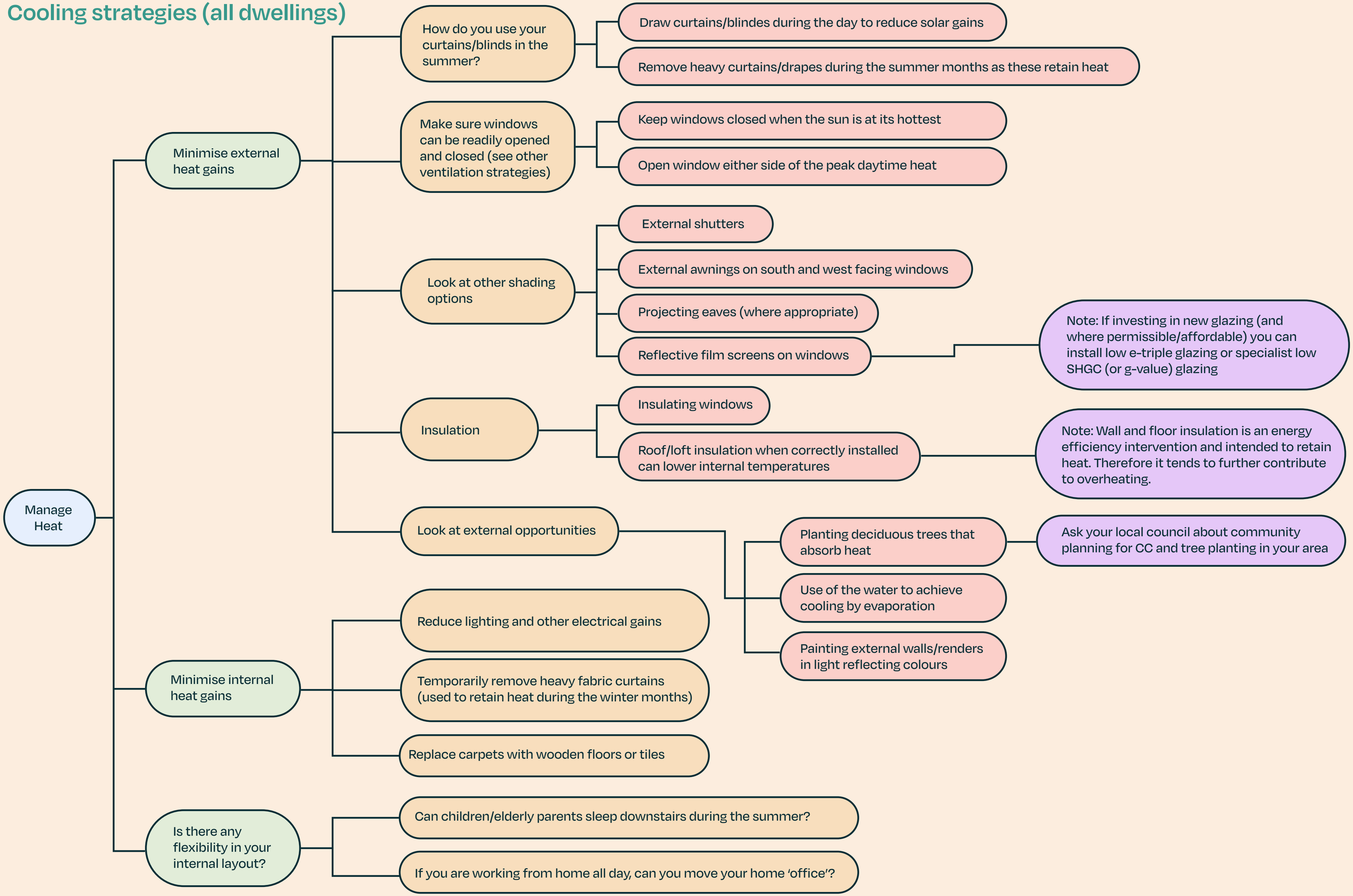
In partnership with stakeholders, we have developed cooling and drying strategies to improve indoor environmental quality, alongside approaches to better managing building fabric climate vulnerabilities, to support those who own dwellings in Wales.

We characterize the proposed climate adaptations as behavioural adjustments, internal fit-out alterations, and building fabric modifications. However, as identified in the literature, these should not be tackled in isolation.

Future risks to energy efficiency, health, and comfort, will be informed by our understanding of climate vulnerabilities and alleviated by joined-up decision-making.

For example, when considering improvements in energy efficiency to reduce winter heating costs, it's important to ensure adaptations won't have a negative impact on overheating in summer. Similarly, when considering adaptations to increase thermal performance, it's important to ensure they won't have a negative impact on ventilation.

Cooling strategies (all dwellings)



Cooling strategies (all dwellings)

- Manage ventilation
  - Passive ventilation strategies
    - Make sure windows can be readily opened and closed
      - Open your windows at night to release internal heat gains
        - Installing windows that enabled secure day and night-time ventilation
      - Reopen windows that have been painted shut
    - Try and cross ventilate. Have windows (and doors) open on opposite sides of the room/house to maximise air circulation
    - Reopen closed ventilation routes, such as blocked chimney flues etc.
  - Active ventilation strategies
    - Portable personal fans for desks/bedtime (renewable batteries)
    - Ceiling fans can help air movement (but only slightly reduce room temperatures)
    - Air conditioning units should only be considered when all other adaptations have been exhausted

- Increase night-time ventilation
  - Passive ventilation strategies
    - Open windows (and doors) as much as possible from late afternoon to early morning
      - Cross-ventilate where possible to better release internal heat gains
        - Installing windows (and doors) that enable secure night-time ventilation

Drying strategies (all dwellings)

- Manage air circulation (ventilation)
  - Air circulation (ventilation) strategies to recude relative humidity which ideally should be 60% or less
    - Make sure windows can be readily opened and closed
      - High humidity at night puts more stress on the human body
    - Try and cross ventilate (have windows open on opposite sides of a room/house) to maximise air circulation
    - Maintain chimneys, flues and air vents, unblocking any that have been sealed
      - Reopen any closed ventilation routes, such as blocked chimney flues, air bricks, etc
    - Ensure roof and under floor spaces are well ventilated
  - Mechanical air circulation (ventilation) strategies
    - Always use an extractor fan in high moisture rooms. Especially washrooms and kitchens
      - Extractor fans renew the ambient air in a room, which limits the emergence or any condensation and the appearance of mould all the while reducing the humidity level
      - Ensure appropriate air filtering present in extractor fans
    - Invest in smart ventilation (and heating) controls
    - Ceiling fans can help with air movement
    - Where air tightness has been increased in your home (e.g. through internal wall insulation for improved energy efficiency) ensure your builders have installed appropriate mechanical ventilation to stop moisture build up
      - Choose constant extraction rather than purge extract triggered by relative humidity setting
      - Ensure appropriate air filtering in mechanical ventilation systems
      - Replace vapour closed insulation with a vapour open system
  - Design and layout issues
    - Are your dishwashers, washing machines and tumble driers in well-ventilated spaces?
      - Check the moisture output requirements of your white goods
    - Do you have effective clothes drying in well ventilated areas?
      - Avoid drying clothes indoors. If this is unavoidable, make sure you can remove the additional moisture from your chosen drying space
    - Review your bath, shower and sink design for effective drainage
    - Use mould-resistant paint in high moisture rooms. Particularly in kitchens and bathrooms
    - Think about the location of furniture to avoid mould in e.g. corners (where there is low air movement)

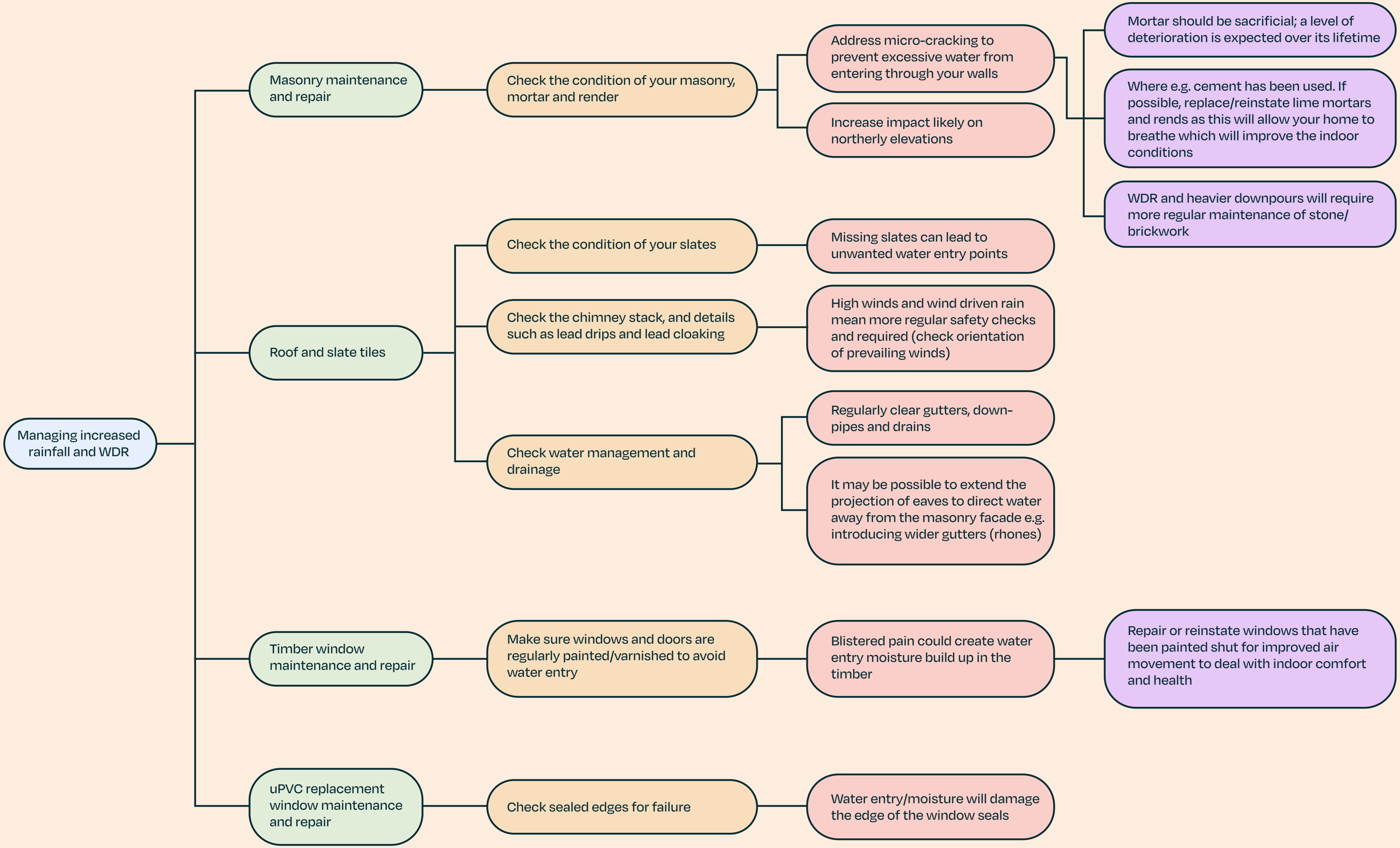
Drying strategies (all dwellings)

- Manage heat
  - Invest in smart heating (and ventilation) controls
  - Try and maintain a minimum indoor temperature. It is recommended that you never let the temperature of your home fall below 14°C
    - Ideal bathroom temperature is 23°C
    - Ideal baby/infant room temperature is 23°C
    - Ideal living room temperature is 20°C
    - Ideal bedroom and kitchen temperature is 16°C
- Manage air quality
  - Fit a temperature and relative humidity monitor in rooms likely to experience higher moisture levels
  - Fit an audible carbon dioxide alarm that meets European Standards (EN 50291)
    - When we burn any solid fuel carbon monoxide is produced
      - This is not normally a problem as all the smoke and gasses should pass harmlessly out the top of the chimney. If however the chimney is blocked or leaky, the appliance is faulty or if the ventilation to the fire is inadequate, carbon monoxide gas may enter your property
  - Fit a carbon dioxide monitor to regulate airflow
    - As carbon dioxide levels rise, the quantity or volatile organic compounds, odours and micro-organisms in the air rise too
  - Fit a Volatile Organic Compounds (VOCs) monitor
    - VOCs are a wide range of carbon based (organic) chemicals (compounds) found in various man-made and naturally occurring solids and liquids
      - Typical indoor VOC sources include paint, cleaning supplies, furnishings, glues, permanent markers and printing equipment. Levels can be particularly high when there is limited ventilation
      - Choosing furnishing, DIY, construction and consumer products with low VOC emissions
    - Some VOCs are harmful to human health and can cause environmental damage. Exposure to high concentrations of VOCs can lead to throat irritation, headaches and damage to internal organs. Continuous low level exposure often causes long-term health effects. The severity depends largely on the type of VOCs present as well as the exposure time
- Stop water from getting into your home
  - Avoid high-moisture activities indoors where possible e.g. drying clothes

Strategies to manage building fabrics (pre-1919 dwellings)

- Manage increased temperature and solar flux (radiation)
  - Painted surfaces
    - Make sure windows and doors are regularly painted/varnished
      - To avoid blistering from increased solar flux
        - Blistered paint could create water entry and moisture build up in the timber
  - Plastics
    - Check sealed edges of any uPVC replacement windows
      - Solar radiation acts on edge seals. Frequency of brittle failure of uPVC may increase on souther elevations exposing masonry to water entry
    - Check other plastic such as rainwater pipes
      - Plastic rainwater drainage pipes can be subject to UV degradation
        - Moisture ingress through cracks and gutter over-spill will occur more frequently
  - Sealants
    - Check sealants used for e.g. windows and door installation
      - A polyurethane sealant will degrade with increased solar flux
  - Design and layout issues
    - Could you add an awning to the outside of your house?
      - An awning can protect your home's exterior from solar radiation
    - See COOLING adaptations for strategies for keeping cool indoors

Strategies to manage building fabrics (pre-1919 dwellings)



Strategies to manage building fabrics (pre-1919 dwellings)

- Managing increased rainfall and WDR
  - Drains, downpipes and guttering
    - Check for pooling and rain splatter at base of walls
      - Increase the capacity of your rainwater goods and/or redirect water away from your home
        - Pooling and rain splatter at base of walls mean they will stay wetter for longer
        - Using a water butt to collect rainwater to use on your garden will help reduce this
        - Introduce a sustainable drainage system (SUD) to manage stormwater locally
        - Install a French drain which will direct subsoil and water away from your property in areas that are prone to flooding or surface water poooling
        - It may be possible to adapt detailing, such as cornices and parapets, cills to divert rainfall from masonry
  - Design modifications
    - Ensure roof and under floor spaces are well ventilated
      - Maintain ventilation/air extraction to avoid build up of moisture
    - Add an awning to the outside of your house?
      - An awning could protect your home's exterior from the effects of prolonged exposure to driving rain
    - Be aware of the impact of any internal wall insulation is having on the breathability of your walls
      - It may be possible to replace vapour closed insulation with vapour open alternatives
    - Could you reduce/remove hard standing from your property's boundary?
      - Reducing immperveous materials will improve drainage
    - Could you increase planting/growing trees?
      - Planting can protect your home's exterior from the effects of prolonged exposure to driving rain
- Manage indoor moisture, mould and damp
  - See DRYING adaptation strategies

Strategies to manage building fabrics (pre-1919 dwellings)

- Floor risk adaptations (where relevant) – Check NRW flooding advice/ map for your area
  - Outdoor adaptations
    - Reinstate or upgrade any broken or blocked drainage/rainwater systems (see Managing increased rainfall and WDR)
    - Install SUDs or a French drain
    - Introduce non-return values for underground drainage
  - Indoor adaptations
    - Check damp proof course is working as it should
      - Repairing/reinstating a suitable DPC will help reduce water entry
    - Check the fit of your doors, windows and floorboards to avoid any unnecessary water entry
    - Relocate electrical services above flood level
    - Relocate gas/electricty meters and boilers above flood level
    - Replace carpets with hard surfaces
      - Rugs can be removed quickly, fitted carpets cannot
    - Use mould-resistant paint
      - Waterproof paints should be avoided as these will prevent the walls from drying out
    - Fit rising hinges so doors can be removed

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Report prepared for the Welsh Government by

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Ariennir gan Lywodraeth Cymru
Funded by Welsh Government

In partnership with Cadw