October 2016 Energy Research Partnership

Heating buildings

Reducing energy demand and greenhouse gas emissions

The Energy Research Partnership

The Energy Research Partnership is a high-level forum bringing together key stakeholders and funders of energy research, development, demonstration and deployment in Government, industry and academia, plus other interested bodies, to identify and work together towards shared goals.

The Partnership has been designed to give strategic direction to UK energy innovation, seeking to influence the development of new technologies and enabling timely, focussed investments to be made. It does this by (i) influencing members in their respective individual roles and capacities and (ii) communicating views more widely to other stakeholders and decision makers as appropriate. ERP's remit covers the whole energy system, including supply (nuclear, fossil fuels, renewables), infrastructure, and the demand side (built environment, energy efficiency, transport).

The ERP is co-chaired by Professor John Loughhead, Chief Scientific Advisor at the Department of Energy and Climate Change and Dr Keith MacLean (formerly Director of Policy & Research at Scottish and Southern Energy). A small in-house team provides independent and rigorous analysis to underpin the ERP's work. The ERP is supported through members' contributions.

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Contents

The Energy Research Partnership Reports

ERP Reports provide an overarching insight into the development challenges for key low-carbon technologies. Using the expertise of the ERP membership and wider stakeholder engagement, each report identifies the challenges for a particular cross-cutting issue, the state-of-the-art in addressing these challenges and the organisational landscape (including funding and RD&D) active in the area. The work seeks to identify critical gaps in activities that will prevent key low-carbon technologies from reaching their full potential and makes recommendations for investors and Government to address these gaps.

This project was guided by a steering group made up of experts from ERP members and other key organisations, as listed below (please note that some steering group members have subsequently moved from these organisations). The views in this report are not the official point of view of any organisation or individual and do not constitute government policy.

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We would like to thank all those who helped inform this work, including the wide range of experts that were interviewed (see Annex). If you have any queries please contact Simon Cran-McGreehin (simon.cran-mcgreehin@erpuk.org).

Executive summary

Heating buildings accounts for 25% of the UK's energy demand and 15% of its greenhouse gas (GHG) emissions. The challenge of reducing buildings' heat demand and GHG emissions can be viewed as a national infrastructure project (as it is in the Scottish Energy Efficiency Programme), with its huge scale and need for a co-ordinated plan; but it differs from other infrastructure projects because it involves millions of separate projects and owners. Cost-effective GHG emission reductions are available for space heating via demand reduction and fabric energy efficiency, which reduce the residual heat demand that will have to be met by low-carbon heat sources. However, uptake of these opportunities has been limited. Regulatory standards for buildings' fabric in new buildings lag behind leading practice, with new homes allowed three times the heat demand of "Passivhaus" standards. Retrofits of existing buildings have large technical scope for emissions reductions, with the average UK home using five times as much heat as a leading practice "EnerPhit" retrofit. The non-domestic sector has some different challenges to the domestic sector, with a wider range of buildings and uses, but it too lags behind leading practice for new and existing buildings.

Ambitious improvements to fabric energy efficiency are challenging for many existing buildings, but should be considered wherever possible and affordable, because if major improvements are not made, the UK could be left with a residual heat demand that is too large to allow sufficient reductions in GHG emissions using available low-carbon heat sources. The UK would face an insurmountable back-log of retrofit projects, including to upgrade new buildings that have missed the opportunity to adopt leading practice from the start. To address the current slow rate of improvements (the "uptake gap") the UK must aim for leading practice in new buildings, and must accelerate the deployment of retrofit solutions for existing buildings.

Increasing the uptake of improvements is not enough: experience has shown that when improvements are carried out, results are disappointing due to a combination of unrealistic expectations of the impacts (the "prediction gap") and an under-delivery in actual performance (the "performance gap"). Experts within the new-build and retrofit sectors have repeatedly proposed solutions to these problems, apparently to little avail against competing pressures. This contrasts with successes in the electrical appliances sector where the uptake gap is kept small as regulations keep track with improvements in leading performance levels; the prediction gap is small due to good feedback from ongoing monitoring and testing; and the performance gap is small due to high quality work and due to regulations that are not necessarily more numerous but that are enforced effectively.

New measures are needed to address these three gaps for space heating: these must be adopted in a pragmatic manner, without pursuing spurious precision or allowing "the best to become the enemy of the good". Deployment must continue for measures that are known to bring benefits, even if exact impacts are uncertain; and early stages of deployment should be treated as a "safe learning environment". For retrofit quality, the Bonfield Review was commissioned to consider customer advice and protection, the standards framework, and monitoring and enforcement. For new-build, all customers already pay the costs for stipulated energy performance, but only some receive the intended benefits: the sector does not necessarily need more energy regulation, but rather more effective regulation through better use of monitoring, testing and enforcement.

Recommendations

We recommend actions to provide ambition and certainty in regulations for the building industry, new approaches to increase the appeal of retrofit to leverage customer interest, research to improve understanding of heat use in buildings, and better quality control and enforcement to deliver performance in practice.

- To guide buildings' energy policies and regulations to be commensurate with the UK's Carbon Budgets, a cross-departmental group should be established with membership from DCLG, BEIS, and relevant organisations (e.g. National Infrastructure Commission), aided by the establishment of an expert advisory panel.
- To provide ambition and certainty for the building industry, DCLG should produce a regulatory trajectory for building energy regulations that reaches leading performance in fabric thermal efficiency, and should maintain this trajectory.
- To leverage customer action on energy efficiency, DCLG should improve its use of light-touch regulations: Display Energy Certificates (DECs) should be applied to all public buildings and promoted for private buildings; Energy Performance Certificates (EPCs) should be promoted more effectively as an important part of purchase and rental decisions.
- To increase uptake of retrofit solutions, product manufacturers and installers should better promote retrofit options and should develop more appealing products, installation methods and "retrofit packages", with support from heritage groups for older buildings and with engagement from government for the development and implementation of policies.
- To increase understanding of thermal performance in buildings, the Energy Systems Catapult (ESC) should expand its network for access to test facilities and expertise to include tests of thermal performance, and should maintain its buildings trials as a longitudinal study and control group for other studies.
- To improve thermal performance in practice, product manufacturers should take a greater role in training and quality control in installation, and the building inspection regime should improve its use of tests and enforcement (better regulation, not necessarily more regulation) including conducting truly random spot checks of energy performance.

To support these recommendations, there is merit in further actions by key organisations in industry and the public sector, to increase uptake of energy efficiency improvements, to improve forecasts of impacts, and to deliver performance in practice.

Uptake of high performance in new buildings

As recommended, an ambitious trajectory for new-build energy regulations is needed. The current limited ambition is partly due to the process of developing regulations, with slow progress prohibiting ongoing involvement by experts from small companies with limited resources. To support this recommendation:

- The involvement of experts in leading practice in developing regulations should be better facilitated, e.g. by offering experts from small companies some form of support to reflect the costs of serving on working groups.

Uptake of retrofit for existing buildings

As recommended, customer interest in retrofit can be leveraged by better use of light-touch regulations (EPCs and DECs), and by industry increasing the appeal of retrofit with support from heritage groups for older buildings and engagement from government on policy development and implementation. To support these recommendations:

- ▶ BEIS should engage with retrofitters, product manufacturers and researchers (e.g. through proposed "hubs" of expertise) to aid in the development and implementation of policies.
- ▶ Policies should seek to incorporate customers' views of costs, cost-effectiveness and barriers to uptake, including to allow government funds to more effectively leverage customers' funds.

Predicting outcomes

As recommended, research is needed to improve understanding of heat use, including wider use of thermal performance testing facilities and the establishment of a longitudinal study. To support this recommendation, there would be merit in further actions to obtain more data and expertise from existing sources, ongoing research programmes, and new projects:

- ▶ Government should increase links with researchers for co-ordination of research and dissemination of results.
- ▶ BEIS should collate the key findings from previous buildings energy studies, and develop a plan for filling knowledge gaps.
- ▶ DCLG and BEIS should continue to consider ways to enhance the English Housing Survey's (EHS) value for energy policy.
- ▶ BEIS should explore sources of heating data and their compatibility with Government-mandated smart meters.
- ▶ BEIS should explore the value of energy data for commercial customers, and triggers to encourage data sharing.
- ▶ BEIS should support access for researchers to smart metering data, e.g. through the SMRP.
- ▶ BEIS should review the SAP model to determine its suitability for assessing energy performance and measures.
- ▶ Public research funders should ensure that data from projects is collected in a consistent manner, is not vetted by lead research organisations, is archived permanently, and is accessible for future research.

Performance in practice

As recommended, the performance gap can be reduced by improved quality of work, facilitated by better training and quality control, and backed up by better use of tests and enforcement. To support this recommendation:

- ▶ Research funding organisations should continue to promote the development of simpler and quicker tests of buildings' thermal performance to allow customers easier access to information.
- ▶ BEIS and consumer organisations should raise customers' awareness of the required level of thermal performance, and support customers' rights to remedial works to address underperformance.
- ▶ Research funding organisations should continue to promote the development of simpler and quicker tests of buildings' thermal performance to allow customers easier access to information.
- ▶ BEIS and consumer organisations should raise customers' awareness of the required level of thermal performance, and support customers' rights to remedial works to address underperformance.
- ▶ BEIS and DCLG should continue their joint working to address the quality of on-site works to facilitate the greater role that is needed for product manufacturers in training and quality control for thermal performance.

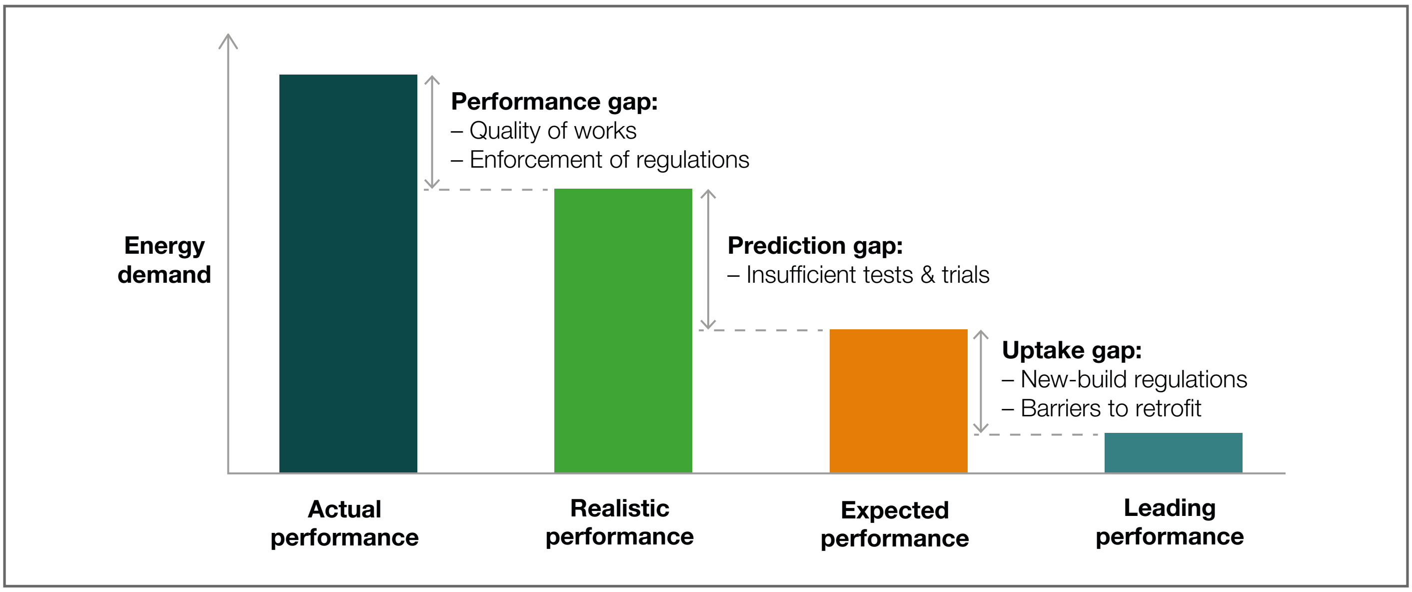

Illustration of different levels of energy usage, and gaps between them.

1 Introduction

Space heating for buildings accounts for ~25% of the UK's energy demand and ~15% of its greenhouse has (GHG) emissions. The UK's buildings stock is forecast to grow out to 2050, by 15% for workplaces and by 30% for housing, further adding pressure to decarbonise space heating. There is scope for large reductions, by using lower-carbon energy sources and more efficient heating systems, and by reducing heat demand through behaviour change, automation, and fabric energy efficiency. Progress has been made: through improving building regulations for new buildings; and through energy supplier obligations (EEC, CERT, CESP, ECO) for retrofitting existing homes. However, much more can be done to reduce the heating demand for new and existing buildings, both homes and workplaces.

This report presents an overview of options for reducing GHG emissions from space heating for buildings. It focusses on fabric energy efficiency as the most logical first step in demand reduction for space heating, and also considers the role of behaviour change, automation, and low-carbon heating systems. The report highlights why these options are not being deployed to their full extent, why there can be inaccurate expectations, and why actual performance can fail to match realistic expectations.

This report considers issues that apply across the UK, but also highlights some issues that are specific to certain jurisdictions; any issues affecting England's regulations have a larger impact because it has the majority of the UK's buildings. For example, building regulations are broadly similar across the UK, but are set separately for England,[1] Wales,[2] Northern Ireland,[3] and Scotland[4] (which has a notably difference of stipulating more insulation), whereas England's approach to enforcement differs from the others.

This report is structured as follows:

- Section 2 introduces background information and key themes for the report by presenting:
  - buildings' energy use in the context of UK's energy demand and GHG emissions;
  - space heating in the context of buildings' energy use;
  - scale of the challenge of decarbonising space heating in terms of the number of buildings and the forecast growth in the sector;
  - space heating performance of leading practice compared to existing buildings and regulatory standards for new-build;
  - gaps between leading practice and actual performance;
  - approaches to reducing those gaps.
- Sections 4 and 5 consider the uptake gap: the difference between what is being attempted (if anything) and what could be attempted (i.e. leading performance), which exists because of barriers or lack of ambition. These sections present the causes of the uptakes gaps for new buildings and existing buildings, respectively, and make recommendations for increasing the uptake of improvements.
- Section 6 considers the prediction gap: the difference between what is expected and what is realistically achievable, which exists because forecasts of buildings' performance can be inaccurate. This section makes recommendations to improve our understanding on heating demand, to aid in policy development and promotion of options to customers.
- Section 7 considers the performance gap: the difference between what is realistically achievable and what is delivered in practice, which exists because of poor quality work and incorrect operation. This section makes recommendations to improve implementation of improvements in order to deliver what the best possible outcome.

This report is based on a review of the literature, and interviews with over fifty organisations (see list in Annex for details) that have a range of interests in the sector: product manufacturers, the construction industry, buildings' engineers, architects, energy companies, charities and campaign groups, Government departments, research organisations, and academics. The project was guided by a steering group drawn from member organisations of the Energy Research Partnership (ERP), as listed above. Some of the issues raised in this project are considered in more detail in other ERP reports, including:

- Smart Grids explores opportunities afforded by new sources of data for the provision of energy services;
- Hydrogen considers potential applications of hydrogen as an energy vector, including for heating;
- Low-carbon heat is an upcoming ERP project in 2016 and 2017, looking at the implementation and implications of low-carbon heating options;
- Community Energy considers customers' engagement with energy usage and uptake of technologies;
- Cities considers energy systems in urban areas, including buildings' heat demand; and
- International Engagement explores links between energy research in the UK and other countries.

[1] Approved Document L – Conservation of fuel and power (DCLG, 2014)
[2] Part L of the Building Regulations – Conservation of fuel and power (Welsh Government, 2014)
[3] Technical Booklets 2012 (Building Control NI, 2012)
[4] Technical Handbooks (Scottish Government, 2013)

2 Scale of buildings' GHG emissions and scope for reductions

This section presents the UK context of buildings' energy usage and GHG emissions, highlighting the contribution from space heating, and discusses the implications of future growth in the sector due to demand for housing and workplaces.

It illustrates the potential for GHG emissions reductions using leading practice, presents the gaps between this leading practice and actual performance, and introduces approaches to reducing these gaps.

2.1 UK context of energy use and GHG emissions

The UK's energy use and GHG emissions vary from year to year, owing to economic performance, fuel mixes and winter temperatures, so it can be useful to use averages from a few years. Typically over recent years, the UK has used ~2,400TWh of primary energy each year (to meet final energy demand of ~1,700TWh)[5], and has made GHG emissions of ~575MtCO_2e (including non-energy sources);[6] the contributions of the major sectors are illustrated in Figure 1. These GHG emissions are 25% lower than the 1990 level of ~800MtCO_2e; they will need to fall by ~75% from now to reach the 2050 target of ~160MtCO_2e. Whilst GHG emissions reductions might not be spread evenly between sectors, it is prudent to consider ~80% reductions (compared to 1990 levels) for all of the major sectors.

The use of buildings (homes and workplaces) in the UK accounts for ~45% of end-use energy demand and ~35% of end-use GHG emissions. The UK's 1.8million workplaces (private and public sector) account for ~15% (~200TWh) of the UK's end-use energy demand, and ~15% (~70MtCO_2e) of end-use GHG emissions. The UK's 27.4million homes[7] (of which over 0.6millions are unoccupied)[8] make the biggest buildings' contribution, accounting for ~30% (~500TWh) of UK final energy demand[9] and ~25% (~140MtCO_2e) of end-use GHG emissions.[10] GHG emissions due to homes have fallen by 15-20% from ~170MtCO_2e in 1990, and would need to fall by ~75% from now to give an 80% reduction (from 1990 levels) to ~35MtCO_2e.

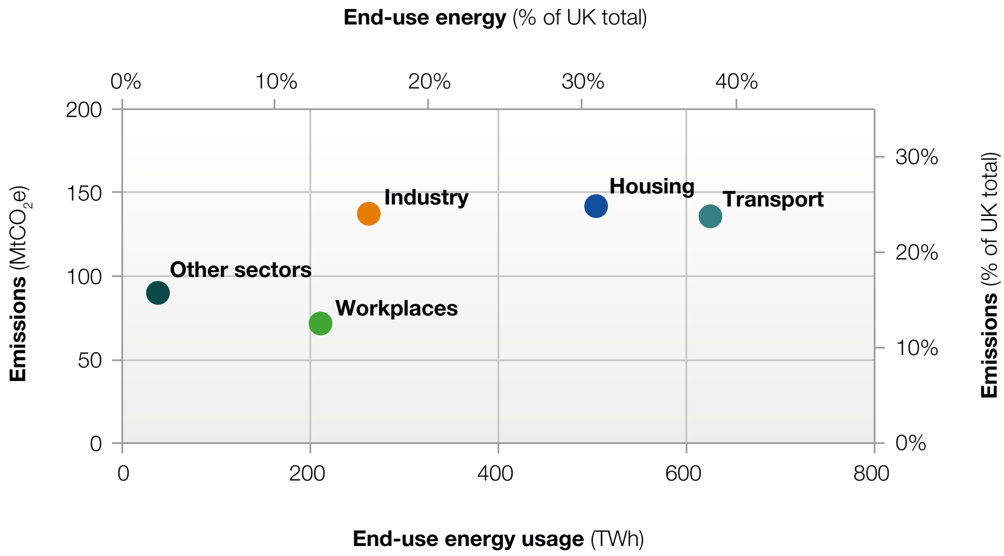

Figure 1 (left): UK energy usage[11] and GHG emissions[12] by sector (absolute values and percentages of totals).[13]

[5] Energy Consumption in the UK (DECC, 2014); and United Kingdom housing energy fact file: 2013 (DECC, 2014)
[6] Meeting Carbon Budgets – 2014 Progress Report to Parliament (CCC, 2014)
[7] United Kingdom housing energy fact file: 2013 (DECC, 2014): There are 22.4million homes in England, ~1.3million in Wales, ~2.4million in Scotland, ~0.7million in Northern Ireland (values do not sum exactly due to assumptions in data, scaling of older data, and rounding).
[8] Increasing the number of available homes (DLCG, 2015).
[9] UK housing energy fact file: 2013 (DECC, 2014)
[10] 2013 UK Greenhouse Gas Emissions (DECC, 2014)
[11] Energy Consumption in the UK (DECC, 2014); and UK Housing Energy Factfile: 2013 (DECC, 2014)
[12] Meeting Carbon Budgets – 2014 Progress Report to Parliament (CCC, 2014). By end-use (not source) sector.
[13] Note that differing definitions affect the exact splits of energy and GHG emissions between workplaces and industry. "Other sectors" includes agriculture, construction and miscellaneous sectors.

2.2 Buildings' energy use and GHG emissions

Within the UK's building stock, energy use and GHG emissions are split between categories as illustrated in Figure 2. Even with weather variations, every year buildings' main demand for energy is for heating services, consisting of: space (air) heating; hot water; and cooking and catering.[14] Space heating is by far the largest single use of energy and cause of GHG emissions for buildings, accounting for ~60% of energy and ~40% of end-use GHG emissions for all buildings: for homes, space heating uses ~65% of the energy and causes ~60% of end-use GHG emissions; and for workplaces, it uses ~50% of the energy and causes ~30% of end-use GHG emissions. Clearly, heating buildings is a major part of the UK's energy demand (~25%) and its GHG emissions (~15%), and has to be addressed. This report focusses on space heating, but it is noted that solutions for space heating can be linked with addressing other energy use as well, primarily hot water. The report also notes the need to consider embedded GHG emissions from building projects, including to improve fabric energy efficiency. [15]

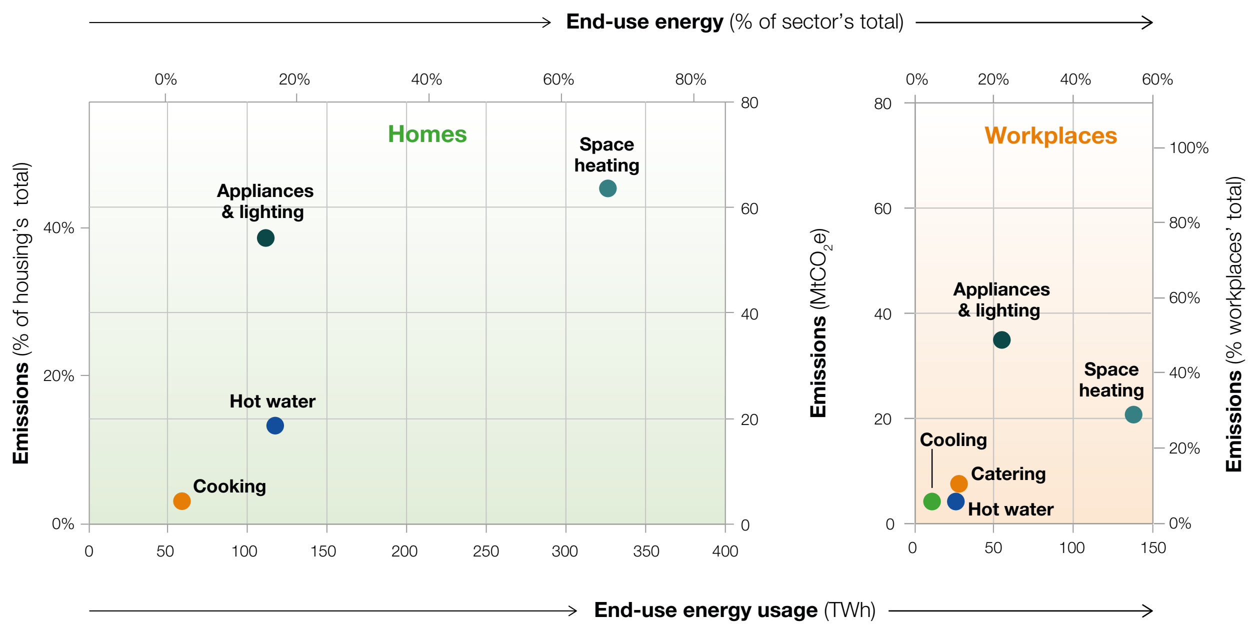

Figure 2: Energy demand[16] and GHG emissions[17] for (left) homes and (right) workplaces by type of energy use: presented in terms of absolute values (lower axes and middle vertical axes) and percentages (upper axes and outer axes) of the totals for each sector.

[14] Some heat for industrial buildings is provided by industrial processes, but does not affect overall splits.

[15] The UK's construction sector (including for buildings) accounts for ~10% of UK GHG emissions. See: Low Carbon Construction (Innovation and Growth Team, 2010)

[16] Energy Consumption in the UK (DECC, 2014)

[17] Emissions from Heat – Statistical Summary (DECC, 2012). Note that data is from 2009.

2.3 Future changes in the building stock

Reductions in space heating demand and associated GHG emissions must be achieved amidst continued growth in the UK's building stock. Figure 3 illustrates forecast expansion from 2010 to 2050 (figures are similar now): there is expected to be a ~15% increase in workplace floor area and ~25% more homes.[18] The figure highlights three key aspects of the challenge (and some related opportunities): existing stock to be renovated, new buildings, and demolitions.

All three issues apply to workplaces and homes, but renovation is the biggest challenge for both sectors, and demolition and replacement is a bigger opportunity for workplaces than for homes.

Firstly, the UK currently has one of Europe's oldest building stocks,[20] and ~65% of workplaces and ~95% of homes that exist today will remain until at least 2050 (when they will make up ~55% and ~75%, respectively, of their building stocks). Energy renovation is the biggest of the three challenges for both the housing and workplace sectors.

Secondly, the other ~45% of workplaces and ~25% of homes that will exist in 2050 have yet to be built, including replacements for those that exist today and will be demolished or repurposed. These new buildings could add to energy demand and GHG emissions, but they offer the opportunity to minimise these impacts. As will be discussed later (see Figure 4), the heating demand from new buildings is small compared to those from existing buildings (and very small in the global context), but it is nonetheless irresponsible to miss such a comparatively easy opportunity to avoid GHG emissions.

Thirdly, ~35% of existing workplaces and ~5% of existing homes will be demolished by 2050. This offers an opportunity to replace poorly performing buildings with high performance buildings, but it also poses the challenge of wasting embedded GHG emissions of the existing buildings and adding more embedded GHG emissions in new buildings.[21] Demolition decisions have to be made carefully, especially for workplaces for which it forms a significant part of the work, but also for the housing sector in which ~10,000–20,000 empty homes (some of which are candidates for demolition) are returned to use each year, providing a valuable social resource at low cost.[22]

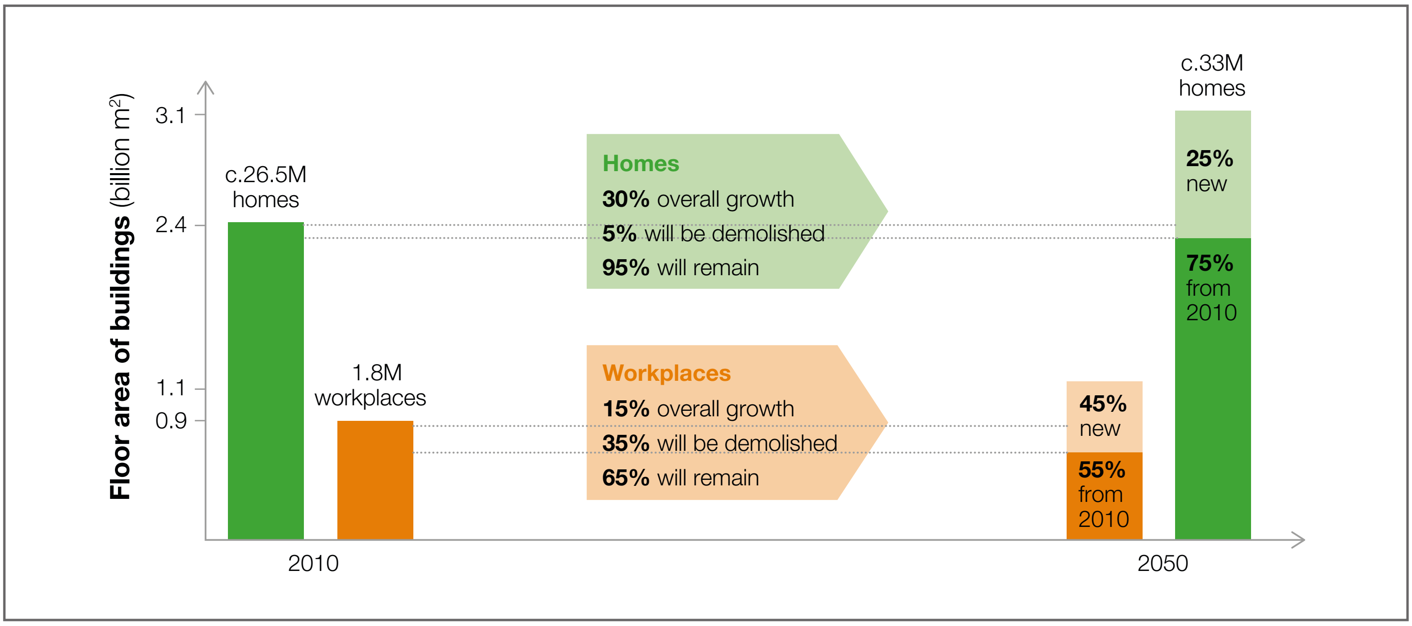

Figure 3: Forecast changes in UK building stock (homes and workplaces) from 2010 to 2050.[19]

[18] These estimates did not consider impacts of Brexit upon build rates in the shorter or longer term.
[19] Energy efficiency in new and existing buildings: comparative costs and CO_2 savings (BRE, 2010)
[20] Europe's buildings under the microscope (BPIE, 2011)
[21] See for example: Building whole-life performance (Innovate UK, 2015 onwards)
[22] Empty Homes Agency Limited Annual Report – Year Ended 31st March 2013

2.4 Approaches to reducing heat demand

GHG emissions can be reduced by reducing the energy's GHG emissions intensity or by reducing energy demand. They are distinct issues, requiring different solutions, albeit there is some overlap, and they can be addressed concurrently. Various methods (and combinations thereof) are available, offering differing potential savings in energy or GHG emissions. It is necessary to weigh up these potential savings against the deployment challenges but also against the likelihood of achieving that potential and maintaining it on an enduring basis. The main approaches are:

- **Reduce losses** from heat distribution (pipework, storage, etc.) and the buildings' envelope (conduction through the fabric[23] and air transfers through openings[24]).
- **Reduce wasteful use of heat by customers** e.g. heating unoccupied rooms, as distinct from heat needed for comfortable conditions in occupied rooms at the right times.[25]
- **Behaviour change** e.g. providing information to allow customers to choose to reduce temperatures for financial[26] or altruistic reasons. It is an option for those that can tolerate lower temperatures[27] and have the discipline to maintain changes,[28] and it is distinct from the problem of self-rationing due to inability to afford sufficient heat.
- **Automation of heating controls** can reduce the scope for inefficiencies in occupants' decisions, e.g. thermostatic controls, zonal controls, timers, monitoring of external temperatures, and algorithms to learn occupants' schedules and optimise ramp rates. Behaviour change and automation are not necessarily mutually exclusive: automation can optimise residual heat provision after behaviour change, or systems can provide information to influence behaviour.
- **Increased efficiency of heating** e.g. by introducing heat recovery units in boiler flues and ventilation ducts, or by upgrading pumps, control systems and boilers. Regulations banning the installation of non-condensing boilers have been very effective at driving improvements,[29] but many new boilers are distressed purchases when an old boiler fails, at which point optimal longer-term decisions are not a priority.
- **Lower-carbon energy sources** e.g. responsibly-sourced biomass,[30] and lower-carbon electricity (via more efficient use of fossil fuels, low-carbon sources, aligning demand with low-carbon generation, and using on-site generation[31] to reduce network losses), or switching from certain technologies (e.g. electrical resistive heating) or switching to certain others (e.g. efficient heat pumps with low-carbon fuel, combined heat and power units, and heat networks).[32]

Fabric energy efficiency to reduce a building's losses is widely agreed to be the most logical first step to reducing heat demand and GHG emissions. Its main benefits are that it:

- provides "passive" performance (i.e. not reliant upon behaviour or equipment) so improvements are "locked in", and at Passivhaus levels the performance is determined almost exclusively by the building irrespective of the occupants;[33]
- reduces heat demand and energy bills (or growth in bills);
- reduces the need for on-site renewables (which can have greater complexity and higher life-cycle costs);
- reduces the use of existing heating systems (and hence the environmental impacts of fuel use);
- reduces the required size (and cost) of any new heating system; and
- increases the range of viable heating technologies (e.g. heat pumps), offsets inefficiencies of energy options (e.g. hydrogen production compared to natural gas), and can even remove the need for a heating system altogether. [34]

To appreciate the potential of fabric energy efficiency, it is instructive to compare the performance that can be achieved through leading practice in fabric energy efficiency, the performance that is seen in the UK's buildings, and the performance that is required by regulations. The standard metric for heat demand is **"specific heat demand", which is the amount of energy for space heating (excluding hot water) per square meter per year (kWh/m^2 per year).[35]** Figure 4 presents examples of the specific heat demand for homes (the messages are broadly similar for workplaces), including high performance standards, the average value for UK homes, and the expected values for homes built in certain years (mostly on the assumption that they meet regulatory standards, and noting that Scottish regulations do require better insulation).

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[23] Thermal conductivity is a measure of how rapidly heat is transferred, stated as a U-value [W/m^2K]. Insulating materials increase the conductivity and hence reduce the rate of heat loss, noted as reduced U-values.

[24] Air tightness is a measure of leakage airflow rate through a building's envelope, measured at a given reference pressure (usually 50Pa, i.e. ~0.05% above atmospheric pressure), and normalised for the building's size.

[25] Some homes are occupied for long durations each day, e.g. those with young children, those with long-term illness, the retired, and the unemployed. Some if these groups have higher heating needs, but also less income to pay for energy.

[26] Cost savings are slightly off-set by the costs of energy suppliers developing and deploying behaviour change interventions.

[27] How much we "feel the cold" is affected by physiology, physical activity, health, and perception and psychological effects.

[28] Energy Demand Research Project: Final Analysis (Aecom, 2011)

[29] Determining the impact of regulatory policy on UK gas use using Bayesian analysis on publicly available data (UCL, 2015)

[30] Biomass can pose challenges, including on-site fuel storage, and competition for limited bio-energy resources.

[31] This can be done by supply-shifting (i.e. storage), or demand-shifting (but the scope is limited with heating).

[32] Heat networks offer economies of scale, more flexibility over fuel supply, more scope to optimise CHP performance, and possibly some energy storage, but they can have larger distribution losses.

[33] An Introduction to Passive House (Justin Bere, 2013)

[34] It can also reduce the need for cooling systems in the UK in summer (and year-round in warmer climates).

[35] The "specific heat demand" is lower than the "specific heat load" (the amount of energy that has to be used in order to meet the space heat demand) owing to inefficiencies in transport and / or conversion of energy.

The chart illustrates that new homes use three times as much heat as they could if built to leading practice. Standards of ~50kWh/m^2 per year for 2014 building regulations for England (currently in force) and for the proposed (but cancelled) Zero Carbon Homes (ZCH) 2016 regulations are better than their predecessors, but lag significantly behind leading practice: building to the higher standards of Passivhaus[36] or AECB Gold[37] of 15kWh/m^2 per year would give ~65% reductions compared to the current building regulations; that is, new homes use three times as much heat as they could do. But even with the current building regulations, new homes should be far better than the average of the existing stock: each new home should contribute around a third as much heat demand as an average existing home, although some new buildings do not meet the regulations.[38]

The chart also illustrates that existing homes' average heat demand of ~140kWh/m^2 per year[39] (~12,500kWh and ~3tCO_2e per year home per year)[40] is over five times higher than leading practice for retrofit. Refurbishing an existing home to the 25kWh/m^2 per year EnerPhit standard delivers ~80% reductions in heat demand (and hence in GHG emissions, even without a new heating source or fuel decarbonisation); this is half the heat demand of new homes that meet the regulations. Recent trials aimed for ~40kWh/m^2 per year, which would deliver ~70% reductions in heat demand.[41] These low levels of demand are only very rarely attempted in the UK; and when they are attempted, some projects do not achieve their aims.[42]

However, that chart also illustrates that heat demand of existing buildings depends upon age,[43] with buildings from 1990 using >200kWh/m^2 per year, compared to <100kWh/m^2 per year for 2002 construction onwards; higher heat demand offers larger scope for reductions, but often with greater difficulty. Other segmentations can also be applied to the housing stock (building type, construction type, fuel type, and some construction features),[44] occupants (age, family size) and workplaces (purpose, occupancy rates, work patterns).

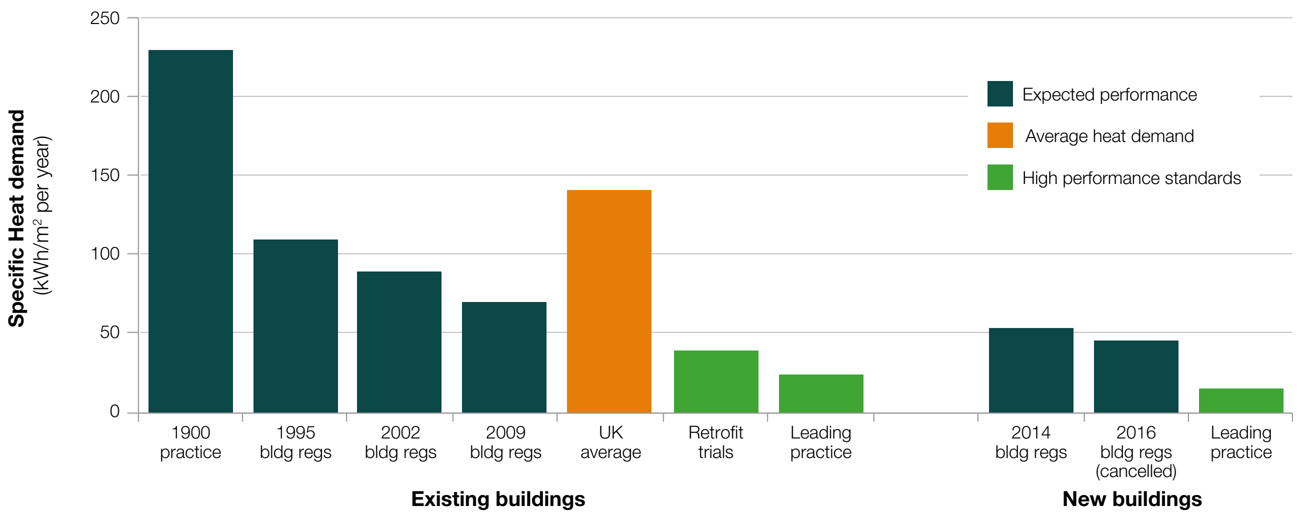

Figure 4: Specific heat demand for: (orange) UK housing stock; (dark green) modelled performance of homes from different eras; and (light green) leading practice.

[36] See: The Passivhaus Standard at www.passivhaus.org.uk/standard.jsp?id=122

[37] See information by Association for Environment Conscious Building (AECB)

[38] See, for example, the underperformance in new buildings in: Building Performance Evaluation (Innovate UK, 2015)

[39] This value is often quoted, and is attributed to the BRE. It can be calculated from the bottom up (using measurements from buildings), or from the top down (averaging out the total heat demand from buildings).

[40] Using values of: average floor area ~90m^2 in England (English Housing Survey 2011-12 (DCLG, 2013)), and assumed here to be similar around UK; 84% of UK homes use gas boilers, the average boiler efficiency in the UK is ~80%, and the GHG emissions intensity of natural gas is ~0.18kgCO_2/kWh (Energy Consumption in the UK (DECC, 2014)).

[41] Retrofit for the Future (Innovate UK, 2014); data available on Low Energy Building Database (AECB, 2014)

[42] See, for example, existing buildings in Retrofit for the Future (Innovate UK, 2014), a trial that included a range of retrofit techniques, including mostly fabric; most projects did not achieve targeted 80% GHG emissions reductions. Similarly, many new buildings in project Building Performance Evaluation (Innovate UK, 2015) did not meet their planned performance, and some failed to meet the building regulations; see for example Building Performance Evaluation Meta-Analysis – Insights from Social Housing Projects (NEF, 2015).

[43] Defining a Fabric Energy Efficiency Standard for Zero Carbon Homes (Zero Carbon Hub, 2009): Results are for modelling of prevailing regulations at the time of construction, or prior to the introduction of regulations according to prevailing building techniques. Issues with modelling and implementation mean that the values might not fully reflect actual performance, but trends are similar. The models were based on English regulations, but broad messages apply to the UK.

[44] Optimising Thermal Efficiency of Existing Housing (The ETI, 2012): divides the UK's housing stock into 40 types, with nine main types accounting for over 40% of the housing stock. Home economics – Cutting carbon and creating jobs, by nation and region (Energy Saving Trust, 2011): identifies 96 different housing types, highlighting those with particularly high GHG emissions.

Fabric energy efficiency is undoubtedly the best approach for new buildings: it maximises the time over which the measures can act, causes no disruption for occupants, and avoids the greater costs and disruption of future refurbishment. **For existing buildings, improving the fabric is also the most logical first approach**, but the scope can be limited by practicalities of a building's characteristics and occupants' circumstances. It is challenging to make major improvements in existing buildings' fabric energy efficiency, but if improvements are not made rapidly, the UK could be left with a residual heat demand that is too large for its low-carbon heat sources. The UK would face an insurmountable back-log of retrofit projects, including to upgrade new buildings that have missed the opportunity to adopt leading practice from the start. The UK needs to increase uptake of improvements by ambitiously improving the energy standards for new buildings, and accelerating the deployment of retrofit solutions for existing buildings. To aid with this deployment, it is necessary to segment the existing buildings stock to allow the development of plans with optimal combinations of fabric improvements and other approaches,[45] but it is necessary to retain large enough groups to justify the effort of devising specific plans and to find economies of scale in implementation.

Alongside an overall ambition for an existing building, it is necessary to develop an implementation strategy. Some experts promote the "one-off" approach of "do it once and do it properly". This can immediately realise significant benefits for occupants and the environment, and it limits the disruption for occupants to a single set of works; but undertaking all improvements at once can pose large upfront costs that many customers cannot afford, and it entails a period of building works that many occupants do not want. The alternative is an incremental approach to cumulatively install measures at different times: it spreads out the expenditure and reduces the disruption at any one time; it provides some immediate benefit to poorer customers who cannot save for a larger retrofit; and it might postpone the more difficult measures until they become easier and cheaper. However, multiple interventions will have higher overall costs and disruption, each set of works will introduce elements of duplication for customers (e.g. finding contractors, preparing the space) and contractors (e.g. initial visits, invoicing). This illustrates a point (discussed in the uptake sections) that some customers do not (or cannot) make economically-optimal decisions: the individual costs of each improvement can matter more than the total costs or the cost-effectiveness, and non-financial factors matter, especially the "hassle factor".

Any incremental approach has to be part of a coherent plan for a building, to ensure that measures are installed in logical order that provides immediate benefits without limiting future options.[46] The risk with an incremental approach is that it degenerates into a "piece-meal" approach that delivers a series of "shallow retrofits". This could leave the UK with many partially-improved buildings that still need the deeper refurbishments that customers were trying to avoid, but with insufficient time and resources to complete the task. In order to avoid these issues, a sensible approach could be to offer packages of improvements, in order to allow customers to trade-off the level of improvement, the costs and the disruption, whilst also giving significant benefits immediately, and leading onto future improvements.[47] Approaches are being developed that are less disruptive and could be applied to large numbers of buildings.[48]

[45] See, for example: Smart Systems and Heat (The ETI, 2014): this programme is developing a tool to assist local authorities to determine the optimal approaches for decarbonising heat in their areas.

[46] Some measures necessarily inhibit future changes, e.g. wall cavity insulation cannot easily be replaced.

[47] See, for example: Optimising Thermal Efficiency of Existing Housing (The ETI, 2012). This project proposed three intervention packages: Retrofix (basic issues); Retroplus (more measures); and Retromax (Passivhaus).

[48] See, for example: Smart Systems and Heat – Novel retrofit of houses (The ETI, 2014 onwards)

2.5 Gaps between performance and leading practice

The high performance options illustrated in Figure 4 are rarely attempted in the UK, whether by fabric solutions alone or in conjunction with lower-carbon energy sources. The main question is why high performance has not been attempted more widely for existing buildings, and why it is not required by the regulatory standards for new buildings. The second question is why, when high performance has been attempted, it has not always been achieved. It is helpful to break the issue into components, as illustrated in Figure 5. The levels of heat demand can be defined as:

- **Leading performance:** the very low energy demand that is proven to be possible using existing products and techniques.
- **Expected performance:** the energy performance that is expected based upon modelling.
- **Realistic performance:** the energy performance that could actually be achieved.
- **Actual performance:** the energy performance that is achieved in practice.

The gaps between the performance levels illustrated in Figure 5 can be defined as:

- **Uptake gap:** the difference between what is being attempted (if anything) and what could be attempted (i.e. leading performance). It exists because of barriers or lack of ambition for space heating demand, and is almost always large, because most projects (new or existing buildings) do not attempt leading performance; but it is even larger because even the simpler improvements are often not attempted on many existing buildings.
- **Prediction gap:** the difference between what is expected and what is realistically achievable; it exists when forecasts of buildings' performance are inaccurate. It gives unrealistic expectations, and hence can prevent optimal use of resource: overly optimistic predictions lead to less efficient measures being promoted, and overly pessimistic predictions deter customers' interest (contributing to the uptake gap). The prediction gap was recently found to be larger than had been thought, owing to inaccurate assumptions; even now its size is uncertain due lack of relevant data.
- **Performance gap:** the difference between what is realistically achievable and what is delivered in practice; it exists because of poor quality work and incorrect operation. It prevents deployed measures from delivering their potential benefits (which can cause reputational damage that contributes to the uptake gap). It is known to be large, due to issues including poor quality work. It can be difficult to disaggregate the prediction gap and the performance gap, and they are often referred to together as a performance gap; but it is helpful to try to separate them out where possible, in order to identify their impacts, causes and solutions.

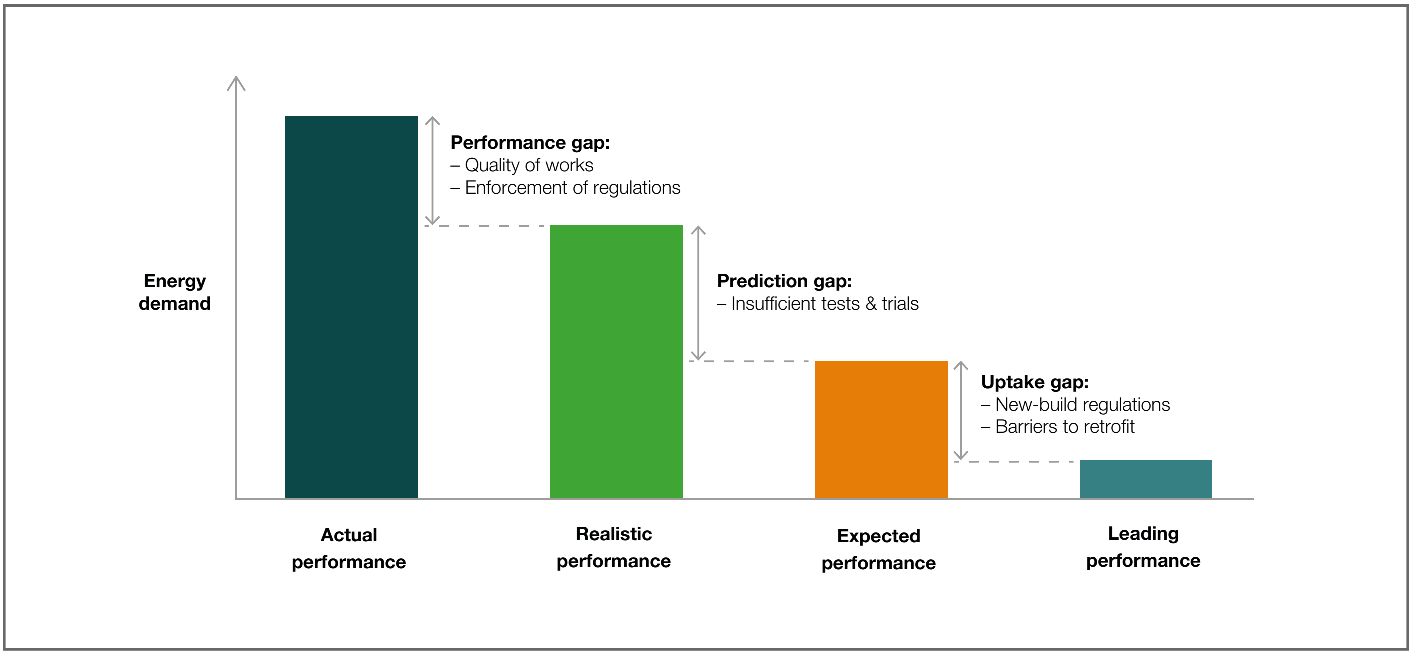

Figure 5: Illustration of different levels of energy usage, and gaps between them.

2.6 Addressing the gaps in uptake, prediction and performance

The challenge of reducing buildings' heat demand by addressing the gaps in uptake, prediction and performance can be viewed as a national infrastructure project (as it is in the Scottish Energy Efficiency Programme), with its huge scale and need for a co-ordinated plan; but it differs from other infrastructure projects because it involves millions of separate projects and owners. **Another perspective is the positive example of energy performance of electrical appliances**: the uptake gap is small because regulations keep up closely with leading performance; the prediction gap is small due to ease of testing; and the performance gap is small due to high quality work and due to regulations that are not necessarily more numerous but that are enforcement effectively. To reach a similar situation for space heating, steps are needed to address the gaps, but these steps should be taken pragmatically:

- It is important to not pursue spurious precision or allow "the best to become the enemy of the good".
- It is necessary to continue with deployment of measures that are known to save energy and reduce emissions, even if their exact impact is uncertain, in order to contribute to GHG emissions reductions, but also to assess performance.
- The early stages of deployment of any measure should be treated as a "safe learning environment" in which all parties recognise the potential for underperformance and for unintended consequences.

The factors that contribute to the gaps in uptake, prediction and performance can be mapped onto the cycle of developing and using improvements in buildings, as illustrated in Figure 6. This cycle starts with research and development, moves to demonstration, then deployment, and finally to use in occupied buildings, with feedback at various points to verify performance, make improvements, and develop future iterations. Sections 3 to 6 consider each gap in turn (with separate sections for uptake in new and existing buildings), and sub-sections within these sections explore the contributing factors shown on the map.

Lack of data and information is a key theme in the factors that contribute to the three gaps. For uptake, many customers lack information about potential energy savings, and policy-makers do not always fully understand customers' motivations. For prediction, there is lack of data about performance, as well as issues with the models used. For performance, the sectors lack knowledge and skills for implementation, and there is limited data about actual performance.

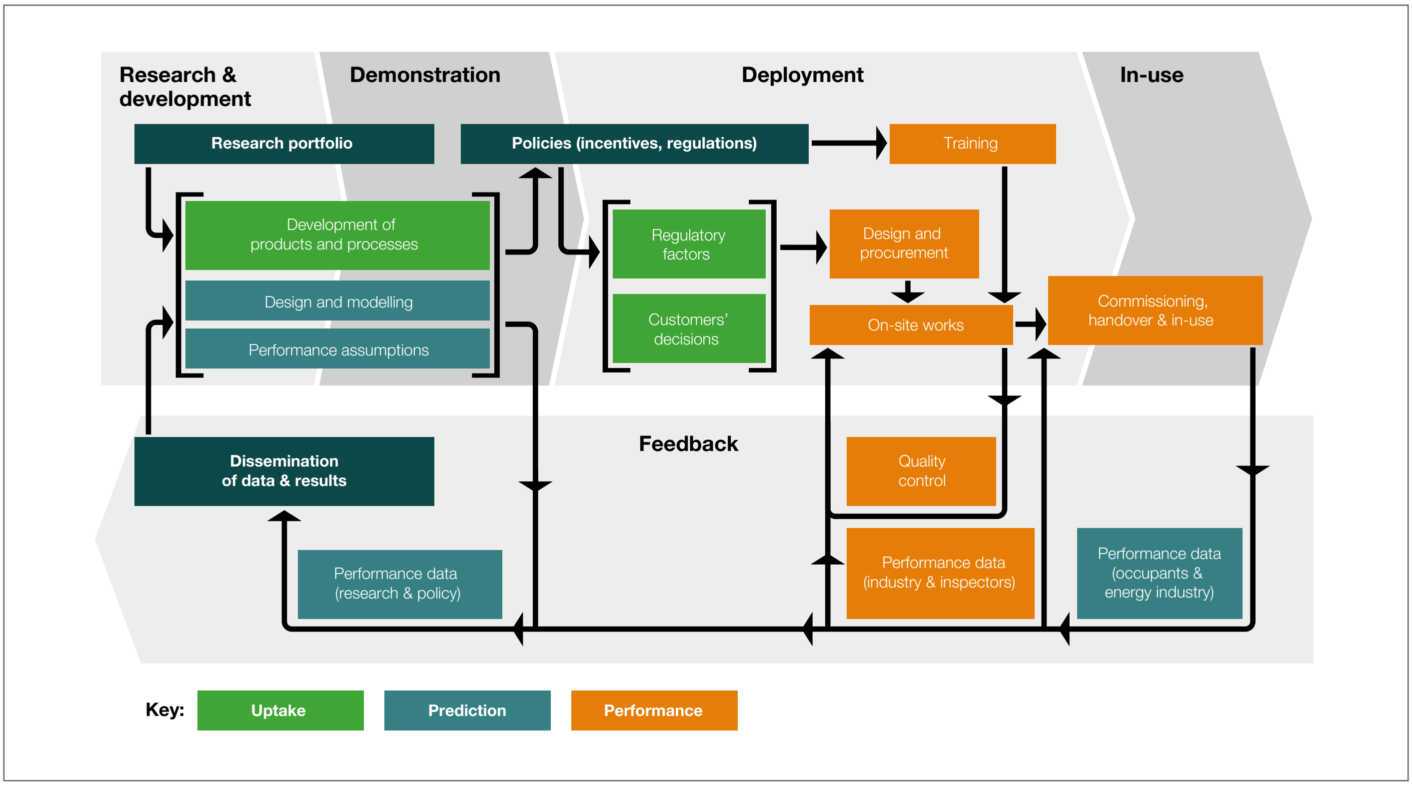

Figure 6: Illustration of: (large arrows) the cycle of developing and using improvements; (boxes) key factors that contribute to successful operation of the cycle; and (thin arrows) key linkages.

However, data is not a panacea: simply having data-gathering capacity does not constitute a solution; and what is actually needed is information that results from processing the data. There is often little understanding of the challenge of getting from data to information. For example, there is currently much interest in "crowd-sourcing" of data from many customers, and the "internet of things" (i.e. appliances, devices, vehicles, etc. that can use internet connections to receive commands and/or transmit data). However, implementing any particular project would take significant effort. There must be a range of expertise to properly scope a project to ensure that relevant data is gathered; careful implementation to ensure that the data is gathered in a reliable and comparable manner; potentially sophisticated algorithms to process data (in real time for some applications); and an understanding of the end-users in order to ensure that the data is translated into useful information for decision-making.

Uncertainties in forecasts have to be properly treated and interpreted. For example, scenario-based forecasts of uptake can be wrongly treated as if the outcomes will lie between the outer scenarios. However, there is intrinsic uncertainty in inputs for scenarios, such that each individual scenario is not a "single line" but rather a "spreading wedge", but this is often not shown on charts and not considered in decisions.

With these caveats, having more (and better) data is a key step to addressing each of the three gaps. Uses of data and information about reducing energy use can be grouped as "direct" and "indirect" uses of data.

Direct uses of data are within individual buildings, for day-by-day decisions about operation of heating systems. Smart meters are intended to improve the quality and value of information available to customers, and new initiatives for gathering and using data are being offered by a range of providers, including new entrants to the energy sector. Examples include: smart meters to provide half-hourly meter data for customers and energy companies;[49] advanced heating controls to optimise performance;[50] mobile communications for customers to monitor and control their heating;[51] thermostatic radiator values that only heat occupied rooms[52] and to record spatial and temporal temperature data;[53] and a wider suite of sensors to measure temperature, humidity and light levels alongside energy consumption, to allow monitoring of the healthiness of living environments.[54] Some services have demonstrated significant reductions in heat demand sometimes in conjunction with providing other benefits (especially convenience for occupants through not having to adjust settings). However, some of the benefits of these data approaches are yet to be fully understood (e.g. there are evidence gaps about the impact of advanced heating controls),[55] most have yet to be deployed at scale across the building stock, and there are questions about interactions and compatibility of these initiatives (see prediction section). However, installing equipment for monitoring and controlling temperature (especially in buildings with limited heating controls) has merit in its own right as a demand reduction tool, and has the potential to inform decisions about further improvements.

Indirect uses are when data informs decisions about making improvements that will reduce energy use in future; the data can come from the individual building, but also from the wider building stock. At present, most recommendations are based upon energy consumption data, and assumptions about the performance of buildings, behaviour of occupants, and impacts of measures (see prediction section). Some recommendations are based upon actual measurements made at the building in question; this is more common for larger workplaces and uncommon for homes. An established (but not yet widely-used) method is thermographic imaging: this provides a visual representation of where fabric solutions are needed. Data from multiple buildings is needed by researchers in order to more accurately understand buildings performance, occupants' behaviour, and the impact of measures. This data can be gathered by more conventional studies (some involving site visits), or by "crowd-sourcing" data using technology that is already in place. The results can help to inform policy and the design and marketing of products, it can also help identify generic improvements for different types of buildings. Solutions can be proposed for specific buildings (without having to visit the specific building) by comparing the energy data with that from other buildings. For example, if a home was using more gas than similar homes with similar occupancy and sensors showed that the temperature fell more rapidly (after the heating was switched off) in one room in particular, then the customer could investigate insulation options for that particular room. However, these data approaches are only useful for identifying issues and proposing solutions; they must be followed up by practical assessments before implementation.

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[49] Energy Demand Research Project: Final Analysis (Aecom, 2011)
[50] For example, Npower is offering the Google-Nest thermostatic heating controls that learn how to meet heating needs more efficiently.
[51] For example, British Gas is offering the Hive smart phone app for controlling heating remotely.
[52] The principles behind OpenTRV (Open TRV, 2013)
[53] The Open Energy Monitory System (Open Energy Monitor, last updated 2015)
[54] Project Chariot (Centre for Sustainable Energy, 2015 onwards): https://www.cse.org.uk/projects/view/1312
[55] How heating controls affect domestic energy demand – A Rapid Evidence Assessment (DECC, 2014)

3 Uptake of improvements for new buildings

The uptake gap for new buildings is the difference between the space heating performance that is attempted, and that which is possible using leading practice. Leading practice is possible in new homes and workplaces with comparatively small additional cost, and it offers the opportunity to avoid unnecessary GHG emissions and the disruption of future refurbishment, but the mass market has yet to take advantage of this opportunity. This section considers the roles of market pull and regulatory push; for the latter, it highlights how limited ambition and future certainty inhibits planning and innovation in the supply chain.

3.1 Customers' decisions

There is limited differentiation between new buildings and the second hand market for existing buildings, and so the majority of builders do not prioritise energy performance in new buildings. Some builders do try to exceed the regulatory standards without customers necessarily requesting it. This can be for reasons of corporate image, or sometimes altruism, it can be to manage risk such that any buildings that happen to perform more poorly than expected are still likely to meet the regulatory standards, or it can be to be "ahead of the curve" by preparing for future regulations.

Energy performance is a consideration,[56] but not the top priority for most customers, who tolerate energy costs because they do not (or cannot) rank them highly enough compared to other considerations (e.g. price, location, amenities, etc.). Customers who might want better energy performance, but who buy mass-produced buildings (i.e. most house buyers and small companies) do not have options to influence the design and construction, although some larger commercial customers can do so. There are initiatives to better inform customers about buildings' quality and performance (e.g. BRE's Home Quality Mark, HQM)[57], and there a need for consistent messaging from industry and government about the benefits of improving buildings.

Some new-build customers do want high energy performance, and they are catered for by specialist companies. Part of this demand in the housing sector comes from self-build and custom homes,[58] which accounts for ~10,000–20,000 new homes per year in the UK.[59] Many builder-owner-occupiers intend to live there for longer than the average occupancy (of seven years in the UK), and take a longer-term view of costs and benefits. This can include aiming for high energy efficiency to give lower running costs and lower lifetime costs. The National Custom & Self Build Association (NaCSBA) recommends that the "most important thing that any self builder can do is invest in really good levels of insulation … significantly more than the levels demanded by the Building Regulations".[60] Costs do vary significantly between self-build projects, and, whilst examples are given and guidance is available,[61] there is limited understanding of the full costs of projects including the time commitment from owners.[62] That said, self-build projects tend to be cheaper than like-for-like mass-market buildings (by removing some profit margins from the process), sometimes by as much as 25%,[63] and some customers use these cost savings to fund better energy performance without increasing overall construction costs compared to mass-market buildings.

3.2 Regulatory factors

The limited market pull means that regulatory standards are needed to bring the desired benefits for customers, and also for the environment and UK energy security. Thermal performance standards for new buildings have been improving,[64] but slowly; and they lag behind the leading practice, hence causing an uptake gap. The sub-section considers reasons for the slow pace of change in regulations and the uncertainty about their future trajectory, and how these impact upon planning and innovation in the industry; it also highlights aspects of proposed regulations that offer lessons for future regulations.

Building regulations for energy efficiency and GHG emissions for new buildings are broadly similar across the UK: they specify limits for GHG emissions, standards for fabric energy efficiency,[65] and requirements for pressure testing and commissioning of building services (a notable difference is that the Scottish regulations require higher levels of thermal insulation). Requirements are supported by detailed statutory guidance. For England and Wales, guidance documents show some ways of meeting the requirements, as well as specifying the prescribed procedures for calculating GHG emissions and fabric energy efficiency. However, the requirements are functional: that is, builders have flexibility to adopt different solutions if agreed with the relevant building control body.

[56] A See, for example, a survey by Money Supermarket (for the development of BRE's Home Quality Mark) found that 97% of customers would, if they had better information, buy a home that was more sustainable and energy efficient.

[57] See: http://www.homequalitymark.com/

[58] Supply and Demand for Low Energy Housing in the UK (University of Cambridge, 2005)

[59] Self build homes – the numbers (NaSBA). The NaSBA (now the NaCSBA) set up the Self Build Portal (endorsed by DCLG).

[60] Eco Guidance (Self Build Portal)

[61] See, for example: Budget Advice (Self Build Portal)

[62] Understanding the changing landscape of the UK self-build market (University of York, 2013)

[63] Report for Investors Chronicle (Stephen Wilmot, 2013)

[64] NEED report: Summary of analysis 2013 Part 2; Annex B: Summary of Building Regulations (DECC, 2013)

[65] Approved Documents L1A, L2A, L1B and L2B (DCLG, 2014)

Financial factors affecting pace of change

On the demand-side, Government is concerned about affordability and availability, especially in the housing market. Building to higher standards does usually add upfront costs; the extra costs vary significantly, perhaps reflecting the wide range of projects types undertaken. One study suggests that Passivhaus and similar standards increase upfront costs by ~25% (but notes that this is based on historical data that might not reflect current costs);[66] another study suggests extra costs of 15%, but notes that in some cases they are less than 5% and that some other cases the total cost is actually lower than for the prevailing building regulations.[67] Whatever the cost difference at present, it will shrink over time for two reasons: improved regulatory standards will increase the cost of the counterfactual; and it is likely that innovations and economies of scale will reduce the cost of Passivhaus (or similar) construction. Furthermore, building to higher standards reduces outgoings on energy bills, and it reduces (or removes) the need for future retrofits; it is important to consider longer-term costs (albeit they are strongly dependent upon the discount rate), as well as other factors (as discussed in the section about uptake for existing buildings).[68]

On the supply side there are pressures on Government to avoid the upfront costs of higher standards, again particularly for the housing sector. However, the costs of better energy performance for both homes and workplaces must be considered in the wider context of builders' costs. The profit on a new building is the difference between its sale price and costs, primarily land purchase and construction; construction costs are well understood, but land costs are more opaque. The maximum price that a builder will pay for land is the difference between the price of a similar existing building nearby (when the land was purchased, and possibly uprated by a "new-build premium") and the sum of the construction costs and the desired profit. Builders compete for land, and profits are aided by having a portfolio of land that has been bought over previous years (when building prices, and hence land prices, were lower). If higher standards increased construction costs, then builders could reduce the price that they are willing to pay for land,[69] so it could be possible to increase standards without increasing costs for customers.

Scale is an important factor for builders. Smaller building companies with lower economies of scale and smaller cash flows can have less scope to cope with increased construction costs, where larger companies arguably have more scope to absorb higher costs.[70] Some small companies might struggle to obtain the training for delivering higher standards; but conversely, smaller companies might more easily adapt their supply chains (and some are already specialists in high performance).

Processes affecting pace of change

The pace of improvements in regulations could be increased by addressing a mismatch of expertise and resources in the development process. Government and its agencies invite industry members to join working groups, in a voluntary capacity. Experts in high thermal performance could quickly develop high regulatory standards, but are often from small companies with limited resources. Some larger building companies lack that expertise, but can commit more resources to the process of developing regulations. A vicious circle develops, whereby experts cannot commit their time over the period taken by larger companies' representatives to learn about high performance, and so the regulations are developed by larger companies alone, to lower standards (referred to by some experts as a "last man standing" approach to developing regulations).

The expert community in the UK should seek greater cohesion in order to better advise on regulations. The sector is quite disparate, in contrast with countries where high-performance approaches have received official endorsement as voluntary national standards that customers can request and that contractors can offer as standard.[71] In the UK, there have been ongoing debates between practitioners about the relative merits of challenges of different high-performance approaches. Whilst some of this is important to answer questions about cost and performance, there is the risk that detailed debates fragment this small industry for high performance, reducing its ability to promote its knowledge to the wider industry and Government.

▶ **The involvement of experts in leading practice in developing regulations should be better facilitated, e.g. by offering experts from small companies some form of support to reflect the costs of serving on working groups.**

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[66] Passivhaus and Zero Carbon – Closing the Cost Gap (Aecom and nvirohaus, 2014)
[67] See for example: The Cost of Building Passive (Kate de Selincourt, 2014)
[68] See for example: An Introduction to Passive House (Justin Bere, 2013)
[69] See Offsite Housing Review (CIC, 2013), including "Note of House-Builders Special Interest Group Workshop"; see also The Financialisation of UK Homes (NEF, 2016): www.neweconomics.org/publications/entry/the-financialisation-of-uk-homes
[70] Report for Investors Chronicle, Stephen Wilmot, 2013: Large house builders are making profits of ~25%.
[71] For example, the Minergie standard is supported by the Swiss Confederation and Cantons.

Buildings' energy policy would benefit from further cross-departmental joint working, and from expert advice from a permanent advisory body. Interest in building regulations is split across the UK Government: DCLG sets regulations, but BEIS has particular interest in Part L relating to energy efficiency, and DfE (previously BIS) has interest in the construction sector's training and skills. Joint working between DECC, DCLG and BIS[72] did occur on building regulations, and senior staff from DCLG and BEIS sit on one another's buildings project boards. The departmental changes of 2016 leading to the creation of BEIS and a shared ministerial post across BEIS and DfE offer an opportunity for closer joint working on building regulations. There is also a need for close working with the National Infrastructure Commission (NIC) and the devolved administrations.

The Energy Innovation Board (EIB) could play a role in facilitating joint working, particularly around applying research findings and innovations to the development of buildings' energy policy. This would benefit from input from a permanent expert panel that Government could draw upon for policy development and monitoring. Previous advisory panels have been established for narrow purposes, used sparingly, and allowed to fade away; it is better to have a panel with permanency (albeit with periodic, staggered changes to membership). This would retain institutional memory, avoid the time required to set up a new body for each new policy issue, and would have greater credibility with government, researchers, and the construction sector. The EIB could seek to appoint such an advisory panel to draw upon industry and researchers to receive advice on co-ordination of research programmes, the use of research resources, and the application and dissemination of research findings.

▶ **We recommend that, to guide buildings' energy policies and regulations to be commensurate with the UK's Carbon Budgets, a cross-departmental group should be established with membership from DCLG, BEIS, and relevant organisations (e.g. National Infrastructure Commission), aided by the establishment of an expert advisory panel.**

Uncertainty about regulatory trajectory

Recent political events and policy changes have significantly increased the uncertainty about the future trajectory of building regulations. In 2015, the UK government abandoned the commitment to introduce the Zero Carbon Hub (ZCH) 2016 standards for new homes, which also affects the development of similar standards for workplaces. In 2016, the UK's EU referendum result introduced uncertainty over whether the UK will retain the EU's Energy Performance of Buildings Directive (EPBD) for 2019.[73] These two events have removed what certainty there was about two key waypoints on the trajectory of building regulations.

Even prior to these changes, the trajectory of future building regulations was uncertain. The incremental improvements have been unpredictable, introducing uncertainty for the industry and inhibiting planning and innovation:

- Changes to Part L regulations for 2014 were subject to long delays, deterring forward planning by industry.
- The final decision for the 2014 regulations chose lower standards than had been consulted on, wasting the efforts of some in the industry that had planned ahead.
- The Housing Standards Review re-opened the debate and decided to limit local authorities' rights to place requirements on building developments.[74]
- The Code for Sustainable Homes is no longer a requirement for new developments.
- The "zero-carbon" standard for homes was developed slowly, and some in the industry were worried that its introduction would be delayed until after 2016. This turned out to be true, and the speculation illustrated the uncertainty that exists within the sector about the future trajectory of building regulations, with damaging impacts upon innovation and planning.

There is a need for Government to develop an ambitious trajectory for future regulations, aided by experts in high thermal performance. This would be of benefit to the building industry and its suppliers, allowing them to undertake research, to train work forces, and to develop supply chain capacity and contracts. Greater involvement by experts in high thermal performance would aid development, and could be facilitated by offering small some form of support to reflect the costs of serving on working groups.

▶ **We recommend that, to provide ambition and certainty for the building industry, DCLG should produce a regulatory trajectory for building energy regulations that reaches leading performance in fabric thermal efficiency, and should maintain this trajectory.**

[72] In 2016, BEIS was formed from DECC and parts of BIS.
[73] EU Directive 2010/31/EU on the energy performance of buildings (European Parliament and Council, 2010)
[74] Some welcome this change as removing a "destabilising influence" in the house building industry; others view it as bringing exemplar local authorities back to a "lowest common denominator" and stifling innovation.

Lessons for future regulations

The UK's original announcement of its ambition for zero-carbon buildings was welcomed, but there were concerns about the UK's ability to deliver. The role of the Zero Carbon Hub (ZCH) was to advise DCLG[75] on the development of a "zero carbon" standard for homes for introduction in 2016,[76] to be followed by a "zero-carbon" standard for workplaces from 2019. These ZCH standards would have led towards the EPBD standards, requiring that from 2020 onwards (but from 2018 for the public sector) new buildings would have to meet a "net or nearly zero" energy standard. Whilst the level of ambition was welcomed by many campaigners, there were no intermediate steps and little detail about how to improve practices quickly, so that some experts expressed surprise at the level of ambition and scepticism about the ability of its buildings' sector to quickly improve practices from existing low levels to Passivhaus standards.

The UK subsequently reduced its ambition, such that new buildings would not have been as high performing as originally envisaged. DCLG accepted the ZCH's proposal for England to use a combination of approaches: carbon compliance, made up of a Fabric Energy Efficiency Standard (FEES)[77] and on-site low carbon heat and power; and "allowable solutions" to offset the remaining GHG emissions. This approach was supported by the major house-builders. However, there were concerns about the proposed 2016 regulations for new homes that should be considered in the development of future standards:

- **The FEES was not as ambitious as leading performance**, leaving a larger residual heat load and missing an opportunity to avoid GHG emissions, so that the buildings would have to be retrofitted in future with greater expense and disruption than if they were built to a better standard in the first place. It would have given more opportunities to justify the use of allowable solutions, and would have reduced incentives for builders and supply chains to innovate to find cheaper ways of providing high fabric energy efficiency.

- **The inclusion of GHG offset funds as allowable solutions[78] would have further weakened action in the building sector**, and was contrary to the previous expectation given by DCLG that they should involve improvements to other buildings in local communities.

- **The "political definition" of zero[79] posed major risks to public understanding and trust.** Under the proposals, whilst net emissions from building project including any offsets might have been zero, the buildings themselves would have used more heat than was provided to them by zero-carbon energy sources, and GHG emissions would have been larger than actual zero. Customers who did not appreciate the distinction might have been complacent about the impact upon the climate. Customers that did notice the distinction, but did not understand it, might have been confused. And customers that both noticed and understood the distinction might have been sceptical about the benefits of the standards. It has been suggested that it could have been more appropriate to call the standard something like "low carbon homes", or even to remove altogether the references to GHG emissions, and simply continue the convention of naming them "building regulations [year]".

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75 Devolved Administrations seek advice from other organisations as well, e.g. the Welsh Government from the Welsh Low/Zero Carbon Hub (WLZCH).

76 Building projects must comply with the regulations in force at the time when planning permission was sought, introducing a lag of years between new regulations being introduced and being used. This is in addition to the lag between leading practice being demonstrated and being incorporated into regulations.

77 All regulations across the UK specify the U-value for each type of element (walls, floors, roofs, windows, etc.), averaged across the building, and state the maximum allowed U-value for any element of each type. Scottish regulations require lower average U-values, and the Welsh Government has decided that U-value backstops will been improved and mandatory.

78 Infrastructure Act 2015 (HM Government, 2015)

79 This is not the same as the legitimate technical debates about how to measure and allocate GHG emissions.

4 Uptake of improvements for existing buildings

The uptake gap for existing buildings is the difference between the space heating performance that is attempted, and that which is possible. The uptake gap has two components: the number of projects that are attempted (which is comparatively small), and the ambition of each project (which is low on average). Progress hasbeen made, for example retrofitting existing homes mainly through energy supplier obligations (EEC, CERT, CESP, ECO),[80] but key measures have still not been deployed in many buildings.[81] Most existing homes and workplaces have large uptake gaps because only limited improvements are attempted; only a very few have a small uptake gaps where customers have attempted a package of measures aiming for leading practice. This section considers why there is limited appetite for improving existing buildings, considering both "market pull" and "regulatory push". It also considers the wider impacts of the uptake gap in perpetuating low uptake by creating a vicious circle: the small market reduces the financial justification for research and promotion of products and services, which reinforces low market demand.

4.1 Customers' decisions

There would appear to be strong market drivers for improving existing buildings, such that most homes and workplaces will have some cost-effective options. However, customers often do not adopt the measures that might be expected, partly due to how cost-effectiveness is viewed, and partly due to other barriers that inhibit uptake, but there are also triggers that encourage uptake and the potential to increase customers' interest with new products, installation methods, and services.

Assessing costs and benefits

For many customers, cost is more important than cost-effectiveness.[82] Some do not have the money available (or are concerned about borrowing it) to make large upfront investments, and hence cannot access a longer-term net financial gain. Easier access to funds can address this issue, as shown by the popularity of the Green Deal Home Improvement Fund (GDHIF) that offered grants instead of loans for expensive measures; and the Scottish Government's Home Energy Efficiency Programmes for Scotland (HEEPS) offers interest-free loans of up to £15,000 per home for energy improvements.[83] Some customers have access to upfront funds, but are unwilling to invest in buildings' improvements; this can because it is a less familiar investment with longer-term returns than they are used to. In both cases, whilst it might appear that some customers do not make economically-optimal decisions, their decisions reflect their circumstances, their other priorities, and their attitudes to risk, and policies have to reflect these realities.

There can be a challenge in designing policy that achieves its environmental aims via customers' financial decisions. Policies seek to optimise the metric of "money spent per tCO_2 avoided", and customers are more interested in the metric of "money spent per money saved". These two metrics often align, but there can be challenges at least in communicating the intentions.

Customers and Government have different approaches to deciding on which (if any) climate change mitigation investments to make, with implications for how funds can be targeted.[84] Government sets aside budgets to be spent on climate policies, either from taxation of energy bills, and can then seek the cheapest options (in £/tCO_2) to optimise use of the funds to maximise the GHG emissions reductions. If some of that money is not spent on one climate policy, it will be available for another. By contrast, most customers do not allocate a budget for climate mitigation, but rather they decide upon expenditure based upon a range of drivers and priorities. For example, solar PV panels have been popular with home-owners for a range of reasons (greater self-sufficiency, FITs income, etc.), but if they decide to not spend money on solar PV panels they are not likely to seek out an alternative climate-related investment of similar cost or impact (e.g. solid wall insulation (SWI) or a hybrid car). They might not spend the money at all (and instead save it, or not borrow it), or might spend it on a (non-energy) home improvement. Customers' decisions to invest in other climate change mitigation measures would likely be independent of each other, e.g. installing SWI involves a rather different "customer journey" than solar PV, and buying a hybrid is usually triggered by transportation needs. If Government funds alone are used to pay for mitigation measures, then those funds can be targeted at the most efficient measures; but if Government funds are used to part-fund mitigation measures in order to leverage customers' funds, then it might be necessary to compromise and target measures that are more popular even if they are less efficient (in terms of £/tCO_2).[85] Compared to optimal investments, the second approach would have higher overall costs (to Government and customers) or less GHG emissions avoidance; but that is preferable to trying to leverage optimal investments that customers do not respond to, and hence failing to leverage their funds for climate mitigation of any sort. **In summary, it can be better to achieve a lot of something sub-optimal than nothing of something optimal.**

[80] A For numbers of measures added to homes see: United Kingdom housing energy fact file: 2013 (DECC, 2014)

[81] Left out in the cold (Association for the Conservation of Energy (ACE), 2015)

[82] See, for example: The Green Deal and the Energy Company Obligation – will it work? (Rosenow and Eyre, 2012). Similar issues are seen in other sectors, e.g. transport: Energy Options for Transport – Deployment and Implications (ERP, 2016)

[83] See: http://www.energysavingtrust.org.uk/scotland/grants-loans/heeps

[84] Government funds come from taxation, and supplier obligation funds come from energy bills, both of which include money from customers who can be purchasers of buildings energy efficiency improvements. But for the purposes of this discussion, customers' funds are distinct from government funds in terms of how they are allocated.

[85] The appeal of measures is a different issue to the appeal of funding mechanisms, which was discussed in a recent report by the Public Accounts Committee into the failure of the Green Deal: Household energy efficiency measures (PAC, 2016).

Cost-effectiveness calculations should include all of the financial costs and benefits that affect customers' decisions, not just upfront costs and energy bill reductions. Policies tend to assess the trade-off between expenditure and lower energy bills (the Green Deal's "golden rule"), but not wider financial matters. For example, some customers place value on protection from the risk of (unknown) future energy prices; and there are financial issues beyond energy bills. Since the 1980s, Ecology Building Society has offered lower mortgage rates for buildings with lower energy demands, on the basis that lower monthly outgoings reduce the likelihood of default, and hence reduce the lender's risk, allowing customers to trade off energy efficiency investments against savings on both energy bills and mortgage payments.[86] A recent report on mortgage affordability concluded that mortgage providers can offer lower interest rates, and hence larger mortgages, for more efficient homes.[87] There is also evidence that a home's value is increased by improved energy performance,[88] providing an incentive for owners to improve the performance. Potentially, improved energy performance could both increase the cost of a home and increase the amount that the buyers can borrow, and the net effect is not yet clear. **If all of these financial factors were included in analysis that was used to promote improvements, customers' decisions could be different to those at present.**

Cost-benefit analysis should include non-financial benefits,[89] including greater comfort, improved health (which also reduces health care costs),[90] improved education,[91] and employment in the buildings sector.[92] Such factors can be powerful drivers for customer decisions,[93] even if they are not easily translated into monetary values (and indeed to convert them into financial values can detract from the fact that they are "good things" in their own right).[94] In Germany, the government considered such wider issues, and saw justification for providing financial support for deep refurbishment, in the form of low-interest loans of several €10,000 per building.[95]

Customers are interested in these wider financial and non-financial benefits, but they do not necessarily associate them with energy savings, or at least they find it difficult to weigh them up to make an assessment. The result is that most customers adopt a limited set of measures, and are too uncertain to do more. This can also set up a vicious circle whereby customers feel that they have "done their bit", and might be resistant if asked in future to undertake a deep refurbishment. To encourage uptake of deeper buildings' refurbishment across the UK's building stock would require consideration of the wider benefits.

Double-glazing is a very important precedent for of an energy efficiency improvement that is popular for a range of reasons. It was popular even before the current concerns over energy security, affordability, and climate change. Its high upfront costs are unlikely to be recouped from energy bills, but it is desirable for a variety of reasons (e.g. ease of maintenance, security, appearance, and sound-proofing), as reflected by the fact that it increases properties' value. Similarly, some decoration or remodelling projects that can be of similar costs to energy refurbishment are not justified by economic rationale, but they appeal to owners. Lessons can be learned from these other projects, to improve the promotion of improvements for energy and GHG emissions.

▶ **Policies should seek to incorporate customers' views of costs, cost-effectiveness and barriers to uptake, including to allow government funds to more effectively leverage customers' funds.**

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86 A See: https://www.ecology.co.uk/

87 EPCs and Mortgages (Wales Low / Zero Carbon Hub, 2014)

88 An investigation of the effect of EPC ratings on house prices (DECC, 2013)

89 See, for example: Energy Efficiency – Recalibrating the Debate (EST, 2016). More background detail is available in: Capturing the "multiple benefits" of energy efficiency in practice: the UK example (EST, 2015)

90 DECC announced in March 2015 that Gentoo's "Boiler on Prescription" pilot would be rolled out more widely.

91 Lower heat demand can allow parents to heat extra rooms for children to study in peace.

92 Home economics – Cutting carbon and creating jobs, by nation and region (Energy Saving Trust, 2011)

93 Some factors are particularly impactful for certain groups, e.g. those with conservative views will engage with concepts of balance, waste and health, more than with overtly environmental concepts. See blog by George Marshall of Climate Outreach (2016): www.green.brightblue.org.uk/blog/2016/6/2/how-to-build-a-conservative-narrative-on-climate-change-and-energy

94 See a similar discussion about community energy projects: Community Energy (ERP, 2015)

95 The German Development Bank (KfW) uses state funds and private investments to fund large scale projects of national importance: post-war reconstruction; reunification; and the "Energiwende" energy transition.

96 Breaking Barriers (National Energy Foundation and Energy Efficiency Partnership for Buildings, 2014)

Overcoming barriers to uptake

Even if cost-benefit analysis included wider benefits, and if customers were more able to consider the overall impacts, there could still be lower uptake than expected. As well as financial barriers such as upfront cost (discussed earlier), there are many other reasons for the lack of uptake of apparently beneficial measures: a report from 2014 provides a comprehensive list of 415 financial and non-financial barriers, grouped into economic, performance, political, etc.[96]

The initial barrier to uptake of measures in existing buildings is lack of interest. Many customers dislike (but are able to pay) high energy bills, and might be concerned about climate change, but are not sufficiently motivated to take action to reduce demand or GHG emissions. This is partly due to lack of effective promotion to customers. Previous Government schemes (EEC 1 & 2, CERT, and CESP) and now ECO have not widely advertised the benefits of improving homes. The Green Deal[97] for homes and workplaces was launched with more direct Government promotion, but the advertising budget was small compared to commercial product launches. Advertising of schemes has largely been left to delivery bodies such as energy suppliers. The messages could have been undermined by public suspicions about why energy suppliers would want to reduce energy demand. The political debate in 2013 about energy bills and the costs of levies on bills did not present the benefits of energy efficiency, and the subsequent decision to change the ECO scheme[98] gave the impression of lower prioritisation of energy efficiency. The narrowing of the focus of ECO2 to only fuel poverty[99] is a valid social policy, but it removes the ambition for wider energy savings.[100] Any policies for private owners following on from the Green Deal will not be announced until 2017, leaving a hiatus for installers and product manufacturers. By contrast, in Germany for example, the government has consistently over a long duration promoted energy performance improvements by clearly advertising the wide range of benefits.[101]

Uptake is also inhibited by lack of information for customers about their scope for demand reduction, and the energy efficiency options for their buildings. Understanding of the scope and options can be improved through promotional campaigns, and there is research into alternative approaches to engaging customers in discussions about their buildings. The HOUSE project uses a "dolls' house" with addable energy components as a prop for discussions with householders,[102] and a range of software solutions are being offered, including apps that collect data from sensors around a building to inform customers.[103] For electrical consumption, examples include monitoring frequencies in electrical wiring to determine which appliances are using power. Some companies are offering packages of data services for customers, including "whole home" automation that incorporates aspects such as internal environment, security, fire safety, baby monitoring, entertainment, etc. Energy is incorporated in these packages, offering the potential that some customers might engage with energy information despite not purchasing the packages for energy reasons. But energy is not the top priority of the packages, posing the risk that energy benefits will not be optimised; they might even by cancelled out by energy demand of other parts of the package.

A common barrier to uptake is split incentives or responsibilities for homes and workplaces, e.g. between current and future occupants (or owners). Often, improvements are not made because the payback (when narrowly defined) time is longer than the expected occupancy period. Another fundamental split is between individual owners and the wider population: costs incurred by owners bring wider benefits (to the energy system, the local environment, and the global climate) that might not feature in their decisions. The most commonly cited example is in the rental sector, between owners and tenants (discussed under regulatory drivers, below), but this can be addressed e.g. in Germany it is landlords that are responsible for the heating systems in their properties, giving them a strong incentive to improve their buildings.

For those customers that are interested and are able to undertake improvements, one of the largest barriers is the "hassle factor". Issues include the effort of arranging a project, lack of confidence about selecting options and contractors, the complexity of administrative processes, and the practical upheaval.[104] It seems that many customers value lack of disruption more highly than lower energy bills; the question is whether they would be swayed by wider benefits.

Some retrofit products lack public popularity. Some retrofit products lack the "kudos" that comes from the usual "innovation journey" from high-end luxury items to mass-market affordability. Some customers can be resistant to products that they associate with social housing (e.g. external wall insulation), although many home owners like solar panels (which have been widely deployed on some social housing) due to FITs subsidies or the visible "green status symbol". More generally, subsidised prices can reduce the perceived worth and desirability of products, with the perverse result of reducing uptake. Finally, lack of public familiarity with the products means that customers can be unsure of whether to trust the claims of manufacturers and installers; and contractors often lack feedback about the performance from their previous projects. There is an opportunity to improve public perceptions of existing products, through Government messages and promotion by manufacturers and sellers.

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[97] Financing scheme for non-domestic customers include Salix Finance UK public sector bodies; NABERS offer finance in Australia to a range of non-domestic customers.
[98] The Future of the Energy Company Obligation Government (DECC, 2014)
[99] See consultation on ECO2 – Help to Heat (DECC, 2015)
[100] See, for example, a blog by Jan Rosenow and Richard Cowart of Sussex University (2016): www.blogs.sussex.ac.uk/sussexenergygroup/2016/07/26/we-need-a-lorry-load-of-energy-savings-in-the-new-eco-the-government-delivers-a-hatchback/
[101] See, for example, a discussion about changes in Germany's energy market: Allies in Energiewende (Alan Simpson, 2014)
[102] The HOUSE project is a research project at the Dyson School of Engineering, Imperial College London.
[103] See, for example: The principles behind OpenTRV (Open TRV, 2013)
[104] The upcoming report of the Bonfield Review will recommend improvements for consumer advice, protection, standards and enforcement for energy efficiency and renewable energy (report due in latter half of 2016).

Utilising customer interest and triggers for retrofit

Just as there are barriers that can make retrofit less likely, there are triggers that can make it more likely to occur. There are also factors can make retrofit more appealing to customers, including ways of providing information about the scope for energy savings and available options, alternative products, and better installation methods. Some novel solutions are being offered by new entrants to the energy sector, and could see greater uptake.

There is merit in developing products that appeal to customers' interests, reduce disruption, and overcome practical challenges. Example of alternative fabric products are: the Dutch Energiesprong[105] method of applying prefabricated modules for insulation and renewable energy production; and building a new structure around part of an existing building to provide a "garden room", with mixtures of insulation (to retain heat), windows (for solar thermal gain) and energy harvesting (heat or photovoltaic). An example of a novel heating system is directed infrared beams that can target occupants and not use energy to heat the air or fabric (although there can be differences in the perceptions of radiative warmth and conductive warmth). Examples of products that overcome challenges include simply manufacturing insulation that can fit through loft hatches instead of using larger sections designed for new-build that have to be cut. Finally, there would be benefits from energy storage (beyond that currently provided by hot water tanks and electrical storage heaters): some products are already available,[106] BEIS is funding research into high-density thermal storage capacity,[107] and researchers are developing further systems.[108]

There are benefits from installation processes that reduce disruption and costs. Studies are underway to develop rapid refurbishment approaches.[109] New processes are also needed to address buildings that are hard to improve (e.g. due to poor access, poor state of repair, etc.), such as the Q-Bot robot for applying underfloor insulation,[110] and the WHISCERS system that uses computerised cutting machines to customise internal wall insulation.[111]

There is merit in utilising certain "triggers" that increase the likelihood of uptake. These triggers tend to occur on specific occasions,[112] generally when other improvements are being done, allowing for efficiencies in planning, costs and disruption. For example, commercial buildings are sometimes renovated between tenancies, and homes are sometimes renovated either before sale to increase the sale price, or after being purchased to make them more suited to the new occupants (although pressures of moving home can add barriers to this). The triggers around moving home were the rationale for the UK Government's funding for some home buyers (in a three year period) to undertake some improvements:[113] this financial incentive was targeted at an event when other triggers are present, in the hope that the combination would be sufficient to overcome the barriers. Proponents of retrofit propose much larger fiscal incentives, such as reducing stamp duty or council tax, and reducing VAT to the same level as for new buildings.[114] More research into triggers has merit, particularly their frequency.

It is beneficial to develop implementation strategies for buildings, tailored to customers' finances, circumstances, and views about disruption in homes and workplaces. As discussed, earlier, a one-off deep retrofit achieves the desired outcome in one go, whereas an incremental approach can be more affordable but does still cause disruption. However, the risk with an incremental approach is that it degenerates into a "piece-meal" approach that delivers a series of "shallow retrofits". This could leave the UK with many partially-improved buildings that still need the deeper refurbishments that occupants have tried to avoid; the task could be too much for too short period of time. In order to avoid these issues, any incremental approach has to be part of a coherent plan for a building, to ensure that measures are installed in logical order that provides immediate benefits without limiting future options.[115] A sensible approach is to offer packages of improvements, in order to allow customers to trade-off the level of improvement, the costs and the disruption, whilst also giving significant benefits immediately, and leading onto future improvements.[116] To further improve the options, approaches are being developed that are less disruptive and could be applied to large numbers of homes.[117]

▶ **We recommend that, to increase uptake of retrofit solutions, product manufacturers and installers should better promote retrofit options and should develop more appealing products, installation methods and "retrofit packages", with support from heritage groups for older buildings and with engagement from government for the development and implementation of policies.**

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105 See Energiesprong UK: www.nef.org.uk/service/programme-management/secretariat/energiesprong-uk

106 See, for example, Telsa's Powerwall electrical storage unit: www.tesla.com/en_GB/powerwall

107 Advanced Heat Competition (DECC, 2012 onwards)

108 See, for example, the SPECIFIC project based at Swansea University that is seeking to integrate energy storage (of various durations) within buildings: www.specific.eu.com.

109 Novel retrofit of domestic houses (The ETI, 2015 onwards)

110 See: http://www.q-bot.co/

111 NEF's Whole House In-Situ Carbon and Energy Reduction Solution: http://www.nef.org.uk/service/search/result/whiscers

112 See, for example: Value propositions for Energy efficient Renovation Decisions, "Project VERD" (UEA, 2014)

113 Autumn Statement 2013 (HM Treasury, 2013)

114 See, for example, the "Cut the VAT Campaign".

115 Some measures necessarily inhibit future changes, e.g. wall cavity insulation cannot easily be replaced.

116 See, for example: Optimising Thermal Efficiency of Existing Housing (The ETI, 2012). This project proposed three intervention packages: Retrofix (basic issues); Retroplus (more measures); and Retromax (Passivhaus).

117 See, for example: Smart Systems and Heat – Novel retrofit of houses (The ETI, 2014 onwards)

The retrofit sector holds a great deal of expertise that is valuable for policy development in terms of training, technical performance, and the promotion of benefits to customers. There are opportunities for the sector to promote new products and practices, and to liaise with Government for the development and implementation of policies. Over recent years there have been various proposals for "hubs" to work with Government, the retrofit sector, product manufacturers, and researchers. None has been endorsed by Government,[118] and funds are unlikely to available to support any such initiatives, but BEIS does seek to engage where possible, including on some joint projects to investigate issues. In the absence of a hub, communications are still possible: Government consults on policies, tenders for expert advice, and is open to discussion.[119]

- **BEIS should engage with retrofitters, product manufacturers and researchers (e.g. through proposed "hubs" of expertise) to aid in the development and implementation of policies.**

4.2 Regulatory factors

There are some regulations that require improvements to existing buildings, and others that can act to encourage customer decisions; but there are also regulations that inhibit uptake. There are different views about the role of regulations: the UK Government views market-based mechanisms as the best way to incentivise delivery at optimal costs; some product manufacturers and utilities are nervous about the scale and pace of proposed changes in the energy sector, and would prefer regulations that they see as being less risky than complex market mechanisms.[120] Whatever the case, policies should be compatible and consistent, and offer stability and predictability over long periods of time. To aid with consistency of regulation, the ERP has recommended that stakeholders should develop a strategic narrative for the low-carbon transition in the energy sector.[121] However, as is the case for new buildings, changes to policies have introduced uncertainty that inhibits planning and innovation in the sector, and deters customers from making investments.

Regulatory drivers

Buildings' regulations stipulate minimum thermal performance for existing buildings undergoing certain changes, and have delivered some improvements. Building regulations set standards for thermal performance of extensions to homes and workplaces,[122] and the Decent Homes Standard set a standard for insulation in social housing.[123] From 2018, tenants in private rental homes will have the right to require landlords to undertake works, to be paid for through the tenants' energy bills,[124] and it will be illegal to rent out homes that are rated F or G for energy efficiency[125] (accounting for 10% of the UK's 4.2million rental homes). "Consequential improvements" require improvements to the entire building when undertaking workplace renovations of a certain scale;[126] a similar proposal for housing been expected to be the major driver for Green Deal projects, but was not implemented. Building regulations from 2006 banned the installation of non-condensing boilers, and the subsequent increase in the numbers of condensing boilers has been seen in data for gas consumption.[127]

Regulations in the form of energy supplier obligations (EEC, EEC2, CERT, CESP and ECO) since 2002 have been responsible for most of the uptake of energy improvements for existing homes. These had increasingly large targets, whether measured in terms of energy savings or GHG emissions reductions. Criticisms of these schemes were that they were input-based (so some measures could be hoarded and not used immediately), and that they had complex market structures (so there was scope for "gaming"). However, despite these issues, these Government-mandated schemes have been responsible for the majority of installations of measures in existing UK homes.[128]

In recent years, installation rates have fallen significantly. The installation of key measures (cavity wall insulation, solid wall insulation, loft insulation, and boilers) in existing homes fell by 80% in the four years to winter 2015,[129] to their lowest level since 2002 (both for those in fuel poverty and the wider population).[130] There are three main reasons for this reduction. Firstly, ECO was targeting a smaller number of measures, albeit those with higher costs and larger impacts, such as insulating solid walls, in particular for households in fuel poverty.

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[118] The most recent proposal was in 2015 by The National Energy Foundation (NEF) for The Existing Buildings Hub (EBH).
[119] BEIS has a dedicated e-mail address for communications about buildings heating: buildingheat@decc.gsi.gov.uk
[120] Some are concerned that market mechanisms can be "gamed" and are less transparent about total costs.
[121] Engaging the public in the transformation of the energy system (ERP, 2014)
[122] See, for example, for England: Approved Documents L1B and L2B (DCLG, 2014)
[123] Decent Homes Standard (DCLG, last updated 2015)
[124] The Green Deal: a way for owners and tenants to pay for home improvements (DECC, 2014)
[125] Private Rented Sector Energy Efficiency Regulations (Domestic) (DECC, 2015); similarly for Non-Domestic
[126] See, for example, for England: Approved Document L2B (DCLG 2014)
[127] Determining the impact of regulatory policy on UK gas use using Bayesian analysis on publicly available data (UCL, 2015)
[128] Energy Consumption in the UK (ECUK) – Domestic Data Tables – 2013 Update (DECC, 2013)
[129] Left out in the cold (Association for the Conservation of Energy (ACE), 2015)
[130] ECO and the Green Deal (Association for the Conservation of Energy (ACE), 2014)

Secondly, the Government's expectation was that other households and businesses would use the Green Deal to fund projects, but uptake was limited.[131] Thirdly, the Government altered ECO's ambition in response to the debate over energy bills in 2013.

There are two "light-touch" regulations (EPCs and DECs) that were expected to use "nudge" techniques to trigger market interest in energy performance, but implementation decisions have limited their impact. Energy performance certificates (EPCs) should show the current performance and potential performance, and they feature in literature for the sale or rental of properties (homes and workplaces). In Scotland, an EPC must be displayed in a building that is for sale or rent, e.g. in the meter cupboard or next to the boiler. However, estate agents often dismiss them as being irrelevant, customers often have to prioritise other factors, and enforcement is limited (e.g. some errors are not noticed, reported or corrected). There is an opportunity to realise benefits by using EPCs to promote the value of knowing about a building's energy performance and potential improvements. Display energy certificates (DECs) were intended to be openly displayed in all workplaces, but are only required for public sector buildings. These DECs (or EPCs in Scotland) provided impetus to reduce waste in public buildings, and cut public sector energy bills.[132] DCLG removed the requirement for some public buildings to display a DEC,[133] by choosing a narrow definition of "public building", and citing a saving a few £100k in costs. DECs are an excellent example of "better regulation": they are an effective, light-touch regulation that "nudges" customers towards voluntary uptake of beneficial improvements. There is an opportunity to realise further cost savings (and wider benefits) for the public sector, and to extend these benefits to the private sector.

▶ **We recommend that, to leverage customer action on energy efficiency, DCLG should improve its use of light-touch regulations: Display Energy Certificates (DECs) should be applied to all public buildings and promoted for private buildings; Energy Performance Certificates (EPCs) should be promoted more effectively as an important part of purchase and rental decisions.**

Regulatory hurdles

Preservation rules for conservation areas can limit improvements to energy performance by obliging owners to maintain the visual appearance and structural integrity of historic buildings. On the grounds of structural impacts, there are concerns about the risk of insulation causing dampness and rot in timbers.[134] On the grounds of visual impacts, fabric measures (including double glazing and external insulation) are often prevented; these rules also limit the uptake of on-site solar panels, as well as non-energy equipment (e.g. rain water tanks). Products are available that mimic existing appearances, including: external insulation that is thinner (e.g. aerogels) and can be patterned to mimic existing surfaces;[135] and double glazing units with thin vacuum layers (to reduce the thickness and the double reflections) with superficial wooden frames (to mimic the existing style).[136] Products that are suitable for conservation areas are being marketed to buildings' owners, and it is important that conservation groups promote their merits.

It is important to weigh up conservation and heat demand in older buildings, including the financial impacts upon occupants. Over 4million homes were built around or before 1900:[137] Figure 4 illustrated that they use ~40% more heat than the UK average (some types are many times worse),[138] and ten times more than the leading practice for retrofit. Occupants pay large energy bills and / or suffer cold conditions. This is particularly pointed in older social housing, much of which was built in cities in the 1800s by philanthropists for the express purpose of providing good quality housing for poor households. It can be speculated that these philanthropists would want current occupants to benefit from improved heating performance and lower energy bills. In addition, from an energy system's perspective, these "thermally-leaky" older buildings contribute disproportionately to spikes in energy demand that pose challenges to the operation of gas and electricity networks. There is an opportunity for preservation experts, product developers and regulators to work together to develop (and actively promote) measures that are sympathetic to the visual style of older buildings, and that avoid the risks to their fabric.

▶ **As discussed above, we recommend that, to increase uptake of retrofit solutions, product manufacturers and installers should better promote retrofit options and should develop more appealing products, installation methods and "retrofit packages", with support from heritage groups for older buildings and with engagement from government for the development and implementation of policies.**

[131] Domestic Green Deal and Energy Company Obligation in Great Britain, Monthly report (DECC, 2015)
[132] See, for example: DECC Energy & Emissions Reduction: Case Studies (DECC, 2012)
[133] The proposal was that DECs be used only in public buildings that are regularly visited by the public. See: Display Energy Certificates: current regime and how it could be streamlined and improved (DCLG, 2015)
[134] Moisture Risk Assessment and Guidance (STBA, 2014)
[135] For example, external cladding coated with brick slips or patterned panels.
[136] For example, Pilkington Spacia double glazing.
[137] English Housing Survey 2011-12 (DCLG, 2013)
[138] Home economics – Cutting carbon and creating jobs, by nation and region (Energy Saving Trust, 2011)

5 Prediction of outcomes

The prediction gap is the difference between the performance that is expected from a building, and the performance that can realistically be delivered. It has impacts for product developers, installers, and policy makers: it can call into question the assumptions that are used in studies, skew the forecast impacts of installed measures, and cause policy to be targeted away from the buildings and occupants where the largest (or easiest, or most urgent) improvements could be made.

The prediction gap stems from an inaccurate view of how buildings and occupants use energy.[139] In order to clarify (and improve) our understanding, it is necessary to break down the problem into stages, as illustrated in Figure 7: thermal properties of materials and components; real buildings in outdoor conditions; and finally occupied buildings. It is important to address knowledge gaps and test assumptions, in order to build up an accurate understanding to allow more realistic predictions of space heating demand and the impacts of improvements, ensuring that data is fed back from all stages so that subsequent iterations build upon accumulated knowledge. It is important to appreciate that real homes and workplaces with real occupants have variability that introduces uncertainties into forecasts; by contrast, the physical and engineering performance of constituent parts can be determined more accurately, helping to reduce overall uncertainty.

It is important to reiterate that inaccurate assumptions and lack of data do not undermine the fact that measures reduce heat demand and GHG emissions. It is necessary to strike a pragmatic balance between delivery and improved understanding: progress can and should be made with installing measures that are known to bring benefits, as part of a logical plan for each building, alongside research to better improve our understanding especially in preparation for more ambitious projects in future. Some of this learning will come out of the early stages of deployment of some technologies, so it needs to be a "safe learning environment", in which all parties recognise the potential for underperformance and for unintended consequences.[140]

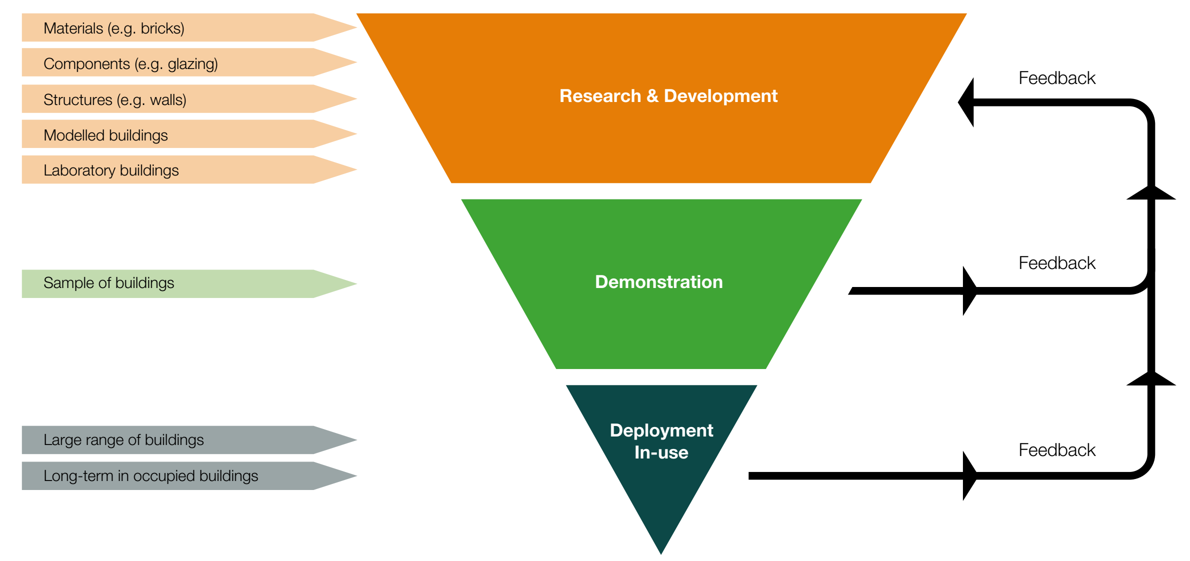

Figure 7: Stages for assessing thermal performance and heat demand.

[139] See, for example: Closing the Gap (Carbon Trust, 2012)

[140] An example of unintended consequences in trials was when some heat pumps increased energy bills instead of reducing them. This was an important lesson for policy makers and technology manufacturers, and has allowed changes to be made to avoid this risk in future. But it was an unfortunate situation for the occupants who had the higher bills, and illustrates the need for frankness about the unknowns and suitable protections.

The models that are used to predict performance can cause inaccurate forecasts. Even if a model is appropriate in principle, there can be errors in the model, inaccurate assumptions embedded within it, or errors in the inputted data.

Suitability of models

Models of buildings' energy performance can lead to unrealistic expectations if they are based too much on engineering and not enough on occupants. There are legitimate concerns about a lack of attention to building engineering physics,[141] but technical understanding is not the whole solution. Models have been produced from an engineer's "mental model" of buildings and energy, whereas they should incorporate an occupants' "mental model". There are concerns about "techno-optimism" in models, whereby they do not factor in the systemic underperformance of measures (as discussed later). Techno-optimism causes an over-estimation of benefits of each installation, and hence an under-ambition for the number of installations required to deliver the necessary benefits overall; it also means that models do not highlight the benefits of measures that can address the systemic under-performance.

There are debates about the suitability of the Standard Assessment Procedure (SAP) model[142] that is used for assessing and comparing buildings' energy and environmental performance. In some studies, the SAP model's predictions agree fairly well with actual performance.[143] However, there are specific concerns that it assumes standard conditions of use and occupancy, and that it cannot value energy storage and demand-side response. The general concern is that SAP is fundamentally the wrong type of tool for the task of assessing energy performance: it was originally designed as a compliance tool, based on the Building Research Establishment's (BRE) Domestic Energy Model (BREDAM). Some experts suggest that it was adopted simply because there was insufficient time to develop a new tool in the tight timeline of policy delivery, without a full appreciation of the nuances. There is merit in reviewing the SAP model, with the aim of determining whether it could be improved for the purposes of assessing building performance and recommending measures, or whether an alternative should be adopted (or developed).

- **BEIS should review the SAP model to determine its suitability for assessing energy performance and measures.**

Use of models

Notwithstanding the existence of guides to help designers to assess the likely energy performance of buildings,[144] a building might not be modelled to properly incorporate the proposed uses, e.g. the assumed occupancy or use might be inaccurate. A common issue is the inclusion of features that will affect the thermal performance, but that are not modelled properly (e.g. a lintel that creates a thermal bridge). Glass-fronted buildings can be particularly complex to model, with natural lighting, solar thermal gain, and the thermal insulation of the window units. It can be complicated to model Interactions between measures (e.g. air-tightness and ventilation), especially if there is a portfolio of low-carbon energy sources or a focus on "prestige solutions" (to attract attention, and maybe win awards). Even if each is modelled correctly individually, when implemented they can conflict with one another (e.g. controls for heating and ventilation) in a way that is hard to model.

The design of a building can cause unintended consequences, i.e. it can specify requirements that, if followed through in construction, can adversely affect the building and / or the occupants. Some of these issues are likely to become worse in future as the climate changes. High levels of insulation, coupled with low thermal mass can lead to over-heating in summer; and high levels of air-tightness without proper ventilation can lead to poor air quality.

There can be errors in the use of models, or the interpretation of results. Policy development based upon the SAP model requires an understanding of the nuances of its purpose and operation. Some planning officials can struggle to assess complex designs. Some Green Deal new entrants might have used the models to identify cheap and easy measures in isolation ("quick wins"), without understanding the models, the wider implications, and potentially better alternatives. It is likely that ECO_2 will require energy suppliers to use deemed savings for measures, rather than SAP to estimate savings[145], reducing these risks.

Life-cycle GHG emissions are not necessarily modelled or properly understood. There is debate about whether it is better to try to fix a poorly-performing building,[146] or to demolish it and start again. The answer can be case-specific, but it is true that, if a building is demolished, the materials should be recycled in order to make more efficient use of embedded GHG emissions.[147] Off-site construction techniques can be helpful in reducing embedded GHG emissions.[148]

141 Engineering a low carbon built environment – The discipline of Building Engineering Physics (RAEng, 2010)
142 Standard Assessment Procedure (DECC, last updated 2014)
143 See, for example: Retrofit for the Future (Innovate UK, 2014)
144 E.g. CIBSE Guide TM54, Evaluating Operational Energy Performance of Buildings at the Design Stage 2013 (CIBSE, 2013)
145 ECO2 consultation: Deemed scores (Ofgem, 2016)
146 New Tricks with Old Bricks (Empty Homes)
147 See, for example: Sustainable Materials: with both eyes open (Julian Allwood, 2012)
148 Offsite Housing Review (Construction Industry Council, 2013)

Limitations of models

Even with improvements in the suitability and use of models, there will always be limitations to models. They cannot capture the full complexity of buildings and occupants: there has to be a trade-off between accuracy (of predictions) and usability (e.g. required level of expertise, time to the run model, etc.). A more detailed model is not necessarily more accurate: it could be providing spurious precision, or perhaps false confidence especially given that similar buildings can differ in so many ways that might seem minor but that can have a significant impact upon energy usage. Indeed, some experts argue that models should be used to simply recommend measures that will have a beneficial impact, without trying to predict the exact value of that impact. They argue that the pursuit of perfection is simply removing pressure from the building and retrofit industry to apply important qualitative lessons (that have been known for many years) regarding workmanship, etc. (see section on performance). This also links to the points about cost-benefit assessments for uptake in existing buildings: customers include in their decision-making a range of non-quantifiable factors, alongside which the precision of the models can look like "overkill".

5.2 Data and assumptions about performance

The understanding of the space heating has been based upon limited evidence and assumptions about buildings' thermal properties and occupants' behaviour. Over recent years, some of these assumptions have been shown to be inaccurate. This has often not been the result of a deliberate attempt to test the assumptions; rather, it has often been that a study looking at less fundamental issues has come to a startling conclusion about an underlying, fundamental assumption.

Inaccurate assumptions

A general assumption has been that buildings conform to the building regulations in force at the times of construction (or to the practices of the time, for those built before the introduction of regulations for thermal performance). But various studies have shown this to be incorrect, and that many buildings do not meet the expected levels; for example, it is widely believed that around a third of new homes fail (by varying degrees) to meet the regulations for thermal performance.[149]

Recent discoveries have challenged assumptions about thermal conductivity in buildings, include:

- Solid walls have a wider range of U-values than was assumed, and most have lower U-values than was assumed.[150]
- Cavity walls have lower U-values than was assumed when empty, and higher than was assumed when insulated.[151]
- Retrofit cavity insulation from the 1980s has become damp in some cases, increasing its thermal conductivity.[152]
- Party walls' cavities act as a "chimney" that sucks heat out of both adjoining buildings and into the loft spaces.[153]
- Window reveals can lose more heat than suggested by models of simply the combination of a wall and a window.[154]
- Loft insulation is often compacted to a thinner layer (under loft floor boards) increasing its U-value.[155]
- Loft insulation can become more conductive as it becomes dirty over time.[156]

Recent discoveries have challenged assumptions about occupants' energy use, including:

- The temperatures to which rooms are heated are generally lower than was thought in older homes.[157]
- The time for which heating is switched on each day is generally less than was thought.[158]
- Weekend heating hours are not different to weekday patterns, contrary to assumptions.[159]
- Assumptions are still made about non-regulated energy usage, because data is lacking to allow differentiation between appliance use by different demographics.[160]
- Non-domestic energy consumption data was from a 1990s survey, and is known to be out-of-date (e.g. lighting).[161]

It is important to emphasise that inaccurate assumptions do not undermine the fundamental prediction that measures save energy: but assumptions have contributed to a prediction gap in terms of the extent of the savings.[162] But it is important to ask why these inaccurate assumptions were used, what can be learned from the experience, and how we can seek to check whether there are further issues contributing to the prediction gap for existing measures or potential future projects. The questions raised by the recent discoveries are being investigated by a series of current projects.

[149] See, for example: Building Performance Evaluation (Innovate UK, 2015)
[150] Developing DECC's Evidence Base (DECC, 2014)
[151] Developing DECC's Evidence Base (DECC, 2014)
[152] Source: Interviews for this project
[153] A current study for DECC will obtain a more accurate value. There are c.5million such party walls, affecting c.10million homes
[154] See, for example: Estimating the impact of reveals on the transmission heat transfer coefficient of internally insulated solid wall dwellings (UCL & GCU, 2016)
[155] See study by National Physical Laboratory and Carbon Trust, 2013
[156] Source: Interviews for this project
[157] How heating controls affect domestic energy demand – A Rapid Evidence Assessment (DECC, 2014)
[158] How heating controls affect domestic energy demand – A Rapid Evidence Assessment (DECC, 2014)
[159] Source: Interviews for this project [160] Source: Interviews for this project
[161] A DECC project has obtained updated data about non-domestic energy consumption; the results will be published shortly.
[162] The Green Deal was subject to consumer protection legislation, such that no recommendation could breach the "golden rule" (each year, measures would save more money on energy bills than they cost in loan repayments). DECC "erred on the side of caution" so as to not overstate potential savings, by using conservative "in-use factors" for measures lacking reliable data.

Reasons for inaccurate assumptions

There were several reasons for the use of assumptions, some of which persisted over the course of several decades. Firstly, it was simply taken for granted that the information had some basis in fact and so no-one suspected that there might be any inaccuracy. Secondly, no-one had the remit (or budget) to review the assumptions; even in the absence of a specific reason to question the information, it would have been good practice to periodically take stock and undertake a "house-keeping" review. Thirdly, the issues were not revealed by chance by any other studies, until the recent examples noted above.

These reasons persisted over several decades in part because of a low priority given to buildings' thermal performance. There was limited investigation of the thermal properties of standard building materials (e.g. bricks, mortar, etc.) for which other characteristics (e.g. strength and cost) were of more interest. Values used in modelling were based upon some historical data augmented by assumptions. Furthermore, it was assumed that this assumed performance of materials would be replicated when they were combined to create structures (e.g. bricks and mortar used to make a wall) in non-test conditions (e.g. with occupants inside and weather outside). By contrast, there was a fairly good laboratory understanding of the thermal performance products that are specifically marketed as energy efficiency products (e.g. insulation material, double glazing units, etc.). They have to prove their claims made to customers and have to conform to regulatory standards, and so are studied in more detail. However, even for these products, there can be assumptions that can contribute to the prediction gap. Some are deemed to be well-understood (e.g. double glazing units), and are studied only by computer models, to which earlier comments about models could apply. There have been controversies over the appropriateness of tests for some products (e.g. "insulating paints") and doubts over the resulting marketing. Furthermore, it is assumed that adding a well-understood component (e.g. adding a window to a wall) will have the simple effect of changing the conductivity over that area, whereas the example of window reveals shows that this is not the case: i.e. a wall is not the sum of simple parts, and needs to be understood in detail.

The discovery of so many inaccurate assumptions and gaps in the knowledge base suggests the need for a wider portfolio of research to systematically test assumptions about energy usage in buildings, with a greater emphasis on using testing facilities and real-world conditions, and less reliance upon pure modelling. It is also important that a means is devised for sharing all such information with the relevant organisations (in what is a very fragmented sector) for policy development, modelling and deployment. There have been proposals for research "hubs" to co-ordinate research and share results,[163] including with Government. BEIS should continue to seek ways of engaging with researchers in order to learn from their research, but also to reassure researchers that their work is received and can have an impact.[164] The UK would benefit from drawing more on expertise and experience from other countries, including those with greater experience of studying thermal performance and with higher standards of buildings' performance. The Energy Innovation Board (EIB) is well-placed to have oversight over these activities for research and innovation.

▶ **Government should increase links with researchers for co-ordination of research and dissemination of results.**

General collection of data for customers and industry

There is a need for more (and better) data about energy use in buildings. This is necessary for the process of testing assumptions (see above), for the design and modelling of buildings, and for wider studies into energy consumption.

The shortage of data is partly due simply to lack of collection. This is partly because the industry's general gathering of data has (understandably) been for commercial or regulatory purposes (e.g. billing and balancing), and not due to interest in buildings' energy performance. So, most buildings have lacked the necessary monitoring equipment to gather data about space heating, i.e. space heating energy usage and buildings' internal temperatures.

This situation is improving, with smart meters and other data services increasing the amount of data that the industry gathers as a matter of course. Each of these initiatives might serve useful purposes. The national roll-out of smart meters will give a better picture of energy demand than is currently available; and new entrants offering innovative data services might be more effective at engaging with customers and realising benefits. But the data is not necessarily sufficient or suitable for studies of buildings' energy performance. Smart metering will improve the temporal resolution of energy data, but will still not differentiate between heating and other energy demand (e.g. gas usage for hot water and cooking), nor show where in the building the energy is used. Smart meters will not monitor internal temperature data (the technical specifications did not require thermometers);[165] some alternative services do monitor internal temperatures (including in different rooms), and this might become more common with future iterations of (and additions to) systems.

[163] The Building Performance Network (BPN) was formed in 2015 with a broad membership from industry and academia.

[164] One researcher likens sending research findings to Government to kicking a ball over a wall: you don't know whether it rolled under a bush and was never seen, or was picked up and pondered but rejected, or was played with and caused much excitement. BEIS does welcome discussions, and has sought to make access easier (e.g. with the establishment of an e-mail address for communications about buildings heating: buildingheat@decc.gsi.gov.uk).

[165] Smart Metering Equipment Technical Specifications (DECC, 2012)

Smart meters and other systems are not necessarily intended to interact with each other, and so there are essentially several different systems operating in parallel, and this lack of interaction could limit the benefits or pose challenges. Duplication of systems could reduce the overall net benefits; and if customers do not interact with smart meters (or the anticipated associated smart grids technology), then this could limit the ability of system operators to understand and manage the system's current operation, and to forecast and invest for its future needs. There is a need to understand the interactions between energy data services, and to allow interoperability without hindering innovation, possibly as part of a smart grids mapping exercise.[166]

▶ **BEIS should explore the sources of heating data, including the compatibility of Government-mandated smart meters and other services, and how this could impact upon the management of energy systems.**

Specific collection of data for research and policy

As well as the limited amount of general data gathered as a matter of course, there has also been a shortage of projects specifically intended to gather data for studies of buildings' energy usage and GHG emissions. The energy and buildings industries have gathered data for which there is a (usually short-term) driver from markets or regulations; and Government has gathered data that has a bearing upon specific policies (e.g. 1980s studies of gas boiler efficiencies). Interest from industry and Government has increased since the mid-1990s, due to concerns over climate change, security of supply and affordability, and there has been an increase in the number of projects to gather data to improve understanding of the topic.

Most of the research projects have had narrow scopes and short durations, focussing on specific policies questions, but there are exceptions such as the English Housing Survey (EHS). This has been run in various forms by BRE since 1967, and includes questions that are applicable to a range of energy policy issues. DCLG streamlined the EHS in 2010, and consulted in 2015 on potential further changes.[167] Respondents strongly opposed reductions in the frequency of the survey and reductions in the number of questions.[168] It is important that data gathering through the EHS continues, in order to provide an ongoing data source for studies and policy work; indeed options should be are explored to enhance its value for energy policy.

▶ **DCLG and BEIS should continue to consider ways to enhance the English Housing Survey's (EHS) value for energy policy.**

There is a need for a co-ordinated portfolio of research to gather a range of data (as opposed to having a narrow focus as per most previous projects) over the long-term (as opposed to the minimum needed to answer a specific question). This involves two aspects: understanding the physical and engineering details of thermal performance,[169] and understanding the uncertainties of occupants' energy use. Figure 7 illustrated the stages in building up an understanding of energy use, but the subsequent discussion has shown that knowledge is patchy in some of these stages. A co-ordinated portfolio of research would help to build up a fuller understanding of these stages, to give greater confidence to policy-makers about the likely outcomes of policies and to product developers about the performance of their products. The Energy Systems Catapult (ESC) is developing a network to facilitate access to testing facilities by developers of products and services. This initiative is very welcome, and could provide valuable advances. The ESC will have to use its social science capabilities to mitigate the potential "culture clash" of engineers testing precisions equipment and software in imperfect real-world buildings with occupants that are changeable and that do not always act rationally. At present, the ESC's network for accessing testing facilities is focussing on energy system solutions, and there would be merit in expanding this network to include facilities that test thermal performance of materials, components, products, and buildings, and experts who study energy use by occupants in buildings over the longer-term.

Randomised control trials (RCTs) offer a robust approach to developing policy and monitoring impact, as promoted by the Cabinet Office.[170] RCTs are common in the health sector. One recent example in energy was a six month trial to assess the impacts of providing households with advice on the use of heating controls.[171] Overall, though, randomised control trials are rare for energy policy development, largely due to constrained budgets and timescales, and instead DECC/BEIS has had to use simpler trials, data from other sources, and assumptions. Once a policy has been developed and implemented, it is prudent to monitor its impacts; but this, too, is rare in energy policy, again partly due to lack of resources. Overall, most of the work by Government (and other organisations) has been for deployment of measures (albeit the Green Deal has been criticised for its limited knowledge of customer uptake),[172] and there has been less research before deployment about likely impacts and less research after deployment about actual impacts.

Large-scale (many buildings), long-term (longitudinal) studies offer three major benefits. Firstly, they build up an overall view of energy usage and GHG emissions, and how to reduce them. Secondly, they can sometimes answer specific policy questions using existing data and without having to set up a new project. Thirdly, they provide robust control groups for other studies that provide comparability and verification, including for developing policy and for monitoring its impacts.

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[166] See, for example, a proposal made by the ERP (Minutes of ERP Plenary Meeting, 15 October 2014)

[167] Consultation on the future shape of the English Housing Survey (DCLG, 2015)

[168] The future shape of the English Housing Survey – Government response to the consultation (DCLG, 2015)

[169] See also, a recent recommendation: "Construction databases to better reflect the thermo-physical characteristics of the construction materials on the market and address materials underperforming compared to their specifications." Building Performance Evaluation Meta-Analysis – Insights from Social Housing Projects (NEF, 2015)

[170] Test, learn- adapt: Developing public policy with randomised controlled trials (Cabinet Office, 2012).

[171] Advice on how to use heating controls: Evaluation of a trial in Newcastle (DECC, 2014)

[172] Household energy efficiency measures (PAC, 2016)

There are questions about how truly longitudinal a study could be, given fairly short occupancies and hence the ongoing recruitment of new participants with their own behaviours; although these change-overs would help to separate out occupants' effects from buildings' effects. A longitudinal study called LUKES (Longitudinal UK Energy Survey) was proposed by UCL[173] and scoped by DECC that would consist of a core sample of buildings that were monitored in great detail, and larger samples that were monitored in less detail but that could be linked to the core group. It would provide information that was useful for a range of policy areas, not just in energy, but also in housing more generally and health. Such a project would require funding commitments over a period of several years, and would need to be funded by a separate research budget beyond that of BEIS or Research Councils.

A subsequent proposal called the Smart Meter Research Portal (SMRP) has been drawn up by UCL that would establish a piece of national research infrastructure for researchers to access smart metering data through the Data Communications Company (DCC). This type of initiative would be of great value for research projects, and could provide control groups for other studies. It could also lead to benefits that are not being explicitly sought, e.g. potentially noticing any interoperability issues between smart metering data and alternative data services.

▶ **Smart metering data (anonymised) should be made accessible to researchers, for example through the SMRP.**

The value of RCTs and of longitudinal studies can be harnessed by maintaining long-term monitoring of a sample of buildings. The Energy Systems Catapult's (ESC) large-scale trials of energy use in buildings offers an opportunity to gather data in the longer-term. This would increasing the information available for research, development of products and services, policy development and policy monitoring, and would provide control groups for other studies.

▶ **We recommend that, to increase understanding of thermal performance in buildings, the Energy Systems Catapult (ESC) should expand its network for access to test facilities and expertise to include tests of thermal performance, and should maintain its buildings trials as a longitudinal study and control group for other studies.**

Availability of data

Data collection does not necessarily result in data availability, as access can be limited by rules for other purposes. Data protection rules can limit (or delay) access to datasets, but the confidentiality of customers' data can usually be addressed by anonymising data. With historic Government-funded projects, there have been issues with research groups claiming commercial confidentiality over the data, so DECC started specifying in its contracts that data from any new trials that it funds has to be made available for wider research. Some Research Councils previously required researchers to archive data purely for auditing purposes, but not for accessibility for future analysis, but the Research Councils now require that "data with acknowledged long-term value should be preserved and remain accessible and usable for future research". [174]

Data needs to be kept up-to-date. For example, DECC recently conducted surveys of energy usage in non-domestic buildings,[175] looking at usage patterns, abatement options, and barriers to uptake, to update information from a 1990s survey.[176] More generally, commercial confidentiality can limit access to data, and so some initiatives have encouraged customers to share data for mutual discussion and study.[177] For data sharing to become more widespread would require incentives; but, as in other parts of the energy sector, it can be difficult to form a business case for the use of data, given the fragmented value chain.

▶ **BEIS should explore the value of energy data for commercial customers, and triggers to encourage data sharing.**

Usability of data

Data collection does not necessarily result in usable data and reliable information, firstly because data is not always comparable between studies. Various small-scale surveys and case studies are not necessarily statistically robust or widely representative, and are perhaps just anecdotal, and combining them into larger data-sets would be hindered by a lack of robust meta-data[178]. However, it would be prudent to catalogue these studies, for reference to identify key knowledge gaps.

▶ **BEIS should collate the key findings from previous buildings' energy studies, and develop a plan for addressing knowledge gaps.**

Secondly, some projects have resorted to using data that is not optimal for the task. For example, the NEED[179] study used metering data to deduce the impacts of energy efficiency measures. Some meter readings were estimates. Moreover, there was no data for homes from before the installation of measures, so it was comparing the "difference of means" of energy consumption of separate groups of homes, rather than the more robust method of "means of differences" for the same homes. Whilst the results did confirm energy savings, it was not possible to make reach nuanced conclusions about effects for different types of buildings and occupants.

Thirdly, suitability of data is an issue when funding structures for some research projects allow lead organisations to "vet" data and over-ride sub-contractors' concerns. This can mean that project reports are missing valuable data, and present unrepresentative results with no warning to others who will use the data in the belief that it is complete and reliable. This is linked to the issue of inspections' data (as discussed in the section about performance).

▶ **Public research funders should ensure that data from projects is collected in a consistent manner, is not vetted by lead research organisations, is archived permanently, and is accessible for future research.**

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173 LUKES feasibility study (UCL, 2014)

174 See: RCUK Common Principles on Data Policy

175 The report is due for publication in the second half of 2016.

176 Developing DECC's Evidence Base (DECC, 2014)

177 See, for example: Carbon Buzz (RIBA & CIBSE) that includes data curation for Innovate UK's BPA project.

178 Metadata is "data about data", i.e. information about how data was gathered and processed.

179 National Energy Efficiency Database (NEED) (DECC, last updated 2015)

6 Performance in practice

The performance gap occurs when a building does not meet reasonable expectations. It affects the comfort and energy bills of occupants, and it affects policy-making by reducing delivered benefits and affecting the cost-effectiveness of spending on climate change mitigation. This section considers the causes of the performance gap at each stage of the process.

Various studies have presented data about the performance gap for homes and workplaces.[180] Experts in the building and retrofit sectors have repeatedly proposed solutions to these problems, apparently to little avail against competing pressures. The performance gap for space heating can occur for many different reasons, sometimes in isolation, and sometimes in combination. Normal variations in materials and workmanship will cause a spread in the actual performance of any set of supposedly identical buildings; and poor quality control allows the range to widen, such that some buildings fail to meet the regulatory standards. For home retrofit, the Bonfield Review was commissioned to consider solutions to the performance, focussing on customer advice and protection, the standards framework, and monitoring and enforcement.[181]

6.1 Design and procurement

The design stage can add complications that contribute to the performance gap, and procurement choices can inhibit performance. If designs are complicated, this can lead to misunderstandings further down the chain (e.g. at procurement) and difficulty in implementation (e.g. at construction). Designers should take into account any such limitations in the chain, and not "set up the project to fail" by making it overly complex.

Designers should be insistent about the importance of materials and equipment that they have specifically chosen for energy performance. Without this insistence, a common problem is that procurement colleagues substitute them for other items with worse thermal performance. This can be before construction, when a procurement expert might be bulk-buying pre-ordered items; or it can be during construction, when a site worker has to quickly buy items to keep the work progressing. Substitution can be done in ignorance of the impact upon energy performance, or in wilful neglect of that issue. It can be driven purely by cost, or by practical issues such as availability of stock and practicality of using materials on-site.

Even if the correct products are used, they themselves can contribute the performance gap if they are difficult to apply. Some applications require fundamentally different products for retrofit as opposed to new-build. For example, new-build wall cavities are filled with sheets of insulating material, of which there is a range to choose from. But for retrofit of wall cavities, the options are limited to those materials that can be inserted via small holes drilled in the walls. Some products can be used for either new-build or retrofit, but face limitations in retrofit. For example, loft ceilings can be insulated using large panels that can be easily put into new buildings during construction; but for existing buildings the panels have to be cut to get them into the loft and then re-joined which increases the risk of gaps in the insulation.

There are steps that could address these issues. Work in design and procurement could be improved by better training and by more engagement by product manufacturers (see below). There would be value in developing products that are designed to overcome the specific challenges of existing buildings (see the section about uptake for existing buildings).

6.2 Training for on-site works

New-build and retrofit require different combinations of skills: new-build requires mostly constructions skills (e.g. concrete pouring, brick-laying, etc.), whereas retrofit requires more craft skills (e.g. carpentry, applying insulation, etc.). Training should be specific to these different groups, and provided via different routes (e.g. specific trade associations).

Most on-site workers (for new-build and retrofit) do not see their tasks as energy-related, but they can have an impact upon energy performance.[182] For example, construction workers building a wall have a role in keeping insulation materials dry. However, most workers do not have a specific interest in energy performance, and improvements in their contribution can best be achieved by incorporating it into wider training with aspirations of "raising the bar" generally. This could lead to a "virtuous circle", as is reported in the German industry, that reinforces: the need for high-quality work; cultural attitudes to quality (including public expectations and industrial reputations); and effective use of regulation.

[180] For retrofit see, for example: Retrofit for the Future (Innovate UK, 2015). For new-build see, for example: Building Performance Evaluation Meta-Analysis – Insights from Social Housing Projects (NEF for Innovate UK's BPE project, 2015). Some studies use overall consumptions of gas and electricity, and some disaggregate these to show space heating demand.

[181] The report is due in the second half of 2016: www.gov.uk/government/publications/bonfield-review-terms-of-reference

[182] On-site workers whose jobs explicitly relate to energy performance need specific training. For example, installation of a heat pump is different to that for standard boilers. The Green Deal accreditation scheme established the PAS2030 framework for such training, but the cost pressures mean that the training is less exacting than, for example, in Germany.

There are concerns about the UK's building industry's skills;[183] indeed, this is believed to be the largest barrier to delivering better energy performance buildings in the UK. The regulatory standards are often not met, simply due to lack of attention to detail and unnecessary errors; and achieving even higher performance requires even better skills and attention to detail. In Germany, each of the building trades is said to be viewed almost as a "building engineering discipline"; workers are said to appreciate the value of good energy performance and their impact upon it, and they have the necessary training and motivation to deliver the necessary quality of work. A key aspect of training is apprenticeships, on which the UK has reviewed its policy.[184] The building industry is trying to improve its appeal as a good career option (e.g. with better working conditions and career prospects), which some in the sector believe will attract environmentally-concerned staff who can affect change from within (perhaps in off-site roles). BIS reviewed how training is funded in different sectors, and it is now the industries that define what training will be provided.[185] This could serve to reinforce inertia in the building industry: energy-related training will be sufficient only to meet commercial or regulatory drivers that the industry faces, but might not be sufficient to enthuse employees about their potential to deliver high (or even just consistent) standards.

DECC, DCLG and BIS worked together on quality assurance as a means of improving performance and avoiding unintended consequences. The 2016 departmental changes might affect the responsibilities for training and skills, but there are ministerial links between BEIS and DfE. There is merit in ongoing work between BEIS and DCLG to provide greater clarity in guidance (to feed into training) and more effective self-certification (as discussed under quality control). A recommendation for benefiting from this opportunity is given in the section below (on-site works).

6.3 On-site works

The quality of the work at a building can impair the energy performance, and can introduce unintended consequences that can adversely affect the buildings and / or occupants. The quality of on-site works is affected by competing pressures. In most projects, the priority is to maximise profit, often by minimising costs. Cost reductions can be achieved by deliberately omitting materials (e.g. it has been claimed that some companies routinely use too little loft insulation, or even none at all); but the most common on-site cost-saving technique is to rush jobs, to the detriment of attention to detail. Time is also pressured by the working conditions, which can be various combinations of cold, wet, muddy, dark, cramped and dangerous; offsite construction would help to reduce these issues and improve quality.

The quality of on-site work is also affected by a lack of appreciation of impacts of actions. This can be simple actions, e.g. putting nails through insulating layers and hence creating thermal bridges; this can be improved by training (as discussed earlier). Or it can be more obvious carelessness, e.g. leaving insulation in the rain or sitting in puddles, such that it will be more conductive of heat and will cause dampness that can harm the building and its occupants. It can even be actions that are well-intentioned but without an appreciation of the impacts, e.g. adjusting the plumbing for heat pumps to fit into available spaces but at the expense of proper performance.

Effort is needed to deliver the necessary quality of on-site works. Some aspects of a building can be difficult to treat (e.g. insulation around windows and doors), but have to be done properly to avoid compromising the building's envelope.[186] Similarly, effort is needed to avoid unintended consequences, e.g.: to avoid insulation from trapping moisture inside walls and causing rot (as discussed above), or limiting where the air's normal moisture can condense and hence causing dampness in unexpected places. The challenges are greater for retrofit, particularly when aiming for higher performance. It is more than a matter of materials and money; it requires good training, hard work, attention to detail, ingenuity to solve problems, and time to implement solutions.

Experts have known about these issues for many years, and have repeatedly proposed solutions, and various enquiries have raised concerns.[187] The wider building industry is now taking an interest, but risks unnecessary delays by duplicating research rather than implementing solutions that have already been proposed. A key route to addressing some of the issues with on-site works could be through product manufacturers. They work in factory conditions to precise specifications; but their interest tends to end once their products are transported away to building sites, because the supply chain interactions are usually purely financial. There would be benefits to more product manufacturers take greater interest in how their products are used in real-world conditions. This would help to improve buildings' performance, and to protect the manufacturers from reputational risks due to poor performance. BEIS is keen that manufacturers take a greater role in the use of their products, including in training and quality assurance, and Innovate UK is providing funding for feasibility studies of such processes and relationships.[188]

▶ **BEIS and DCLG should continue their joint working to address the quality of on-site works, including to facilitate the greater role that is needed for product manufacturers in training and quality control for thermal performance.**

[183] See, for example: A new professionalism: remedy or fantasy? (Bill Bordass and Adrian Leaman, 2012)
[184] The Future of Apprenticeships in England: Implementation Plan (BIS, 2013)
[185] Skills for Sustainable Growth – Strategy Document (BIS, 2010)
[186] The impact can be larger than just conduction through an uninsulated patch; e.g. an uninsulated patch of loft will cause convection currents that draw heat out more rapidly.
[187] See, for example, an enquiry into quality and workmanship: More homes, fewer complaints (APPGEBE, 2016)
[188] Supply chain integration in construction (Innovate UK, 2015)

It is widely believed that around a third of new homes fail (by varying degrees) to meet the regulations for energy performance.[189] It is claimed that this is sometimes due to builders deliberately not using the necessary measures (an uptake issue); but it is more often due to builders using the necessary measures badly (a performance issue).

For new-build, all customers are paying the costs for stipulated energy performance, but only some are receiving the intended benefits. All are paying a few £1,000 per home[190] for builders to buy materials and spend time on-site installing them; and all are paying from a few £10 up to around £100 per home[191] for inspectors to go through assessment steps (see below, under inspection and enforcement). Many customers are not receiving the required quality, and face higher heating costs of several £10 to ~£100 per year;[192] furthermore, these customers will face higher refurbishment costs in future to remedy the shortcomings. Over the lifetime of several decades of a building, customers will pay several £1,000 that people in similar buildings will not, and that could have been avoided simply by consistent construction to the required standards. The problem with quality and consistency in new-build is due to the approach taken by regulations, and the industry's approach to compliance, inspection and enforcement.

Retrofit of existing buildings can also suffer from issues of quality and consistency, to the extent that they are subject to building regulations (e.g. extensions and workplaces covered under "consequential improvements") or to performance of installed measures (e.g. heating systems). The Bonfield Review will recommend steps to address customer advice and protection, the standards framework, and monitoring and enforcement.[193]

Regulations and compliance

The approach taken in new-build regulations reduces the pressure to adopt fabric solutions. For England, the requirements are "functional"; that is, builders have flexibility to adopt different solutions if agreed with the building control body. The regulations require that builders make "reasonable provision for the conservation of fuel and power", and they offer opportunities to use alternatives to fabric solutions. The word "reasonable" (which also occurs in reference to insulation and air-tightness) could be hard to define or to enforce as an objective standard. By contrast, issues such as fire safety and the strength of foundations are treated seriously because they pose a "threat to life"; although, by that argument, energy performance should also be taken seriously because high energy demand can be unaffordable for some occupants, leading to illness (and death), and extra GHG emissions contribute to climate change that poses a threat to livelihoods (and lives).

The approach to new-build compliance by the industry varies, but the general attitude is that energy and GHG emissions are low priorities. Some builders are said to treat the regulatory standards as a benchmark (i.e. something to aim for, and perhaps to meet on average), instead of the baseline that must be met or exceeded in all cases. Some builders use alternative solutions allowed by regulations, instead of fabric solutions; some are alleged to deliberately omit measures, knowing that the buildings will not meet the regulations; and others install measures, but not carefully enough to deliver the benefits.[194]

Inspection and enforcement

The approach to new-build inspection does not apply pressure to adopt (and to implement effectively) the necessary solutions. There is a presumption of compliance with the requirements if builders follow the guidance.[195] The Competent Persons Scheme allows contractors to self-certify some types of work, without input from an inspector.[196] When inspectors are involved, they check whether the modelled performance meets the regulations (but see issues with models, above), but they do not usually inspect visible measures (e.g. measure the thickness of loft insulation) or investigate concealed measures (e.g. wall insulation using thermal imaging).

Inspectors do not test the thermal conductivity of the fabric. The only actual measurement that inspectors make is the air-tightness test, about which there are concerns. Firstly, the test is limited in scope: it measures the overall air-tightness of the building, but does identify locations of leaks. Secondly, different inspectors conduct the air-tightness test differently, and can obtain different results on the same buildings.[197] Thirdly, builders can essentially direct inspectors to the best buildings; and there are claims that some builders take temporary action to improve them further for the test (e.g. filling gaps with mastic).

This "cherry-picking" means that inspections and building regulations give a false impression of the performance of the buildings. Poor quality buildings enter the building stock, without any warning for owners and occupiers (even the test homes would revert to poorer performance as the mastic fails over time). Furthermore, misleading test results will skew any modelling and policy development that uses the data. Policy makers cannot simply assume that buildings perform in line the regulations from the time of construction. That is, building regulations do not provide an accurate proxy for baseline performance, and instead analysis should use actual measurements from buildings of each era. This is a significant issue for prediction of performance of measures (as discussed above), and hence also for cost-benefit analysis about uptake of measures.

The approach to enforcement for new-build does not instil the industry with a sense of the importance of buildings' energy performance. No building company has ever been prosecuted for failing to meet the regulations for energy performance. This is partly due to limited pressure from customers or Government for enforcement of the regulations, and there are concerns that the competitive market for buildings inspectors[198] weakens their motivation to highlight energy performance issues.

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[189] See, for example: Building Performance Evaluation (Innovate UK, 2015)

[190] As discussed earlier, costs for higher performance could be offset by lower land prices.

[191] Inspection costs vary depending upon the number of homes in a development, and the arrangements between each builder and inspector, and are often commercially confidential.

[192] This values depends upon the extent of the quality failures.

[193] The report is due in the second half of 2016: www.gov.uk/government/publications/bonfield-review-terms-of-reference

[194] Source: Interviews for this project.

[195] Approved Document 7 – Material and workmanship (DCLG, 2013): These regulations for England say that building work should be carried out in a "workmanlike manner" with "adequate and proper materials".

[196] Competent Persons Schemes (DCLG, last updated 2014) [197] Closing the Gap Between Design and As-Built Performance – End of Term Report (Zero Carbon Hub, 2014)

[198] In England and Wales, since the 1980s, there have been private buildings inspectors, in addition to the local authority building inspectors. In Scotland and Northern Ireland, there are only local authority inspectors.

Better regulation

The attitude to the new-build regulatory standards could be improved by better regulation. Better regulation does not mean more regulation, but means making the existing regulations (which customers are already paying for) more effective at delivering the intended benefits for customers (that they are all paying for, but are not all receiving). With better regulation, there would not need to be any more costs for consumers: builders and inspectors would simply spend the money and time in ways that focussed on delivering the required standards. Inspectors should conduct truly random spot-checks on new buildings, without builders' prior agreement. There is a strong contrast with the way that the National Measurement Office (NMO) regulates performance of electrical appliances. It has significant powers, but uses them sparingly; it supports businesses to improve compliance, but also conducts spot checks. It took action against a company that breached the regulations; this attracted the industry's attention, which now complies more strictly with the regulations, with minimal further use of the NMO's powers. Similarly, the building industry could be motivated to comply with the regulations if a precedent was set by inspectors taking action against non-compliance.

- ▶ **We recommend that, to improve thermal performance in practice, product manufacturers should take a greater role in training and quality control in the building sector, and the building inspection regime should improve its use of tests and enforcement (better regulation, not necessarily more regulation) including conducting truly random spot checks of energy performance.**

Performance-based contracting is a market-based system that could be applied to buildings.[199] Builders and refurbishers would be contractually obliged to deliver the require performance; under-delivery would either reduce the payment for the work, or necessitate remedial works. Performance-based contracting could be challenging to implement, partly because subcontracting in the industry tends to put risks onto smaller companies that are least able to pay for failures (and that are easily liquidated without paying their liabilities), so some form of insurance scheme might be needed. It would require monitoring of buildings, which might be provided independently by emerging data-based measures discussed in this report. Despite these challenges, performance-based contracting should be considered: it is very powerful in driving regulatory compliance, and would encourage more effective hand-overs (see below). It would bring the industry more into line with other industries, most of which offer customer redress if a product underperforms. A precedent could be set if a customer commissioned tests on a building that is under warranty and found under-performance against the regulations, and then took action against the builders. There is an opportunity for Government and consumer rights organisations to raise customers' awareness of expected performance, and to support their rights to remedial works.

- ▶ **Government and consumer organisations should raise customers' awareness of the required level of thermal performance, and support customers' rights to remedial works to address underperformance.**

To aid with better regulation and performance-based contracting, there is an opportunity for further research into new tests that would be quicker and less disruptive for builders, retrofitters and occupants, including: systems to gather and analyse heat use and temperature to identify wasteful areas;[200] thermal imaging to assess a building's thermal insulation, and useable not just in cold weather; heat loss tests (quicker than the two week co-heating tests); and U-value measurements.[201]

- ▶ **Research funding organisations should continue to promote the development of simpler and quicker tests of buildings' thermal performance to allow customers easier access to information about performance.**

6.5 Commissioning, handover and in-use

A buildings' thermal performance depends partly upon the operation of equipment, including active systems (e.g. heating systems and mechanical ventilation) and passive equipment (e.g. windows). Systems might not be installed or commissioned correctly, and project workers should check this before handover. Active systems will have recommended steps for commissioning and checks, and will usually give clear indications about their status and operation, whereas passive fabric measures do not give clear indications, and their performance has to inferred separately.

Systems can become less optimal over time, due to degradation, errors in settings, or changes in buildings' use, and so should be reviewed periodically. These reviews should be conducted alongside regular maintenance of key systems, but with a "whole building" mind-set rather than looking at each system separately.

A building's occupants might not use its systems optimally (or at all), or they might inadvertently diminish their effects. In some cases, occupants use a building differently to the way that was envisaged at the design stage, e.g. the rebound effect means that energy use is higher than was expected. In some cases, occupants use a building's systems incorrectly, e.g. if a CHP unit generates more heat than is needed, its output should be adjusted, whereas some occupiers counteract it with air-conditioning, using more energy. Similarly, Passivhaus buildings' heat demand is self-limiting almost independent of occupants, if they simply leave the mechanical ventilation (with heat recovery) to do its job, but there is a tendency in the UK to open windows which undermines Passivhaus performance. This habit could be due to concerns about pulmonary illnesses in the UK's damp climate, and a continuing cultural mistrust of indoor air, but Passivhaus buildings will have good quality indoor air.

The best way to address issues that are introduced at hand-over and during occupancy is to avoid them in the first place, by making better use of guidelines for occupants and building operations managers. This is increasingly important as larger buildings become more complex: there needs to be a proper hand-over between the project workers and the occupants, as provided by the "soft landings" approach[202] that has been adopted for government buildings. The bigger challenge could be with homes as they become more complex, and trials have identified the need for households to have effective instruction and then follow-up discussions after a period of several months.[203] This was expected to have become commonplace in preparation for the introduction of the EEPD in 2020, but Brexit could call this ambition into question.

[199] See, for example: Energy Performance Contracting for New Buildings (Huston Eubank and Browning, William, 2004).
[200] See, for example: CIBSE Guide TM22, Energy Assessment and Reporting Methodology, 2nd Edition (CIBSE, 2006)
[201] See for example: Saint-Gobain's "Quick U-value of Buildings" (QUB) test that takes a day or two.
[202] The soft landings framework (Useable Buildings Trust and BSRIA, 2009)
[203] Energy Demand Research Project: Final Analysis (Aecom, 2011)

7 Conclusions and recommendations

This report illustrates the scale of the challenge of decarbonising buildings' space heating, by presenting the UK's energy demand and GHG emissions, the number of buildings, and the forecast growth in the sector. This report highlights the potential of leading practice in fabric energy efficiency, but this is not being adopted. Regulatory standards for building fabric in new buildings lag behind leading practice, with new homes allowed three times the heat demand of "Passivhaus" standards. Retrofits of existing buildings have large technical scope for emissions reductions, with the average UK home using five times as much heat as a leading practice "EnerPhit" retrofit, and all buildings having some cost-effective options. The non-domestic sector has some different challenges, but it too lags behind leading practice for new and existing buildings.

This report recognises that it is challenging to implement major improvements in fabric energy efficiency in existing buildings, and highlights the roles of demand reduction through behaviour change and automation, and of lower-carbon energy sources and more efficient heating systems. The report notes that if fabric energy efficiency is not improved more rapidly, the UK could be left with a residual heat demand that is too large for its low-carbon heat sources. The UK would face an insurmountable back-log of retrofit projects, including to upgrade new buildings that have missed the opportunity to adopt leading practice from the start. The UK needs to increase uptake of improvements by ambitiously improving the energy standards for new buildings, and accelerating the deployment of retrofit solutions for existing buildings.

The report considers the gap between leading practice and actual performance of buildings, broken down into three gaps:

- **Uptake gap:** difference between what is attempted (if anything) and leading performance; exists due to barriers or lack of ambition.
- **Prediction gap:** difference between expectation and what is realistically achievable; exists due to inaccurate forecasts of performance.
- **Performance gap:** difference between what is realistically achievable and what is delivered in practice; exists due to poor quality work and incorrect operation.

The UK needs a pragmatic balance between deployment and research. It needs to encourage uptake of measures that are known to bring benefits, and to improve the skills and enforcement to bring about the desired outcomes. Alongside this deployment and improved performance, the UK also needs to conduct research to obtain an improved understanding of heating demand and how to reduce it, in order to deploy enough measures and to target them efficiently, particularly for the more ambitious projects. Research should seek to clarify details of physical and engineering performance, and should seek to better understand the nuances of real-life energy use, whilst recognising that variations between building and occupants introduce intrinsic uncertainties: research should avoid spurious precision or allowing "the best to become the enemy of the good". Deployment and research are linked: the early stages of deployment are part of the process of research and learning, so there must be effective feedback in a "safe learning environment" in which all parties recognise the potential for underperformance and for unintended consequences.

Uptake gap in new buildings

This report highlights reasons why leading practice for new-build fabric energy efficiency has not yet been taken in the mass market, despite its advantages of comparatively small additional cost, avoiding unnecessary GHG emissions, and avoiding the disruption of future refurbishment. The main reasons are limited customer interest compared to other priorities, and limited regulatory ambition. To improve uptake of higher thermal performance in new buildings, we recommend:

- ▶ To guide buildings' energy policies and regulations to be commensurate with the UK's Carbon Budgets, a cross-departmental group should be established with membership from DCLG, BEIS, and relevant organisations (e.g. National Infrastructure Commission), aided by the establishment of an expert advisory panel.
- ▶ To provide ambition and certainty for the building industry, DCLG should produce a regulatory trajectory for building energy regulations that reaches leading performance in fabric thermal efficiency, and should maintain this trajectory.

To support these recommendations:

- ▶ The involvement of experts in leading practice in developing regulations should be better facilitated, e.g. by offering experts from small companies some form of support to reflect the costs of serving on working groups.

Uptake in existing buildings

This report highlights reasons why existing buildings are not being improved to the levels that are achievable, including how costs and benefits are viewed, non-financial considerations, and regulatory barriers, but also explores potential triggers for adopting energy efficiency improvements. The current low uptake is perpetuated in a vicious circle: the small market reduces the justification for research and promotion of products and services, reinforcing low market demand.

To increase uptake of retrofit of existing buildings, there needs to be action from industry to increase the appeal of retrofit, and policies to encourage its uptake. In particular, we recommend:

- ▶ To leverage customer action on energy efficiency, DCLG should improve its use of light-touch regulations: Display Energy Certificates (DECs) should be applied to all public buildings and promoted for private buildings; Energy Performance Certificates (EPCs) should be promoted more effectively as an important part of purchase and rental decisions.
- ▶ To increase uptake of retrofit solutions, product manufacturers and installers should better promote retrofit options and should develop more appealing products, installation methods and "retrofit packages", with support from heritage groups for older buildings and with engagement from government for the development and implementation of policies.

To support these recommendations:

- ▶ BEIS should engage with retrofitters, product manufacturers and researchers (e.g. through proposed "hubs" of expertise) to aid in the development and implementation of policies.
- ▶ Policies should seek to incorporate customers' views of costs, cost-effectiveness and barriers to uptake, including to allow government funds to more effectively leverage customers' funds.

Prediction of outcomes

The report highlights that the prediction gap stems from an inaccurate view of how buildings and occupants use energy. This does not undermine the fact that measures reduce heat demand and GHG emissions. Progress can and should be made with installing measures that are known to bring benefits, as part of a logical plan for each building, alongside research to better improve understanding especially in preparation for more ambitious projects in future. Some of this learning will come out of the early stages of deployment of some measures, and it is important that this is a "safe learning environment" in which all parties recognise the potential for underperformance and for unintended consequences.

- ▶ We recommend that, to increase understanding of thermal performance in buildings, the Energy Systems Catapult (ESC) should expand its network for access to test facilities and expertise to include tests of thermal performance, and should maintain its buildings trials as a longitudinal study and control group for other studies.

To support this recommendation, there is merit in further actions to obtain more data and expertise for research and policy, from existing sources, from ongoing research programmes, and new projects:

- ▶ Government should increase links with researchers for co-ordination of research and dissemination of results.
- ▶ BEIS should collate the key findings from previous buildings' energy studies, and develop a plan for filling knowledge gaps.
- ▶ DCLG and BEIS should continue to consider ways to enhance the English Housing Survey's (EHS) value for energy policy.
- ▶ BEIS should explore the sources of heating data, including the compatibility of Government-mandated smart meters and other services offered to customers, and how this could impact upon the management of energy systems.
- ▶ BEIS should explore the value of energy data for commercial customers, and triggers to encourage data sharing.
- ▶ Smart metering data (anonymised) should be made accessible to researchers, for example through the SMRP.
- ▶ BEIS should review the SAP model to determine its suitability for assessing energy performance and measures.
- ▶ Public research funders should ensure that data from projects is collected in a consistent manner, is not vetted by lead research organisations, is archived permanently, and is accessible for future research.

Performance in practice

The performance gap occurs when a building does not meet reasonable expectations (accounting for the prediction gap) due to poor practices and incorrect operation. It affects energy bills and comfort; it means that building regulations do not provide researchers and policy-makers with an accurate proxy for performance; and it reduces policies' benefits and cost-effectiveness. Normal variations in materials and workmanship will cause a spread in the actual performance of any set of supposedly identical buildings; and poor quality control allows the range to widen, such that some buildings fail to meet the regulatory standards. This contrasts with the electrical appliances sector: the uptake gap is small because regulations keep up closely with leading performance; the prediction gap is small due to ease of testing; and the performance gap is small due to high quality work and due to regulations that are not necessarily more numerous but that are enforcement effectively. For improving the quality of work for space heating, the Bonfield Review was commissioned to consider issues for retrofit. For new-build, all customers are already paying the costs for stipulated energy performance, but only some are receiving the intended benefits: the sector does not necessarily need more energy regulations, but rather more effective regulation through better use of time and funds.

- ▶ We recommend that, to improve thermal performance in practice, product manufacturers should take a greater role in training and quality control in the building sector, and the building inspection regime should improve its use of tests and enforcement (better regulation, not necessarily more regulation) including conducting truly random spot checks of energy performance.

To support this recommendation:

- ▶ Research funding organisations should continue to promote the development of simpler and quicker tests of buildings' thermal performance to allow customers easier access to information.
- ▶ Government and consumer organisations should raise customers' awareness of the required level of thermal performance, and support customers' rights to remedial works to address underperformance.
- ▶ BEIS and DCLG should continue their joint working to address the quality of on-site works, including to facilitate the greater role that is needed for product manufacturers in training and quality control for thermal performance.

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UK housing energy fact file: 2013 (DECC, 2014)

Understanding the changing landscape of the UK self-build market (University of York, 2013)

United Kingdom housing energy fact file: 2013 (DECC, 2014)

Value propositions for Energy efficient Renovation Decisions, "Project VERD" (UEA, 2014)

List of organisations interviewed for project

ARUP

Association for the Conservation of Energy (ACE)

BASF

Bere Architects

Buildings Research Establishment (BIS)

Centre of Retrofit Excellence (CoRE)

Chartered Institution of Building Services Engineers (CIBSE)

Chelsfield Advisers LLP

Committee on Climate Change (CCC)

Construction Industry Council (CIC)

Construction Products Association (CPA)

Department for Business, Innovations and Skills (BIS)

Department for Communities and Local Government (DCLG)

Department for Business, Energy and Industrial Strategy (BEIS) (formerly Department of Energy and Climate Change (DECC))

Dyson School of Design Engineering

Economic and Social Research Council (ESRC)

Empty Homes

Energy and Physical Sciences Research Council (EPSRC)

Energy Efficiency Partnership for Buildings (EEPB)

Energy Institute, University College London

Energy Saving Trust (EST)

Energy Systems Catapult (ESC)

Energy Technologies Institute (ETI)

English Heritage

Environmental Change Institute (ECI), Oxford University

Faculty of Engineering, Imperial College London

Federation of Master Builders (FMB)

Forum for the Future

Green Alliance

Green Construction Board (GCB)

Homes and Communities Agency (HCA)

Housing and Communities, London School of Economics (LSE)

Innovate UK (formerly Technology Strategy Board, TSB)

National Australian Built Environment Rating System (NABERS)

National Energy Foundation (NEF)

National Physical Laboratory (NPL)

National Self Build Association (NaSBA)

Ofgem

Open TRV

Research Councils Energy Research Programme

Royal Academy of Engineering (RAE)

Royal Institute of British Architects (RIBA)

Saint-Gobain

Sustain

Sustainability Research School, Loughborough University

Swansea University

Tyndall Centre, University of East Anglia

UK Energy Research Centre (UKERC)

UK Green Building Council

UCL Energy Institute, University College London (UCL)

Useable Buildings Trust (UBT)

Willmott Dixon

Zero Carbon Hub

ENERGY RESEARCH PARTNERSHIP

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