

The Building Stock: Impacts and Adaptation

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Executive Summary

The information contained in the Position Paper, *The Building Stock: Impacts and Adaptation* needs to be understood within the context of the environment from which it has emerged.

International research has been taking place to determine the impact of climate change on susceptible communities and to understand the policy changes that will be necessary as a consequence (*IPCC 4th Assessment Report, starting page 14*). At a national level, research has determined the financial losses that are likely to be incurred by the building stock as a result of climate change (*Framing Current and Past Research, starting page 4*).

The significance of these data needs to be understood within the context of the UK's substantial investment in the regeneration of its towns and cities following the demise of industries that were previously located there. New building has taken place and continues to do so, almost in parallel with concerns over the lack of response to climate change within design and refurbishment (*Linking the Housing Stock and Energy Supply Systems, starting page 12; Characterising the Past and Future Stock, starting page 19*).

Research has indicated that the methodologies and professional knowledge required for sustainable design and refurbishment of cities and neighbourhoods needs to be improved (*Linking the Housing Stock and Energy Supply Systems, starting page 12*). As part of this effort, tools are being developed to predict the effect of urban heat islands in a changing climate (*Quantifying the Urban Heat Island, starting page 16*), allowing analysis to be undertaken during the design of new settlements. Further work has been undertaken that re-assesses the benefit of the existing building stock and its contribution to a low CO₂ footprint (*Adapting the Building Stock to Increased Temperatures, starting page 5; Characterising the Past and Future Stock, starting page 19*). The development of predictive tools is enabling the sensitivity of historic buildings to be evaluated for the first time for their response to climate change, specifically increased flood risk, rainfall and temperature variations (*Building Knowledge for a Changing Change, starting page 9*).

The regulatory framework in Europe has taken on board the need for mandatory energy targets for building design (*Developing a Policy Framework, starting page 22*) in the context of a range of probable futures (*Dealing with Uncertainty, starting page 18*) and significantly it is also adopting preliminary technical standards on air quality, temperature and ventilation in the internal environment as metrics of 'fitness for purpose' (*Developing a Policy Framework, starting page 22*).

Questions to consider in the context of future research:

- How do the differences or advances in understanding climate change (including changes in the associated uncertainties and the projections, which are likely to continue over time) affect adaptation strategies and adaptive capacity?
- To what extent will the developing pattern of use of domestic air conditioning have a role to play in adapting to climate change?
- How will provision be made to enable the testing of the robustness of design options to future climates?
- What is required to achieve better coherence in policy terms among the different branches of Government that deal with the Building Stock? For example, planning for the built heritage does not reflect mainstream concerns for mitigation and adaptation to climate change.

1. Background

This paper is one of three position papers prepared for the Sustaining Knowledge for a Changing Climate (SKCC) workshop for researchers and stakeholders held in Birmingham on 14-15 May 2007. Its aim was to help map out the future direction of research in adaptation of climate change. The three papers relate to the following three tasks that were identified in the original proposal:

“1 Evaluation of adaptation options across sectors

This task will examine the climate adaptation measures emerging across all of the Building Knowledge for a Changing Climate (BKCC) projects, to develop an assessment of the inter-relationships between these measures, to evaluate their combined impacts and to identify any potential conflicts. We will begin by identifying measures that have potential benefit across multiple sectors and will then, through literature review and workshop activities, evaluate and rank the most promising options.

2. Linking adaptation and mitigation strategies

There are a number of areas in the built environment where strategies for adaptation to climate change might have an adverse effect on greenhouse gas emissions and hence mitigation efforts - for instance, if energy-intensive air conditioning is installed to cope with higher temperatures. Many of the materials and engineering solutions for adaptation may have significant energy implications. To date, little work has been done to evaluate the impacts on mitigation of these adaptation strategies, though the FP6 project ADAM is making early progress in this field. This scoping will pave the way for new research on combining adaptation and mitigation.

3. Impacts and adaptation in existing and new building stock

This task will expand upon the research in the Engineering Historic Futures project to scope important gaps in the BKCC portfolio including existing and new buildings. The existing building stock represents a particular challenge in terms of climate impacts and adaptation. The DCLG’s recent revision of the Building Regulations (Part L) following the European Energy Performance of Buildings Directive, as well as the emerging new Code for Sustainable Buildings lend weight to the need to focus attention on existing buildings more than new build at this time. Recent DTI, English Heritage and CRISP funded research projects have made useful contributions to knowledge in this area. “

This paper focuses on Task 3: ‘Implications and adaptation in existing and new buildings’. The direction of the paper has been driven by the original proposal definition of this Task. It is beyond the scope of this paper to provide an exhaustive review of all relevant climate change research undertaken in relation to the built stock – the special issue of ‘Built Environment’ (Vol 33 – 2007) for example, specifically addresses what climate change means for the UK urban environment in terms of impacts, risk assessment, adaptation, and decision-making under uncertainty. [<http://www.atypon-link.com/ALEX/toc/benv/33/1>] Instead this paper introduces the topic of adaptation in buildings; reviews previous research undertaken as part of the EPSRC BKCC programme, and other programmes focusing on key areas where knowledge is missing and key areas of development for both new build and existing stock. The opportunities for adaptation that exist over the next 50 years in new and existing stock are then reviewed. Much of the adaptation in the built stock

will be driven by legislation, standards and other policy instruments, a summary of which is given at the end of the paper.

2. Framing Current and Past Research

In 2001 CRISP (Construction Research and Innovation Strategy Panel), undertook a review of the impacts and adaptation that climate change would have on the built environment

The objective of the report 'was to identify and collate recent work on climate change and its impact on the built environment, form a view on its effectiveness and impact (or lack of impact), and the underlying reasons'.

CRISP identified a number of key issues for research. These were the impacts of coastal and riverine flooding, subsidence and wind and storm damage and the impacts of warmer summers on thermal comfort. Research in the first two impacts was underway at the time of the report. However, significant gaps in the effects of warmer summers on thermal comfort were identified

One of the most important findings of this study was on ensuring climate change adaptation strategies were developed with due consideration to other agendas for change within the construction industry. These agendas included the movement towards industrialisation, concern for the health and safety of employees, the training of those working in construction, the process of economic growth and the impact of measures needed to control carbon emissions.

The CRISP report of 2001 concluded that:

One of the most important factors in developing climate change adaptation strategies is the very high degree of uncertainty that surrounds all aspects of climate change. Taking the full range of uncertainty presented in the IPCC Third Assessment Report (IPCC 2001), estimates of global sea level rise in 2001 range from under 10 cm to about 85 cm. The implication of such uncertainty is that strategy needs to be based on an acceptance of the precautionary principle, on the maximisation of future flexibility, and on the expectation that perceptions of risk may change repeatedly over the next 50 years. This in turn suggests that the process of establishing and maintaining consensus for action will need to be a continuous one.

It is important to keep the impacts on climate change in proportion. While, at any given location, climate change will rapidly drive weather outside the range of existing variability, weather at most UK locations will remain inside the range of existing variability for the whole of the UK, and weather at all UK locations will remain inside the range of existing variability for Europe and North America. Adaptation to climate change is unlikely, for a century at least, to require anything that is not done somewhere already, either in the UK or in neighbouring countries. This is not to say that innovation is of no value. Improvements to the wheel will always be of value, but the UK construction industry and research community can afford to spend significant resources ensuring that they do not re-invent it.

The CRISP report concluded that the problem of adapting to the demands of a vigorously pursued mitigation agenda might well pose greater problems than adapting to climate change. A major omission from this report was the potential for large scale, climatically induced migration, and its impact on all categories of infrastructure.

Since this work was carried out, several key research projects have been commissioned and/or completed. The UK Climate Impacts Programme (UKCIP) Adaptation Actions database has been launched showing how organisations in the UK are adapting to climate change. This database shows how risks can be minimised and opportunities exploited by identifying what others are doing to adapt, and to help organisations identify what actions they might need to take to reduce their risks. The database is searchable by region, sector or adaptation activity. Used with other UKCIP tools, particularly the Risk, Uncertainty and Decision Making Framework and the Adaptation Wizards, adaptation options can be identified. The UKCIP02 climate change scenarios, which show how the climate of the UK might change over the 21st century, have become a standard reference for much UK impacts and adaptation work. The next package of climate change information for the UK, UKCIP08, will be released in 2008. Climate data will be available for the UK based on 25km x 25km grids, in comparison UKCIP02 produced information on 50km x 50km grids. Overlapping 30 year time slices for 3 emissions scenarios will allow the evolution of changes in climate to be observed. As well as reports including maps, technical information and guidance, UKCIP will provide a dedicated web interface to deliver tailored climate change outputs.

Discussion Box 1:

How do the differences or advances in understanding climate change (including changes in the associated uncertainties and the projections, which are likely to continue over time) affect adaptation strategies and adaptive capacity?

2.1 Adapting the Building Stock to Increased Temperatures

Populations typically display an optimum temperature range at which the death rate is lowest. Mortality rates rise at temperatures outside this optimal zone. Whilst the impacts of increased temperatures inside buildings may be beneficial during the heating season, it is important to examine the impacts in summer. In the hot summer of 2006 in the UK, there were 680 excess deaths due to high temperatures compared to 25,700 excess winter deaths in 2006. Therefore the direct impact of rising temperatures may be an overall reduction in excess deaths and not an increase.

If increased mortality represents an extreme consequence of rising temperatures, it is clear that the proportion of the time that people will feel 'uncomfortable' has the potential to increase. This raises the possibility of a large increase in the use of mechanical cooling

systems and a consequent rise in energy use. Again though, there will be energy benefits during the heating season.

In broad terms, adaptation of buildings will be required to minimize energy use, maximize winter indoor temperatures, minimize indoor temperatures during heat waves (of varying characteristics) and allow sufficient ventilation to prevent any adverse impacts on air quality, health and rarely on building conservation – this is clearly a non-trivial task.

Two recent key studies have dealt with the issue of overheating and a changing climate. The first, a modelling-based investigation by FaberMaunsell ¹ concluded that:

- *“...a review of experience in real buildings confirms the concern that high temperatures may be felt in very well-insulated houses if no measures are taken to control overheating.”*
- *“The cure for overheating involves redressing the balance between heat gains to the space and heat losses – one may either reduce the heat gains, increase the heat losses, or both – and use thermal mass acting as a heat sink or source as appropriate.*
- *“Adopting a combination of measures can be the most effective. Reducing solar and casual gains will mean that less thermal mass and night cooling will be required to remove the gains.*
- *“...during warm periods, highly insulated spaces will assist with maintaining favourable (cool) environments, but conversely, they may worsen unfavourable ones, i.e. spaces that are already overheating.”*

So it would seem that well designed highly insulated houses perform better than less well insulated houses in very hot weather. This suggests the possibility of a double win, with a single measure achieving both mitigation and adaptation goals. Similar results have been reported by the Passivhausinstitut for very highly insulated dwellings in the hotter climate of Germany²

Unfortunately, good design and construction cannot be taken for granted – indeed the opposite might be more likely. We must therefore factor in the possibility that in the UK better insulation will increase risks of higher energy use and increased mortality due to overheating. As will be discussed later behaviour lifestyles and maintenance can significantly affect the efficacy of adaptation options.

¹ Orme M and Palmer J (2003) Control of overheating in future housing – design guidance for low energy strategies. FaberMaunsell, UK

² Feist, W., Schneiders, J., Gerber, A. & Kuhn, T. (1999) *Passivhaus-Sommerfall. Protokollband 15.* Darmstadt: Passivhausinstitut.

The Chartered Institution of Building Services Engineers (CIBSE) TM36³ report details the results of the second key study - the likely implications of climate change for increased thermal discomfort in existing buildings are examined through computer modelling of a number of case study buildings for three different locations: London, Manchester and Edinburgh. The study concluded (in an associated summary document⁴):

- *The majority of buildings in the UK are cooled by opening windows. Traditionally, this approach has prevented thermal discomfort. But summers are getting warmer because of climate change. When it is hotter outside then we want it to be inside a building, opening windows provides no real cooling benefit. Climate change means, that buildings in the UK are likely to become increasingly uncomfortable in summer unless other methods of cooling are used.*
- *Passive measures can greatly reduce mechanical cooling needs. For homes in London, they have been shown to work well into the 2080s. For London's offices and schools, it is likely they will need to be supplemented by mechanical cooling from the 2050s onwards.*
- *In London, it was found that increased thermal discomfort is likely to be a major problem for many existing buildings unless they are adapted for the changing climate.*
- *These findings indicate that significant variations will exist across the UK with regard to potential for summertime thermal discomfort. Consequently, a 'one size fits all' form of architecture will become less and less appropriate for the UK.*

The main report noted that, with respect to performance criteria, it is essential that the building industry has:

- Appropriate overheating risk criteria
- A standardised calculation method
- Standardised climatic data
- Standardised methodology

These issues present significant challenges but are beginning to be addressed. For example, CIBSE now has a new climate task group which is tackling some of these issues.

Relevant research has recently been undertaken at University College London as part of the Carbon Visions Carbon Reductions in Buildings (CaRB) project and the EPSRC Domestic Air Conditioning project. Attempts to reduce the energy consumed in UK homes

³ Climate change and the internal environment: impacts and adaptation, (2005) TM36, CIBSE, (Principal authors: Hacker J.N., Holmes M.J., Belcher S.B. and Davies G.D)

⁴ Hacker, JN, Belcher, SE & Connell, RK (2005) Beating the Heat: keeping UK buildings cool in a warming climate.

have met with limited success. One reason for this is a lack of understanding of how people interact with domestic technology. CaRB aims to create a socio-technical model of energy use which will predict carbon emissions in the UK's residential and commercial properties. Hundreds of homes will be surveyed and the energy uses of occupants will be monitored. This will enable the consequences of implementing energy efficient initiatives and renewable energy technologies to be monitored. The research provides both measured data in real dwellings of the degree of overheating and the potential energy use of domestic air conditioning. The CaRB research looks at current occupant behaviour rather than what might happen in the future. Behaviour may be determined by the available technology. The easy availability of air conditioning units might change existing patterns of behaviour, with people becoming reliant upon them in hotter summers.

Living Room Monitored Data

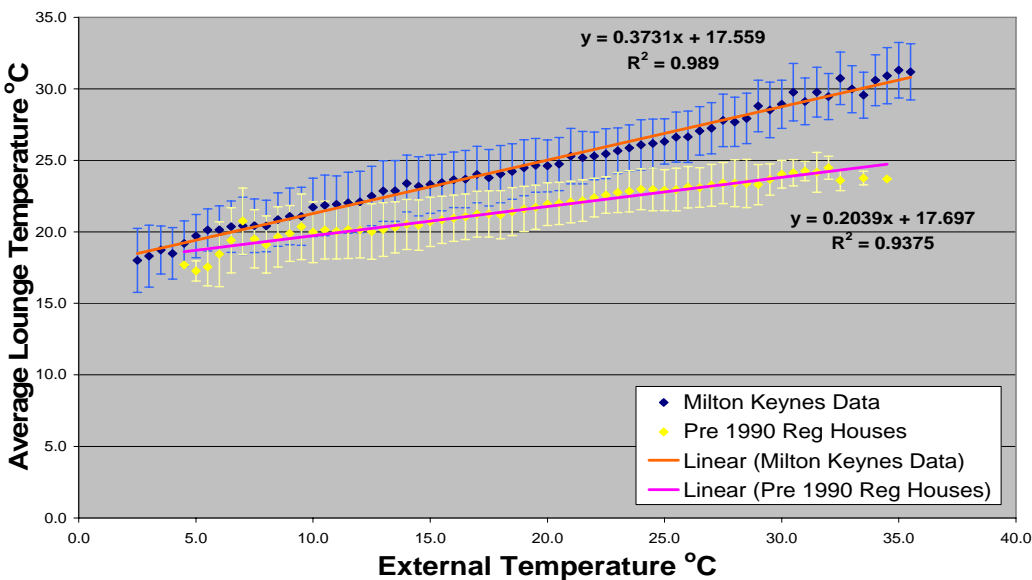


Figure 1: Plots of Average Living Room Temperature against External Temperature for Insulated Milton Keynes Houses and pre 1990 houses. Source: Final Report: Domestic Air Conditioning - Occupant Use and Operational Efficiency (EPSRC GR/S45423/01) October 2006 by A N Young, A Pathan and T Oreszczyn, The Bartlett School of Graduate Studies, University College London

Interestingly modern built dwellings (the top curve in Figure 1) can overheat more (4.9°C warmer at 30°C outside) than traditionally constructed older, uninsulated properties. Note, the modern properties were built before regulations came into force to design dwellings to avoid summer time overheating. This data is therefore the first empirical evidence of the importance of regulating for warmer summers and may provide evidence that the current regulations will need to be tightened further in terms of their potential to limit summer time overheating.

Domestic air conditioning is likely to increase significantly in the future in part as an adaptation measure to climate change thereby following the trend in increased air conditioning in non-domestic buildings.

The following summarises some of the main conclusions from the final report of the domestic air conditioning project⁵:

- *Typical patterns of use of residential cooling in the UK have been established. The average switch-on temperature in day use rooms was 25.0°C, while for bedrooms it was 23.9°C. The duration of a single operation was 5 hours in day use rooms and 9 hours in bedrooms. The average cooled temperature was 24.6°C in day use rooms and 20.3°C in bedrooms.*
- *Electricity consumption, attributable to mechanical cooling in houses in the south-east of England, is estimated to be 0.012% of the total UK electricity consumption, and as such is not a major source of UK carbon emissions. Consumption is predicted to double by 2020.*

Therefore it appears that if current patterns of domestic air conditioner use are maintained then the overall impact on mitigation may be small. However if whole house air conditioning is introduced, then the impact may be significant.

Discussion Box 2:

To what extent will the developing pattern of use of domestic air conditioning have a role to play in adapting to climate change?

2.2 Building Knowledge for a Changing Climate (BKCC)

Through a portfolio of nine projects, EPSRC and UKCIP funded a programme of research, BKCC, which has advanced knowledge of the impacts of climate change on urban drainage, engineered slopes, the electricity supply industry, the aviation industry, historic buildings and infrastructure and the urban environment more generally

One of the projects tackled the dynamic relationship between the exterior, interior and wall thickness in a changing climate. The aim of *Engineering Historic Futures* was to investigate how the moisture content of walls in historic buildings will change as a result of the predicted changes in wind driven rain. Would this lead to higher moisture contents? Would future ambient conditions lead to changes in drying times of flooded walls? The findings were based on a study of two sites: Blickling Hall in Norfolk and Brodick Castle on the Isle of Arran.

One piece of good news is that drying times after flooding will be shorter in the future. The moisture content within walls at Blickling Hall was calculated at 4 depths: external surface,

⁵Young A.N., Pathan, A., Oreszczyn, T. (2006) Domestic Air Conditioning - Occupant Use and Operational Efficiency (EPSRC GR/S45423/01)The Bartlett School of Graduate Studies, University College London

middle of the wall, 10cm from internal surface and on the internal surface, see Figure 2. In 2040, conditions are predicted to be largely unchanged from the present. In 2080 walls begin to dry in the summer periods. So during non-flooding episodes, walls were predicted to be drier under 2080 conditions than present and natural drying was found to be faster under 2080 conditions than present day at Blickling Hall.

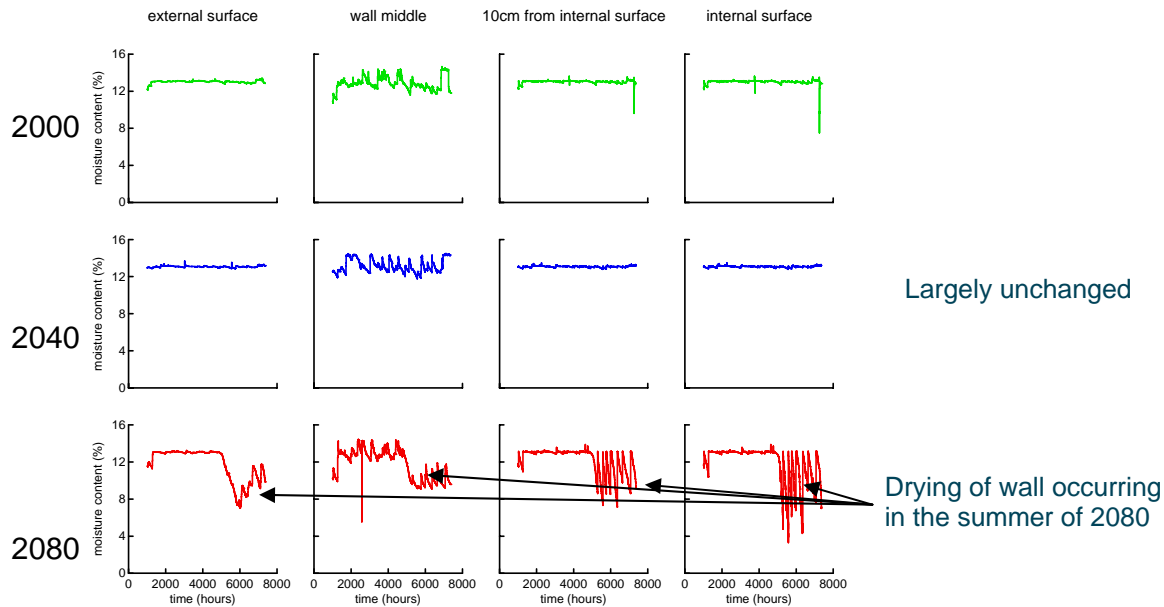


Figure 2: Moisture content within wall at Blickling Hall, Norfolk calculated at 4 depths: External surface, Middle of wall, 10cm from internal surface, internal surface

At Brodick Castle, where the moisture content was also similarly calculated at 4 depths, the middle of the wall remains unchanged in 2040 from 2000, while surfaces of the walls facing the interior are predicted to dry in the summers of 2040 and 2080, see Figure 3. On the other hand, no great change was predicted in wall moisture content due to wind driven rain. If walls are wet due to driving rain under present conditions they will be wet in the future. No step change in moisture content of the wall was predicted.

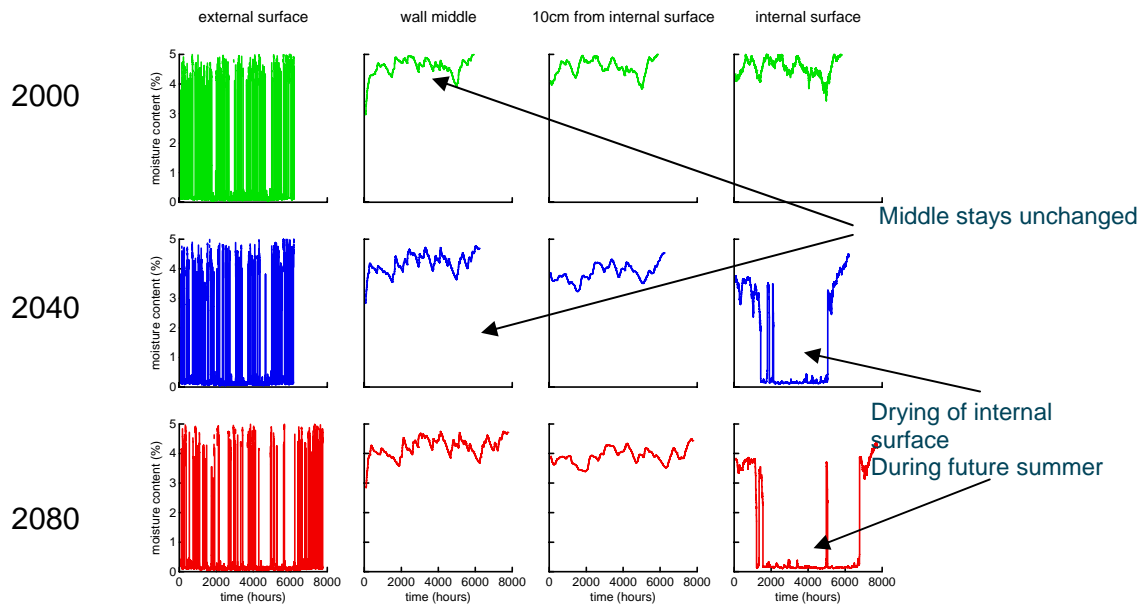


Figure 3: Moisture content within wall at Brodick Castle, calculated at 4 depths: External surface, Middle of wall, 10cm from internal surface, internal surface

The project also considered the effect of forced drying of walls after a flood both tested in the laboratory and on site. Artificial drying of flooded brick walls using dehumidification and rapid heating dried the interior wall surfaces, but did not dry the centre of the thick historic walls. Forced drying at Blickling Hall had an immediate and powerful effect. After between 40-50 days of dehumidification the wall surfaces showed significant drying with the air moisture content of the room reduced to a similar level to that outside. Significantly after more than a 100 days of dehumidification when the equipment was switched off conditions returned to the original ones within a few days. Natural drying of flooded brick walls takes in the order of years, however even small restrictions on room ventilation can drive up airborne moisture by up to 40%.

These findings are not conclusive. The simulation model that was developed needs further validation. Measuring moisture measurement in situ is necessary but difficult – historic walls are not homogenous and salts and other contaminants may affect the measurements. Moisture measurement is also invasive, requiring holes to be drilled in walls and in a listed structure will require listed building consent. Can other methods be used? New techniques are needed especially for dynamic measurement of moisture movement that can cope with the presence of salts that can measure transient effects, do not affect local moisture content or deteriorate themselves in an aggressive environment. Predictions of the frequency of local flooding also need to be developed, using local topography and drainage capacity, as well as predicted climate conditions. *Engineering*

Historic Futures examined what happens to flooded walls but not the frequency of flooding under future climate scenarios.

Following on from this project, the European funded project *Global Climate Change Impact on Built Heritage and Cultural Landscape* (also known as The Noah's Ark project) built on the work undertaken in the *Engineering Historic Futures* project. It is important to explain why drying strategies are important. Flooding caused by sea, rivers, more intense rainfall, inadequate drainage or poor surface water management is likely to increase building fabric saturation. Yet there is often pressure to bring buildings back into use for conservation, health, economic and social reasons. So the scene is set for tensions between the need for rapid repair and long-term conservation.

The methodology that was developed for applying hygrothermal modelling to the built heritage under different climate conditions, took into account building use as well as measured indoor and outdoor relative humidity and temperature; building design and construction as well as the IPCC climate change predictions for the near future (2020s) and far future (2080s). A hygrothermal model was validated and used to simulate the impact of wetting and drying on a wooden, brick and stone building under future climate conditions. Both natural and forced drying were simulated and compared to what might have been if the model had not been flooded. Forced drying brought the moisture content down more quickly. Looking at this situation under the 2020 and 2080 climate scenarios, natural drying reduced the moisture content of the wood to the 'no flood' condition but forced drying in both cases was a rather blunt instrument. With our overall state of knowledge, it appears that the moisture content of wooden walls will decrease slightly in future while forced drying leads to over drying and large changes in the internal moisture profile. Simulations are now being run on brick and stone buildings.

2.3 Linking the Housing Stock and Energy Supply Systems

The journal 'Building Research and Information' (35:4, July/August 2007) has published its second special edition on Climate Change. A preview of the key messages from this special issue shows that:

- ***the UK housing stock cannot be considered in isolation from energy supply systems***
- ***plausible developments in energy supply and conversion systems over the period from 2010 to 2050 may make CO₂ emissions from the housing sector insensitive to dwelling demolition rate***
- ***external insulation of solid walls means that solid-walled houses can outperform new cavity walled properties in energy and CO₂ terms.*** "In this light, solid walls should be seen as an untapped strategic opportunity, rather than as an insuperable barrier to decarbonisation."

- ***embodied energy and CO₂ emissions associated with the infrastructure for new housing developments may be at least as large as that for the buildings alone***
- ***despite the above emphasis on reducing domestic sector emissions by tackling upstream energy supply systems,*** [the] performance of dwelling envelopes and final energy conversion systems is [...] likely to be a key determinant of the extent and rate of decarbonisation of the housing sector and of the costs associated therewith. Reductions in end-use demand propagate back through the energy supply and conversion chain and reduce all upstream costs. Improvements to envelope and final energy conversion systems pre-shrink the task of supply systems, e.g. enabling limited tranches of lower cost renewables to achieve significant penetration into a slowly growing or even declining overall demand for electricity.
- *“Other inconsistencies in the case for demolition emerge. The dwellings that will be the most difficult to insulate are likely to be those with the highest heritage value, but these are unlikely to be demolished. Existing housing, particularly the oldest housing, is compact and has co-evolved with public transport systems and other systems which in many cases are still operational. There is no indication that new developments will have anything like the compactness and organic relationship to services. There is also no indication that current design and planning practice is able to capture the intimacy and human scale of most remaining pre-First World War housing.”*

2.4 IPCC 4th Assessment Report

At the time of writing, the IPCC 4th Assessment Report Working Group I Report, ‘The Physical Science Basis’ has published both its Summary for Policy Makers and its full report. The Working Group II Report, ‘Impacts, Adaptation and Vulnerability’ and the Working Group III Report, ‘Mitigation of Climate Change’ published their Summary for Policy Makers on 6th April and 4th May respectively. See <http://www.ipcc.ch/>

- The full IPCC 4th Assessment Report (4AR) will be published in November 2007. Compared to its 3rd Assessment Report (TAR) in 2001, 4AR pays greater attention to the integration of climate change with sustainable development policies and the inter-relationships between mitigation and adaptation. Specific attention is given to regional issues, uncertainty & risk, technology, climate change & water.
- The Working Group (WG) I report summarizes the present knowledge on the physical science basis of Climate Change: atmospheric composition, observation of various climate parameters, coupling between changes in climate and biogeochemistry, evaluation of models and attribution of Climate Change.
- The WG II Summary for Policy Makers has a detailed analysis of observed and projected impacts on natural and human systems in response to actual and expected

climate change stimuli. The Summary further addresses key vulnerabilities as well as adaptation measures for main sectors and regions. Although the adaptation report does not specifically address the building stock it does highlight issues relating to ‘Industry, settlement and society’:

- *Costs and benefits of climate change for industry, settlement, and society will vary widely by location and scale. In the aggregate, however, net effects will tend to be more negative the larger the change in climate.*
- *The most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources, and those in areas prone to extreme weather events, especially where rapid urbanisation is occurring.*
- *Poor communities can be especially vulnerable, in particular those concentrated in high-risk areas. They tend to have more limited adaptive capacities, and are more dependent on climate-sensitive resources such as local water and food supplies.*
- *Where extreme weather events become more intense and/or more frequent, the economic and social costs of those events will increase, and these increases will be substantial in the areas most directly affected. Climate change impacts spread from directly impacted areas and sectors to other areas and sectors through extensive and complex linkages.*

It also notes that:

- *“Studies in temperate areas (mainly in industrialised countries) have shown that climate change is projected to bring some benefits, such as fewer deaths from cold exposure. Overall it is expected that these benefits will be outweighed by the negative health effects of rising temperatures world-wide, especially in developing countries.*
- *“Confidence has increased that some weather events and extremes will become more frequent, more widespread and/or more intense during the 21st century; and more is known about the potential effects of such changes.” An extract from Table SPM-2 in the Working Group II Summary for Policy Makers, page 14-15 that closely relates to the building stock follows:*

| Phenomenon and direction of trend | Likelihood of future trends based on projections for 21st century using SRES scenarios | Industry, settlement and society |
|--|--|---|
| Over most land areas, warmer and fewer cold days and nights, warmers and more frequent hot days and nights | Virtually certain | Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism |
| Warm spells/heat | Very likely | Reduction in the quality of life for |

| | | |
|---|-------------|--|
| waves. Frequency increases over most land areas | | people in warm areas without appropriate housing; impacts on elderly, very young and poor. |
| Heavy precipitation events. Frequency increases over most areas | Very likely | Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property |
| Area affected by drought increases | Likely | Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potentials for population migration |
| Intense tropical cyclone activity increases | Likely | Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers, potential for population migrations, loss of property |
| Increased incidence of extreme high sea level (excludes tsunamis) | Likely | Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above |

- The WG III Summary for Policy Makers analyses mitigation options for the main sectors in the near-term, addressing also cross-sectorial matters such as synergies, co-benefits and trade-offs. It also provides information on long-term mitigation strategies for various stabilization levels, paying special attention to the implications of different short-term strategies for achieving long-term goals. Of specific relevance to the building stock the Summary notes:

“Energy efficiency options for new and existing buildings could considerably reduce CO2 emissions with net economic benefit. Many barriers exist against tapping this potential, but there are also large co-benefits (high agreement, much evidence):

- *By 2030, about 30% of the projected GHG emissions in the building sector can be avoided with net economic benefit*
- *Energy efficient buildings, while limiting the growth of CO2 emissions, can also improve indoor and outdoor air quality, improve social welfare and enhance energy security.*
- *Opportunities for realising GHG reductions in the building sector exist worldwide. However, multiple barriers make it difficult to realise this potential. These barriers include availability of technology, financing, poverty, higher costs of reliable information, limitations inherent in building designs and an appropriate portfolio of policies and programs.*
- *The magnitude of the above barriers is higher in the developing countries and this makes it more difficult for them to achieve the GHG reduction potential of the building sector”.*

- *An extract from Table SPM 3 in the Working Group III Summary for Policy Makers, page 13 that relates to the building stock follows:*

| Sector | Key mitigation technologies and practices currently commercially available | Key mitigation technologies and practices projected to be commercialised before 2030 |
|-----------|--|--|
| Buildings | Efficient lighting and day lighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigerant fluids, recovery and recycle of fluorinated gases | Integrated design of commercial buildings including technologies, such as intelligent meters and provide feedback and control; solar PV integrated in building |

2.5 Quantifying the Urban Heat Island

The concept of the ‘urban heat island’ (UHI) is now well established. In London, for example, general excess temperatures of several degrees Celsius are typical. However, the distribution of local temperatures within the urban environment and their relation to land use and building form is much less well understood.

The UHI can amplify and extend the rise in temperature due to the ‘background’ changing climate. Appropriate policies for urban planning, housing and transport are thus required (Hunt 2005⁶). But before policies can be developed, quantitative tools are required to identify and quantify the effectiveness of mitigation and adaptation strategies.

One strategy for passive cooling of buildings is through storing heat within the building fabric during the day and cooling through ventilation at night. But this method relies on the night-time temperatures being sufficiently low. The urban heat island is typically most pronounced at night, and so it is important to know whether or not this method remains viable. In general, strategies which may have served historic buildings well such as opening windows may no longer be appropriate. Buildings both respond to and contribute to the local microclimate. Effective building design requires a knowledge of, and ways of dealing with, this microclimate. Infrastructure changes need to be planned now as these changes can take up to 30 years to implement

What is the way ahead? It is clear that the local character of the built environment can have a strong influence and generate a localised microclimate, which leads to variation in the strength of the urban heat island across a city. For example, green space and bodies of water interspersed into the urban landscape can substantially reduce undesirable impacts of buildings on the microclimate. Green roofs might be seen as providing a cheap way of alleviating flooding, combating global warming and improving air quality. In particular Switzerland and Germany have been planting green roofs for almost 100 years. They

⁶ Hunt, JCR (2005) London’s Environment: Prospects for a sustainable world city, edited JCR Hunt, NJ: World Scientific Publishing Co, 350 pp.

provide locally tailored conservation and can be retrofitted. Green roofs have been found in Europe for decades. According to the London Climate Change Partnership an area 28 times the size of Richmond Park is able to be retrofitted⁷ suggesting green roofs are achievable on existing buildings as well as new developments. However, intensive green roofs with a thick soil or substrate layer and artificial irrigation are heavy systems and can have structural implications for the building. Extensive green roofs have a thin layer of soil and place less stress on the building. Intensive green roofs will require regular maintenance, such as mowing, weeding and ensuring irrigation systems do not fill with silt. Extensive green roofs, with limited vegetation variety, might need an annual maintenance visit⁸. Temperature has risen in Tokyo by 3°C over the past 100 years. The Tokyo Metropolitan Government (TMG) has produced a Thermal Environment map showing thermal loading from anthropogenic sources and ground surface conditions allowing them to develop appropriate adaptation strategies. These include green roofs and re-vegetation projects and developing wind ventilation paths through the city. Cool roofs have light coloured coatings that reflect and emit heat. They can be retro-fitted to roofs lacking the structural integrity to support green roofs.⁹ However, the LCCP feels that their impact on winter temperatures needs to be established first. In these and other ways, intelligent master planning of large-scale development can alleviate overheating in urban areas. Planners must be careful, as planting trees might have negative effects on the buildings. Higher summer temperatures and lower rainfall will lead to a lowering of the water table and soil shrinkage. In 2003 insurers received over £400 million in subsidence claims, 70% of them due to trees and shrubs close to houses¹⁰. However, at present there are no suitable quantitative tools available to architects, planners, and designers to analyse the impact of urban development on the microclimate across this range of scales.

Within the UK, two recently funded EPSRC projects are attempting to move knowledge forward with regards to the UHI:

1. 'LUCID' (The Development of a Local Urban Climate Model and its Application to the Intelligent Development of Cities) is developing methods for calculating local climate and air quality in the urban environment. The impact on the internal built environment, energy use and the consequences for health will then be explored.

2. 'SCORCHIO' (Sustainable Cities: Options for Responding to Climate Change Impacts and Outcomes) aims to develop tools to help planners, designers, engineers and users to adapt urban areas, with a particular emphasis on heat and human comfort.

⁷ London Climate Change Partnership (2006) Adapting to Climate Change: Lessons for London, Greater London Authority, London

⁸ English Nature (2003) Green Roofs: their existing status and potential for conserving biodiversity in urban areas. English Nature, Peterborough

⁹ London Climate Change Partnership (2006) op cit

¹⁰ Daily Telegraph Heat wave will lead to homes subsidence, warn experts. 24 July 2006

2.6 Dealing with Uncertainty

The next generation of climate change data is being presented in probabilistic terms. A recent related call for proposals from EPSRC notes that:

“A key challenge in this area is the capacity to accept probabilistic information and its integration into regulations, standards, best practice and policy. “

Significant gaps in our knowledge contribute to the overall uncertainty. For example, a very useful recent paper (Persilly – 2006¹¹) deals with the current state of the art with regards to ventilation. Persilly notes:

“While much time and effort is spent developing and debating ventilation requirements, compliance with these requirements in design and ultimately operation is rarely given the attention that it deserves. Addressing actual ventilation performance in buildings requires measurement, which is more difficult to conduct in the field than often realized and is too often omitted from building management practice as well as indoor air quality research. When ventilation rates are measured, the results often reveal significant gaps between design intent and actual performance, which can have serious implications for both indoor air quality and energy. Given the importance of ventilation, the research that has been done and the many questions that remain, it is reasonable to ask how much we really know about ventilation.”

In March 2007, EPSRC and UKCIP announced a call for research proposals into The Use of probabilistic Climate Scenarios in Adaptation Decision within the Buildings Sector. Projects funded under this call will focus on the practical uses of probabilistic climate scenarios in the planning, design and construction of new buildings and the retrofitting and maintenance of existing buildings ‘ to ensure that when climate change occurs buildings continue ..to function safely, comfortably, cost-effectively and without excessive need for energy-intensive adaptation. The final announcement of projects funded will be made in December 2007.

Discussion Box 3:

How will provision be made to enable the testing of the robustness of design options to future climates?

¹¹ Persilly A (2006), What we Think we Know about Ventilation, International Journal of Ventilation 5(3) pp 275-290

3. Characterising the Past and Future Stock

The UK built stock is often discussed as a very static stock with very low demolition rates (less than 0.1% per annum) and with a very large proportion of older properties. Such statements need to be interpreted with care.

The age structure of the British housing stock is illustrated in figure 4. The median dwelling was built between 1939 and 1959. Given the slow rate of construction in the first 6 years of this period, the median construction date is likely to have been after 1950 and the median age therefore likely to be no more than 56 years. Fewer than 20% of existing dwellings were built before 1918.

This age structure is largely determined by historical patterns of population growth and household formation – from 1801 to 1901 the population of England and Wales grew nearly four-fold, from just over 8 million to more than 32 million (Jevons 1906). Over the next century, population grew more slowly, by a further factor of 1.6 (Government Actuary's Department 2001), but mean household size fell from around 7 to less than 3. Even with no demolition, one would therefore expect around 75% of all of existing dwellings to have been built since 1900. The combination of rapid population growth, falling household size and the demolition of large numbers of dwellings built in the 19th century means that less than 10% of the current stock was built before 1850. It is clear from this brief description that the housing stock in the UK is very far from steady state. Patterns of construction, renovation and demolition are dynamically determined and statistics such as implicit dwelling life based on the ratio of total household numbers to annual demolition rate have little to do with the actual longevity of housing and, despite suggestions to the contrary, carry no direct implications for public policy towards the stock.

*(Lowe **Technical options and strategies for decarbonising UK housing.** Building Research and Information. 35:4 July/ August 2007)*

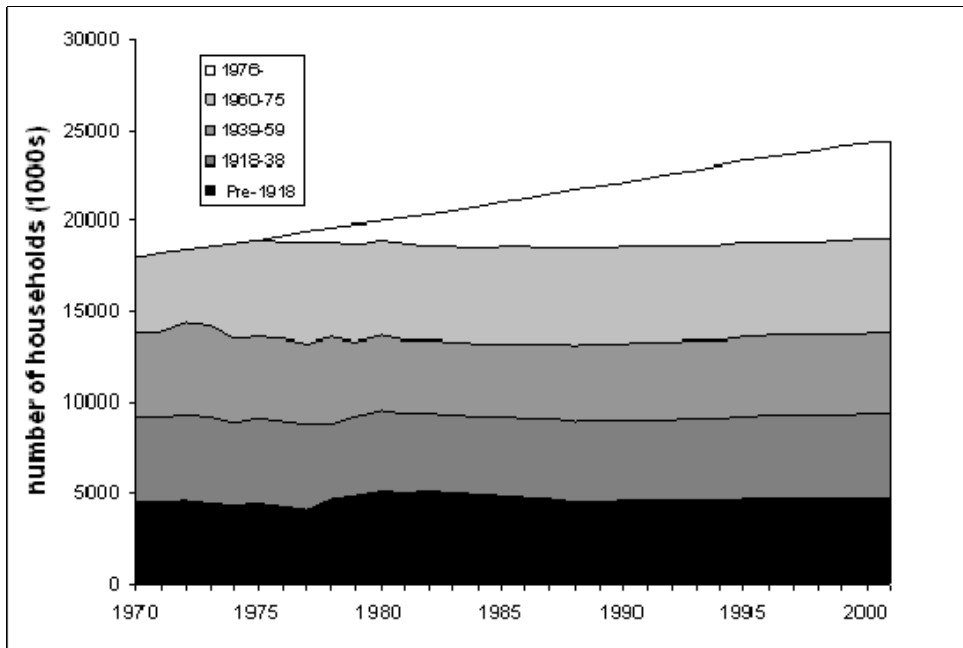


Figure 4. Age structure of the British housing stock (Shorrocks & Utley 2003). Quoted in Lowe (2007b) *Technical options and strategies for decarbonising UK housing*. Building Research & Information.

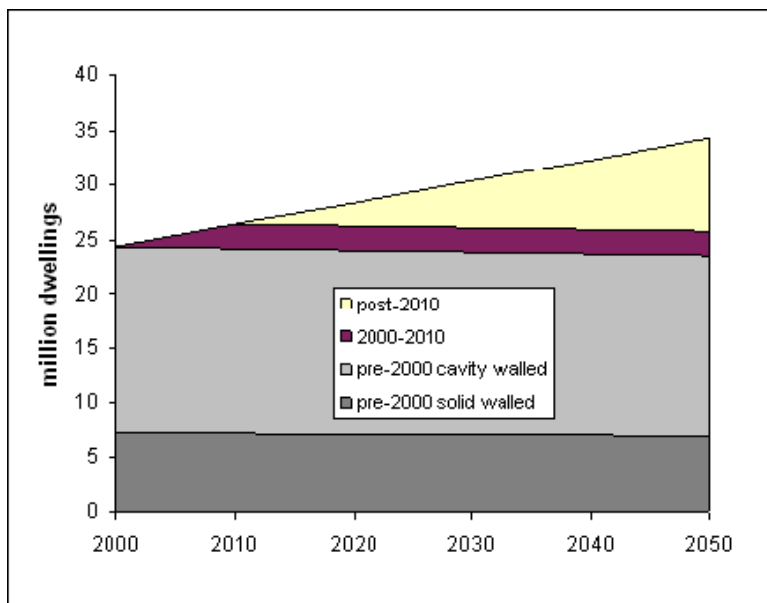


Figure 5 Originally published in: Lowe (2004) *Raising the energy performance of the existing housing stock: reflections on policy goals, technologies, implementation mechanisms and potential paradoxes from a UK perspective*. in *Proc. Towards Sustainable Use of the Building Stock*, OECD Workshop, Tokyo, 15-16 January, 2004

While new construction adds less than 1% to the housing stock each year, by 2050 around 40% of all housing will have been built since 2000, see figure 5. (Higher rates of

construction and demolition in the non-domestic sector mean that the majority of non-domestic buildings in 2050 will have been built since 2000.) This highlights that both old and new buildings are important for adaptation. Older properties are sometimes seen as being frozen in time yet this is far from the case (even with listed buildings) and much is done to the existing stock. For example, over the last 30 years the energy efficiency of the housing stock has improved by 30%. Annual expenditure on DIY is approximately 2% of total consumer expenditure, but around 20% of expenditure is on housing. Also existing properties are constantly being extended. For example in the UK approximately 200,000 new conservatories are added to dwellings each year. Policies of enhanced demolition rates might result in the replacement of durable, long-lived buildings with new, short-lived buildings, and that the overall benefit to the environment may be less than expected (Lowe, 2007a).

Dwellings are not monolithic. Different sub-systems have widely different rates of renewal. This is illustrated in Figure 6:

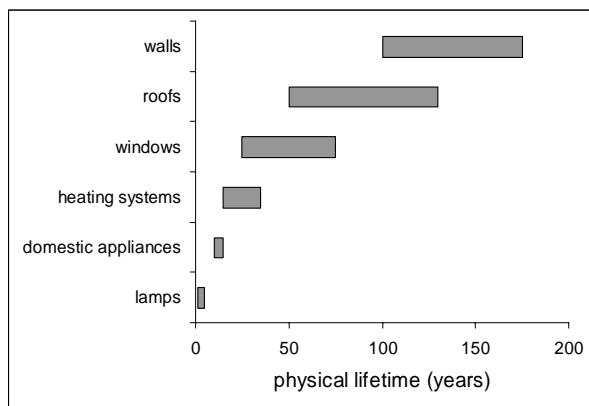


Figure 6. Lowe (2005) Preparing the built environment for climate change, Presentation to joint SB05/IPCC session at Sustainable Building 05, Tokyo.

Even in Conservation Areas there is often considerable potential to undertake adaptation. For example, while the facades of Victorian terraces may be difficult to alter, often the rear facades have already been significantly altered and so offer the potential for the installation of adaptation measures. Also, many adaptation measures may not involve changes to the fabric but simply improved or more frequent maintenance and this can be applied easily to new, old and heritage properties.

While this discussion has stemmed from the domestic stock, it is important to consider the relevance and application of these arguments to the non-domestic stock. The opportunities for adaptation in terms of refurbishment are if anything greater in non-domestic properties where change of use and major refurbishment occur more frequently. Both the existing stock and new stock need to be tackled in adaptation terms and the opportunities to do this need to be identified at regional and local levels.

4. Developing a Policy Framework

Alongside the necessary 'building science' it is vital to consider the policy framework within which adaptation will occur. At a strategic level 2006 and 2007 have seen the publication of the European Union *Action Plan for Energy Efficiency*, *The Stern Review*, and the IPCC's *Fourth Assessment Report*. The *Fourth Assessment Report* confirms the urgency of the climate change problem. *The Stern Review* outlines the economic and political cases for early action. He favours market based mechanisms but recognizes the need for regulatory interventions where market failures exist:

Regulatory measures can play a powerful role in cutting through these complexities, and providing clarity and certainty (Stern 2006, p. xx)

David Shipworth in *The Stern Review: Implications for Construction* (Building Research and Information 35:4) highlights the consequences of *Stern* for construction. At the broad policy level there might be a shift from voluntary measures on the part of the industry towards market-based instruments, such as an extension of the EU Emissions Trading Scheme down to commercial building level. Within the field of environmental compliance there might be increased transference of the burden of proof onto project developers. However, Shipworth points out that the true legacy of *Stern Review* will be 'more and faster'. Governments may be driven to achieve mitigation targets and the built environment will be a likely target to deliver improved performance. Finally there will be pressure for construction and research communities to react to *Stern*.

The EU *Action Plan for Energy Efficiency* aims to achieve a 20% energy saving by 2020. It is reasonable to expect that major house builders and developers, for example, are not going to change unless *obliged* to do so. Within the current policy framework, there are essentially two main policy levers that can affect the performance of new and existing building stock: *planning and regulation*.

- the planning system includes the Barker Review,, the Department of Communities and Local Government's Draft Planning policy Statement 1 *Planning and Climate Change* (DCLG, December 2006) *Planning for a Sustainable Future-White Paper* (DCLG, DEFRA, DTI and Department for Transport, May 2007) and the Department of Culture, Media and Sport's '*Heritage Protection in the 21st Century*' (DCMS and Welsh Assembly Government March 2007).
- The Building Regulations and *the Code for Sustainable Homes* which may be extended to non-domestic buildings in time. The purpose of the *Code* is to be a single national standard to guide industry in the design and construction of new homes *The Review of Sustainable Building-a Summary* (DTI October 2006) is seen a first step in the development of industry targets, with targets and visions for sustainable construction to 2015 and beyond laid out.

Building Regulations and the Code are focused on the performance of the buildings themselves. The Building Regulations apply to both domestic and non-domestic buildings – they also now cover both new and existing buildings. There are at least two key issues:

- the reliability of the current Building Regulations performance criteria; and
- changes required to these criteria and the Regulatory process itself.

The European Energy Performance of Buildings Directive (EPBD) became European law on 4 January 2003. Member States, including the UK, have had three years in which to implement the Directive. The EPBD contains 17 'Articles' which must be implemented. Articles 3 to 6 of the Directive (setting of defined energy performance requirements in new and existing buildings) were satisfied under the Building and Approved Inspectors (Amendment) Regulations 2006. Article 7 requires Energy Performance Certificates (EPCs) –the relevant Regulations were laid before Parliament in March 2007. In England EPCs will be implemented as part of Home Improvement packs from 1st August for houses with 4 or more bedrooms and will be phased in for all houses as more inspectors are trained. *The Code for Sustainable Homes* (DCLG December 2006) is intended to complement the EPCs. The aim of the Government is for the *Code for Sustainable Homes*, the strengthening of the Building Regulations and PPS1 *Planning and Climate Change* to provide clarity about the framework for advancing zero carbon development. PPS1 will set out the role of regional and local spatial strategies, with local level development plan documents (DPDs) setting policies on the provision of low carbon energy.

A suite of Commitee Europeen de Normalisation (European Committee for Standardisation) standards¹² have been developed and approved in February 2007 to support the EPBD. Those related to ventilation include **prEN 15251** which is perhaps the most interesting. This is an ambitious document with a very wide scope. Many of the suggested environmental values in the Standard inevitably differ to some extent from UK levels. In cases where 'no national regulations are available', the Standard gives, in informative annexes, recommended input values. However, the recommended criteria for 'indoor air quality' and 'thermal environment' are given for several categories.

In a normative section of the Standard it is noted that:

“The information of indoor environment of the building should be included with the energy certificate of the building (EPBD article 7) so that total performance of building can be evaluated. For this certificate the classification of indoor environment is necessary.”

¹² CEN standards relating to ventilation include:

prEN 13779: Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems

prEN 15239: Ventilation for buildings – Energy performance of buildings – guidelines for inspection of ventilation systems

prEN 15240: Ventilation for buildings – Energy performance of buildings – guidelines for inspection of air-conditioning systems

prEN 15241: Ventilation for buildings – Calculation methods for energy losses due to ventilation and infiltration in commercial buildings

prEN 15242: Ventilation for buildings – Calculation methods for the determination of air flow rates in buildings including

prEN 15251: Criteria for the Indoor Environment including thermal, indoor air quality, light and noise

Assuming that national criteria will already exist (but not in the form of the several different categories), this raises the question as to how the criteria will be applied at a national level. How will this work in practice? How will existing national requirements and the European Standard criteria be harmonised? Would it be acceptable in terms of Regulation in England and Wales to use simply the recommended values in the Standard?

In March 2007 the Government published its draft Climate Change Bill. The focus of the Bill are the targets for the UK to reduce its carbon dioxide emissions; a reduction of 60% of 1990 levels by 2050 and interim reductions of 26-32% by 2020¹³. With over 30% of the UK's carbon emissions coming from the domestic sector these targets will have a major effect on the UK construction industry. It is important also to note the impacts and adaptation components of the Bill. Currently there is a reporting requirement. However, the Government has stated that it is minded to strengthen adaptation within the Bill.

Discussion Box 4:

What is required to achieve better coherence in policy terms among the different branches of Government that deal with the Building Stock? For example, planning for the built heritage does not reflect mainstream concerns for mitigation and adaptation to climate change.

5. Conclusions

Considerable research has already been undertaken and action to intergrate adaptation into future policy e.g the introduction of an overheating calculation in the building regulations and the Department of Health Heatwave Plan. Key issues still remain in tackling summer time overheating in buildings and urban areas and moisture damage to buildings, both of which have health implications. The former is a slightly more serious problem in more modern and converted properties; the latter is more serious for older properties not specifically designed to exclude moisture. Examples of particular challenges which research may help to address could include the following:

1. **Adaptation keeping pace with mitigation.** Research into adaptation needs to keep pace with rapid changes to the building stock which will take place as a result of mitigation. Buildings produce almost half of the carbon emissions and radical changes in their construction and refurbishment are planned in the next decade. For example all new dwellings are planned to be zero carbon by 2016. Adaptation research needs to develop strategies which use this rapid change as an opportunity to introduce appropriate mitigation measures.

¹³ For comparison UK Carbon dioxide emissions have fallen by about 5.25% between 1990 and 2006 (source DEFRA). www.defra.gov.uk/news/2007/0707329a.htm . Accessed 11th July 2007

2. **Conflicts between adaptation and mitigation.** Although in most cases mitigation can also result in better adaptation, there are several key areas where this may not be the case and these need to be further researched. For example, it is very likely that in the next decade heat pumps will provide the lowest carbon emitting space heating in the UK while also providing cooling to prevent summertime overheating. However the increased energy use for cooling may mean that heat pumps provide no net reduction in carbon emissions!
3. **Adaptation of the old and the historic building stock.** What distinguishes the old from the historic is the value and significance of historic buildings and ensembles and their cultural, economic, environmental or technological meaning to communities. These can be lost by adaptations that may be suited to other building types. There are currently no adaptation strategies for the historic building stock that bridge this physical and cultural divide. Adaptation measures need to fit within an ethical framework that accepts that climate change pressure on historic buildings may take conservation management out of our hands. Research is needed to improve understanding of the vulnerability of traditional materials, the application of remote sensing such as aerial and satellite technology to evaluate the impact of climate change and advanced monitoring and modelling to predict the behaviour of historic buildings in response to different climate change adaptation strategies.
4. **Changing occupant behaviour.** Occupants will have to change their behaviour in relation to how they use and interact with buildings as the future climate changes. Although in theory occupant behaviour can change very quickly, in practice occupants have very little understanding of their interaction with the built environment. Many issues such as dealing with overheating will need better designed solutions to cope with occupant behaviour. For example, many occupants open windows thus letting the heat into buildings during the hottest part of the day.
5. **Better maintenance and management.** Many building related adaptation measures will depend on good maintenance and management of the building stock. For example, increased torrential rain will require more frequent maintenance of rain services including cleaning of gutters. These are generally poorly researched areas.
6. **Changing Lifestyles.** There is also a need to consider adaptation options and their implementation in the context of changing lifestyles. This is a balance where adaptation measures can only be effective if they are properly implemented and maintained. They may require use and maintenance that is counter to changing lifestyles, which will increase the challenge of acceptance and increase the potential for failure.
7. **Turning theory into practice.** Buildings are often complex bespoke items which are difficult to control, with little feedback on their real operation and actual performance. Research is required to provide this feedback and to provide evidence of the need for better enforcement of regulation, training, monitoring etc.

8. **What's the problem?** The biggest problems in adapting to climate change will be those areas that nobody has yet identified as problems. For example, increased outdoor winter temperatures are likely to result in higher external vapour pressures leading to higher internal relative humidities which in turn will lead to more house dust mites and possibly an increase in asthmatic symptoms. Once the problem areas have been identified it is relatively easy to put into place research and appropriate measures to tackle the problem. The complex systems impacts of future scenarios need to be fully explored.

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