ENERGY EFFICIENCY IN NEW AND EXISTING BUILDINGS

Comparative costs and CO_2 savings

Fiona MacKenzie, Christine Pout, Les Shorrock, Alison Matthews and John Henderson

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- a higher quality built environment
- built facilities that offer improved functionality and value for money
- a more efficient and sustainable construction sector, with
- a higher level of innovative practice.

A further aim of BRE Trust is to stimulate debate on challenges and opportunities in the built environment.

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Registered Office: Bucknalls Lane, Garston, Watford, Herts WD25 9XX

BRE Trust
Garston, Watford WD25 9XX
Tel: 01923 664743
Email: secretary@bretrust.co.uk
www.bretrust.org.uk

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Cover images:
Main: Photovoltaic panels (courtesy of Radian Group)
Top right: Solar hot water panel
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LIST OF ACRONYMS

CCS	carbon capture and storage
CLG	Communities and Local Government
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
LZC	low and zero carbon
MAC	marginal abatement cost
NAC	net annual cost
N-DEEM	Non-Domestic building Energy and Emissions Model
NPV	net present value
PV	photovoltaic
TER	target emissions rate
TRV	thermostatic radiator valve

EXECUTIVE SUMMARY

This BRE Trust Report considers the relative impact on UK CO_2 savings targets of constructing new zero-carbon buildings as opposed to improving the energy efficiency of the existing stock. It concludes that, in terms of the cost of saving one tonne of CO_2, the returns from tackling existing buildings are both much larger and more cost-effective than focusing on new buildings alone. However, in order to achieve the UK government's target to cut CO_2 emissions by 80% on 1990 levels by 2050, it will be necessary to make significant progress on both fronts.

Carbon dioxide emissions from UK buildings accounted for 226 million tonnes of carbon dioxide ($MtCO_2$) in 2006. This was around 40% of the total CO_2 emissions in the UK, which amounted to 555 $MtCO_2$. The UK government has stated its aim to reduce greenhouse gas emissions by 80% by 2050. In order to achieve such challenging reductions in emissions, improving the energy efficiency of buildings – both new and existing – will clearly have a vital role to play.

The Code for Sustainable Homes[a, b] became operational in England in April 2007 and a Code rating for new-build homes became mandatory from 1 May 2008. The Code provides a single national standard aimed at driving continuous improvement in sustainable home building. The Code sets six progressively tougher performance levels, where Level 6 represents a zero-carbon home. While moving towards zero carbon for all new buildings can undoubtedly achieve a significant reduction in CO_2 emissions in the future, existing buildings will form the majority of the UK's building stock for many years to come. The work presented here uses existing data to explore the extent to which improving the energy efficiency of the existing UK building stock would be a more cost-effective route for achieving CO_2 savings than constructing new buildings to the higher levels of energy performance required to meet low- and zero-carbon (LZC) targets.

The analysis indicates that, for the domestic sector, constructing new dwellings to Code Level 2 and above is not yet a cost-effective means of reducing CO_2 emissions. However, constructing to Level 5 of the Code is actually slightly more attractive, in terms of the cost per tonne of CO_2 saved, than constructing to levels 3, 4 or 6, with the CO_2 savings for Level 6 considerably greater (23 $MtCO_2$ per annum) than for levels 3 or 4.

For the non-domestic sector, the results indicate that although none of the low-carbon new-build levels considered here* are cost-effective, Level 4 has the greatest CO_2 savings (20 $MtCO_2$ per annum). However, these savings are extremely non-cost-effective and the least cost-ineffective option (in terms of the cost per tonne of CO_2 saved) is Level 3 rather than Level 1 or Level 2.

In contrast to new build, the cost-effective potential for CO_2 savings in the UK's existing building stock is very much greater at 96 $MtCO_2$ per year, the vast majority of which is in the domestic sector. Therefore, in terms of a conventional economic assessment, the results indicate that there are much more significant and more cost-effective CO_2 savings to be obtained by improving the existing building stock.

However, implementing cost-effective refurbishment of the building stock will not, on its own, be enough to achieve the 80% CO_2 reduction target for buildings by 2050. It will also be necessary to move rapidly towards a requirement for LZC new buildings. Even with full implementation of both LZC new build and comprehensive refurbishment of the existing building stock, there will be a shortfall of 50 $MtCO_2$ per annum, which would need to be addressed by other means such as decarbonisation of the electricity grid.

The Committee on Climate Change[c] and the government's recent White Paper[d] recognise several options and approaches for reducing CO_2 emissions, including energy efficiency improvements in buildings and industry, decarbonisation of the power sector, transport sector emission cuts, heat sector decarbonisation and decarbonisation of industry. Because some of these approaches are still in the early stages of development – carbon capture and storage associated with power production from fossil fuels, for example, has not yet reached demonstration stage[e] – it appears even more vital to push forward improvements in both existing and new buildings as part of the overall solution to achieving an 80% reduction in emissions by 2050.

There are several other important factors that should be noted in respect to this study:

- This work only represents one view of the future; in reality, what happens in the future could be very different.

* As there is no equivalent code for non-domestic buildings, four levels were defined for the purposes of this analysis and it was assumed that non-domestic buildings would not be expected to reach zero unregulated carbon (as opposed to the domestic sector for which Level 6 represents zero regulated and unregulated carbon).

- There are practical reasons why it might be necessary to build to intermediate levels of the Code for a short period of time.
- The analysis does not take account of the shadow price of carbon or the embodied carbon associated with the construction of buildings and installed technologies; further research is required in these areas.
- The 80% reduction target relates to the entire CO_2 emissions for the UK, and some sectors (eg transport) may present even greater challenges. This could result in the building sector being asked to exceed even the 80% target to make up for shortfalls in other sectors.

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1 BACKGROUND

Carbon dioxide emissions from UK buildings (domestic and non-domestic) accounted for 226 million tonnes of carbon dioxide ($MtCO_2$) in 2006. This was around 40% of the total CO_2 emissions in the UK, which amounted to 555 $MtCO_2$.

The UK government has stated its aim to reduce UK greenhouse gas emissions by 80% compared with 1990 levels by 2050. Furthermore, the Committee on Climate Change[1] has published its recommendations for cuts to greenhouse gas emissions based on the first three legally binding carbon budgets introduced under the Climate Change Act 2008. The three budget periods are 2008–2012, 2013–2017 and 2018–2022 and set an upper limit on the level of greenhouse gas emissions over each five-year time period. The Committee on Climate Change recommends that the UK government commits to a minimum reduction of 34% by 2020 and that this should increase to 42% by 2020 if a global deal on climate change is reached.

In order to achieve these challenging reductions in greenhouse gas emissions, improving the energy efficiency of buildings will clearly have a vital role to play, both for existing and new buildings. The Code for Sustainable Homes[2, 3] became operational in England in April 2007 and a Code rating for new-build homes became mandatory from 1 May 2008. The Code provides a single national standard aimed at driving continuous improvement in sustainable home building. The Code covers nine aspects of sustainability, including energy, and is closely linked to the 2006 Building Regulations† for England and Wales. The Code for Sustainable Homes uses a rating system of one to six levels to communicate the overall sustainability of a new home. For the energy aspect, the lowest level of the Code (Level 1) requires that the energy performance should be 10% better than the target emissions rate (TER) required by the 2006 Building Regulations[4], and that the highest level (Level 6) would equate to a zero-carbon home. The UK Green Building Council's Zero-Carbon Task Group Report[5] proposed a definition for zero carbon where:

- strict energy efficiency parameters – ie building design and appliances – must come first, followed by
- a minimum level of carbon mitigation on or near site (eg 100% regulated energy).

† Throughout this report, the term '2006 Building Regulations' is used to denote the 2006 amendment to the Building Regulations (2000).

Where this is not achievable, the constructor must:

- demonstrate additional off-site solutions built specifically for the development, and
- pay into a Community Energy Fund for equal or greater CO_2 savings (which should be priced to clearly incentivise on-site or near-site solutions).

At present, there is no equivalent code for non-domestic buildings. However, the UK Green Building Council's Zero-Carbon Task Group Report, published in May 2008, examined whether similar targets could be set for the non-domestic sector and considered the cost and timescales. This report predicted that, because electricity use is significantly higher than for housing and the opportunities for on-site renewables more limited, it is likely that additional near-site and off-site solutions will be needed to reach zero-carbon developments. The report also estimated the additional cost of zero-carbon developments as being 10–50% above current costs and concluded that it might be feasible to require this standard to be met for new buildings by 2020.

In December 2008, Communities and Local Government (CLG) issued a consultation document[6] relating to the definition of zero-carbon homes that will apply to new homes built from 2016. This document also sought views on the government's ambition that new non-domestic buildings should be carbon neutral from 2019. Alongside this, a consultation stage impact assessment has also been produced[7].

This consultation identifies the government's current thinking on the routes for achieving zero-carbon targets for new-build housing, and discusses the kinds of targets that might be appropriate for non-domestic new build. One issue of particular relevance here is that the consultation specifically excludes consideration of existing buildings and notes that this will be dealt with in a later consultation. This separation of new build and existing buildings is the very issue that this report specifically seeks to address.

The consultation elaborates on the views set out in *Building a greener future*[8] concerning the government's policy on all new homes meeting the zero-carbon standard from 2016. This publication identifies a zero-carbon home as one that will have net zero-carbon emissions over the course of a year when taking account of emissions from space heating, ventilation, hot water and fixed lighting, as well as expected emissions from energy-using appliances and imports/exports from the development.

The consultation document sets out the government's preferred approach for achieving this aim based on the following hierarchy (Figure 1):

1. *Energy efficiency* – Building regulations should be underpinned by a very high minimum standard of energy efficiency.
2. *Carbon compliance* – A minimum standard of carbon compliance should be achieved through a combination of energy efficiency, on-site low- and zero-carbon (LZC) energy supply technologies and directly connected heat (within the range of a 44–100% reduction in regulated emissions compared with the 2006 requirements).
3. *Allowable solutions* – A range of allowable solutions will be used for dealing with the residual emissions remaining after applying the above standards. The government will set out a maximum cost that it would expect to be spent on such allowable solutions and will review the policy in 2012 to confirm that this cost will not need to be exceeded.

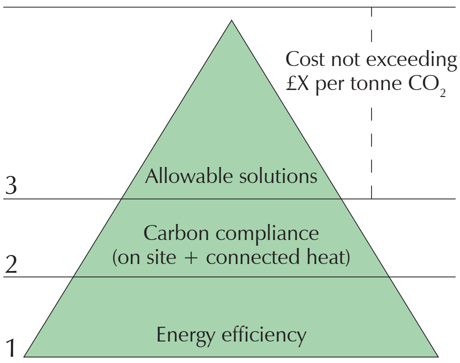

Figure 1: The UK government's preferred hierarchy for achieving zero-carbon homes

However, this definition of zero carbon differs from the one outlined in *Building a greener future* in that renewable energy sources were originally only allowable towards the carbon calculation if they were connected via 'private wire'. The definition of zero carbon under Level 6 of the Code for Sustainable Homes is the requirement that a heat loss parameter of 0.8 W/m^2K be achieved, and this may or may not become the energy efficiency backstop underpinning the zero-carbon homes standard. Hence, there is an issue as to whether the Code for Sustainable Homes Level 6 should be revised so that it is consistent with the proposed definition.

1.1 ZERO-CARBON NON-DOMESTIC BUILDINGS

In November 2009, the government issued a second consultation document[9] on non-domestic buildings. This proposed that the domestic hierarchy approach could also be applied to non-domestic buildings. However, there is much more diversity in the non-domestic stock, and the range of challenges and opportunities means it is unlikely that it would be practicable or reasonable to apply the domestic solution in exactly the same way.

2 INTRODUCTION

The aim of the work underlying this report is to explore the extent to which improving the energy efficiency of the existing UK building stock would be a more cost-effective route for achieving CO_2 savings than constructing new buildings to the higher levels of energy performance required to meet LZC targets for new build. The work is based on existing data and analysis, much of which has been carried out by BRE, and seeks to determine where the best balance lies between high energy performance standards for new build and refurbishment of the existing building stock.

While moving towards zero carbon for all new buildings can undoubtedly achieve a significant reduction in CO_2 emissions in the future, existing buildings are expected to form the majority of the UK's building stock for many years to come since around three-quarters of houses and 60% of non-domestic buildings in 2050 are likely to have been built before 2010. Most existing buildings in the UK were constructed before building regulations were extended to consider energy, and while many will have undergone some energy efficiency improvements (eg installation of double glazing, replacement of inefficient boilers), significant potential for further energy efficiency savings remains. Recent estimates indicate that the technical potential for reducing CO_2 emissions in the UK building stock is around 40%, and of this around 20% can be saved cost-effectively.

In order to assess the size of savings available and the cost-effectiveness of those savings for both refurbishing existing buildings and constructing new buildings to LZC standards, this project looks at:

- the potential future building stock broken down by age of construction
- the energy efficiency improvements that could be made to the existing building stock
- the energy efficiency improvements required to achieve LZC standards in new buildings
- the investment costs and the CO_2 and cost savings associated with refurbishing existing buildings and constructing new buildings to LZC standards‡

This project makes use of existing data generated for other projects for Defra and the Committee on Climate Change. Domestic and non-domestic buildings have been assessed separately due to the very different nature of both the buildings involved and the data available.

‡ Although we use the term 'savings' for both existing and new buildings, the savings in the latter should more accurately be referred to as 'avoided future emissions' since these buildings do not yet exist.

3 ASSESSING COST-EFFECTIVENESS

In order to determine the cost-effectiveness of CO_2 savings, discounted cash flow calculations were used to take account of the fact that an investor could reasonably expect returns from any monies used to purchase energy-saving equipment if invested elsewhere. The discount rate used was 3.5%, which reflects Treasury guidance on investment.

Two measures of cost-effectiveness were employed: net annual cost (NAC) and net present value (NPV).

3.1 NET ANNUAL COST

To determine NAC, the following formula was used:

$$NAC = EAC - S$$

where S is the annual cost saving and the equivalent annual cost (EAC) is determined using the following formula:

$$EAC = \frac{Cr}{1 - (1 + r)^{-n}}$$

where C is the cost of the measures installed, r is the discount rate and n is the lifetime of the measure in years.

To provide a comparison between the energy-saving/low-carbon measures, the NAC per tonne of CO_2 saved was also calculated. A negative NAC/tCO_2 value indicates that a particular option or package is cost-effective.

3.1.1 Marginal abatement cost curves

The results of the NAC/tCO_2 assessment were then ranked according to the cost-effectiveness of each measure to produce a marginal abatement cost (MAC) curve, which shows the potential cost-effective savings below the x-axis and the potential non-cost-effective savings above the x-axis (see Figure 3 for an example).

3.2 NET PRESENT VALUE

To determine NPV in a given year, the following formula was used:

$$NPV = \frac{C_n}{(1 + r)^n}$$

where C_n is the net costs incurred in the specified year, r is the discount rate and n is the number of years in the future. These annual NPVs are then summed over the relevant period to give the total NPV for the option or package under consideration.

Converse to the NAC/tCO_2 measure, a positive NPV indicates that a measure is cost-effective.

4 DOMESTIC BUILDINGS

4.1 AGE PROFILE OF THE DOMESTIC BUILDING STOCK

For domestic buildings, it was assumed that the current stock comprises around 26 million homes[§]. It was then assumed that eight million new homes would be built by 2050[¶], and this was pro-rated over the period to give an annual increase of 200 000 new homes. Although this rate is in reality likely to be non-linear and there is inevitably some uncertainty, particularly over whether this will be achieved in the short term, it is likely that the actual figures will be somewhere in this order. The demolition rate in the domestic sector is negligibly small[**] and so the modelling takes no account of demolitions. The projected age profile for the domestic building stock (Figure 2) indicates that, by 2050, around three-quarters of dwellings will have been built prior to 2010.

4.2 EXISTING DOMESTIC BUILDINGS

The potential number of existing homes that could benefit from a range of energy efficiency measures was determined based on the most recent and comprehensive data available at the time of carrying out the research project for the Committee on Climate Change (ie 2005). Based on these data and the domestic energy model, the potential energy and CO_2 savings for each measure were estimated. In general, these estimates have been made assuming a semi-detached dwelling, this being the most common and most representative dwelling type within the stock. The annual cost savings were also determined from the energy savings and corresponding fuel prices and these, along with the capital costs of each measure and an estimate of the lifetime, were used to assess the cost-effectiveness. The energy costs and CO_2 emission factors used are shown in Table 1.

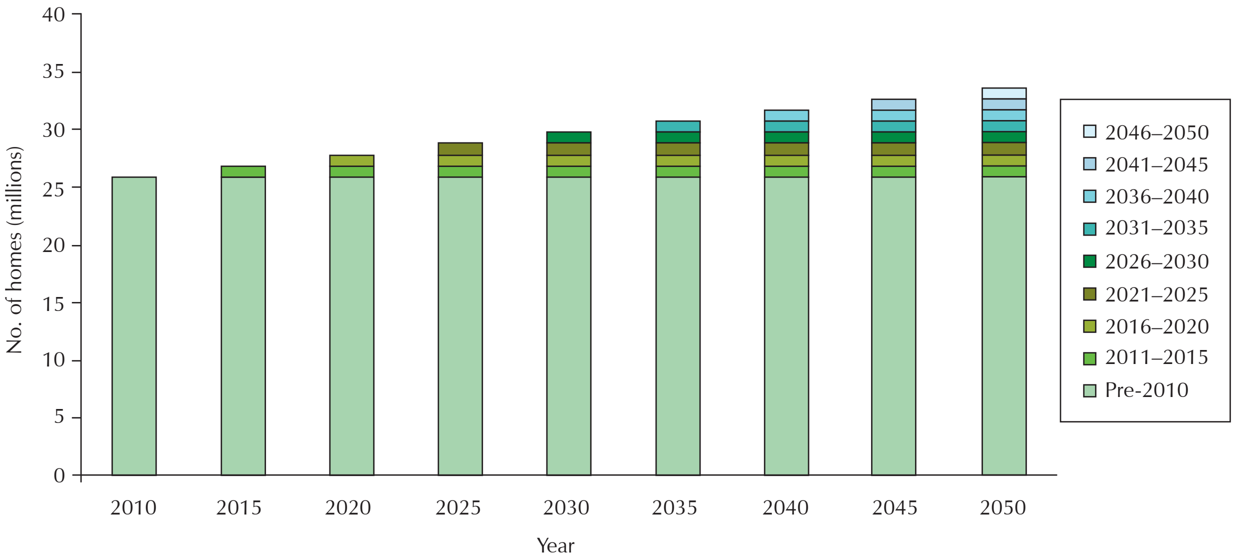

Figure 2: Projected age profile for UK domestic building stock

§ CLG's dwelling stock by tenure table indicates a UK stock figure in March 2006 of 26.42 million. Of more relevance to energy use is the number of households (ie occupied dwellings), which live table 401 indicates was 25.75 million in mid-2006. www.communities.gov.uk

¶ Eight million is an estimate, but CLG has also quoted a figure of an additional eight million homes to 2050 in the 'Notes to editors' section of the news release of 17 December 2008, 'New proposals to make the 2016 zero-carbon homes target a reality', www.communities.gov.uk

** CLG live table 111 indicates that about 20 000 dwellings in England were demolished in 2000–2001 (the latest year available), which represents less than 0.1% of the stock. Moreover, the demolitions are largely offset by 'change of use' gains to the stock so the net loss is even smaller. www.communities.gov.uk

Table 1: **Energy costs and CO_2 emission factors used for the domestic sector analysis**

Fuel type	**Energy cost (£/kWh)**	**CO_2 emission factor (kgCO$_2$/kWh)**
Electricity	0.100	0.542
Heating fuel (weighted average of mixed fuels/gas)*	0.029	0.218/0.191

* For the analysis of existing dwellings, a weighted average of heating fuels, based on the known current fuel mix within the stock, was used. For new dwellings, the baseline assumption was as detailed in *Cost analysis of the Code for Sustainable Homes*[10], this being the source of the new-dwelling costs and carbon saving figures used for this study – ie gas heating.

The resultant MAC curve is shown in Figure 3. The largest of the CO_2 savings are labelled so, for example, Figure 3 shows that cavity wall insulation, solid wall insulation and condensing boilers are particularly important measures. The details for all of the 39 measures that were considered, some of which save relatively little CO_2, are given in Table 2.

In reality, there can be interactions between specific energy efficiency/low-carbon measures, and such interactions have been taken into account as far as possible. Thus, the savings from low-energy appliances have been adjusted to allow for the fact that their use lowers the incidental gains, meaning that the heating system has to supply more heat to meet the same comfort conditions. This is commonly referred to as the 'heat replacement effect'[11]. Additionally, the boiler savings have been adjusted to allow for the fact that they would be reduced by the installation of the insulation measures that have been considered. These adjustments allow the savings to be added together to identify the potential cumulative CO_2 savings.

However, where the analysis considers alternative technologies, eg solar water heating and photovoltaic (PV) panels, it is not possible to take into account the overlaps in the same way. This effectively leads to an overestimation of the total CO_2 savings shown on the charts. However, as these alternative technologies do not appear in the cost-effective portion of the curve, the cost-effective savings shown are correct.

Furthermore, the savings from all fabric insulation measures have been downgraded to allow for comfort taking, using the best estimate that we have of the magnitude of this effect in practice[12]. Additionally, the savings that have been ascribed to cavity wall insulation and loft insulation have been adjusted to take account of the fact that, for reasons that are still not understood, the savings that are achieved in practice fall well short of what energy modelling would suggest should be achieved[12]. If we could identify the reasons why cavity wall insulation in particular falls short of achieving the expected savings, then it may be possible to recover some of these lost savings in future. For such reasons, the savings that are presented in Figure 3 are considered realistic rather than optimistic.

The cost-effective savings indicated in Figure 3 amount to approximately 90 MtCO$_2$/year. It would, of course, take time to install all of these measures, but it should be feasible to do so by 2050 and for the purposes of this analysis it is assumed that this is the case††. That said, some measures such as solid wall insulation would require significant support and promotion to increase their uptake rates, which are currently very slow.

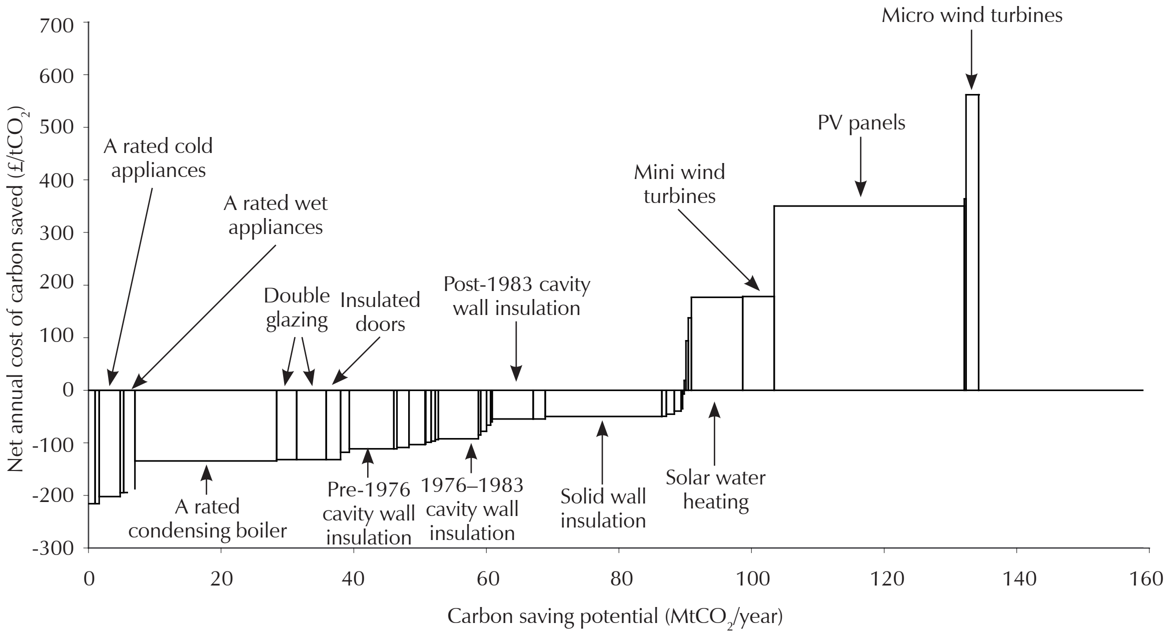

Figure 3: Cost-effectiveness and CO_2 savings in the existing domestic building stock

†† This is different to the non-domestic sector analysis of existing buildings, which assumes a refurbishment schedule of 4% of the stock per annum over the time period under consideration.

Table 2: **Cost-effectiveness and CO_2 savings for all measures considered**

Measure	NAC/tCO_2	$MtCO_2$/year	Cumulative
Reduced standby consumption	-215.93	1.00	1.00
Integrated digital TVs	-215.90	0.60	1.61
A++ rated cold appliances	-202.34	3.17	4.78
A rated ovens	-195.00	0.52	5.30
A+ rated wet appliances	-194.53	1.69	7.00
A rated condensing boilers	-134.44	21.38	28.37
Glazing – old double to new double	-132.04	3.02	31.39
Glazing – single to new double	-131.97	4.46	35.85
Insulated doors	-131.89	2.19	38.04
Loft insulation 0–270 mm	-117.89	1.31	39.34
Pre-1976 cavity wall insulation	-111.53	6.70	46.04
Induction hobs	-111.26	0.49	46.53
DIY floor insulation (suspended timber floors)	-108.69	1.82	48.35
Efficient lighting	-103.22	2.41	50.76
Loft insulation 25–270 mm	-102.65	0.09	50.86
Uninsulated cylinders to high-performance cylinders	-99.03	0.81	51.67
Insulated primary pipework	-96.76	0.62	52.29
1976–1983 cavity wall insulation	-93.95	0.48	52.77
Glazing – single to future double	-92.37	6.05	58.81
Loft insulation 50–270 mm	-85.19	0.34	59.15
Room thermostat to control heating	-78.00	0.88	60.04
Loft insulation 75–270 mm	-66.29	0.60	60.64
Post-1983 cavity wall insulation	-60.14	0.24	60.89
Glazing – old double to future double	-54.71	6.19	67.08
Installed floor insulation (suspended timber floors)	-54.61	1.82	68.90
Solid wall insulation	-49.78	17.59	86.49
Loft insulation 100–270 mm	-49.52	0.67	87.16
Thermostatic radiator valves	-45.45	1.19	88.35
Improved airtightness	-39.69	1.04	89.39
Loft insulation 125–270 mm	-35.22	0.22	89.62
Loft insulation 150–270 mm	-7.00	0.24	89.86
Glazing – new double to future double	18.71	0.27	90.13
'Paper' type solid wall insulation	94.07	0.33	90.46
Modestly insulated cylinders to high-performance cylinders	137.69	0.48	90.94
Solar water heating	176.77	7.72	98.66
Mini wind turbines	178.14	4.76	103.42
Photovoltaic generation	350.25	28.68	132.10
Hot water cylinder thermostats	363.84	0.25	132.35
Micro wind turbines	561.81	1.90	134.25

The analysis shows that the 90 $MtCO_2$ saving from undertaking all of the cost-effective measures (plus 8.5 $MtCO_2$ already achieved between 1990 and 2006) represents only a 64% reduction on the 1990 emissions from the housing stock, so it is clear that to achieve an 80% reduction will involve going beyond cost-effective measures. Therefore, it follows that measures to decarbonise the supply of both electricity and heat will be essential if this target is to be achieved.

4.3 NEW DOMESTIC BUILDINGS

It is clear that new homes will just add to the housing stock emissions unless they are built to zero-carbon standards. Simply continuing to build new homes to the 2006 Building Regulations standards would result in additional emissions of around 23 $MtCO_2$/year by 2050, all other things remaining equal. This section, therefore, looks at the potential costs and savings to be achieved from applying the different levels of improvement specified in the Code for Sustainable Homes.

The Code became operational in England in April 2007. It sets out six levels of sustainability, which, in terms of CO_2 emissions, represent different levels of improvement relative to the requirements of the 2006 Building Regulations[4, 13]. Levels 1–5 relate to regulated energy only – ie the elements of the energy use that are covered by building regulations, namely space heating, water heating, ventilation and lighting. Level 6 also encompasses the elements of energy use that are not presently subject to regulations (eg energy used for appliances and cooking), and achieving this level corresponds to a zero-carbon home. As already noted, the UK government has an aim that, from 2016, all homes built should achieve this standard.

CLG has undertaken work to assess the costs of achieving different levels of the Code[10]. The department examined costs for four different dwelling types (detached, end terrace/semi-detached, mid terrace and flat), within four different 'development scenarios' (small development, city infill, market town and urban regeneration). It was assumed that wind power could be used in two of the four development scenarios. The figures that CLG produced have been used for the present study‡‡. For this purpose, the costs for an end terrace/semi-detached house have been selected, and the high costs (corresponding to the case where wind power cannot be used) have been used§§. In general, the calculations relating to the existing housing stock have been undertaken using a standard semi-detached house. As this is the most common house type in the UK, representing about one-third of the stock, it is a further reason for selecting this dwelling type for new homes as well.

The packages of measures applied to the selected standard dwelling to correspond to each of the levels of the Code (assuming that levels 4 and above must also include the measures listed against levels 1–3) were as follows:

- *Level 1* – Improved controls (10% improvement on 2006 Building Regulations – the base case)
- *Level 2* – Improved air tightness and insulation levels (18% improvement)
- *Level 3* – 4 m^2 flat panel solar water heating (25% improvement)
- *Level 4* – Biomass heating (44% improvement)
- *Level 5* – PV panels installed (100% improvement, ie zero-carbon regulated energy)
- *Level 6* – Advance practice energy efficiency¶¶[14] (Level 5 plus non-regulated energy)

Based on the costs and CO_2 savings from the CLG report and the assumed new-build rates for domestic buildings, the NAC/tCO_2 measure for expected savings in the future was determined in exactly the same way as for existing homes. The same fuel price, CO_2 emission factors and discount rate were also used. A lifetime of 100 years was used since it would be expected that a dwelling should have a lifetime of at least this length***. Clearly, however, at least some of the technology incorporated within the dwellings would not last this long so there is an inevitable uncertainty about the most appropriate figure to use (as, indeed, there is for the lifetimes of the individual measures considered in Figure 3). Fortunately, it is a characteristic of this type of cost-benefit analysis that the results are not very sensitive to the assumed lifetime once it is reasonably long, so this uncertainty should not significantly affect the general conclusions. Furthermore, it is assumed that no further marginal capital costs will be incurred over the time period under consideration.

The following MAC curves (figures 4–9) are the same as Figure 3, except that they also include within the ranking the savings that would be achieved by 2050 by building all new dwellings to levels 1–6 of the Code rather than to the requirements of the 2006 Building Regulations.

The Level 1 savings are cost-effective but, compared with the existing home savings, they are very small, emphasising the importance of improving the existing stock. It also needs to be borne in mind that although the Code figure is shown as a saving (so that it can be compared with the existing housing stock savings), this is actually just a small reduction to the additional emissions that new homes constructed up to 2050 will produce if they are built to the current building regulations.

Levels 2–6 of the Code are all indicated as being non-cost-effective. However, it is interesting that levels 5 and 6 appear more attractive than levels 3 and 4. Level 5 has a lower cost per tonne of CO_2 saved than levels 3 and 4 and considerably larger savings, while Level 6 has a cost per tonne that is almost the same as levels 3 and 4 and a much larger saving†††.

‡‡ Only costs relating to the energy efficiency aspects of the Code have been used here. There are some other costs associated with achieving different levels of the Code but they are small in comparison.
§§ Examination of the figures in the CLG report showed that the averages of the cost figures across all four dwelling types were very close to those for this dwelling type, so it is an appropriate choice for this study.

¶¶ Energy Saving Trust advanced practice energy efficiency – enhanced U-Values for floors, exposed walls and windows, together with improved air tightness, whole-house ventilation, heat recovery and boiler efficiency.
*** Many existing homes in the UK have already lasted longer than this and almost 20% of UK homes were built before 1918.
††† Bearing in mind again that these are not savings as such – they are reductions to the additional emissions that would otherwise occur by building new dwellings to the 2006 Building Regulations, and only Level 6 reduces these emissions to zero.

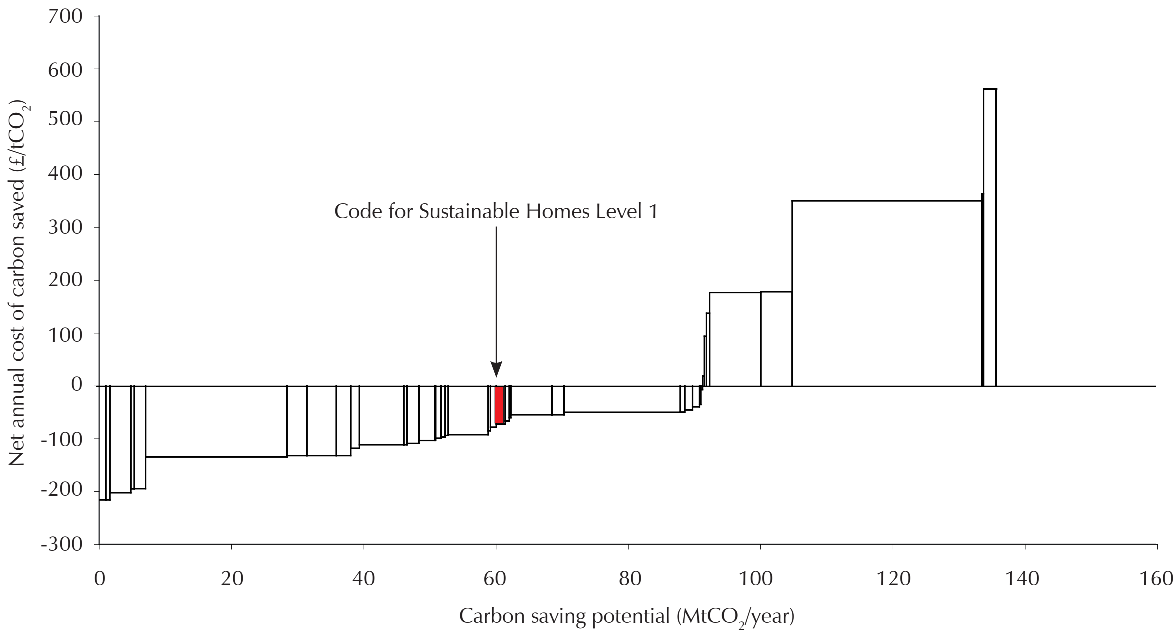

Figure 4: Cost-effectiveness and CO_2 savings in the existing domestic building stock (Code Level 1 for new homes also shown)

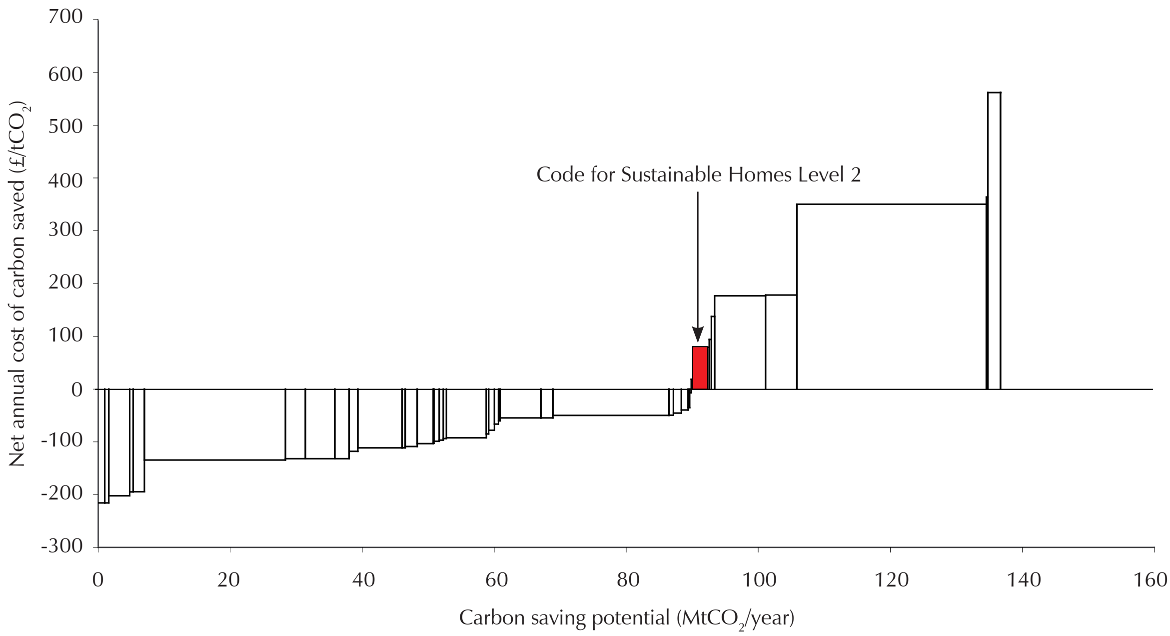

Figure 5: Cost-effectiveness and CO_2 savings in the existing domestic building stock (Code Level 2 for new homes also shown)

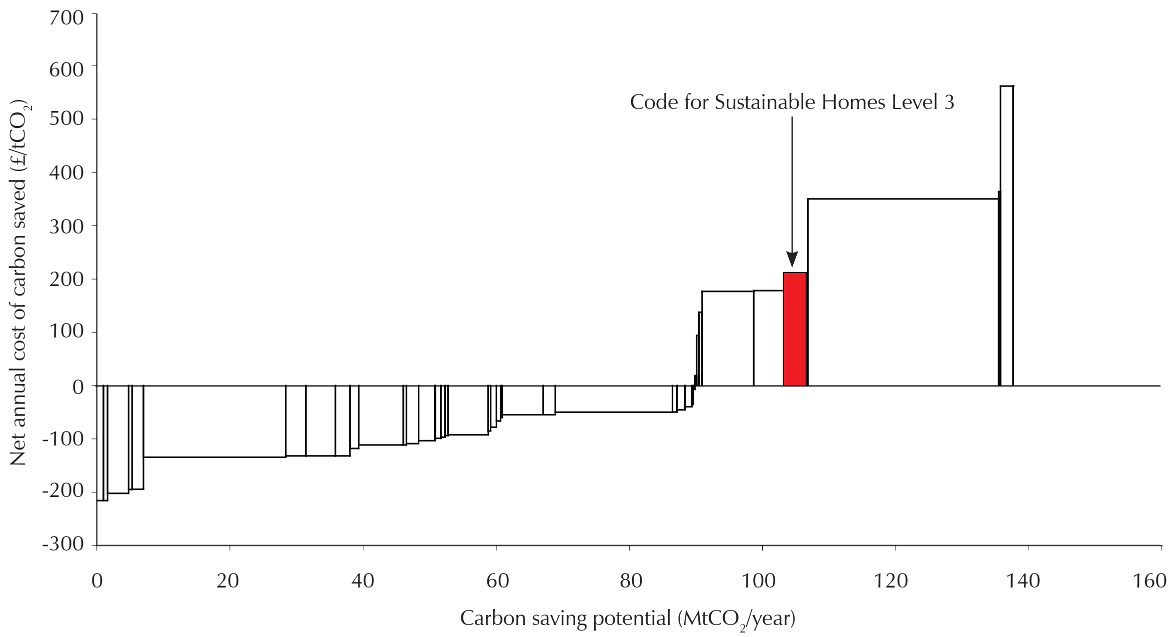

Figure 6: Cost-effectiveness and CO_2 savings in the existing domestic building stock (Code Level 3 for new homes also shown)

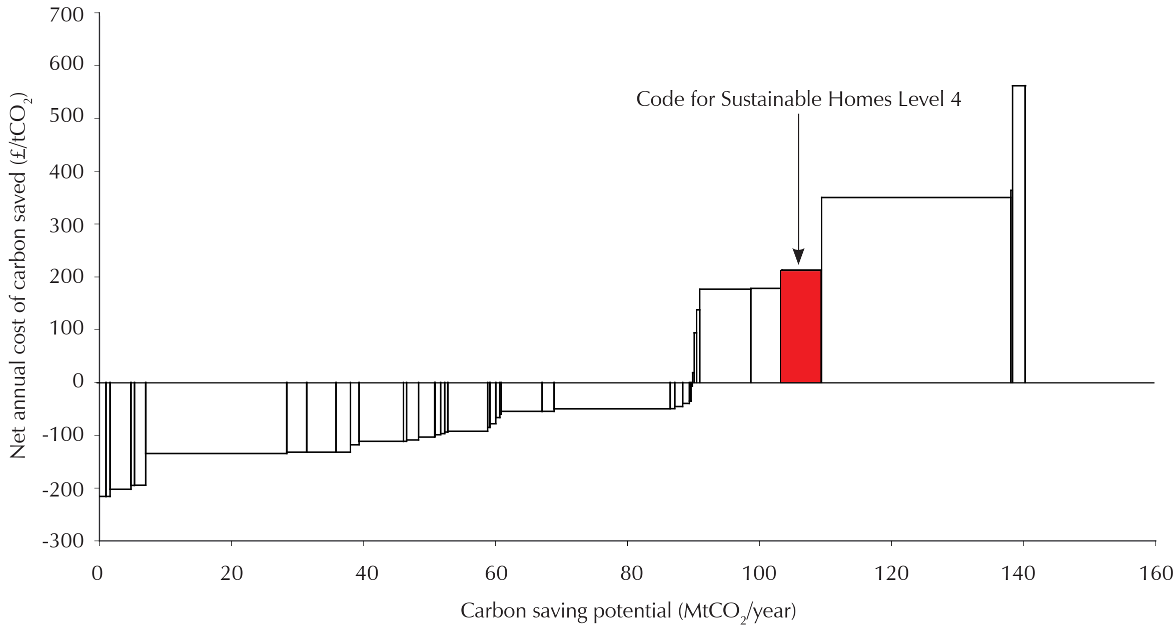

Figure 7: Cost-effectiveness and CO_2 savings in the existing domestic building stock (Code Level 4 for new homes also shown)

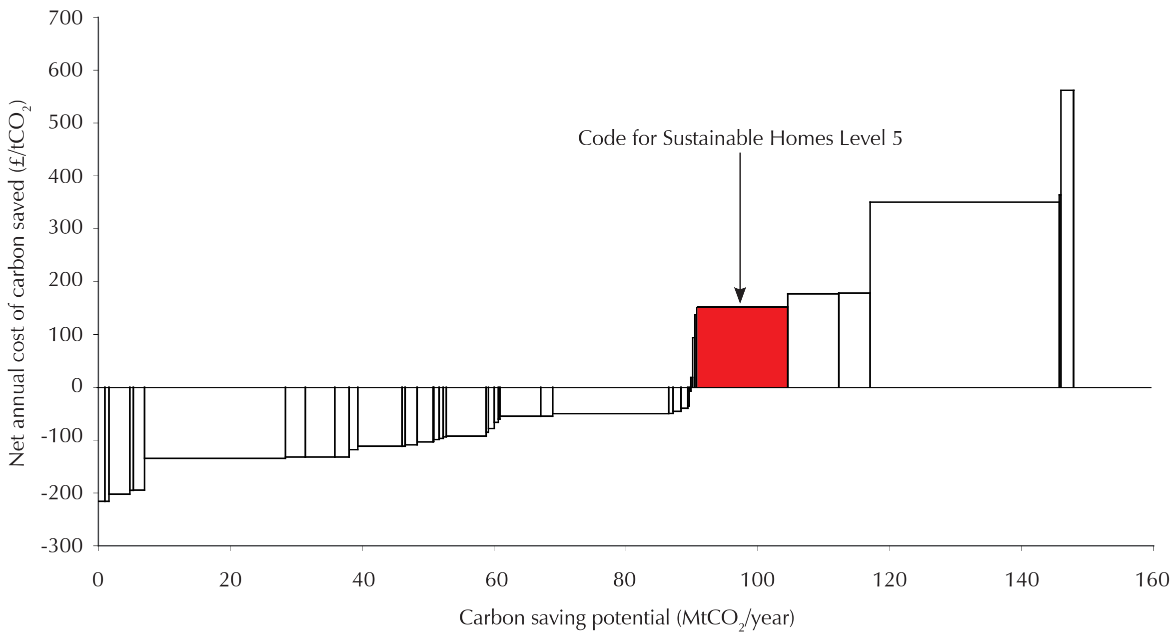

Figure 8: Cost-effectiveness and CO_2 savings in the existing domestic building stock (Code Level 5 for new homes also shown)

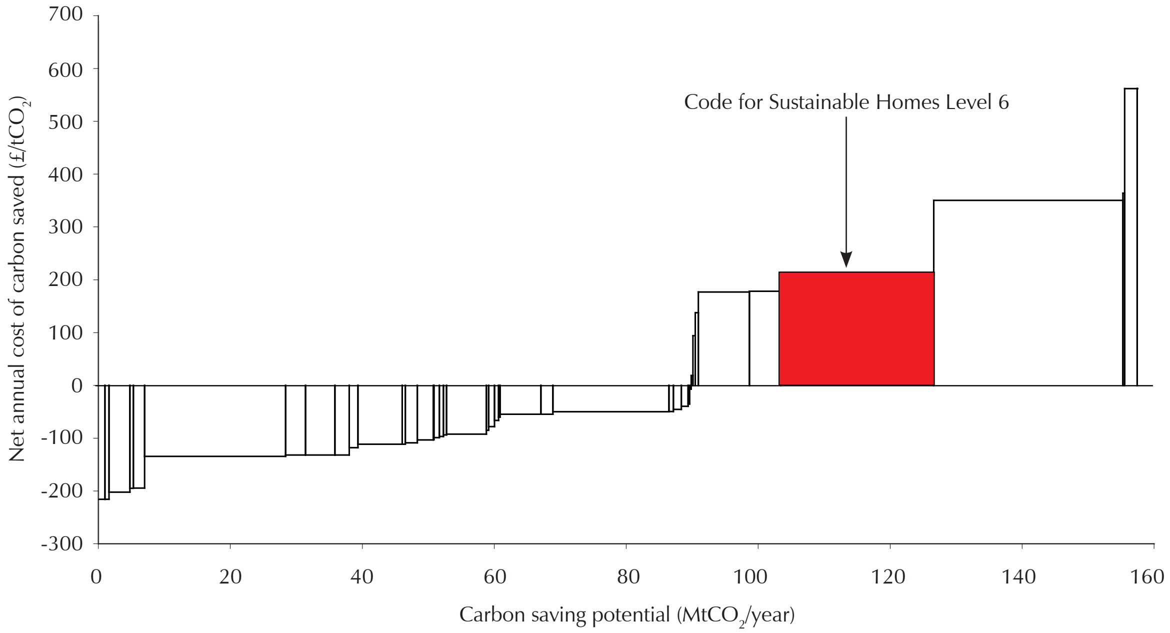

Figure 9: Cost-effectiveness and CO_2 savings in the existing domestic building stock (Code Level 6 for new homes also shown)

Table 3 summarises the CO_2 emission reductions that the different levels of the Code might achieve in 2050 together with their NAC and NPV for all new-build housing. The order of cost-effectiveness is different between the NAC and the NPV since the former is determined here on a per tonne of CO_2 saved basis and takes into consideration the greater CO_2 savings per pound sterling (£) spent achieved for Level 5, for example.

Figures 10 and 11 show the annual and cumulative CO_2 savings to 2050, respectively, for the different levels of the Code for Sustainable Homes. The graphs illustrate the greater CO_2 savings achieved under levels 5 and 6 compared with levels 1–4. Cumulatively, the CO_2 saved by 2050 under Level 6 is estimated to be around 475 $MtCO_2$ compared with around 275 $MtCO_2$ for Level 5 and only about 125 $MtCO_2$ for Level 4.

Table 3: **Cost-effectiveness and CO_2 savings from different levels of the Code (projections for 2050)**

Code for Sustainable Homes Level	NAC/tCO_2	$MtCO_2$/year	NPV (£M) for all new-build housing
Level 1	-72.40	1.36	1546
Level 2	79.21	2.45	-2698
Level 3	211.13	3.40	-10 369
Level 4	213.06	5.98	-18 420
Level 5	151.83	13.60	-29 566
Level 6	213.67	23.19	-71 329

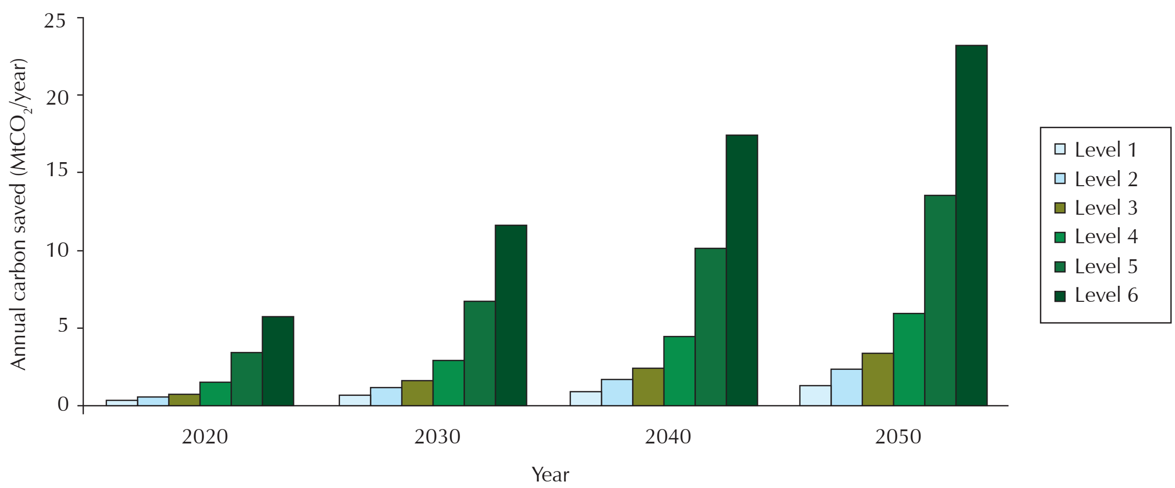

Figure 10: Annual CO_2 savings to 2050 for the different levels of the Code

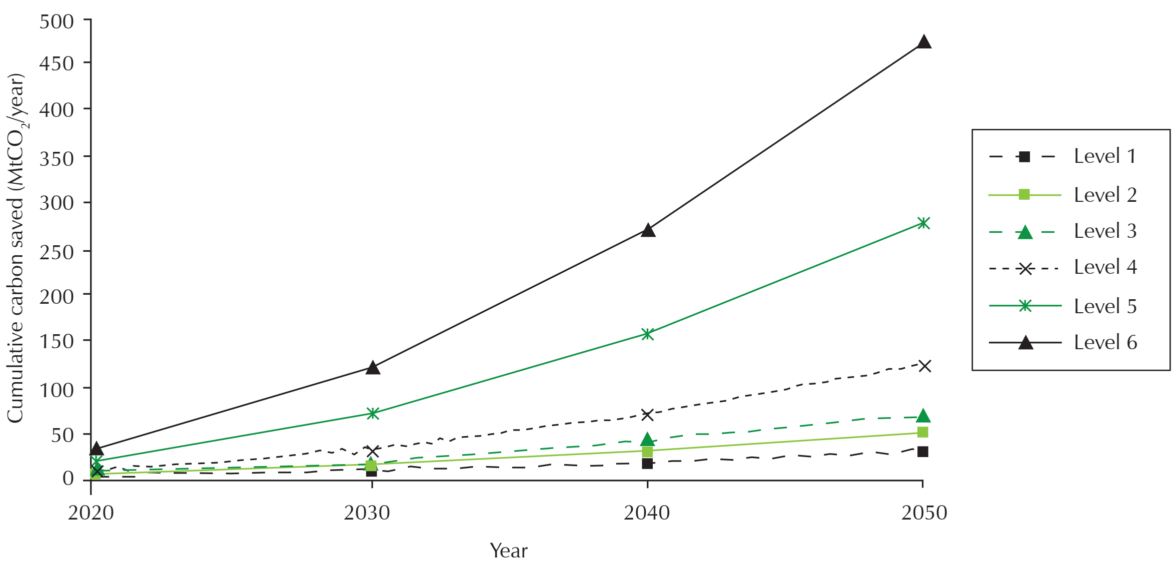

Figure 11: Cumulative CO_2 savings to 2050 for the different levels of the Code

4.4 CONCLUSIONS AND RECOMMENDATIONS: DOMESTIC BUILDINGS

It is important to consider that this work only represents one view of the future and that the reality could be very different. This is particularly true when projecting so far into the future.

There are two ways to look at the results of this analysis: firstly, to look at the cost-effectiveness of the different options; and secondly, to look at the potential CO_2 savings and their impact on the government's 80% reduction target.

In terms of a conventional economic assessment, the construction of new zero-carbon homes is non-cost-effective and there are much larger, and more cost-effective, savings to be obtained by improving the existing housing stock.

However, in terms of the aim of achieving an 80% reduction in CO_2 emissions by 2050, this analysis indicates that the construction of zero-carbon new homes is in fact essential. By undertaking all cost-effective improvements to existing dwellings, and by building all new homes to the 2006 Building Regulations, the reduced emissions from the housing stock in 2050 will only be in the region of 49%. By building new homes to zero-carbon standards, this would be improved to about 64%, which still falls short of the government's 80% target (Figure 12). To achieve the target, it would be necessary to go further and employ other options, such as decarbonising the supply of both electricity and heat.

Therefore, the 80% target is extremely challenging and it will not be met in the domestic sector unless the standards for new homes are increased to zero carbon at the earliest opportunity. Indeed, it will not be met unless essentially all practical energy efficiency options are pursued with urgency.

This analysis has also shown that constructing new homes to levels 5 and 6 of the Code is actually more attractive, in terms of the cost per tonne of CO_2 saved, as well as the amount of CO_2 saved, than constructing to levels 3 and 4. Level 5 has a lower cost per tonne of CO_2 than levels 3 and 4 and considerably larger savings, while Level 6 has a cost per tonne that is almost the same as levels 3 and 4 and a much larger saving. This is a further indication, therefore, that there needs to be a rapid movement towards a requirement for zero-carbon homes.

It should be borne in mind, however, that there are practical reasons why it may be necessary to build to the intermediate levels of the Code for a short period of time. The higher levels of the Code represent a difficult challenge for house builders and designers and some time will be needed for them to adapt to such requirements. Thus, it is currently anticipated that the building regulations requirement introduced in 2010 will be to build to Level 3, rising to Level 4 in 2013 and finally to Level 6 in 2016[15].

Finally, it should be noted that this analysis does not take account of the shadow price of carbon. In addition, without taking account of embodied carbon associated with the construction of the building and the installed technologies, it is not clear what the most accurate picture of CO_2 savings would be, and further research is therefore required in this area.

It is also worth noting that the 80% reduction target for 2050 relates to the entire CO_2 emissions of the UK, and some sectors (ie transport) will present even greater challenges. This means that the housing sector (and buildings generally) will probably need to exceed the 80% reduction target to make up for shortfalls in other sectors. The Committee on Climate Change[1] recognises several options and approaches for reducing CO_2 emissions, including energy efficiency improvements in buildings and industry, decarbonisation of the power sector – including renewable generation and carbon capture and storage (CCS), transport sector emissions cuts, heat sector decarbonisation and decarbonisation of industry. Because some of these approaches are still in the early stages of development – CCS, for example, has not yet reached demonstration stage[16] – it appears even more important to push forward improvements in existing and new buildings as part of the overall solution to achieving an 80% reduction in CO_2 emissions.

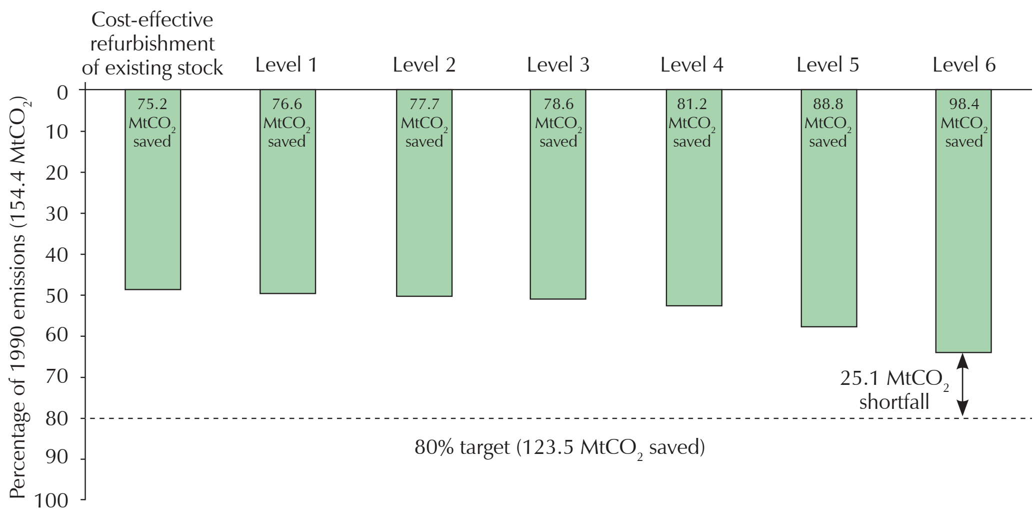

Figure 12: CO_2 emission reductions in 2050 relative to 1990 compared with the 80% target

5 NON-DOMESTIC BUILDINGS

5.1 NON-DOMESTIC BUILDING ENERGY AND EMISSIONS MODEL

In order to provide good estimates of national CO_2 emissions and the potential for reducing them, a bottom-up model of energy use in the UK non-domestic building stock has been developed[17] under contract to Defra. This model is known as the Non-Domestic building Energy and Emissions Model (N-DEEM). The model makes use of detailed energy use data collected specifically for this work, covering a range of different building types and national-level data on the building stock, as well as other data sources.

The bottom-up approach of this model has the advantage of providing a greater degree of accuracy as data from various sources can be brought in to augment or check modelling results. Moreover, the ability to determine the emissions reduction potential at the sector and technology levels is important for developing policy approaches and market barriers, respectively. The flexible framework of the model enables the many disparate sources of data to be brought together to form a comprehensive and coherent picture of energy use in UK commercial, public and industrial buildings (although the latter have not been considered in this analysis).

5.2 AGE PROFILE OF THE NON-DOMESTIC BUILDING STOCK

The non-domestic building stock modelling is based on floor area. Due to the diversity of the non-domestic building types and uses, projections were generated for each sub-sector (eg offices, education) based on changes in demographic size, structure and distribution of the workforce between the various sub-sectors‡‡‡[18]. Limiting factors were applied to restrict the overall percentage of the working population that could be employed in the service sector§§§. Net floor area projections were generated from the employee projections based on the current occupancy density in each sector plus expected future changes to the occupancy density[18].

The annual new-build rates for future years were based on past new-build rates and an inferred demolition rate, and the age profile of the building stock in future years was determined by assuming that the demolitions are equally likely for any age of building¶¶¶. The resultant age profile for the projected non-domestic building stock is shown in Figure 13. Using the best available information, this analysis assumes existing buildings are those built prior to 2010. These projections indicate that, by 2050, 60% of the building stock will have been built prior to 2010.

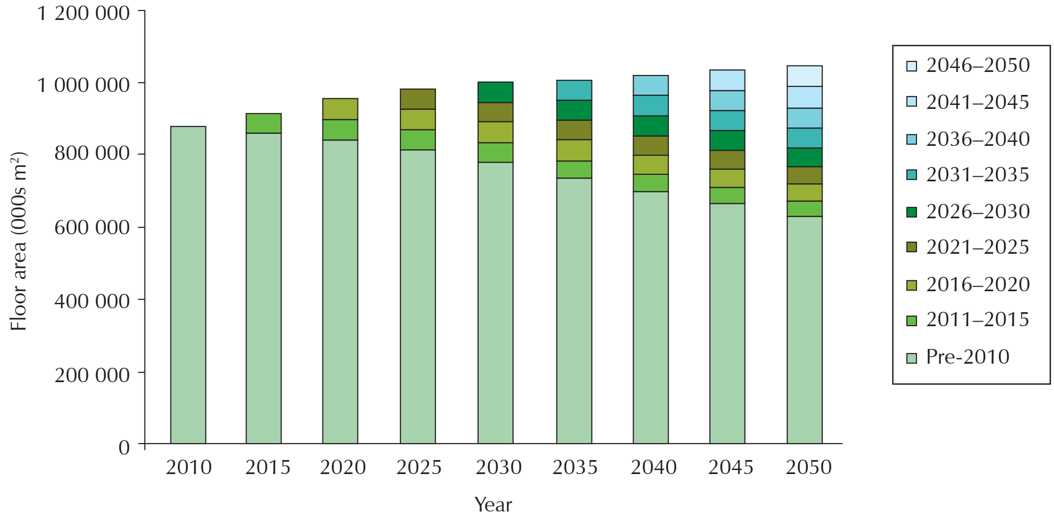

Figure 13: Projected age profile for UK non-domestic building stock

‡‡‡ The building stock age profiles were originally generated for a Defra research project.
§§§ Without applying this limiting factor, the extrapolated values would result in >100% of the working population being employed in the service sector.
¶¶¶ This is a reasonable approximation given the long lifetime of many old buildings – as evidenced by the high proportion of the current stock that predates 1900 – and the shorter lifetime of many newer buildings.

5.3 EXISTING NON-DOMESTIC BUILDINGS

Previous work for Defra and the Committee on Climate Change using N-DEEM was employed to produce a MAC curve for applying various energy efficiency and low-carbon measures in the non-domestic building stock. Figure 14 shows the distribution of the ranked measures for the non-domestic sector. Because of the diversity of the non-domestic building stock, a specific energy efficiency measure may be cost-effective in some instances, but not in others. This is reflected in the modelling work, which was based on applying each individual measure in a sample of buildings (hence some measures appear twice on the MAC curve, such as double glazing in Figure 14).

In total, over 80 measures were assessed and these were split into current/conventional technologies and alternative technologies. The former refers to standard, readily available and common technologies such as insulation. The latter, alternative technologies may involve fuel switching as when changing to a heat pump, or on-site generation of renewable energy using solar hot water heating or PV arrays. For many conventional measures, there may be different levels of CO_2 savings arising from different levels of improvement, eg replacing an existing fridge freezer with an A or A+ rated model or installing increasing levels of roof insulation. This issue was accounted for in the modelling so that the maximum cost-effective potential was determined for each replacement by first implementing the option that will save the most CO_2 in all instances where it is cost-effective to do so. Following this, the costs and benefits that arise from the option that saves the next most CO_2 were applied to the remainder where it was cost-effective to do so, and so on, down to the point where the cost-effective limit was reached.

It is also important to note that, as for the domestic sector, various levels of interaction occur between individual measures, so that if all the cost-effective CO_2 savings for each individual measure were added together this would significantly overstate the actual potential savings achievable. The MAC curve shown in Figure 14 takes into account overlaps between measures that affect the same end use – for example, condensing boilers can replace standard boilers and thermostatic radiator valves (TRVs) may also be fitted. The savings in the MAC curve also take into account interactions between measures, in particular a reduction in the overall level of savings arising from the heat replacement effect****.

As for the domestic sector, it is not possible to take into account the overlaps for alternative technologies such as heat pumps, solar water heating and PV panels in the same way. This effectively leads to an overestimation of the total CO_2 savings shown on the charts. However, as these alternative technologies do not appear in the cost-effective portion of the curve, the total cost-effective savings shown are correct.

The MAC curve in Figure 14 shows that around 14 $MtCO_2$ could be saved cost-effectively in the non-domestic building sector (based on a simultaneous application of measures and taking into account overlaps and interactions).

Existing non-domestic buildings were assessed slightly differently to domestic buildings since the diversity in the non-domestic building stock results in a large number of very different potential energy/CO_2 saving measures to be considered. Here, different packages of measures were defined, starting at low-cost measures and moving towards high-cost, 'alternative' measures. The packages

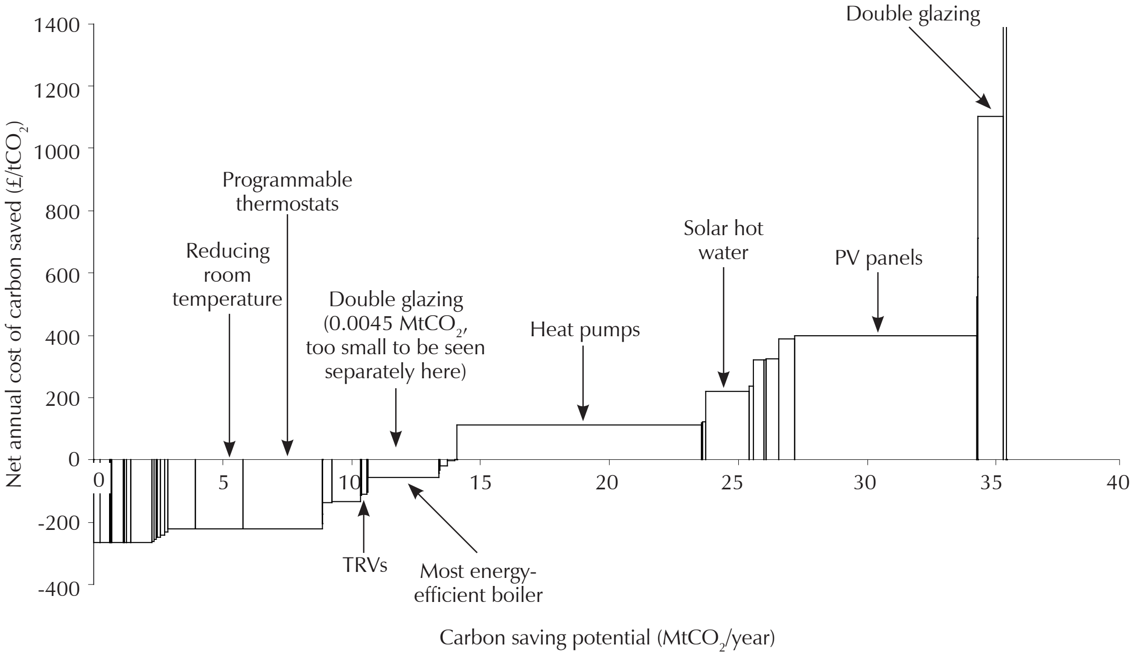

Figure 14: Simultaneous application of technologies, taking account of interactions but also including alternative technologies (eg heat pumps, solar hot water and PV) with no account taken of interactions

****There is also an equivalent effect in terms of reducing the demand for cooling. However, this was not explicitly included in the detailed modelling studies and so cannot be included here. This would only affect air-conditioned buildings, which account for a relatively small proportion of the existing building stock.

Table 4: **Lifetimes of the different packages of measures**

Package	Package name	Lifetime (years)
Package 1	Equipment measures	4
Package 2	Building services measures	15
Package 3	Fabric measures	25
Package 4	Alternative measures	15

Table 5: **CO_2 emission factors used for the non-domestic analysis***

	CO_2 emission factor ($kgCO_2/kWh$) (as at 2009)				
Fuel type	2011	2020	2030	2040	2050
Electricity	0.51	0.47	0.44	0.44	0.44
Gas	0.19	0.19	0.19	0.19	0.19

* Note that the factor for electricity changes over time due to the assumed change in the grid mix, but in this table it was assumed that the factor for gas remains constant over time.

Table 6: **Fuel prices used for the non-domestic analysis**

Fuel type	Energy cost (£/kWh)
Electricity	0.09
Gas	0.03

of measures assessed were as follows, and each package assessed also included the preceding package so that the results were cumulative:

- *Package 1* – Equipment measures (eg more efficient monitors, variable speed drives)
- *Package 2* – Building services measures (eg replacing boilers, installing programmable thermostats)
- *Package 3* – Fabric measures (eg roof insulation, double glazing)
- *Package 4* – Alternative measures (eg heat pumps, PV panels)

For consistency with the domestic sector analysis, the packages of measures do not include behavioural measures such as turning lights off (note that these measures are included in the non-domestic MAC curve in Figure 14 and account for around 20% of the cost-effective savings). Furthermore, although there are large potential savings from such measures, the actual savings achieved are hard to estimate due to the influence of human behaviour. Only the cost-effective portion of savings from standard measures (packages 1–3) has been considered as it is assumed that these measures will only be implemented where it is cost-effective to do so. However, for alternative measures (Package 4) all savings were included since generally these measures are non-cost-effective. Packages 1–3 cover around 68% of the total cost-effective savings shown in Figure 14.

Each package of measures incorporated a number of different measures with a similar lifetime and an appropriate lifetime assumed for the overall package. The lifetimes assumed for the different packages of measures are shown in Table 4.

The CO_2 emission factors and the fuel costs used are shown in tables 5 and 6[††††]. The factor for electricity changes over time due to the assumed changes in the grid mix. These projected factors are based on the Department of Energy and Climate Change's (DECC) *Updated energy and carbon emissions projections*[19] to 2025 and thereafter are assumed to remain at 2025 levels since the DECC projections do not go beyond that year.

Furthermore, the packages of measures were assessed for their cost-effectiveness and CO_2 saving potential based on the estimated refurbishment rate of existing non-domestic buildings between 2010 and 2050. (This differs from the assessment made for the domestic sector, which assumes that by 2050 all the potential measures will have been implemented.) A refurbishment rate of 4% of the existing stock per annum (based on an analysis of N-DEEM) was used and the amount of refurbishment was limited so that it was not possible to refurbish the same floor space more than once in the time period under consideration[‡‡‡‡]. It was assumed that measures would be replaced over time to take into account like-for-like replacement at the end of a measure lifetime – this was important since some measures have a relatively short lifetime of only four years. (Again, this differs from the domestic sector, which models measures with lifetimes of generally 15–40 years, with the shortest lifetimes of seven to eight years for only a small number of measures.)

†††† Although these figures are slightly different from the domestic sector analysis, they are consistent for the existing and new non-domestic sector analysis, which is what is being compared in this analysis, rather than a comparison between the domestic and non-domestic sectors.
‡‡‡‡ Although this is not necessarily likely to be the case in reality, it was important to apply such a limit so that the savings were applied to a known starting point (ie an existing building) rather than to an unknown starting point (eg a building that may have already been refurbished at least once).

Table 7: Cost-effectiveness and CO_2 savings from the different packages of measures			
Package	**NAC/tCO_2**	**MtCO_2/year**	**NPV (£M) for entire stock of existing buildings**
Package 1	-63	0.1	135.4
Package 2	-118	5.3	5672.4
Package 3	-160	5.9	6016.5
Package 4	67	19.5	-45 445.7

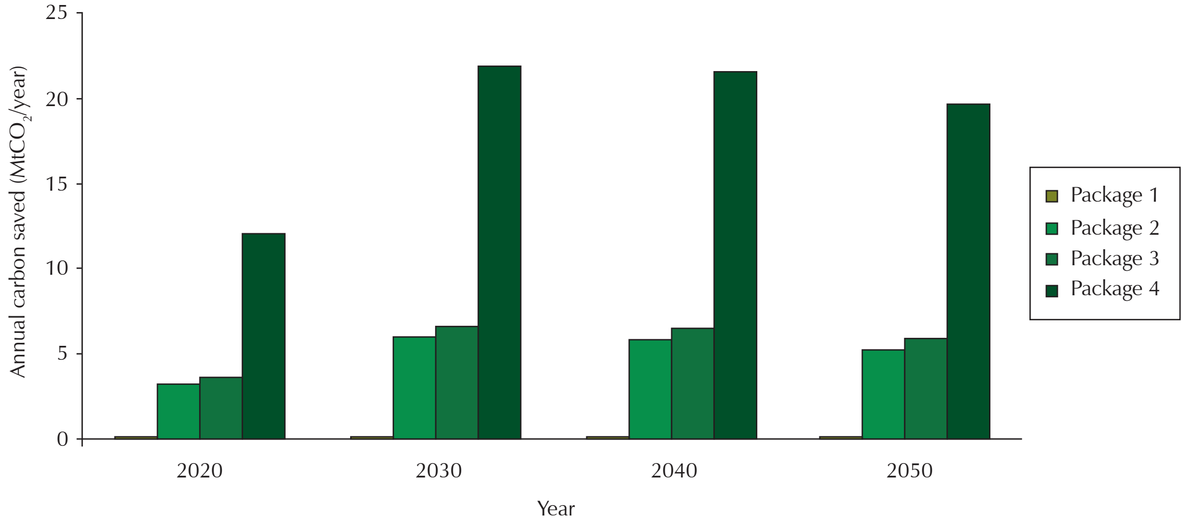

Figure 15: Annual CO_2 savings to 2050 for different packages of measures applied to existing buildings

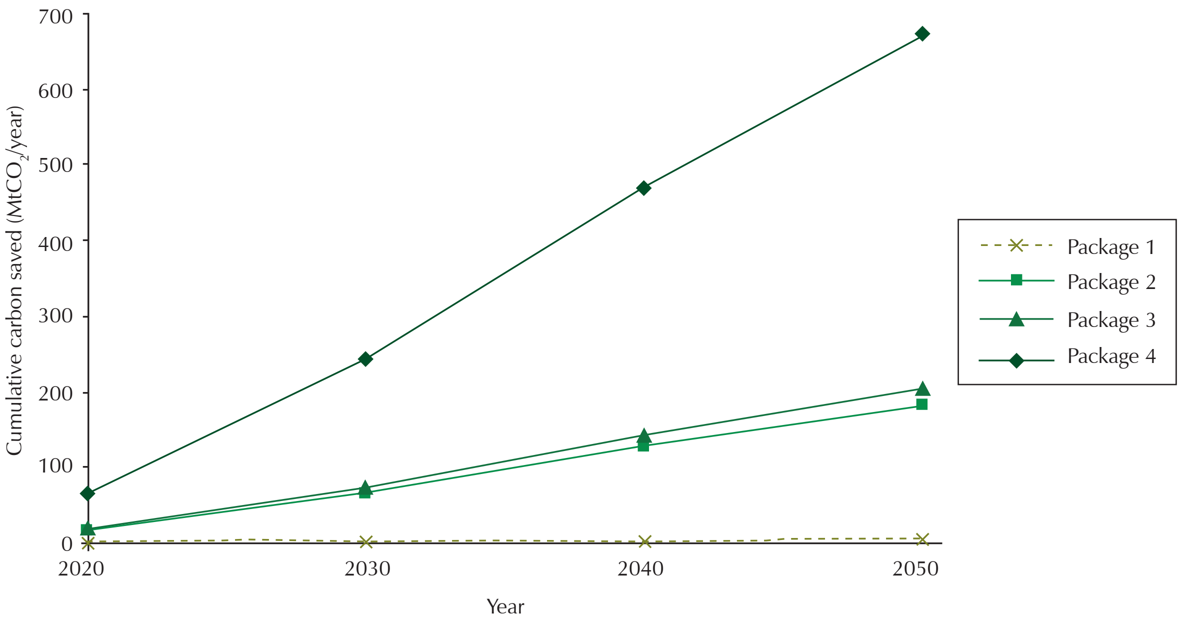

Figure 16: Cumulative CO_2 savings to 2050 for different packages of measures applied to existing buildings

Table 7 shows the results of the cost-effectiveness analysis and CO_2 savings for the different packages of measures applied to the annual refurbishment of existing non-domestic buildings.

Figures 15 and 16 show the annual and cumulative CO_2 savings, respectively, from applying the different packages of measures to existing buildings at a 4% refurbishment rate. Packages 1–3 are all cost-effective, although Package 1 only saves a small amount of CO_2 and the cost-effectiveness in terms of NAC/tCO_2 is more attractive for packages 2 and 3. Unsurprisingly, Package 4 saves a large amount of CO_2 but these savings are not cost-effective. Furthermore, as discussed previously in relation to the non-domestic MAC curve, there are inevitably going to be overlaps between conventional measures (packages 1–3) and alternative measures (Package 4). Packages 1–3 can be looked at cumulatively since overlaps and interactions have been accounted for. However, the savings under Package 4 also include the savings under the preceding packages and as such are likely to be an overestimate. There are also overlaps within Package 4 – ie to some degree there will be overlaps between biomass boilers and heat pumps, which have not been modelled due to the complexity of such interactions. Given that Package 4 is non-cost-effective, this issue does not affect the assessment of the cost-effective savings achievable. The peak in annual CO_2 savings for each package occurs around 2040 because using the 4% refurbishment rate results in the assumption that the entire stock will have been refurbished by 2040, thus savings tail off after this point.

5.4 NEW NON-DOMESTIC BUILDINGS

This section looks at the potential costs and savings to be achieved from applying different levels of improvement, compared with the 2006 Building Regulations, to the future levels of non-domestic new-build floor space shown in Figure 13. Based on the information in the CLG consultation document on defining zero-carbon buildings[6], it has been assumed that only zero-carbon regulated energy use will be possible in the non-domestic sector, as opposed to zero carbon regulated and unregulated energy use in the domestic sector. This is because the non-domestic building stock is hugely diverse and the range of challenges and opportunities in this sector means it is unlikely that it would be practicable or reasonable to apply the domestic solution in exactly the same way.

The levels applied to non-domestic new buildings relative to the 2006 Building Regulations are as follows (note that each level assessed also includes the preceding level so that the results were cumulative):

- *Level 1* – Improved fabric and building services
- *Level 2* – Solar water heating
- *Level 3* – Biomass boilers
- *Level 4* – PV panels

For comparison, the same CO_2 emission factors and fuel costs have been used here as for the non-domestic existing building analysis. For each level, the capital cost of implementing the measure and the potential CO_2 savings were determined on a per unit of floor area basis in order to apply to the annual new-build rate. A lifetime of 30 years has been assumed for both the building and the installed energy technologies, and it has also been assumed that no further marginal capital costs will be incurred (in most instances the marginal cost of replacement will be very much smaller than the initial implementation cost).

Table 8 shows the results of the cost-effectiveness analysis and CO_2 savings for each of the different levels applied to the new non-domestic building stock. Figures 17–20 show the same MAC curve as depicted in the existing buildings analysis, but with the savings from each of the different levels assumed here also shown for comparison. Level 4 inevitably has the greatest CO_2 savings. From Table 8 and figures 17–20, it can be seen that none of the levels are cost-effective. Although the greatest amount of CO_2 savings are achieved from Level 4, it is extremely non-cost-effective, and interestingly the most cost-effective option in terms of NAC/tCO_2 is actually Level 3 rather than Level 1 or Level 2.

Figures 21 and 22 show the annual and cumulative CO_2 savings, respectively, from applying the different levels to non-domestic new buildings. The peak in annual CO_2 savings for each level occurs at around 2040 and tails off thereafter due to the 30-year lifetime assumed for both the buildings and the energy/CO_2 saving measures applied.

***Table 8:* Cost-effectiveness and CO_2 savings from the different levels of measures**

Level	NAC/tCO_2	MtCO_2/year	NPV (£M) for entire stock of new buildings
Level 1	586	8.2	-72 154.2
Level 2	648	9.2	-73 264.0
Level 3	504	11.0	-69 492.4
Level 4	1001	15.5	-104 826.7

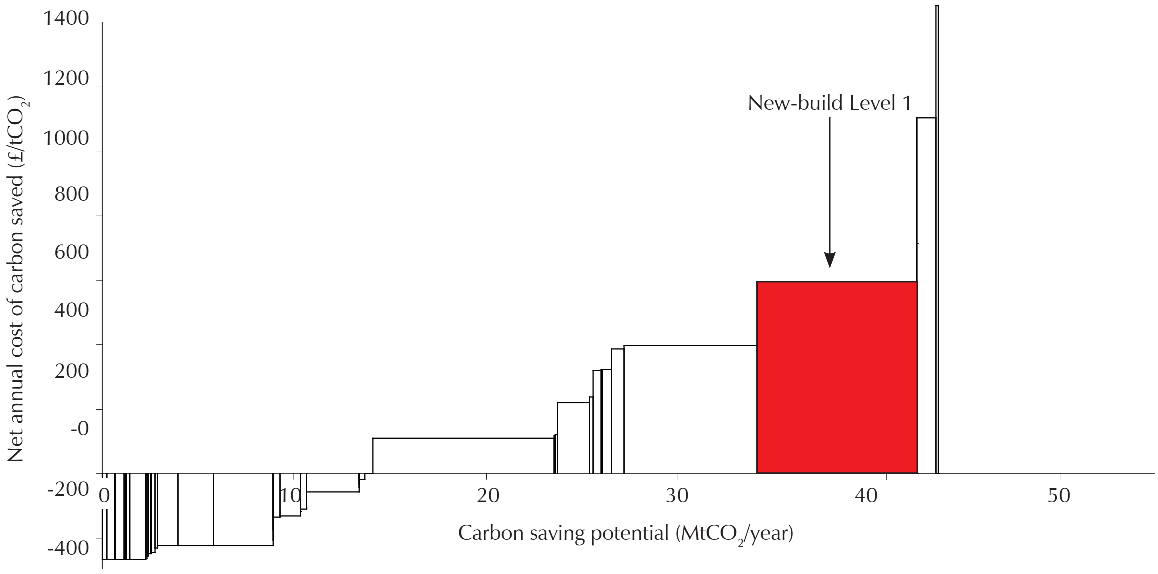

Figure 17: Cost-effectiveness and CO_2 savings in the existing non-domestic building stock (new-build Level 1 also shown)

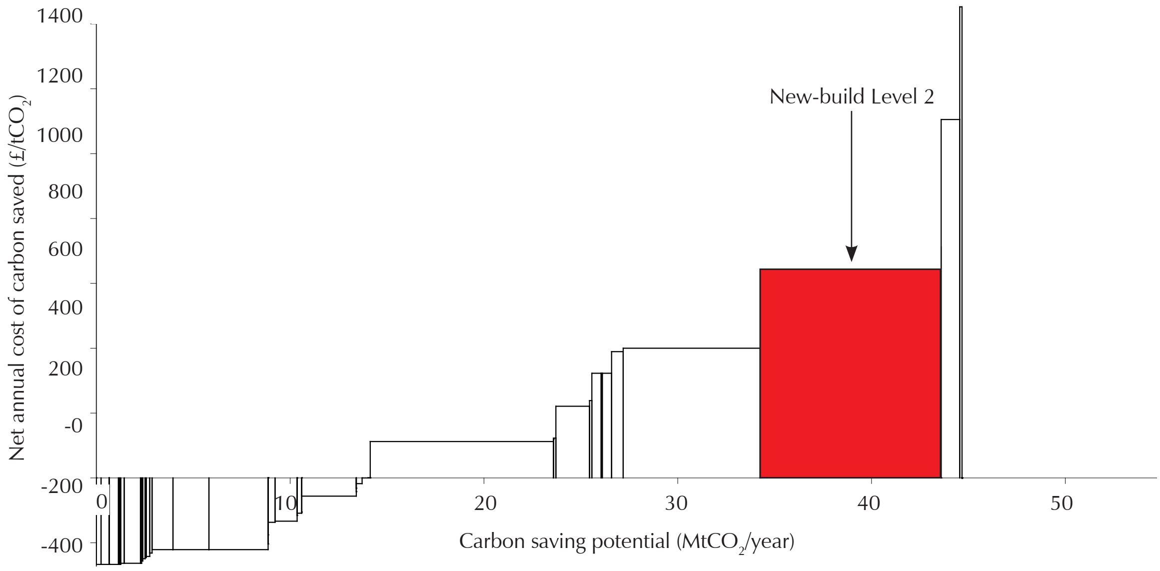

Figure 18: Cost-effectiveness and CO_2 savings in the existing non-domestic building stock (new-build Level 2 also shown)

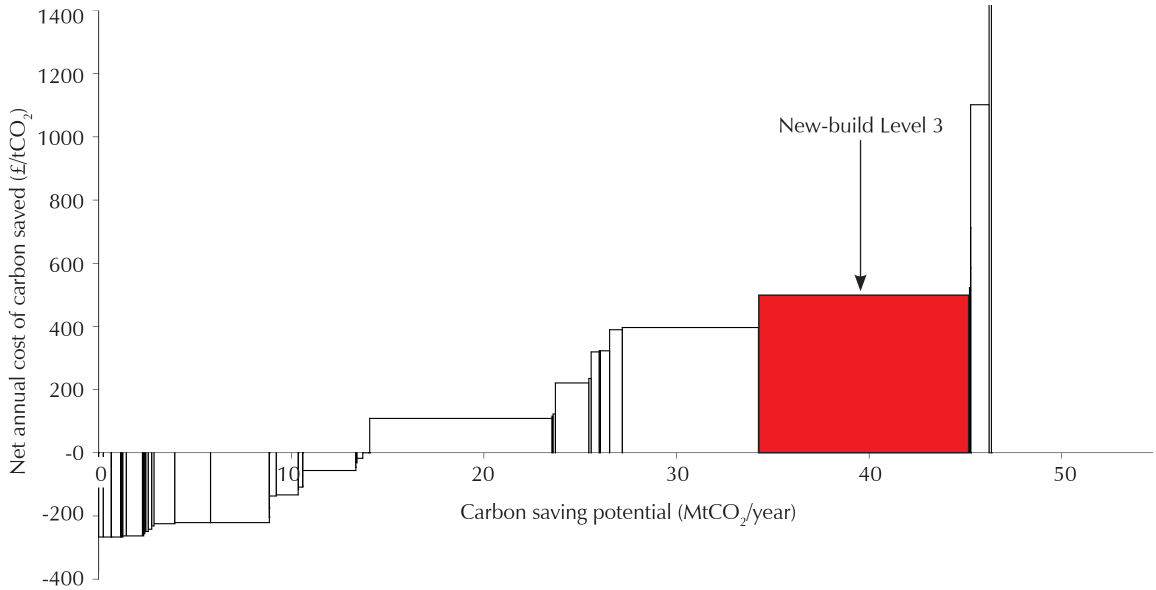

Figure 19: Cost-effectiveness and CO_2 savings in the existing non-domestic building stock (new-build Level 3 also shown)

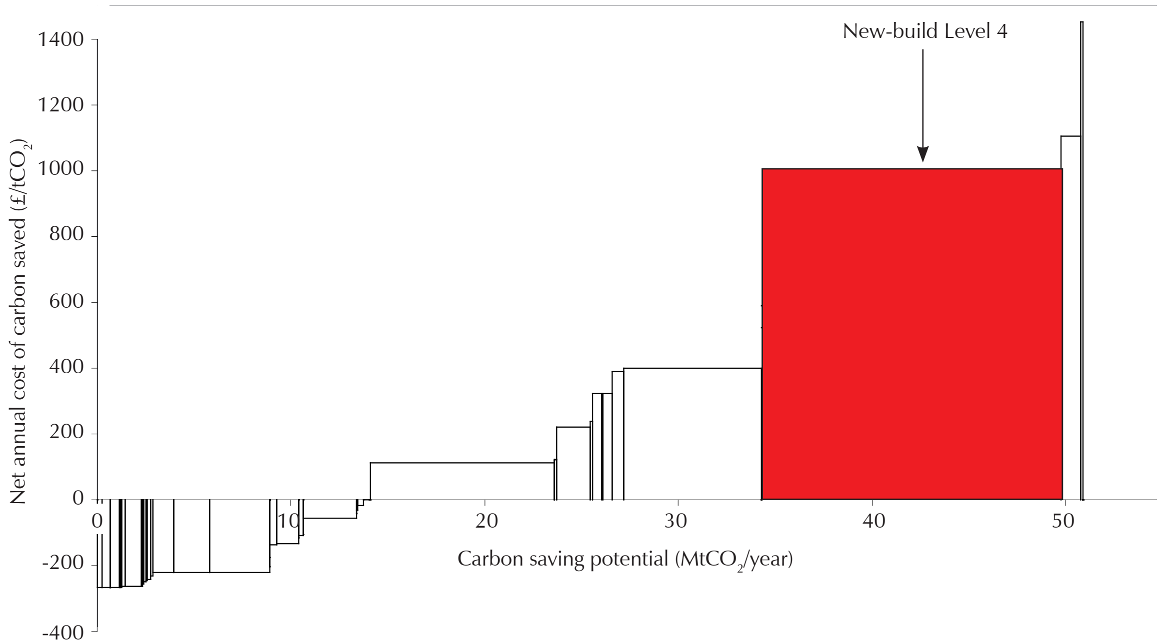

Figure 20: Cost-effectiveness and CO_2 savings in the existing non-domestic building stock (new-build Level 4 also shown)

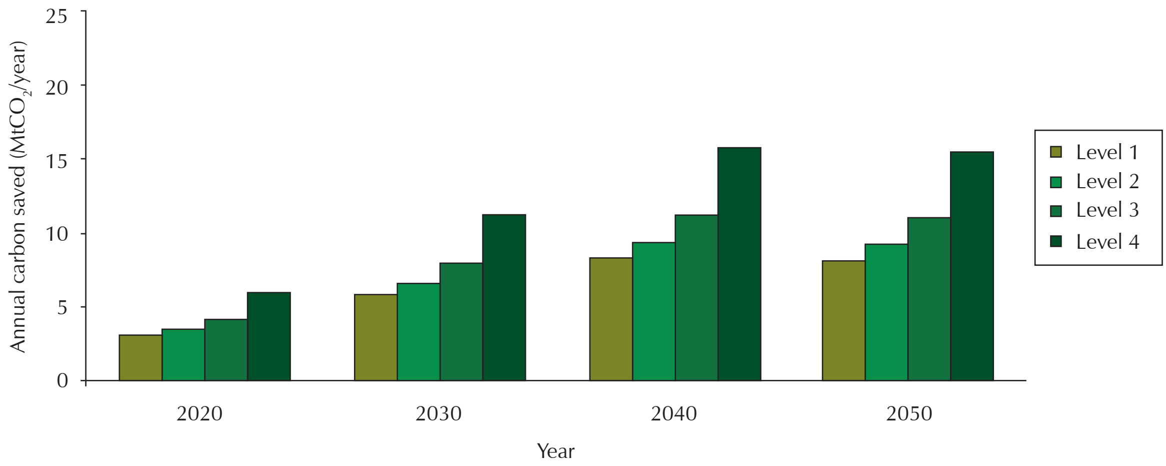

Figure 21: Annual CO_2 savings to 2050 for different levels of measures applied to zero-carbon new buildings

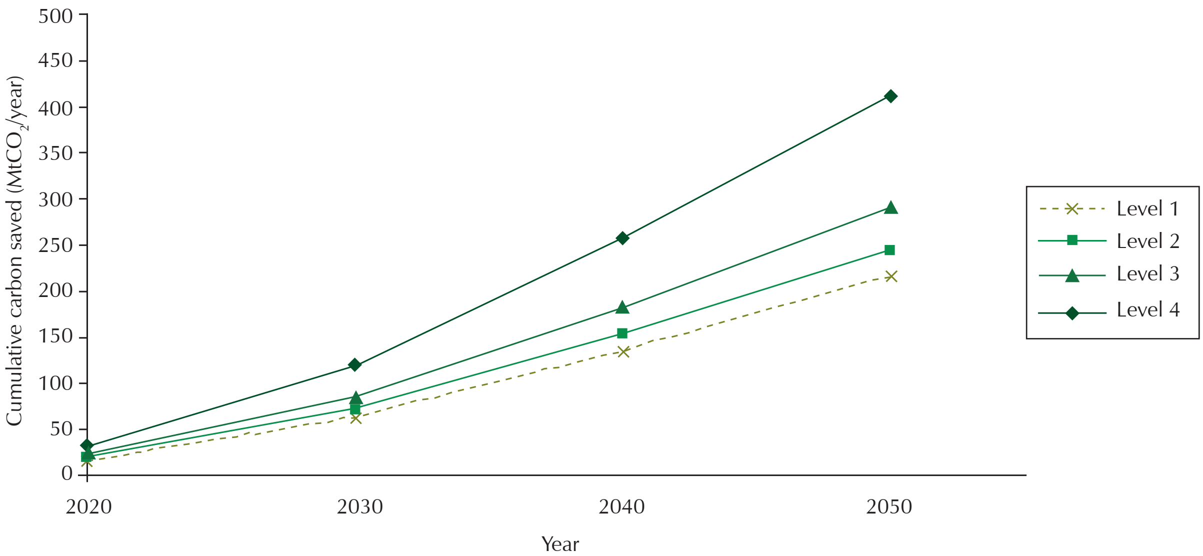

Figure 22: Cumulative CO_2 savings to 2050 for different levels of measures applied to zero-carbon new buildings

5.5 CONCLUSIONS AND RECOMMENDATIONS: NON-DOMESTIC BUILDINGS

It is important to consider that this work only represents one view of the future and that the reality could be very different. This is particularly true when looking so far into the future.

As for the domestic sector, there are two ways to look at the results of this analysis: firstly, to look at the cost-effectiveness of the different options; and secondly, to look at the potential CO_2 savings and their possible contribution to the government's 80% CO_2 emission reduction target.

In terms of a conventional economic assessment, the construction of new zero-carbon regulated non-domestic buildings is not cost-effective and there are many cost-effective savings that could be achieved by improving existing buildings.

However, in terms of the aim of achieving an 80% reduction in CO_2 emissions by 2050, this analysis indicates that the construction of new zero-carbon regulated non-domestic buildings is likely to be an essential part of achieving this aim. However, the potential impact made by cost-effective CO_2 saving improvements to existing buildings will also be required in order to move further towards the 80% reduction target.

Figure 23 shows the percentage savings on 1990 levels that could be achieved by 2050. The first two percentage savings are based on existing buildings only, and it should be remembered that the savings from Package 3 are cost-effective but those from Package 4 are not. The remaining percentage savings shown on the graphs are for each of the four levels considered for new buildings but also include the savings from Package 4 of existing buildings. All of the percentage savings take into account the reduction of 6.6 $MtCO_2$ that has already happened since 1990 in this sector[§§§§]. It is clear, however, that the CO_2 emissions reductions still fall well short of the target. In order to make some progress towards the target of an 80% reduction in CO_2 emissions in the non-domestic sector, there is a need to pursue a combination of both refurbishment of existing buildings and to put in place a 'code' for non-domestic buildings covering regulated energy use. Despite this, to achieve the target it will be necessary to go further still and employ other options such as decarbonising the supply of both electricity and heat.

There are practical reasons why it may be necessary to build to intermediate levels of improvement for a short period of time as the higher levels represent a major challenge for both builders and designers and they will require a reasonable amount of time to be able to adapt to such requirements. Therefore, as for the domestic sector, it might be that any code that is introduced in the non-domestic sector will need to be introduced gradually.

This analysis makes use of existing data that were generated for other projects for Defra and the Committee on Climate Change. Some of these data are now several years old – in particular, the data on the capital and marginal costs of CO_2/energy-saving measures in the non-domestic sector. A reassessment of these costs would be beneficial in improving the accuracy of this work. For many measures, the costs are unlikely to have changed significantly in the timescales involved. However, for some measures – in particular those involving IT and electronics – the costs may have decreased significantly. Therefore, it could be said that the analysis for existing non-domestic buildings is, if anything, likely to represent a cautious view of cost-effectiveness.

Finally, it should be noted that this analysis does not take account of the shadow price of carbon. In addition, without taking account of embodied carbon associated with the construction of the building and the installed technologies[¶¶¶¶], it is not clear what the most accurate picture of CO_2 savings would be, and further research is therefore required in this area.

As for the domestic sector, it is also worth noting that the 80% reduction target for 2050 relates to the entire CO_2 emissions for the UK and some sectors (ie transport) will present even greater challenges. This means that the domestic and non-domestic buildings sector may well need to exceed the 80% reduction target to make up for potential shortfalls in other sectors.

§§§§ This is the difference between CO_2 emissions from non-domestic buildings of 85.4 $MtCO_2$ in 1990 and 78.8 $MtCO_2$ in 2006.

¶¶¶¶ For example, the number of years it takes for a PV panel to generate enough electricity to offset the carbon used to produce the panel in the first place.

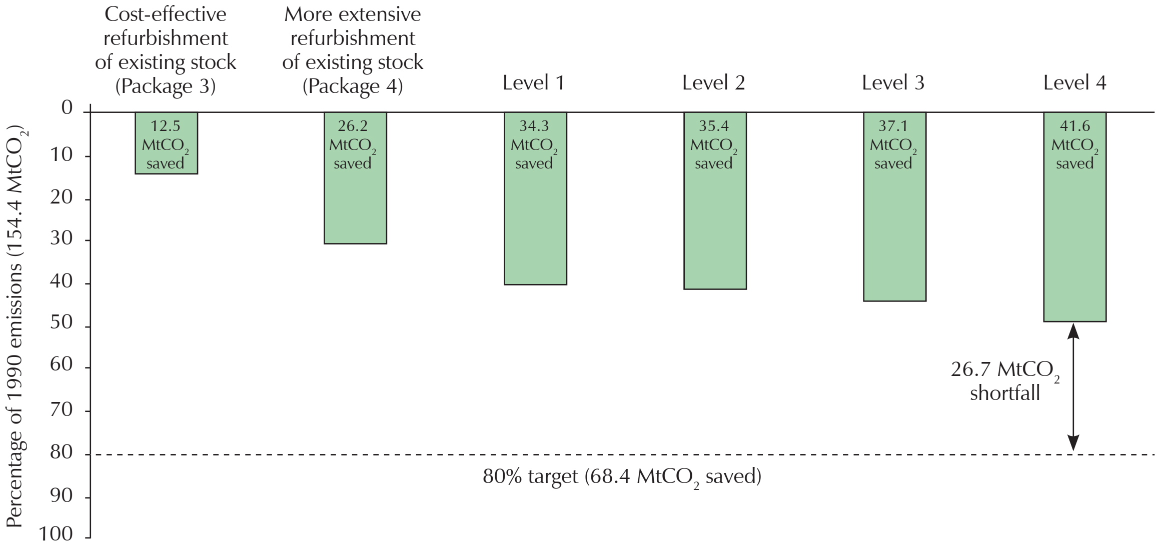

Figure 23: CO_2 emission reductions in 2050 relative to 1990 compared with the 80% target
(Note that existing Package 3 is cost-effective but Package 4 is not. The savings in levels 1–4 also include the savings from existing Package 4)

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ENERGY EFFICIENCY IN NEW AND EXISTING BUILDINGS
Comparative costs and CO_2 savings

This BRE Trust Report considers the relative impact on UK CO_2 savings targets of constructing new zero-carbon buildings as opposed to improving the energy efficiency of the existing stock. Carbon dioxide emissions from UK buildings accounted for around 40% of total UK CO_2 emissions in 2006. The UK government has stated its aim to reduce greenhouse gas emissions by 80% by 2050. In order to achieve such challenging reductions in emissions, improving the energy efficiency of buildings – both new and existing – will clearly have a vital role to play.

The Code for Sustainable Homes became operational in England in April 2007 and a Code rating for new-build homes became mandatory from 1 May 2008. The Code provides a single national standard aimed at driving continuous improvement in sustainable home building. While moving towards zero carbon for all new buildings can undoubtedly achieve a significant reduction in CO_2 emissions in the future, existing buildings will form the majority of the UK's building stock for many years to come. The work presented in this report uses existing data to explore the extent to which improving the energy efficiency of the existing UK building stock would be a more cost-effective route for achieving CO_2 savings than constructing new buildings to the higher levels of energy performance required to meet low- and zero-carbon targets.

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