MAC Curves for the Domestic and Non-Domestic Building Sectors - Technical Documentation

Prepared for: Edward Hogg
Committee on Climate Change

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Contents

1 Background and Introduction

The Committee on Climate Change (CCC) was set up as an expert body that will independently assess how the UK can optimally achieve its emissions reductions goals for 2020 and 2050. One of its tasks is to provide advice on the three carbon budget periods defined in the Climate Change Bill – 2008 to 2012, 2013 to 2017 and 2018 to 2022. The aim of this current work was to provide CCC with marginal abatement cost (MAC) curves for the existing stock of domestic and non-domestic building to assist in that task.

The purpose of this work was to develop two flexible spreadsheets – one for the domestic buildings sector and one for the non-domestic (public and commercial) buildings sector. These spreadsheets will then feed into a separate consultancy contract which will review, revise and where possible update and consolidate existing MAC curves for all sectors. Due to the carbon budget periods it was necessary to construct MAC curves for the years 2012, 2017 and 2022.

The flexible spreadsheets were to include the following functionalities:

- Ability to change the following inputs:
    - Discount rate (0.5 % - 50%).
    - Carbon emission factors for the main fuel types.
    - Fuel prices.
- Allow additional data on costs to be added in – this covers one-off and on-going management and other hidden costs.
- Allow the addition of alternative technologies (though note that no account will be made of overlaps and interactions for these technologies).

In addition, it was important that the outputs from the spreadsheets could be disaggregated by:

- Devolved Administrations.
- Fossil fuel and electricity savings.

And additionally for the non-domestic sector:

- Public and commercial sectors.
- Sectors affected by the Carbon Reduction Commitment (CRC) and non-CRC sectors.

The spreadsheets were also to take into account the remaining potential for energy savings of each energy efficiency measure in future years. This was to be based on uptake rates of the measures taking into account the climate change policies included in the baseline of the most recent energy and carbon projections from the DTI[1]. It is important to note that data relating to the market penetration of energy efficient and low carbon technologies is scarcer for the commercial and public sectors than for the domestic sector.

Interactions between measures were to be taken into account when determining the total savings; for example if a building has a new condensing boiler installed *and* improved insulation the savings from each of these individual measures cannot simply be added together. More information on the types of overlaps and interactions is given in Section 2.2. The measures included in the analysis have been split into conventional technologies and alternative technologies. The former refers to standard, readily available and common technologies such as insulation and replacing equipment, whilst the latter includes alternative technologies like heat pumps which involve fuel switching and onsite generation of renewable energy such as solar hot water heating. The interaction of alternative technology measures with the conventional technology measures is complex and would require additional scenario modelling to resolve, therefore these alternative technology measures have not been included in the analysis of interactions.

Bearing in mind the impact of these interactions, a number of MAC curves have been generated in each of the flexible spreadsheets; firstly, to indicate the ranked savings from each individual technology only and secondly, to show the savings from technologies when interactions are taken into account. The savings in the former cannot be added together since this is a simple ranking of the measures in terms of cost effectiveness and so this would significantly overestimate the savings potential; however, the savings in the latter take account of interactions and can, therefore, be added together.

It should be noted that the domestic and non-domestic spreadsheets differ in some ways because of the very different natures of the two sectors and the different data available for each.

This technical document is split into three sections:

- **General Discussion** – on MAC Curves, alternative technologies and types of interactions. This section also includes a discussion on caveats and recommendations.
- **Domestic Buildings** – describes the assumptions on the energy calculations and the uptake and remaining potential of each measure. Use of the spreadsheet is not covered because notes are included within it.
- **Non-Domestic Buildings** – provides a description of the functionalities and how to use the spreadsheet, a description of the background methodology behind the MAC curves and provides a description of the energy efficiency measures considered and their associated assumptions.

The focus of the domestic and non-domestic sections are very different and reflect the different nature of the building stocks, different data availability and hence the nature of the work carried out for this project.

2 General Discussion

Marginal abatement cost (MAC) curves provide a means of comparing the carbon savings that different technologies can potentially provide, together with their cost-effectiveness. Such curves are therefore useful for ranking measures and deciding on those which are worth pursuing. MAC curves only show what the potential is and say nothing about how fast it could be reached. Scenario modelling would be required to address these types of dynamic issues.

It is important to realise that the energy calculations that feed into MAC curves have to be done with detailed models that take account of many factors, including interactions. These calculations cannot be built into the MAC curves themselves, so it is necessary to define a set of assumptions that are to be used when developing MAC curves using the detailed models. Thus, although a spreadsheet producing MAC curves can have some flexibility built into it, there are limits as to what is possible.

MAC curves present a snapshot of the position at a particular point in time. This is most usually taken to be the current day (or, at least, the latest year for which one has all the relevant data or else good estimates), but it is also possible to develop MAC curves for future years by projecting the anticipated uptake of individual measures taking account of observed past rates and the expected effect of policies. In other words, an underlying scenario has to be defined if future years are to be considered. For the OCC work we have used this approach to develop future MAC curves, by considering the uptake of individual measures in the existing stock. The analysis is based on a ‘static’ building stock, and therefore ascertains the savings that are still available in the current building stock in future years and as such does not consider other possible changes to the stock over time.

In presenting MAC curves it is usual to consider the savings from individual measures in isolation. This is entirely appropriate for the purposes of ranking measures; however, it is important to note that the individual measures cannot be added up since this significantly over-estimates the total carbon savings because of interactions between measures. For the domestic sector the MAC curves for individual measures do take account of the heat replacement effect, whereas for the non-domestic sector the heat replacement effect is not taken into account at this stage[a].

It is also possible to generate MAC curves which take account of the interactions between measures. One method is to consider the savings from an individual measure by applying all measures together and then allocating the proportion of the total that is relevant to that measure (as used for the non-domestic sector modelling). Another is to calculate the savings from an individual measure assuming that all other relevant measures have already been applied (as used for the domestic sector modelling). These two methods will provide estimates of the minimum savings that each measure is likely to achieve – i.e. they will underestimate the savings in the shorter term.

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[a] *Instead the heat replacement effect is taken into account as part of the interactions. This is why there is a greater difference between the individual measures and combined measures for the non-domestic sector.*

The approaches of “individual measures in isolation” and “measures combined” can be applied for each year of interest to produce MAC curves identifying upper and lower bounds for the remaining total technical and cost-effective potentials. Over time, as the remaining total potential reduces due to measures being taken up, the difference between the upper and lower bound figures reduces.

As already noted, only one underlying scenario has been adopted for developing the future MAC curves, this representing the likely uptake of measures based on past trends and the expected effects of policies. It is not possible to vary the uptake rate assumptions used in the MAC curves without defining an alternative scenario and re-calculating the savings figures (although small variations that would not alter the savings very much could be contemplated).

Thus, for example, the effect of prioritising the installation of measures, based on cost effectiveness considerations, cannot be addressed in the MAC curves. In principle, such prioritising would reduce the savings achieved by subsequent measures and this would then require recalculation outside of the MAC curves using the detailed energy models. In practice, however, the size of the reduction, for any reasonable assumption about the additional uptake of the preferred measure, can be shown to be small in relation to the uncertainties in the energy savings figures[b].

If there was a requirement to consider alternative scenarios then this would be best done by developing such scenarios using a specific scenarios tool that has been constructed around a detailed energy model (this is what N-DEEM and BREHOMES are designed to do). Such tools take full account of the interactions and they provide energy use projections at the level of the entire stock. Therefore, the savings of a scenario can be established by determining the difference between it and the “business as usual” scenario. Note, however, that savings at the level of individual measures cannot be determined from a scenarios tool. Thus, although scenarios provide the best possible estimates of carbon savings, they cannot provide the apportionment of savings that the MAC curves allow.

Therefore, MAC curves and scenarios tools should be seen as being complementary to one-another. They each provide useful information on likely carbon savings but they do so in different ways. It is for this reason that past work in this area, for Defra’s Global Atmosphere Division, has always used both techniques and has made a clear distinction between them.

2.1 Inclusion of Alternative Technologies in the MAC Curves

In general, the measures considered in MAC curves relate specifically to the sector under consideration. It should be noted, however, that there are alternative technologies that could be introduced which, if applied in large numbers, would alter the potential savings from those measures, and would also impact on other sectors as well. For example, this could include fuel switching, such as replacing boilers with alternatives like heat pumps, or renewable energy technologies, such as PV and solar water heating. Such technologies

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[b] *This has been checked analytically by considering the hypothetical case of introducing additional installations of condensing boilers in the domestic sector and assessing the reduction that then would be required to subsequent insulation savings. For an additional ten percentage point increase in condensing boiler ownership (which, over the short term, is considerably more than would be achievable in practice) the reduction to insulation savings was calculated to be just 3%. This is a small adjustment bearing in mind that a reduction factor five times larger than this is already applied to account for the highly uncertain effect of comfort taking. Thus, the conclusion is that this type of ordering effect can be safely neglected.*

displace existing technologies, and in the case of on site generation from renewables, displace conventional generation on the supply side.

The uptake of such technologies is not expected to be significant within the timescale of the first three carbon budgets (see the uptake curves which have been determined for PV, wind generators, and solar water heating, presented in the domestic sector technical note), so the effect that they will have on the savings potentials from other measures will be small enough to be safely neglected.

The potentials for these alternative technologies can be shown in the MAC curves that present the savings from individual measures in isolation (i.e. where the intention is just to rank measures in terms of their overall potential and cost-effectiveness), but they cannot be included in the MAC curves that consider the combined effect of all measures.

If such alternative technologies were to be taken up in significant numbers this would require the development of an alternative scenario which defines the trajectories of these technologies in terms of uptake rates, and then re-running the detailed models to calculate the costs and benefits arising.

2.2 Types of Interaction

The discussion of alternative technologies above is illustrative of one kind of interaction. There are in fact many ways in which the various energy efficiency measures might interact to decrease, or occasionally increase[c], the level of carbon saving achieved in practice. The different types of overlaps and interactions that can occur and the way in which they are dealt with in the MAC curve work are listed below. Some of these may be more important in either the domestic or the non-domestic sector.

Parallel “like for like” measures – e.g. cavity wall insulation and external insulation

In instances where different technologies can be used to achieve the same result in different circumstances, they are considered in parallel. So for this example only where cavity walls are not present is external insulation considered to be a practically viable option. This approach avoids overlaps.

Alternative efficiency levels for “like for like” measures – e.g. replace existing glazing with double or triple glazing

This is dealt with within the existing MAC curves and the cost effective potential for carbon savings is based on the maximum carbon savings that can be achieved cost effectively, whilst the technically feasible potential will be based on the maximum achievable carbon savings regardless of cost.

Interactions between different types of measures which act on the same end use – e.g. simultaneous application of fabric insulation, more efficient heating equipment and more effective heating controls

These interactions can only be dealt with effectively by carrying out detailed modelling studies as there will be non-linearities in the way in which the system interacts with the building arising from the timing of the service demand and the layout of the building.

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[c] *For example, in air conditioned offices increasing the energy efficiency of lighting and office equipment will decrease the demand for cooling which may more than offset any increase in carbon emissions arising from the increased demand for heating.*

Interactions between different end uses – e.g. installing more efficient lighting and office equipment

This will lead to an increase in heating demand and, for air conditioned buildings, a decrease in cooling energy use. Again these interactions can only be dealt with by carrying out detailed modelling studies.

Alternative technologies – e.g. replace boilers with heat pumps

Here the total carbon savings arising for heat pumps overlaps with those for condensing boilers and so cannot be added together. Instead the proportion of boilers replaced by heat pumps (rather than by more efficient boilers) needs to be defined and this is provided by the technology uptake rates.

On-site generation of heat and/or power – e.g. installation of PV panels on roof

Whilst these are additional rather than alternative measures, their impact is on the energy supply side rather than the building side, and so really needs to be measured in terms of a change to the relevant carbon emission factor, rather than a carbon saving attributable to buildings. As noted earlier, these sorts of alternative technologies cannot be added into the MAC curves that present the combined effect of all measures.

2.3 Further Considerations

This Section has highlighted some issues that are relevant to MAC curve work in general and has outlined how certain elements have been approached within the present project. Sections 3 and 4, for the domestic and non-domestic sectors respectively, will provide more details of the key assumptions that have been used in the project.

However, there are a number of general caveats that should be noted about the assumptions:

1. Firstly, it should be noted that the study has considered the key measures that are applicable to each sector, but it should be borne in mind that there are likely to be some other measures that could further contribute to savings.

2. Secondly, the study has inevitably looked at current technologies only. It is, of course, possible that future technologies could significantly add to the potential savings, although this would be unlikely over the timescale that has been considered.

3. Thirdly, in general the curves assume that all technologies are installed and used correctly and thus achieve the expected savings. There are some exceptions to this where we have hard evidence that the performance in practice falls short of expectations. For example, for the domestic sector, it is known that cavity wall insulation does not achieve the U-values, and hence energy savings, that theory would suggest. The reasons for this are not clear but the broad magnitude of the effect is known and so it has been built into the calculations.

4. Finally, it is worth noting that much of the data relating to the cost of measures is now several years old and for some measures this could have a significant impact on the cost effective savings. This

is more of an issue for the non-domestic sector than it is for the domestic sector. For the domestic sector, costs have been reviewed on a reasonably regular basis because doing this was a necessary part of developing schemes such as EEC and CERT.

Furthermore, this study only considers existing buildings and does not address the potential for reducing carbon emissions from buildings that have not yet been built. Although the new build rate for both domestic and non-domestic buildings is relatively low, currently around 1-2% pa, if this continues they will still account for around 20% of the building stock by 2022. Tighter Building Regulations mean that the scope for cost effective improvement to the building envelope will be very small, and as the Regulations also cover the main building services, the scope for improvement here will also be limited - although perhaps less so for air conditioning where there is still significant technical headroom for improving plant efficiency. So the majority of the potential for carbon savings in new building is likely to lay with lighting, appliances and (particularly for the more complex non-domestic buildings) improved energy management. More radical options such as zero carbon buildings could also be considered.

In addition avoiding air conditioning could achieve significant carbon reductions in non-domestic buildings. New non-domestic buildings are much more likely to be air conditioned than those in the existing building stock. And air conditioning typically accounts for around half the carbon emissions from a building, so options which restrict the use of air conditioning could make a significant impact.

3 MAC Curves for the Domestic Buildings Sector

3.1 Introduction

This note describes the key assumptions used for the domestic sector MAC curve spreadsheet. It does not describe the spreadsheet itself or how to use it. There are notes within the spreadsheet that address this.

The focus, therefore, is on the assumptions used in determining the energy savings of each measure and on the assessment of the uptake rates and remaining potentials for each measure. The note is accordingly divided into two parts that address these issues in turn. The discussion of energy saving calculations is quite brief, aimed simply at providing the reader with an understanding of the overall approach and indicating the specific assumptions used (U-values, etc.). The discussion of uptake rates and remaining potentials is more extensive as these have a key role in determining the national potential carbon dioxide savings that are shown by the MAC curves.

3.2 Energy saving calculations

One of the key inputs into the MAC curve calculation is the table of energy savings for each of the measures considered. These are used to calculate the CO_2 and fuel cost savings that are fundamental to producing the MAC curves. The following describes the method by which the energy savings were calculated and the assumptions that were made in that process.

It is important to remember that the savings for a measure for any given year depend on the ownership of other measures in the list (i.e. they interact), so they are subject to the uncertainty in the predicted future uptake rate of measures for future years.

The general procedure to arrive at an energy saving figure was to model the energy consumption of a ‘typical’ UK dwelling before and after the addition of the measure, such that the difference between the energy consumption figures could be attributed to the measure. Firstly therefore a typical UK dwelling had to be devised for each of the years considered, since in future years, as insulation standards and heating efficiency improve, energy savings from individual measures change. This was done by calculating the stock average U-values of the main heat-loss elements (walls, floors, roofs, windows), based on the statistics for the existing housing stock and the predicted uptake rates of insulation measures. The average boiler efficiency for each year was taken from the Market Transformation Programme boiler energy model. Other factors expected to vary over time were varied according to what data was available, or in some minor cases simply estimated. The following table shows the key parameters that describe the typical dwelling for each year.

	2005	2008	2012	2017	2022	ULTIMATE
Wall U-value	1.29	1.22	1.06	0.96	0.95	0.40
Roof U-value	0.58	0.52	0.37	0.24	0.22	0.16
Floor U-value	0.65	0.65	0.64	0.63	0.62	0.25
Window U-value	3.50	3.40	3.10	2.90	2.80	2.00
Door U-value	3.00	3.00	3.00	3.00	3.00	1.50
Infiltration rate	12.50	12.50	12.50	12.50	12.50	11.50
Boiler efficiency	73.2%	76.6%	79.5%	83.5%	86.2%	90.0%
HWC insualtion mm	52	54	60	72	87	150
Primary pipework loss	55	52	49	46	43	40
Appliance factor	100%	105%	110%	111%	114%	115%
Cooking factor	100%	100%	100%	100%	100%	80%
No room stat	10%	9%	8%	7%	6%	0%
TRVs present	50%	60%	70%	80%	90%	100%
HWC thermostat	1	1	1	1	1	1
% low energy lights	10%	20%	30%	60%	90%	100%

- Where ‘HWC’ means Hot Water Cylinder and ‘TRV’ means Thermostatic Radiator Valve.

As expected, most of the values improve over time. The appliance factor and cooking factor are multipliers which reflect expected changes to the energy use for these purposes over time (notably that energy used by appliances is expected to increase). The column labelled ‘ULTIMATE’ contains values that represent a house from a hypothetical future year, when all homes have been upgraded to a good standard for all the measures in the list. Since many of the measures looked at have long lifetimes, this may give a better assessment of their long term savings potential.

The following sections list specific assumptions made in the energy saving calculation for each type of measure. These assumptions are the same for each year, but result in different energy savings because of the interactions with other measures, which do differ each year.

3.2.1 Cavity wall insulation

Cavity walls of homes built before 1976 were assumed to have a U-value of 1.5 W/m²K, prior to being insulated and 0.5 thereafter. Cavity walls of homes built between 1976 and 1983 we assumed to have a U-value of 1.0 prior to insulation reducing to 0.45 afterwards. Fillable cavity walls built after 1983 were assumed have a U-value of 0.7 prior to insulation and 0.4 thereafter.

A post calculation ‘correction factor’ was applied to the savings from cavity wall insulation on walls of all ages, and to those for loft insulation, of 58.8% (i.e. reducing the raw savings by 41.2%), to take account of recent evidence that savings are in practice lower than the modelling suggests. A ‘comfort taking’ correction factor was assumed to reduce the saving by a further 15%. These are the same assumptions that were used for the recent CERT illustrative mix work.

3.2.2 Solid wall insulation

An un-insulated solid wall of any age was assumed to have a U-value of 2.1 W/m²K. Once insulated either internally or externally, the U-value was assumed to be improved to 0.4. For the much thinner ‘insulated wall paper’ materials, it was assumed to be improved to 1.58 W/m²K. A comfort factor of 15% was applied to the savings in each case.

3.2.3 Loft insulation

Upgrades from various starting thicknesses to 270mm of mineral wool (today’s standard) were considered, giving an upgraded U-value of around 0.16 W/m²K. The starting depths considered were 0mm, 25mm, 50mm, 75mm, 100mm, 125mm and 150mm. The U-values assumed for each of these thicknesses were, respectively, 2.3, 1.12, 0.74, 0.55, 0.44, 0.37 and 0.3 W/m²K.

A correction factor of 58.8% was applied to the savings in each case, for the same reason described for cavity wall insulation. A 15% comfort factor was also assumed.

3.2.4 Floor insulation

The U-value of a floor prior to the addition of insulation was assumed to be 0.65 W/m²K. Enough insulation was assumed to be added to improve this to 0.25 (which is typically the standard achieved in new build). A 15% comfort factor was applied to the saving.

3.2.5 Glazing

Several upgrade possibilities were considered: From single glazing to new double glazing, from old double glazing (i.e. that installed prior to 2002, after which a better retrofit standard was required), from single glazing to ‘future’ double glazing, from old double glazing to future double glazing and from new double glazing to future double glazing. The ‘future’ standard relates to the fact that it is possible to go well beyond the current required standard and it is probable that in future building regulations the standard will be raised. The U-values assumed for single, double, new and future were, respectively, 5, 3.2, 2 and 1.2 W/m²K. A 15% comfort factor was applied to the savings.

3.2.6 Doors

The average U-value of an existing door is about 3. It was assumed that an insulated door has a U-value of 1.5. A 15% comfort factor was applied to the saving.

3.2.7 Improved air-tightness

Prior to improvement, the air infiltration rate for the house was assumed to be 15 m³/h/m². After improvement this figure was decreased to 11.5.

3.2.8 Boilers

The stock average boiler efficiencies for each year were tabulated above. The efficiency after upgrading was assumed to be 90%.

3.2.9 Heating controls

For each of the heating controls considered (room thermostats, thermostatic radiator valves and hot water cylinder thermostats), before upgrading it was assumed the measure was not present and after that it was present.

3.2.10 Hot water cylinders

Two upgrades were considered: From an old un-insulated cylinder to a new high performance cylinder and from one with some insulation to a new high performance one. The assumptions on insulation thickness used were 0mm (for un-insulated), 50mm (for one with some insulation) and 150mm (for a new unit), all given in terms of a thickness of mineral wool jacket.

3.2.11 Appliances, lights and cooking

A++ rated cold appliances were assumed to reduce electricity consumption by 380 kWh/yr, A+ rated wet appliances by 203 kWh/yr, efficient lighting by 319 kWh/yr, IDTVs (Integrated Digital Televisions) by 72 kWh/yr and reduced standby consumption by 120 kWh/yr. A-rated electric ovens and induction hobs were each assumed to reduce electricity consumption by 26 kWh/yr. The heat replacement effect associated with each of these savings was taken into account (even in the MAC curves that otherwise considered measures in isolation, rather than measures combined).

3.3 Uptake rates and remaining potentials

The following considers the uptake of energy efficiency measures in the housing stock focusing on the period encompassing the CERT scheme from 2008 to 2011 and then looking beyond this to 2022. It is essentially an update of, and extension to, the note that appeared in the appendix to the study previously undertaken for Defra [2].

The basic approach has been to review whatever data and estimates were available and, where possible, to update projections for the likely uptake of measures. The uptake has been based on either:

- the continuation of historical trends where there is no reason to suppose that these will change significantly due to policies (bearing in mind that any recent historical data already reflects the influence of current policies)
- a known starting point (i.e. from recent ownership data) with the effect of policies (mainly EEC figures and CERT Illustrative Mix estimates) added on to establish an s curve that can be projected forwards to 2022. It is assumed that such projection is entirely appropriate given the Government announcement that some form of supplier obligation, with a level of ambition at least as great as that of CERT, will be in place until at least 2020.
- figures simply taken from other studies (e.g. recent EST work) where appropriate

In undertaking these updates, comments made on the previous work have been kept in mind and some assumptions have been amended to reflect these. In particular, the ultimate potential for cavity wall insulation has been raised as the previous Illustrative Mix-based assumption that some 20% of cavity walls would be virtually impossible to reach was at odds with information from CIGA that suggested that very few cavity walls could not be insulated.

Conversely, the previous assumption about the uptake of solid wall insulation was considered far too optimistic (indeed, the figures finally presented in the Defra study were halved to reflect this), so new information has been sought (from the English House Condition Survey) to try to amend the assumption and put it on firmer ground.

Note that in the following, and in the MAC curves, the remaining potential is always based on the total number of homes that could actually have the measure but lack it. Thus, for example, for condensing boilers the uptake curve assumes that only 95% of the potential (the potential being homes with gas boilers) will ultimately be achieved, but the 5% that is left over continues to form part of the remaining potential.

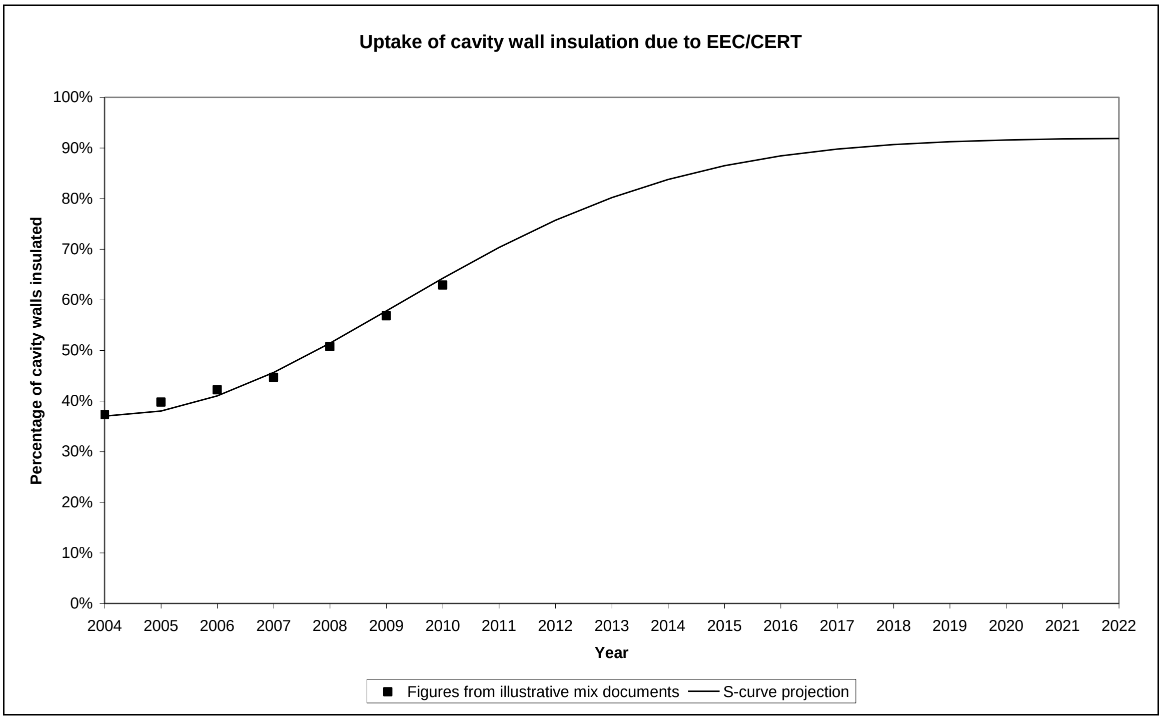
In some cases, the total number of homes that could actually have the measure is not such a well defined figure as in the above example. Wind generators, for example, are highly unlikely to be suitable for all homes but exactly how many might be suitable is unknown. In this case, because it has been assumed that urban wind generation is unlikely to be significant (as suggested by recent work), the potential has been set at a figure that roughly corresponds to the number of rural dwellings.

Depending upon the data source used, the remaining potentials that are quoted in the following relate to the UK, Great Britain or England. For the purposes of the MAC curve spreadsheet the figures have been scaled (based on figures for the numbers of households in each region) to represent the UK. Thus, the numbers that appear in the following will often not be the same as those that actually appear in the spreadsheet – but they are entirely consistent with those numbers.

3.3.1 Cavity wall insulation

The rates of uptake assumed in the CERT Illustrative mix (which appear feasible from a supply chain perspective according to the ESD report [3] , although at more than 3 million in three years they are close to the capacity limit identified by ESD), when projected forward to 2022 imply an uptake as shown in Figure 1.

Figure 1



The curve shown actually assumes that about 8% of cavity walls will probably never be insulated (although CIGA experience suggests that from a technical perspective very few of these could not be insulated, so this potential remains in future years). The points shown in the chart are based on the information in the CERT consultation document [4]. It can be seen that the s curve is consistent with the Illustrative Mix figures and that saturation occurs by about 2020. (Note that this s curve is not the historic curve for this measure. It is instead assumed that there must be a discontinuity as the uptake shifts onto a steeper curve as a result of EEC and CERT).

Based on the above curve, the remaining potentials (millions of dwellings) are as indicated overleaf. These figures have been split into different age bands (i.e. walls having different U-values) using ownership data from the GfK Home Audit.

There is an important caveat to the above analysis. Other data on the uptake of cavity wall insulation suggests that the rates of uptake are not as high as those reported by Ofgem under EEC. The reasons for this are unclear and it is therefore difficult to know for certain what uptake is actually being achieved. Thus, it is thought quite possible that data from the English Housing Survey (the successor to the English House Condition Survey) in the years leading up to 2022 may indicate that the potential is not being achieved as quickly as shown in Figure 1.

Estimated remaining potential (millions)

	Assuming all cavities can be filled	**Pre 76**	**1976-83**	**Post 83**
2004	10.911	8.659	1.148	1.104
2005	10.486	8.321	1.104	1.061
2006	10.061	7.984	1.059	1.018
2007	9.636	7.647	1.014	0.975
2008	8.576	6.806	0.903	0.868
2009	7.516	5.964	0.791	0.761
2010	6.456	5.123	0.679	0.653
2011	5.167	4.100	0.544	0.523
2012	4.231	3.358	0.445	0.428
2013	3.448	2.736	0.363	0.349
2014	2.825	2.242	0.297	0.286
2015	2.354	1.868	0.248	0.238
2016	2.014	1.598	0.212	0.204
2017	1.779	1.412	0.187	0.180
2018	1.624	1.289	0.171	0.164
2019	1.526	1.211	0.161	0.154
2020	1.467	1.164	0.154	0.148
2021	1.432	1.137	0.151	0.145
2022	1.413	1.121	0.149	0.143

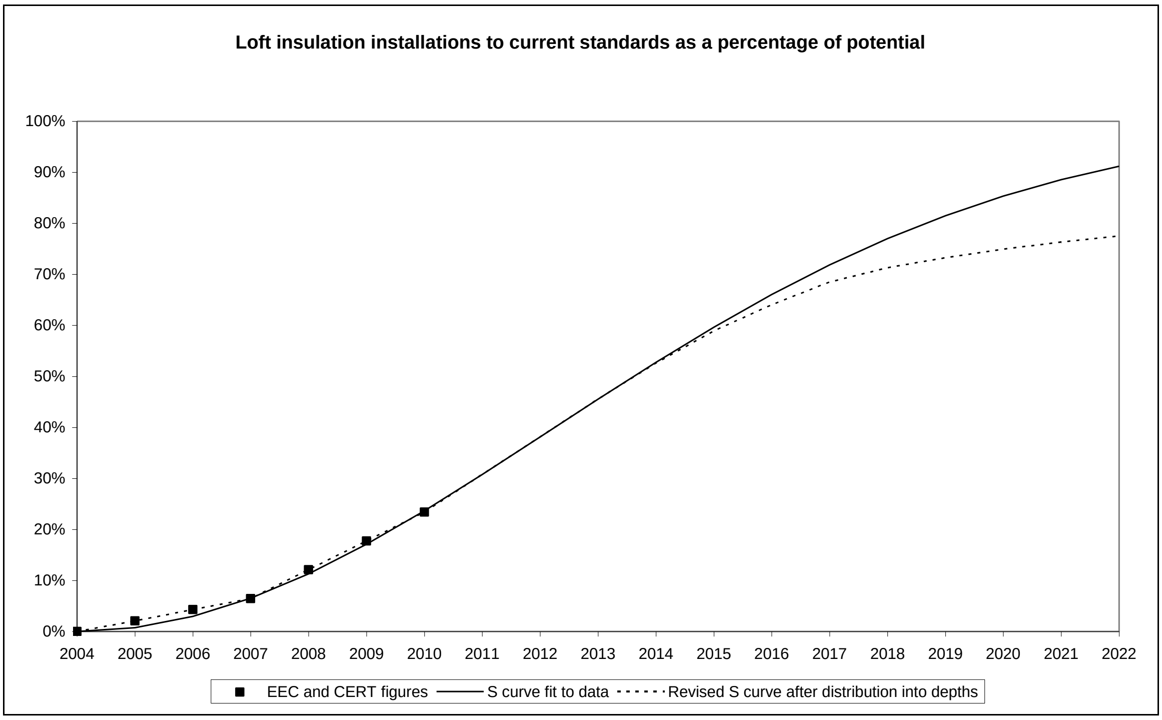
The overall potential for cavity wall insulation is taken to be 17.41 million existing homes (in UK).

3.3.2 Loft insulation

The CERT Illustrative Mix indicates about 3 million loft insulation installations over three years. Data for EEC 2 indicates about 1.14 million over three years. Thus the CERT assumptions are a considerable step up from EEC 2. Moreover, the industry capacity limit estimated by ESD was 1.057 million installations per year (although it was reported that the industry has the ability to switch production at short notice between rolls and slabs so this figure could possibly be increased a little). It is also worth noting that in the late 1970s and early 1980s the rate of loft insulation installations did get up to this sort of level, so it is clearly not entirely out of the question. Moreover, it should not be difficult, at least initially, to identify homes that could benefit since very few homes currently have loft insulation to the current standard of 270mm (figures from GfK indicate that only about 20% of lofts are insulated to 150mm or better – so, at the most, 10% might meet current standards).

Figure 2 shows the EEC and CERT figures for loft insulation installations as a percentage of the potential for such improvements (assumed to be 17.7 million, based on the Defra analysis[5], although the precise number used here does not really matter since it is only the likely uptake rates that we are trying to estimate from the s curve). An s curve has been fitted to these and projected on to 2022.

Figure 2



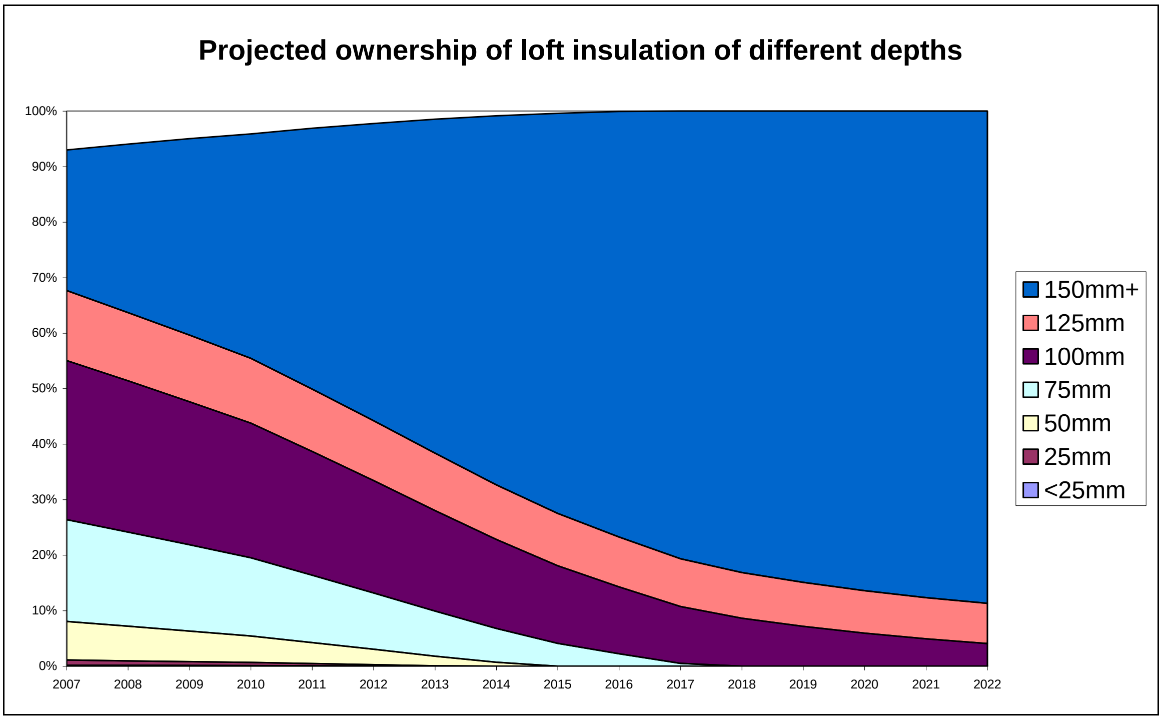
The s curve implies about 11 million loft insulation installations between 2011 and 2020 (this agrees well with the Defra figure of 11.2 million). The s curve implies maximum annual uptake rates of around 1.3 million per year and an overall average rate of 1.1 million per year between 2011 and 2020 (which, again, agrees well with the rate implied by the Defra analysis). Such a rate is beyond the capacity limit estimated by ESD and so this is challenging but, as noted above, probably not entirely impossible.

However, when these uptake figures are looked at in more detail when working out the different thicknesses (see below) they prove to be too optimistic and have to be scaled back in order to make sense (as shown by the dotted line in Figure 2). Thus, it is effectively the dotted line that has been used for the uptake assumption.

The uptake rates implied by Figure 2 can be applied to the known starting point in 2006 (based on GfK Home Audit data) to look at the likely ownership of loft insulation of different depths in future. This analysis also makes use of historical trend data (again from GfK) on the split of loft insulation acquisitions between those that are first time installations and those that are top up installations. Figure 3 shows how the analysis suggests that the thicknesses will be distributed.

The ownership levels (thousands of households) implied by this analysis are also shown overleaf. These figures provide the remaining potentials for each thickness. The exception is the 150mm+ category. We assume that all acquisitions of loft insulation are up to the CERT target level of 270mm (and so they go into the 150mm+ ownership category). Thus the growth in this category over time does not represent an increased potential as most of them are already up to the required standard of 270mm. The remaining potential within this category is probably best approximated by using the starting figure (4.645 million) for all years, and this is what has been used. Of course, the exact assumption used here is not critical to the MAC curves since the savings from topping up insulation that is already at least 150mm thick are small (and probably not cost-effective).

Figure 3



Ownership of loft insulation of different depths (thousands)

	None	<25mm	25mm	50mm	75mm	100mm	125mm	150mm+
2006	1480	37	193	1433	3743	5795	2529	4645
2007	1392	36	184	1381	3641	5690	2506	5025
2008	1181	31	160	1240	3366	5406	2444	6025
2009	989	26	136	1097	3085	5116	2381	7025
2010	817	22	112	950	2796	4818	2316	8025
2011	618	15	79	753	2412	4421	2229	9329
2012	443	9	45	552	2018	4015	2140	10633
2013	293	2	10	346	1614	3597	2049	11944
2014	172	0	0	140	1210	3180	1958	13195
2015	80	0	0	0	817	2775	1870	14313
2016	16	0	0	0	445	2391	1786	15216
2017	0	0	0	0	101	2035	1709	16011
2018	0	0	0	0	0	1713	1638	16504
2019	0	0	0	0	0	1427	1576	16853
2020	0	0	0	0	0	1182	1522	17150
2021	0	0	0	0	0	978	1478	17399
2022	0	0	0	0	0	810	1441	17604

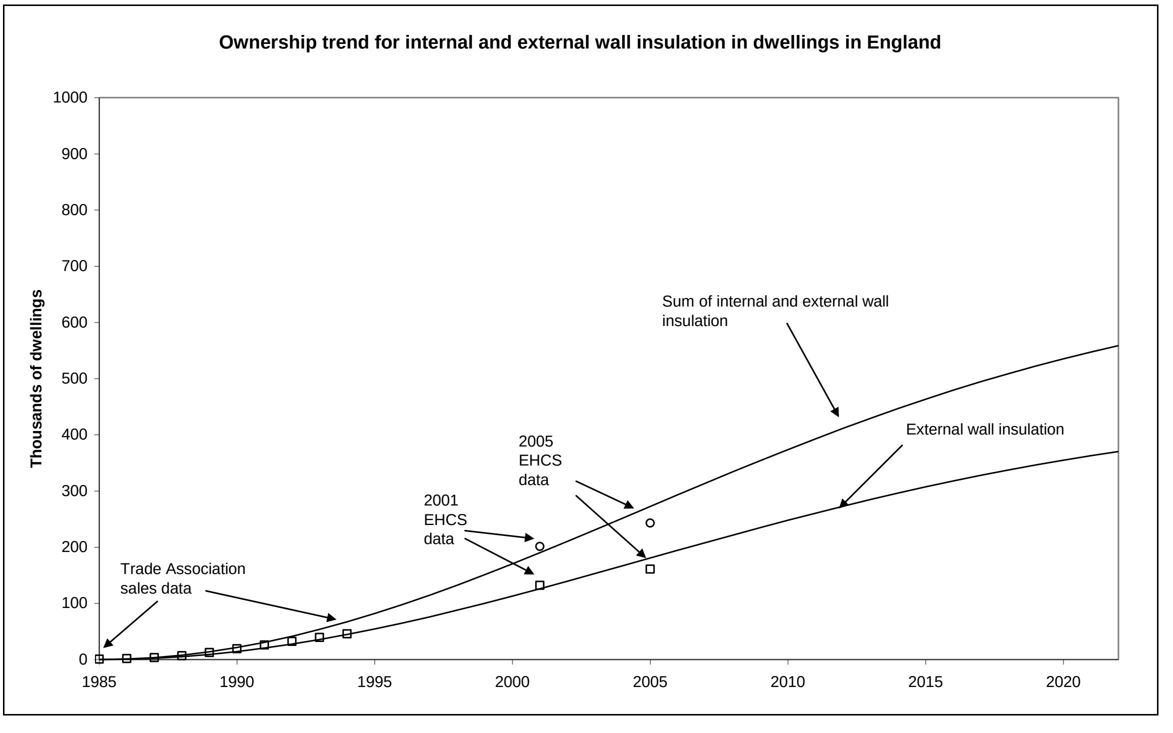
The overall potential for loft insulation is taken as 19,855 thousand existing homes (in GB).

3.3.3 Solid wall insulation

The uptake of solid wall insulation (both external and internal) is subject to considerable uncertainty. A piece of BRE analysis a few years ago used old Trade Association sales data and some ownership figures from the 2001 English House Condition Survey to estimate the likely uptake trend. Data from the 2005 EHCS [6] has now been added to this. Also the internal insulation figures (which were thought to be far too optimistic because they related to dry lining rather than internal insulation) have now been adjusted based on preliminary information from the current EHCS on internal wall insulation (the surveyor briefing has recently changed to include identification of internal wall insulation but there is not yet a full year's worth of data available).

This suggests that the number with internal insulation is no more than 10% of those with dry lining (although the sample size is very small – 64 dwellings with dry lining and 5 with internal wall insulation - so there is obviously still some doubt over this). The revised data and s curve assumptions are shown in Figure 4. It is clear that the growth from 2001 to 2005 is relatively slow and this implies an s curve, as shown, that is likely to saturate at perhaps only 10% of the 6.7 million solid wall dwellings (in England) being treated. About 8% are treated by 2022 according to the curve.

Figure 4



The above chart leads to remaining potential figures (for England) as shown below.

Remaining potential estimates (thousands)

	External wall insulation	Internal wall insulation	All solid wall insulation	%
2005	4274	2172	6446	95.9%
2006	4260	2165	6425	95.6%
2007	4247	2158	6404	95.3%
2008	4233	2151	6384	95.0%
2009	4220	2144	6364	94.7%
2010	4207	2137	6344	94.4%
2011	4194	2131	6325	94.2%
2012	4182	2125	6307	93.9%
2013	4170	2119	6289	93.6%
2014	4158	2113	6271	93.4%
2015	4147	2107	6255	93.1%
2016	4137	2102	6239	92.9%
2017	4127	2097	6224	92.6%
2018	4117	2092	6209	92.4%
2019	4108	2087	6196	92.2%
2020	4100	2083	6183	92.0%
2021	4092	2079	6171	91.9%
2022	4084	2075	6160	91.7%

Note that the above assumes that a fixed potential applies to each measure separately. In practice, the potential for either measure could increase or decrease depending on market factors (i.e. these are competing technologies).

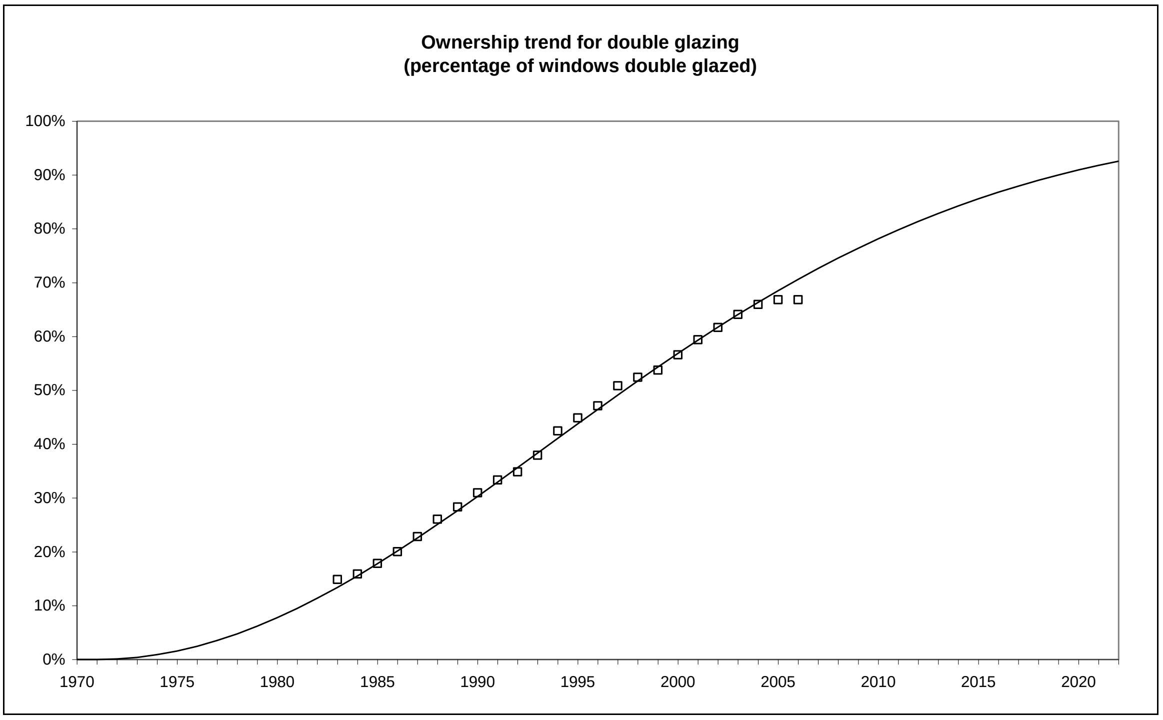
The overall potential is taken to be 6718 thousand existing homes (in England) – split, for the purposes of the above, into 4455 thousand and 2263 thousand for external and internal wall insulation respectively.

3.3.4 Double Glazing

Double glazing is a measure that has been popular for a long time and there has been a strong uptake of it for reasons that will often have nothing to do with energy efficiency (improved sound insulation, reduced maintenance requirements and the belief that the measure adds value to the home, all being important motivators). It is now effectively required by Building Regulations and this should ensure that ownership continues to grow strongly.

The chart below shows the historical trend for the ownership of double glazing. Note that the figures are transformed for the purposes of the analysis into the percentage of windows that are double glazed. For modelling purposes, this can then be taken to represent an equivalent percentage of homes that have full double glazing (with the remainder representing the equivalent percentage of homes that lack any double glazing). In practice, more homes than this actually have double glazing, but it is not always present on all windows. However, more than half of the homes that have double glazing now have at least 80% of rooms/windows treated. Thus, full double glazing is rapidly becoming the norm and the curve indicates that by 2022 it will effectively be present in 90% of homes. Note that the apparent departure from the line in the last two years is not thought to be real – it is related to a problem with the data, caused by an increase in the number of “not known” responses from householders.

Figure 5



The remaining potentials implied by Figure 5 are shown overleaf. These are expressed as the equivalent number of homes that lack any double glazing as described above.

Remaining potentials for double glazing (equivalent number of homes that lack any double glazing) (thousands)

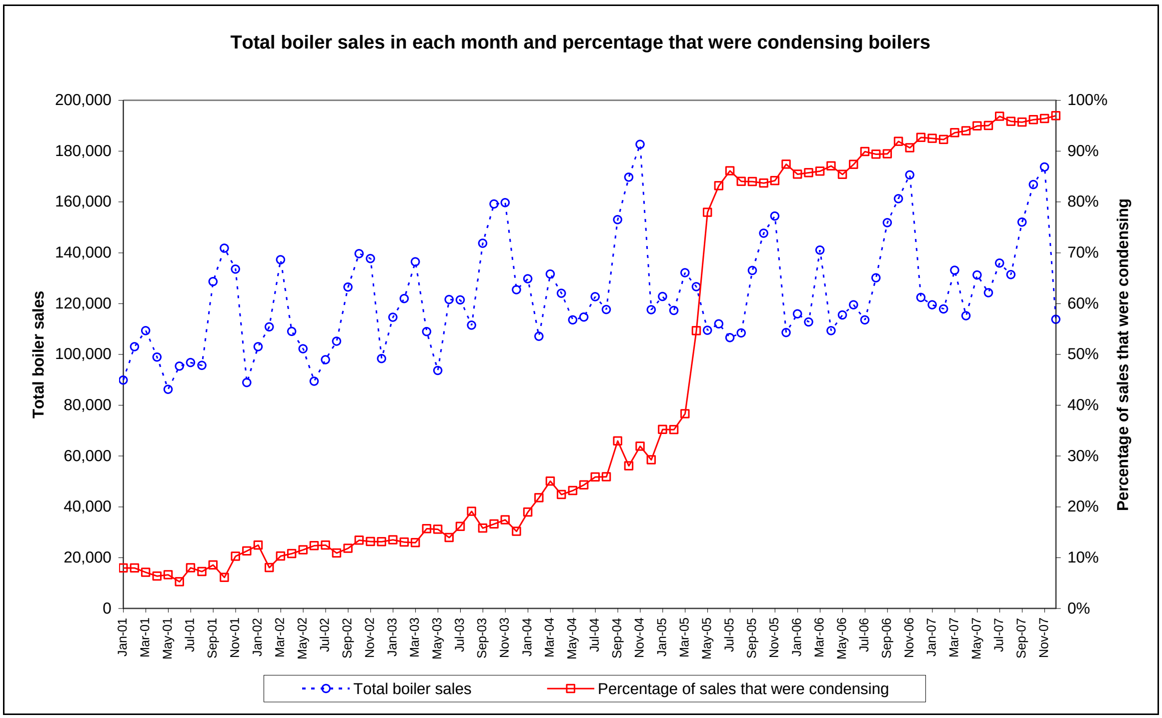
2006	7428
2007	6919
2008	6432
2009	5967
2010	5525
2011	5105
2012	4708
2013	4333
2014	3980
2015	3648
2016	3337
2017	3047
2018	2777
2019	2525
2020	2292
2021	2076
2022	1876

The overall potential is taken to be 25,285 thousand homes (in GB).

3.3.5 Condensing boilers

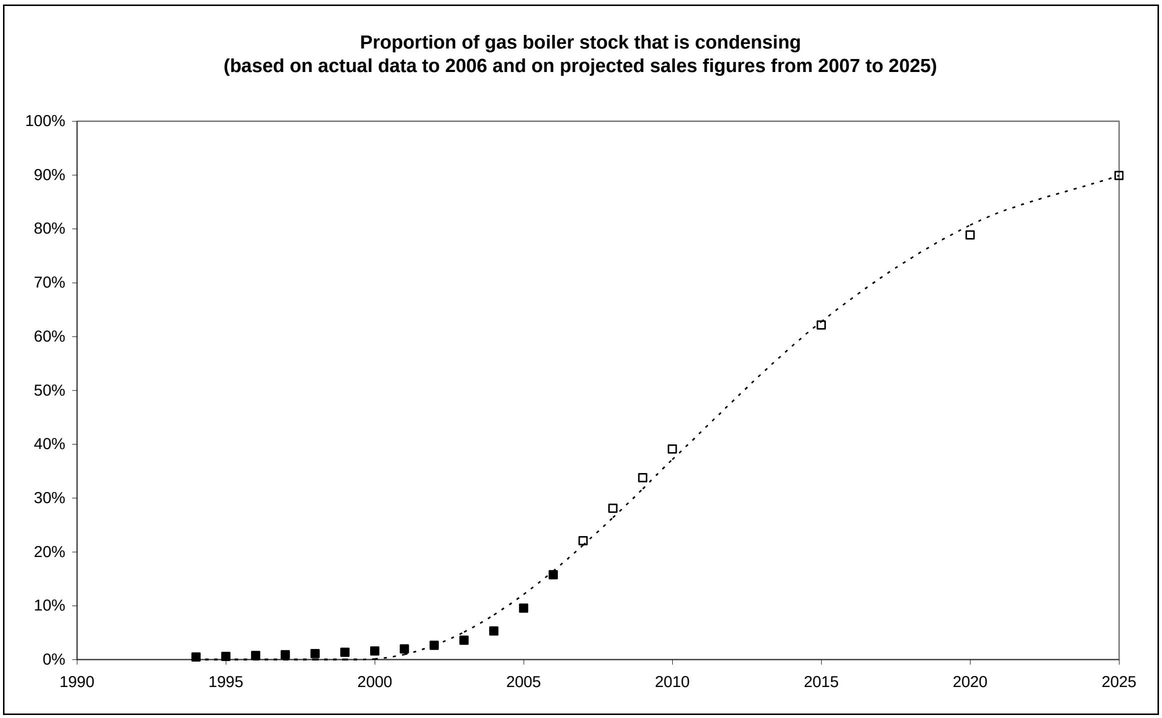
The uptake of condensing boilers has been dramatically transformed by the Building Regulations requirement that was introduced in April 2005 whereby all gas boiler installations, whether new or replacement, have to be condensing models (with just a few exceptions allowed). The effect of the Building Regulations requirement on the market is illustrated in the chart below which shows monthly sales of gas boilers between January 2001 and December 2007 [7].

Figure 5



Given that there are well over 1 million gas boiler sales in a year, the step change shown above is clearly going to rapidly change the ownership of condensing boilers in the housing stock. This is modelled in detail using the Market Transformation Programme Boiler Energy Model[8] and the results from that model have been used for the present study. The resulting ownership development is illustrated in the chart overleaf and the corresponding remaining potential figures are tabulated below.

Figure 6



This suggests that by 2022 around 80% of gas boilers in the housing stock will be condensing boilers. It is assumed that the ultimate potential for this measure is only 95% of gas boilers, because of the small number of allowed exceptions. The sales data in Figure 5 suggests that 5% exceptions may actually be a slight over-estimate.

Remaining potential estimates (thousands) - UK

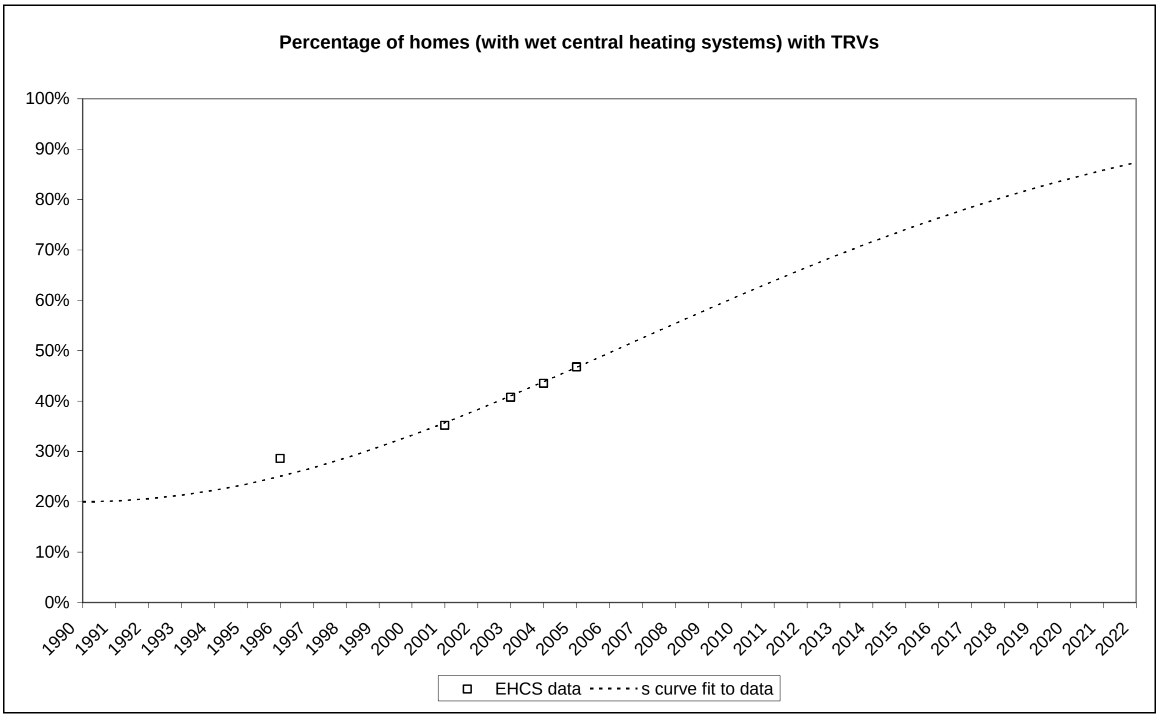
		Overall potential
2006	17571	20850
2007	16593	21290
2008	15581	21670
2009	14569	21995
2010	13561	22265
2011	12603	22446
2012	11646	22627
2013	10689	22808
2014	9731	22989
2015	8774	23170
2016	8023	23282
2017	7272	23394
2018	6521	23506
2019	5770	23618
2020	5019	23730
2021	4503	23815
2022	3986	23900

(Note that in this case the overall potential is not taken as being fixed. It grows because of new build – which would all be condensing boilers anyway – and because of the installation of new systems in existing homes).

3.3.6 TRVs

Data from the English House Condition Survey [9] from 1996, 2001, 2003, 2004 and 2005 has been extracted to determine the growth in the presence of TRVs in wet central heating systems. Figure 7 shows this data and an s curve projecting the likely growth to 2022. This indicates that approaching 90% of wet central heating systems should be fitted with TRVs by 2022.

Figure 7



The remaining potentials (for England) implied by the above are shown below.

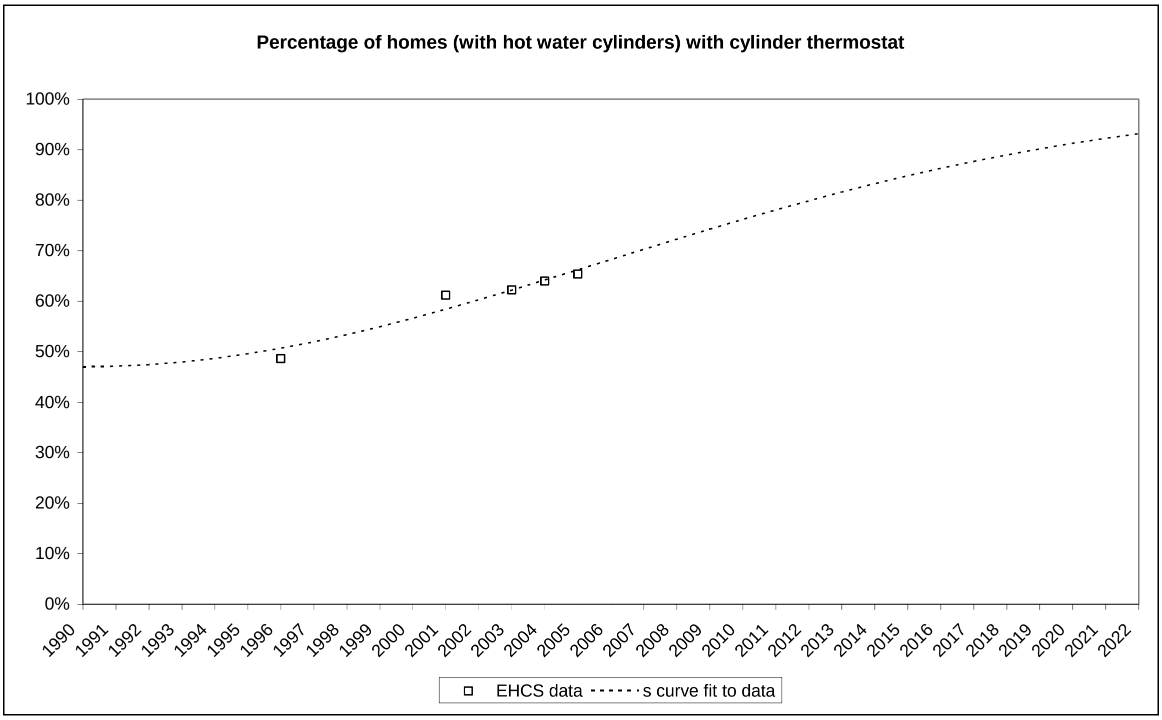
	Remaining potential (England) 000s
2004	10340
2005	9900
2006	9381
2007	8840
2008	8300
2009	7765
2010	7239
2011	6724
2012	6223
2013	5739
2014	5273
2015	4828
2016	4405
2017	4004
2018	3627
2019	3273
2020	2943
2021	2637
2022	2354

The overall potential is taken to be 18,590 thousand existing homes (homes with wet central heating systems) – in England.

3.3.7 Cylinder thermostats

Data from the English House Condition Survey (8) from 1996, 2001, 2003, 2004 and 2005 has been extracted to determine the growth in the presence of cylinder thermostats. Figure 8 shows this data and an s curve projecting the likely growth to 2022. This indicates that by 2022 around 93% of hot water tanks should have cylinder thermostats.

Figure 8



The remaining potentials (for England) implied by the above are shown below.

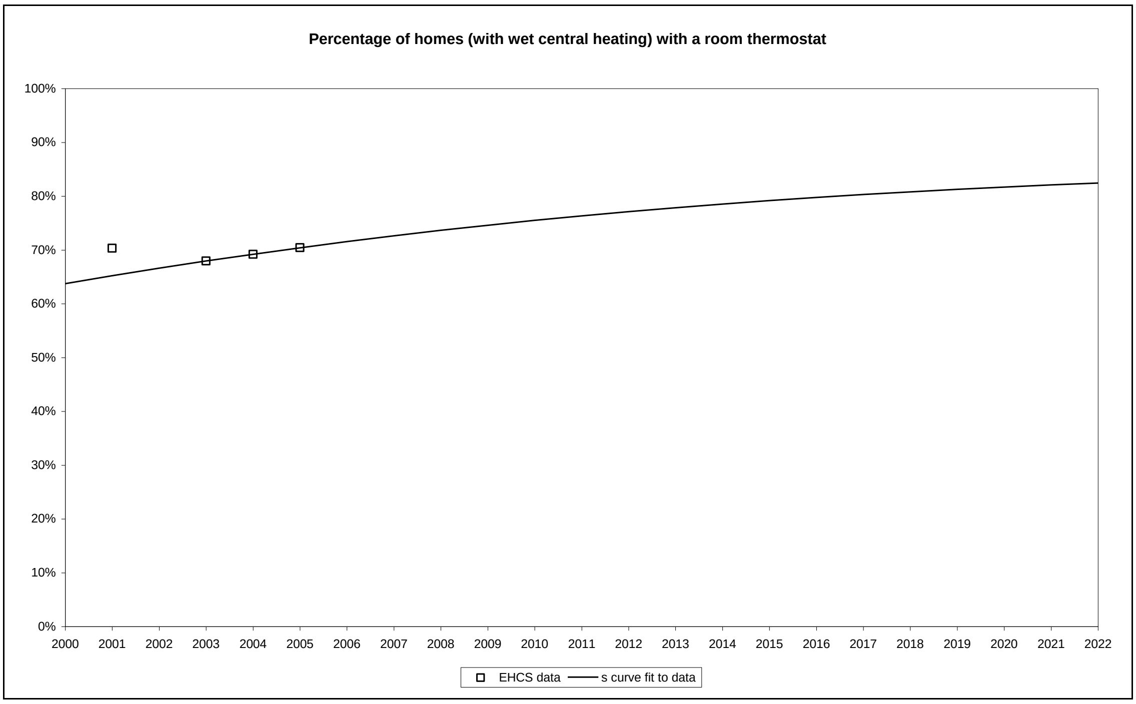
	Remaining potential (England) 000s
2004	5370
2005	5000
2006	4587
2007	4294
2008	4003
2009	3718
2010	3439
2011	3168
2012	2907
2013	2657
2014	2418
2015	2193
2016	1980
2017	1781
2018	1595
2019	1424
2020	1265
2021	1120
2022	987

The overall potential is taken to be 14,440 thousand existing homes (homes with hot water cylinders) – in England.

3.3.8 Room thermostats

Data from the English House Condition Survey (8) from 1996, 2001, 2003, 2004 and 2005 has been extracted to determine the growth in the presence of room thermostats in wet central heating systems. The trend from the data is unfortunately not clear – it actually shows no growth in room thermostats between 1996 and 2005, which is probably due to a problem with the survey (i.e. surveyors having difficulty identifying when room thermostats are actually present) rather than being real. The last three years do indicate some small but steady growth and so the projection has therefore been based on these years and data from earlier years has been ignored. Figure 9 shows the data and an s curve projecting the likely growth to 2022. This is obviously rather uncertain but it indicates saturation at around 85% of potential (but given the above comments, this could just be an artefact of the imperfect survey results).

Figure 9



The remaining potentials (for England) implied by the above are shown below.

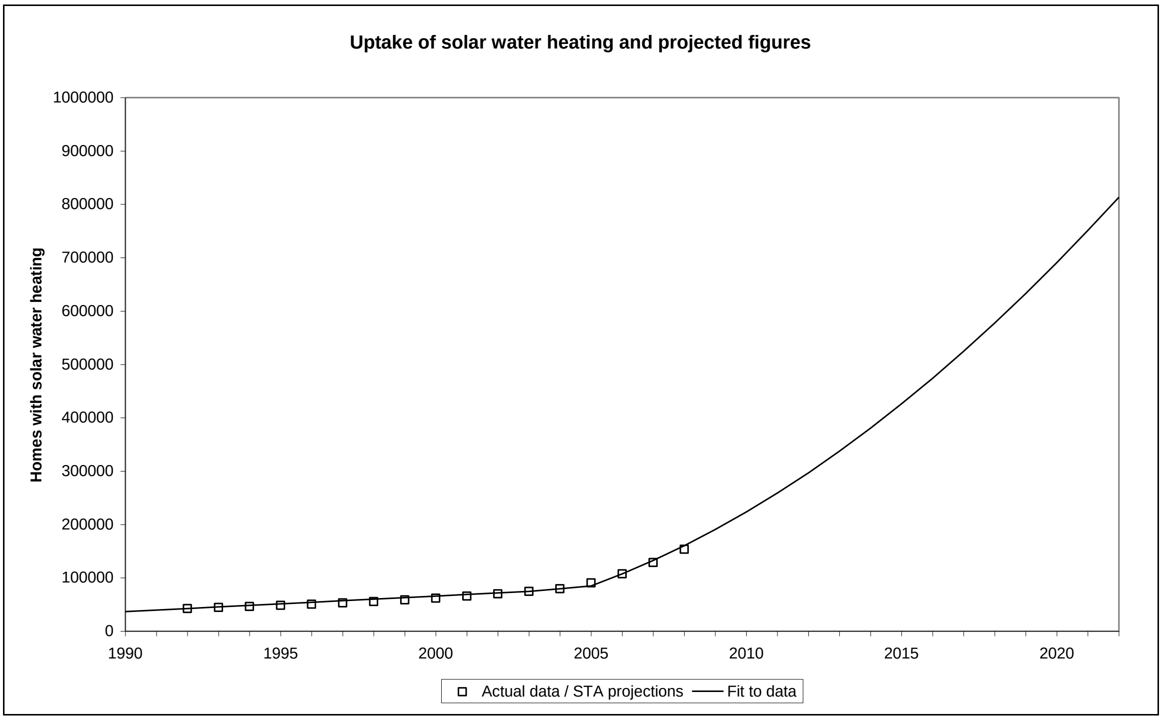
	Remaining potential (England) 000s
2004	5635
2005	5501
2006	5289
2007	5089
2008	4900
2009	4723
2010	4556
2011	4400
2012	4254
2013	4118
2014	3991
2015	3874
2016	3764
2017	3663
2018	3570
2019	3484
2020	3405
2021	3332
2022	3266

The overall potential is taken to be 18,590 thousand existing homes (homes with wet central heating systems) – in England.

3.3.9 Solar water heating

Data on the ownership of solar water heating systems is available from an ETSU study covering the period 1992 to 1997 [10]. It is also known that at the time of the Clear Skies grants the uptake of solar water heating under this scheme was about 3000 per year and that these accounted for the majority of installations (and, indeed, accounted for more than 90% of all the Clear Skies grants) [11]. More recently, in response to the CERT consultation, the Solar Trades Association has indicated that sales in 2006 amounted to 17,000, so the market has increased significantly since the time of Clear Skies [12]. They also previously indicated that sales in 2008 were expected to be 25,000, which they now think is an underestimate. Based on this information, and interpolating as necessary, it is possible to develop an s curve as shown in Figure 10. This indicates that currently the ownership of solar water heating is probably around 130,000 homes (corresponding to only about 0.7% of homes that might potentially benefit from this measure).

Figure 10



It is clear that the uptake of solar water heating is currently still within the early adopter region of the s curve and so it is necessarily highly uncertain how the curve will develop. Thus, the curve shown above may present a pessimistic view of the future (certainly more pessimistic than Defra's assumptions (4)) even though it fits the available data. It is worth noting, however, that the uptake shown by the curve greatly exceeds some recent figures produced by the EST [13]. However, EST advised us that their model was intended to look at the very long term – i.e. out to 2050 – and the figures were not expected to be reliable over short timescales, so they would not properly capture the early adopters.

Regardless of any uncertainties, it has to be recognised that the uptake to 2022 represents only a few percent of the potential (the above curve implies 4%), so the remaining potential figures in all the years to 2022 are very close to the overall potential. In other words, the potential savings in future years to 2022 are large and not very sensitive to the assumptions about uptake rates. The remaining potentials that the above curve implies are shown below.

Remaining potential estimates (thousands)

		%
2005	18915	99.6%
2006	18893	99.4%
2007	18867	99.3%
2008	18840	99.2%
2009	18809	99.0%
2010	18777	98.8%
2011	18741	98.6%
2012	18703	98.4%
2013	18663	98.2%
2014	18619	98.0%
2015	18574	97.8%
2016	18526	97.5%
2017	18475	97.2%
2018	18422	97.0%
2019	18367	96.7%
2020	18309	96.4%
2021	18249	96.0%
2022	18187	95.7%

This assumes that there are overall about 19 million dwellings in the UK that could have solar water heating panels (i.e. roughly equating to all dwellings with roofs). This overall potential may be optimistic if combi boilers continue to grow in popularity (because these heat water directly and dispense with the hot water tank that would normally form an integral part of a solar water heating installation).

3.3.10 Photovoltaic panels

There is data available from the IEA on photovoltaic panels in the UK (see Table 1) [14]. The data is presented in terms of the kWp installed rather than the number of installations. Furthermore, there is not a clear demarcation between installations in domestic properties and other types of installation. Thus, the numbers are inevitably a little uncertain.

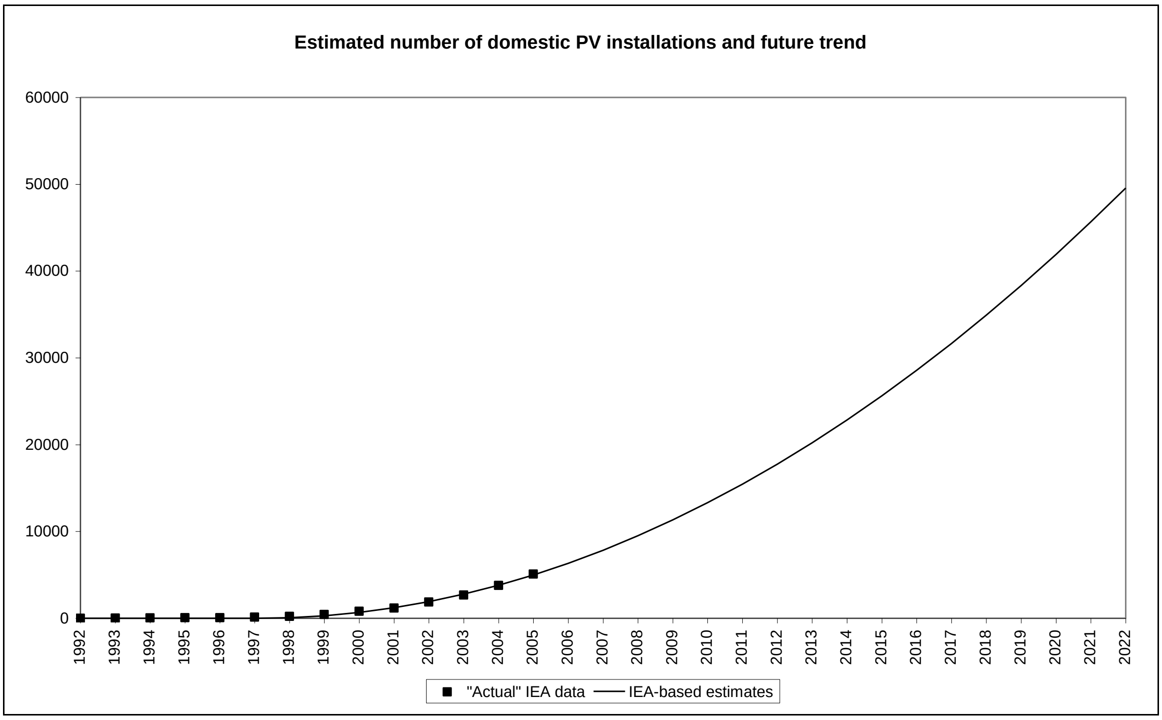
Table 1

	Cumulative installations at the end of each year (kWp)													
Sector	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Standalone domestic	7	47	52	57	69	83	108	119	121	135	162	172	193	227
Standalone non-domestic	166	213	232	252	279	316	254	276	302	385	406	542	585	697
Grid-connected distributed	0	6	54	59	75	190	328	736	1506	2226	3568	5189	7386	9953
Grid connected centralised	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	173	266	338	368	423	589	690	1131	1929	2746	4136	5903	8164	10877

If we assume that “grid connected distributed” is predominantly domestic and that the average domestic installation is 2 kWp (this may be slightly generous – in the domestic field trials the average was 1.56 kWp) it is possible to estimate the number of installations and then fit an s curve to the figures. This is shown in Figure 11.

Bearing in mind that there are currently estimated to be less than 10,000 installations (i.e. less than 0.05% of the potential) we are clearly still in the very early adopter phase and it is highly uncertain how the market will actually develop (the curve implies only 0.2% of potential achieved by 2022). Thus, the comments made about the remaining potential for solar water heating apply equally here – i.e. the potential savings from PV in future years to 2022 are large and not very sensitive to the assumptions about uptake rates.

Figure 11



The remaining potentials implied by the above s curve are shown below. This assumes that there are 25 million homes in the UK that could have PV panels mounted on the roof or wall (i.e. essentially all homes).

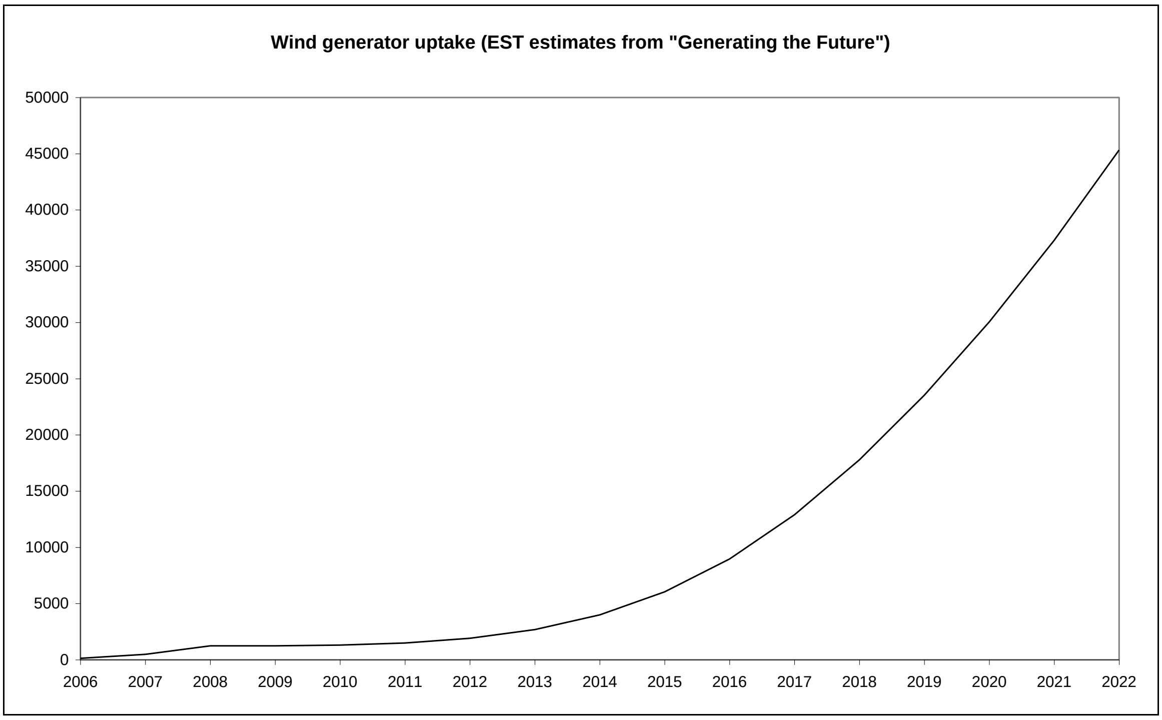
Remaining potential (thousands)

2006	24994	100.0%
2007	24992	100.0%
2008	24990	100.0%
2009	24989	100.0%
2010	24987	99.9%
2011	24985	99.9%
2012	24982	99.9%
2013	24980	99.9%
2014	24977	99.9%
2015	24974	99.9%
2016	24971	99.9%
2017	24968	99.9%
2018	24965	99.9%
2019	24962	99.8%
2020	24958	99.8%
2021	24954	99.8%
2022	24950	99.8%

3.3.11 Wind generators

Figures for the uptake of wind generators within the housing stock have been taken from information used for the EST's recent "Generating the Future" report [13]. The figures used are those that assume that wind generation in the urban environment is unlikely to be considered promising (i.e. as recent research suggests). Thus, we have assumed that the relevant potential corresponds roughly to that part of the housing stock that is classed as rural (EHCS data suggests that this is about 20% of homes - i.e. around 5 million). Figure 12 shows the uptake assumed. It will be noted that the numbers are very small (of similar magnitude to those for PV panels) – even by 2022 they correspond to only 1% or so of potential having been reached. The remaining potential figures (assuming that 5 million UK homes could potentially have wind generators) are shown below.

Figure 12



Remaining potential for wind generators

Assuming 5000000 homes can potentially have the measure

2006	4999862	100.00%
2007	4999517	99.99%
2008	4998753	99.98%
2009	4998753	99.98%
2010	4998692	99.97%
2011	4998505	99.97%
2012	4998090	99.96%
2013	4997310	99.95%
2014	4995996	99.92%
2015	4993959	99.88%
2016	4991030	99.82%
2017	4987109	99.74%
2018	4982207	99.64%
2019	4976463	99.53%
2020	4969960	99.40%
2021	4962696	99.25%
2022	4954666	99.09%

3.3.12 Other measures

The above has described the calculation of the uptake rates and remaining potentials for the major measures. There were several other measures considered for which the available information is much less comprehensive and the following outlines how the relevant figures were estimated for these. Given the relative paucity of data, the assumptions used in many cases necessarily amount to little more than a professional judgement (in general based on the same s curve approach that has been used for the major measures).

For the ‘wallpaper’ types of solid wall insulation, it was assumed that 1 million solid walled homes which might not be suitable for other solid wall insulation methods was the initial potential in 2005 and that this will be taken up only slowly. An s curve was constructed to model this uptake rate which gives an installation rate of a few thousand homes per year by the middle of the time period of interest (i.e. around 2015).

Floor insulation was assumed to be installed only where a floor is to be taken up anyway (since it would be rather disruptive otherwise). Hence a low, but constant estimate of the annual number of installations was made, at 100,000 per year. Around half of all floors (12 million) were assumed to be suitable for retrofit insulation in 2005.

Insulated doors were assumed to be extremely rare in 2005, so an initial potential of all 25 million UK dwellings was assumed. An s curve was constructed showing insulated doors being installed eventually at similar rates to double glazing – around 800,000 homes per year by the middle of the period of interest.

For hot water cylinder upgrades, it was assumed that the remaining potential in 2005 was around 1.5 million un-insulated cylinders and 5 million poorly insulated ones. S curves were constructed that appeared to show a reasonable uptake rate of this potential, such that around 350,000 cylinders will be upgraded to good standard per year by the middle of the period of interest. (For context, around 600,000 are sold per year at present, though that figure is declining due to the popularity of ‘combi’ boilers.)

An s curve was constructed to model the uptake rate of primary pipework insulation, such that the rate around the middle of the period of interest is around 600,000 per year (which is similar to the number of condensing boilers going in around the same time).

S curves were devised for each of the appliance categories, for low energy lights and for efficient hobs and ovens. The resulting mid-period uptake rates (in homes per year) were: 800,000 for A++ cold appliances, 900,000 for A+ wet appliances, 1.2 million for efficient lighting, 1.4 million for IDTVs, 1.1 million for reduced standby consumption, 0.6 million for A rated ovens and 0.4 million for induction hobs. All of these figures are rather uncertain, in part because of the faster changing nature of this sector compared to heating and hot water related measures.

4 MAC Curves for the Non-Domestic Buildings Sector

4.1 The Flexible Spreadsheet

The non-domestic MAC curve spreadsheet calculates the economic and technical potential for implementing energy efficiency measures in UK public and commercial sector buildings. Cost effectiveness is determined for each individual measures by calculating the net annual cost (NAC) per tonne of carbon saved where a negative value indicates a measure is cost effective.

Since the calculations are based on applying each individual measure in a sample of buildings, in some instances a cost effective and a non-cost effective portion for each measure is determined, hence some measures appear twice on the MAC curve.

The measures are split into current/conventional technologies and alternative technologies. The former refers to standard, readily available and common technologies such as insulation and the latter refers to alternative technologies which may involve fuel switching such as heat pumps and on site generation of renewable energy, such as solar hot water heating and PV.

There are three main sheets

- Inputs - which has input variables in the blue cells - other cells should not be altered – it also the command button which runs the macro which recalculates the costs and benefits for the current input variables.
- Results – which displays the results and key input parameters for the most recently run input data.
- Original data - which shows the primary data which drives the model, specifically the total EAC and GWh energy saving for implementation of each measure across the existing UK public and commercial building stock and the percentage of this potential that is expected to remain in future years. This data is based on detailed modelling carried out previously (mainly based on 2002 data)which separately grouped cost effective and non-cost effective instances for each measure. There are other additional data processing sheets which are hidden, except when the macro is run to recalculate the results. These pages should not be altered in any way.

4.1.1 Inputs Sheet

Input cells are highlighted in blue and are either drop down lists or cells where the user can enter the chosen values.

Input parameters

On the inputs sheet the user can select various options from the following functionalities:

- Discount rate – select from the drop down list from: 0.5% to 50% in 0.5% increments.
- Fuel price – any price in pence/kWh can be entered for electricity, gas, oil and solid fuels.

- Carbon emission factor – any factor in $kgCO_2/kWh$ can be entered for electricity, gas, oil and solid fuels.
- Year – select from the drop down list from: current day (2002), 2010, 2012, 2017 or 2022.
- Country – select from the drop down list from: UK, England, Wales, Scotland or Northern Ireland.
- Sectors – select from the drop down list from: all sectors, CRC sectors or non-CRC sectors.
- Building sector – select from the drop down list from: public and commercial, public or commercial.

Adding an alternative measure

Additional measures can be included in the analysis via the blue cells in the table at B19:U29, where the typical lifetime (years), the cost of implementing the measure (£M) and the savings generated by the measure (GWh) are required. The proportion of each fuel type the measure affects is also required.

For measures involving fuel switching data needs to be entered for both the total fuel saving (for the fuel switched away from) and the additional fuel consumption (for the fuel switched to).

Note that alternative measures cannot be taken into account when modelling interactions. See Section 2.2 for further explanation.

Adding one-off and ongoing costs

For each individual measure included in the analysis there is an option to add one-off and ongoing costs for example costs relating to installation and maintenance. To add in a one-off cost (cells C38:C135) enter a percent of the capital cost where this exists, where there a no capital costs associated with a measure, enter an absolute cost in £M. To add an ongoing cost (cells H38:H135) an absolute cost in £M can be entered for each individual measure. Note that absolute cost values will need to relate to sectors selected.

Once the options for each of the functionalities have been chosen, click on the “Update Now” button which will implement the chosen options and take the user through to the results sheet.

4.1.2 Results Sheet

Key input parameters

The results sheet shows the key input parameters which have been selected by the user in the inputs sheet – discount rate, year, country, sector and fuel prices and emission factors by fuel type.

Summary table and summary graphs

A summary table is provided which gives the carbon savings from all fuels, carbon savings from electricity, NAC/tCO_2 and the NPV for all measures and split into cost effective measures and non cost effective measures.

Four different sets of results are provided:

1. All technology trajectories – individual measures no account of interactions nor of overlaps with alternative technologies – this includes current and alternative technologies and ranks them according to their cost effectiveness.
2. Alternative technologies – individual measures no account of interactions - this includes alternative technologies only and ranks them according to their cost effectiveness.
3. Current technologies – individual measures no account of interactions - this includes current/conventional technologies only and ranks them according to their cost effectiveness.
4. Current technologies – simultaneous application including interactions – this includes current/conventional technologies only and includes the modelling of interactions.

Each of these sets of results (with the exception of 2) is plotted on a MAC curve. It is important to note that the savings in 1 to 3 cannot be added together since they don't take interactions between measures into account and this would significantly overestimate the potential savings. Curve 4 however, takes into account interactions and therefore can be used as an indication of total potential savings.

Detailed results

The detailed results provide information on the cumulative carbon savings, the individual carbon savings, the NAC/tCO_2 saved and the carbon savings from electricity and the NPV arising from each measure. This is provided for the relevant technology type breakdowns (current and alternative technologies) for all measures and all cost effective measures.

Two sets of detailed results are provided:

1. Individual measures – the potential savings arising from implementing each measure across the existing building stock – no account of interactions.
2. Combined savings – savings attributed to each measure from simultaneous implementation of current technology measures – i.e. accounting for interactions.

4.2 Background Methodology

4.2.1 Overview of Methodology

The principal aim of this work was to produce MAC curves for the commercial and public sector buildings representing the cost effective and total potential savings available in the current building stock as a function of discounted cost per unit of carbon saved. The basis for this current analysis was the outputs from a previous cost abatement analysis carried out for Global Atmosphere Division, Defra. The analysis required a number of inputs from N-DEEM (Non-Domestic buildings Energy and Emissions Model) and other data sources.

Product data was collected for both the energy efficient measure and, where appropriate, the less efficient measure being replaced. A variety of sources were used, from manufacturers and suppliers brochures to case studies. The information collected included costs of products, energy savings achieved and lifetimes and any further pertinent information that might influence the assumptions made about the application of a measure. Where applicable such information was checked by BRE experts in the relevant fields.

These measures were then “applied” to the c.700 premises contained in the detailed energy audit data[15] and covering a wide variety of building types. This detailed sample data allowed individual items of energy consuming equipment and their energy use to be estimated. This allowed the total potential and cost effective potential carbon savings achievable from the implementation of energy efficient measures to be assessed across a wide range of circumstances.

These sample savings were then scaled up to the UK level. For most measures the scaling up was carried out via national fuel consumption by end use from N-DEEM estimates of national energy use. For fabric measures, however, national fabric areas inferred from typical fabric to floor area ratios were used to scale results to the UK level[16].

The data generated from this previous analysis was then used as the basis for the input data into the flexible spreadsheet.

4.2.2 Data for the Energy Efficiency Measures

The full list of over 80 measures is the culmination of a review undertaken for the previous project for Global Atmosphere Division, Defra of around 1,500 products and from case studies (mainly from the Carbon Trust) so that where possible, product and manufacturers data were checked against case studies and other sources

From this assessment average figures for each of the bulleted points below were determined. For each measure the following data was collected for both the energy efficient measure and, where appropriate, the less efficient item it was replacing:

- Energy / efficiency saving (as a percentage or, for fabric measures, as a change in U-value)
- Price / cost (including labour and maintenance costs where applicable)
- Life expectancy / lifetime
- Any further information affecting the potential application of the measure (e.g. instances in which it would be unsuitable).

The price and life expectancy are discussed in more detail below. Specific information pertaining to the application of individual measures is discussed in more detail in Section 4.3.

4.2.3 Measure Costs

To determine the costs of a measure the following assumptions were made:

- An investment decision has already been made, thus measures were applied in all possible instances regardless of the age of existing equipment – i.e. the opportunity to replace all measures is available immediately. The only exception to this is boilers, where only boilers more than 8 years old were considered for replacement.
- Where a measure is a replacement for a less efficient item the marginal cost was used.
- Where a measure is an “add-on” measure, such as fitting additional controls, and as such incurs additional costs, the full capital cost was used.

- Non-domestic customers are likely to buy wholesale, therefore wholesale prices have been used where possible.
- Costs are exclusive of other charges such as VAT and delivery.
- For replacement measures it was assumed that labour costs would be the same for both the more efficient and the standard item that was being replaced, thus no labour cost was included.
- For add-on measures incurring a full capital cost labour costs were included. Where such information was not available 10% of the cost of the item was used as a standard factor for labour costs.
- Where a measure included additional servicing costs these have been included in the analysis where such costs were considered to be significant.

4.2.4 Life Expectancy

In most cases lifetimes are reported by manufacturers or in case studies. Where this information was not available, however, a rule of thumb was used whereby mechanical items were assumed to last 10 years and electrical items 5 years.

4.2.5 Description of Measures and Assumptions

The conventional/current energy efficient measures modelled can be broken down into fabric measures, technology measures and control measures. There is a further section on “alternative measures” which save carbon due to reducing the carbon intensity of the fuel used at a building level, such as photovoltaics. In all instances it was assumed that measures and technologies were installed and used correctly and that the opportunity to replace all measures is available immediately and therefore does not take into account the replacement cycle of equipment currently in place.

Any benefits other than energy/carbon savings which may occur as a result of installing any of the measures considered have not been taken into account (e.g. additional benefit of reduced noise from installing double glazing). It should also be noted that only energy efficient measures offering a comparable level of service to their less efficient counterparts were considered.

A more detailed description of each of the measures is provided in Section 4.3.

4.2.6 Determining Cost Effectiveness

In order to determine the cost effective and total potential savings of each measure in the UK commercial and public sector it’s impact across the wide range of building types and energy use patterns was established by modelling the installation of each measure in a wide variety of existing buildings. The energy audit data within the N-DEEM database holds detailed energy use patterns for individual items within each of around 700 hereditaments[d], and this was used as the basis for determining potential savings before being scaled up to represent national potential savings.

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[d] *A hereditament is a unit of rateable property. It may refer to a single premise with a unique address, to more than one building on a single site, or to a part of a premise, typically where there is more than one occupier at an address or where different activities occur within the same premise.*

4.2.7 Fuel Prices and Carbon Emission Factors

Fuel prices and carbon emission factors are both input parameters which can be changed in the flexible spreadsheet by the user. The default values currently in the spreadsheet are for 2002.

4.2.8 CRC and Non-CRC Sectors Disaggregation

The sectors affected by the Carbon Reduction Commitment (CRC) (which will targets large organizations whose annual mandatory half hourly metered electricity use is above 6,000MWh) were identified using information from the partial RIA[17]. From this the proportion of each end use covered by the CRC was identified and these were applied to the relevant carbon saving measures.

4.2.9 Public and Commercial Sectors Disaggregation

The results were split into the public and commercial sectors based on the latest N-DEEM estimates by sub-sector, fuel type and end use. Energy used in further and higher education, government estate, other government, health and schools has been allocated to the public sector split by fuel type and end use so that the energy efficiency measures considered apply to the representative proportion of fuel type and end use in the public sector.

4.2.10 Devolved Administrations Disaggregation

The results were disaggregated into each of the Devolved Administration using the latest fossil fuel and electricity consumption figures for the Devolved Administrations published by BERR[18].

4.2.11 Dealing with Different Options for an Individual measure

For many conventional measures there may be different levels of carbon savings arising from different levels of improvement. For example, replacing an existing fridge freezer with an A or A+ rated model, or installing increasing levels of roof insulation. The primary input data used here is considered the costs and benefits associated with a ranges of similar options. So to determine the maximum cost effective potential we have assumed that, where there are different options which are cost effective, the one which saves most carbon will be implemented in all instances where it is cost effective to do so, then the costs and benefits that arise from the option which saves the next most carbon will be applied to the remainder where it is cost effective to do so, and so on down to the point where the cost effective limit is reached. The costs and benefits associated with instances where none of the options are cost effective are determined based on the total carbon savings that would be achieved by implementing the options which saves the most carbon minus the cost and benefits associates with the cost and benefits arising from the mix of cost effective options identified.

This “cascade” analysis is performed in order to determine the maximum potential for cost effective and non-cost effective carbon savings from an individual measure.

4.2.12 Accounting for Overlaps and Interactions

The cost abatement analysis for individual measures provides a means of ranking each individual measure according to the potential cost effective carbon savings; however, adding all these individual measures together will significantly overstate the actual potential savings achievable. This is due to the overlaps and interactions between measures (see Section 2.2 for more details on the various types of interactions).

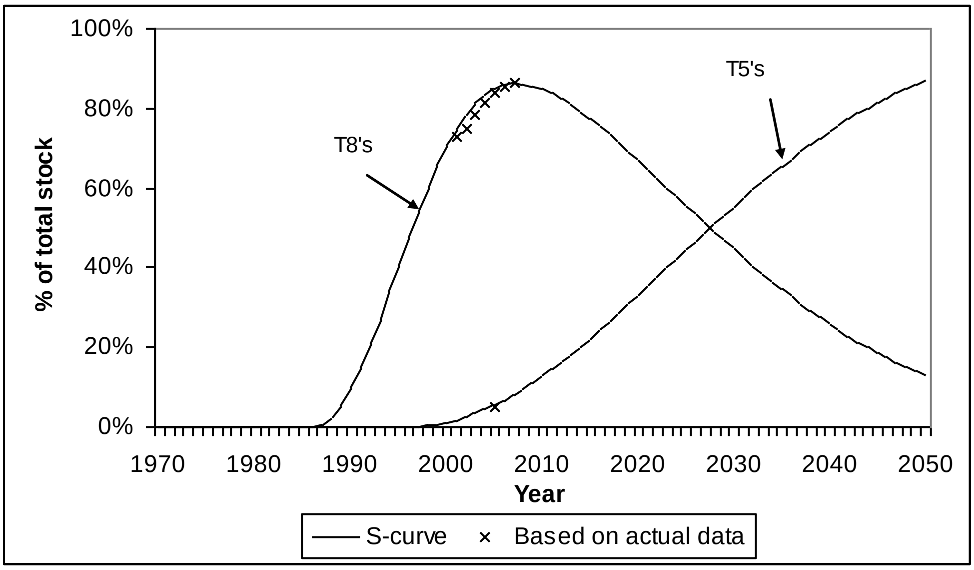
Firstly, there are measures which overlap because they affect the same end use, for example, condensing boilers can replace standard boilers and thermostatic radiator valves (TRVs) may also be fitted. Then there are interactions between measures, in particular a reduction in the overall level of savings arising from the heat replacement effect[19] (See Section 2.2 for further explanation).

To take account of the thermal interactions between measures we have applied measure specific adjustment factors derived from previous runs of the N-DEEM's thermal simulation model (3TC). These runs were based on the simultaneous implementation of all measures and the resultant savings have been reallocated between the measures based on the extent to which they overlap with each other.

4.2.13 MAC Curves for Future Carbon Budget Years

The analysis is based on a 'static' building stock, and therefore ascertains the savings that are still available in the current building stock in future years. Here we have taken into account the fact that a proportion of the potential for carbon savings in the sample data (representing c. 1997) will have already been taken up ("remaining potential analysis"). Using S-curves depicting the uptake of each measure[e] (see Figure X below for an example) across the UK non-domestic building stock[f] the remaining potential at any point in time can be determined. The remaining potential analysis took into account the climate change policies included in the baseline of the most recent energy and carbon projections from the DTI[1].

Figure X: S curve showing the uptake of T8 and T5 linear fluorescent lighting



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[e] *Where data were available.*

[f] *The S-curves were originally produced for the future scenarios work carried out under contract to Global Atmosphere Division, Defra.*

4.3 Detailed Description of Measures and Associated Assumptions

The energy efficient measures modelled can be broken down into fabric measures, technology measures and control measures. There is a further section on “alternative measures” which save carbon due to reducing the carbon intensity of the fuel used at a building level, such as photovoltaics.

4.3.1 Fabric Measures

Insulation

Information on hereditaments[d] already insulted is contained within the sample data, therefore the application of insulation measures was only considered for hereditaments which do not currently have any insulation. As this is an add-on measure total costs, rather than marginal costs, were applied. In addition, there is no specific information on the size of wall cavities, therefore, a maximum thickness of around 100mm has been applied and is assumed to be suitable. Where a hereditament does not have cavity walls, the application of external wall cladding/insulation is considered. The effect of the change in U-value between the insulated and uninsulated fabric area was used to calculate the reduction in heat loss over the heating season.

Windows

For double-glazing a marginal cost was used based on the assumption that the windows were being replaced anyway. Only the glazing unit (i.e. not the frame) has been analysed. As for insulation, the change in U-values was determined and used to calculate the reduction in heat loss. Innovative glazing[g] is included in the analysis and this refers to chromogenic glazing which works to either reduce excessive brightness and solar gains or to improve the insulative materials contained within the glass to control internal heat gains and glare during the summer and heat losses during the winter.

4.3.2 Technology Measures

Lighting

Savings were calculated by determining the difference in luminous efficacy between the standard and energy efficient measures for both lamps and ballasts. Luminaires were not included in the modelling. Light Emitting Diodes (LEDs)[g] are included in the analysis – it is assumed that this measure can replace fluorescent tubes.

Boilers

It was assumed that all replacement boilers would be of the condensing type and that the average efficiency of the existing boiler stock was 65%. The cost of both standard and condensing boilers was based on the average cost of boilers of 106kW size which was taken as a reasonable representation of the

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[g] *This was one of the technologies which came out of the FES (2005) Assessment of Emerging Innovative Energy Efficient Technologies as part of the Energy Efficient Innovation Review and was modelled as an additional measure in previous work carried out for Enviros.*

size of a boiler in the non-domestic building stock. Radical boiler re-design[g] is included in this analysis and refers to the potential to redesign the boiler heat exchange surfaces to allow more effective heat exchange across variable fuel burn rates experienced within a modulating boiler. It was assumed that these boilers are most likely to be suitable in situations with a high heat demand that require large boilers.

Refrigeration and freezers

Since the energy audit data does not provide a breakdown of the energy rating (A+ to G) of each appliance, it was assumed that the average rating of fridges and fridge-freezers in the stock was C. Since freezers generally have a much longer replacement cycle it was assumed that the average rating of freezers in the stock was D[h]. Changes to more efficient ratings were therefore modelled. The costs were determined based on the same size of refrigeration unit and average prices were calculated according to the energy rating category.

Office equipment

The only direct technology replacements modelled were replacing standard CRT (cathode ray tube) monitors with flat screen LCD (liquid crystal diode) monitors or Organic Light Emitting Diode (OLED) monitors[g]. It was assumed that all monitors currently in the sample database stock were standard CRT monitors and that all of these could be replaced.

Changes to the power management strategies of computers, monitors, printers, photocopiers, faxes and vending machines were also modelled. Here the level of savings that could be achieved through good management practices was applied[20]. For computers and monitors two power management strategies were applied; firstly the use of standby and sleep modes and secondly turning the equipment off overnight. For printers, photocopiers and faxes only turning equipment off overnight was applied since these items are pre-programmed to go into standby mode when they are not actively printing/copying. For vending machines only standby power management options were applied. Where each individual item of equipment was used for more than 3,000 hours a year it was assumed that it was being left on overnight and the savings which may be achieved from switching equipment off overnight were applied.

Motors and Variable Speed Drives (VSDs)

Although four different types of motor were identified (2 to 8 pole indicating the power output/rating of the motor), the energy audit data does not differentiate between these types. It was therefore assumed that all the motors in the sample data were 4 pole motors and that all could be replaced by the most efficient EFF1 type motors.

VSD's were divided into small (<2kW), medium (2 – 4 kW) and large (>4kW) in order to take account of the fact that potential savings vary according to the size of the motor.

Fans

An average efficiency gain from the efficient versions of a variety of different fans (window, wall, roof and panel fans) was used. The efficiency gain was determined by calculating the airflow per unit of energy used.

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[h] *Freezers have an average lifetime of 11.8 to 16.2 years, whereas for fridges this is 10.4 years and for fridge-freezers this is 8.7 years – www.mtprog.com, Briefing Note 8: Assumptions underlying the energy projections for Cold appliances.*

Compressed air

Savings from both reducing the pressure by 1 bar and reducing the inlet temperature by 4 degrees Celsius were modelled. Reducing the pressure assumes that the pressure requirements are still met but that they were originally over-specified[21].

Air conditioning

It was assumed that in all instances, currently installed air conditioning systems could be replaced with systems which are 20% more efficient and incurring no additional cost[22]. This could be achieved through a combination of more efficient components (e.g. chillers, fans) and more appropriate sizing and design of the system.

4.3.3 Control Measures

Lighting controls

These were separated into two types of operation; building level management control e.g. turning lights off when not required, and room based controls such as presence detectors or stairwell timers. These include behavioural controls as well as technology-based controls. Light detectors were only applied in rooms where good daylight was deemed to be available and other controls were applied according to room type and size. Some controls, e.g. presence detectors were applied on a per m^2 basis.

Heating controls

Heating controls refers mainly to building based controls such as programmable thermostats. Thermostatic Radiator Valves (TRVs) were applied to all radiators not currently fitted with TRVs.

4.3.4 Additional Measures - Renewable and Low Carbon Technologies

Photovoltaics (PV)

The total potential for electricity generated by PV in the UK commercial sector was obtained from a report produced by the University of Northumbria[23]. The total capacity provided in the report includes instances where PV may provide an over-generation of power in the summer months and therefore be available to feed into the grid; since we are only interested in the useful power supplied to the building, this was taken into account by using monthly demand and generation data for a sample building[23] to estimate that around 20% of the generated power may be fed into the grid. It was assumed that approximately 30% of the total potential was for roofs and the remaining 70% was for walls, based on a breakdown of annual solar input per unit surface area for walls and roofs taken in sample in Plymouth[23]. Where PV could be fitted to walls as an alternative to cladding, a marginal cost was used. For roofs, it is possible to replace standard roof tiles with PV tiles; however, more detailed analysis indicated that this was the least cost effective option for roof PV systems. Since the energy audit data cannot provide information on the angle of the roof, the direction in which it faces and the shading from other buildings and trees it was not possible to break down the analysis into the cost effective and non-cost effective potentials. As it is widely acknowledged that at current prices PV is not cost effective, this does not present a major issue. A figure of 732 kWh/kWp[i] was determined from DUKES[j] figures for total installed PV capacity and total power generation from PV to indicate the expected power supplied from the potential to be installed.

Solar Hot Water (SHW) panels

The total potential for hot water generated by SHW panels in the UK commercial sector was determined in the same way as for the PV potential, but for roofs only[23]. A figure of 450 kWh delivered to the hot water tank per m^2 installed was assumed based on the figures for the more efficient evacuated tube SHW systems given in SAP 2005 (draft)[k] and an average figure of 1.5 kWp per m^2 installed was assumed[l]. As was the case for PV, since the energy audit data cannot provide information on the angle of the roof, the direction in which it faces and the shading from other buildings and trees it was not possible to break down the analysis into the cost effective and non-cost effective potentials.

Heat pumps

Here, the marginal costs and savings compared to a condensing boiler were considered and for ground source heat pumps the cost of installing the pipework was also included. Ground source heat pumps were considered first and, in instances where these were not appropriate, air source heat pumps were considered. The building stock was split into five sections (which were further split into 9 size bands) for analysis:

- Buildings with air conditioning where a reversible heat pump could be fitted in place of a non-reversible one
- Buildings with potential for ground source heat pumps with large heat emitters (either because heat emitters are already oversized or become so due to increased insulation or because under floor heating was/is to be fitted)
- Buildings with potential for ground source heat pumps with standard sized heat emitters
- Buildings with no potential for ground source heat pumps with large heat emitters (either because heat emitters are already oversized or become so due to increased insulation or because under floor heating was/is to be fitted)
- Buildings with no potential for ground source heat pumps with standard sized heat emitters.

Combined Heat and Power (CHP)

The economic and cost effective potential for CHP was considered for buildings with a high heat demand. The following sectors were therefore assumed to be suitable for CHP; swimming pools, leisure centres (with and without pools), police stations, hotels, hostels, hospitals and fire stations. It was assumed that for these building types gas-fired CHP was installed where appropriate and the CHP system was sized based on heat-led operation running for 16 hours per day and that additional heating was available. Savings were compared to heat from a condensing boiler and electricity from the grid.

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[i] *kWpeak is the power generated under optimum conditions, the kWh/kWp figure provides an indication of the actual power likely to be generated in UK conditions.*

[j] *DTI, Digest of UK Energy Statistics, HMSO, 2004.*

[k] *http://projects.bre.co.uk/sap2005/*

[l] *Personal communication, Nick Davies, BRE.*

References

[1] DTI, Updated Energy and Carbon Emissions Projections, The Energy White Paper, May 2007.

[2] Delivering cost effective carbon saving measures to existing homes. BRE Client Report 239-552. October 2007.

[3] UK Insulation Sector Supply Chain Review. Final Report. February 2007. Prepared by ESD (Energy for Sustainable Development Ltd) and published by Defra.

[4] Carbon Emission Reduction Target April 2008 to March 2001. Consultation proposals. May 2007. Defra.

[5] Potential carbon savings from energy efficiency and microgeneration appliances installed in the domestic sector over the period 2011-2020. Defra draft V1.0

> *References 2 to 5 can all be found on the Defra website at: http://www.defra.gov.uk/environment/climatechange/uk/household/supplier/index.htm*

[6] Personal Communication. Solid wall insulation data provided by Tad Nowak, BRE

[7] Sales data provided to BRE every month by the Trade Association, HETAS.

[8] The Domestic Heating Boiler Energy Model. Briefing Note (currently being revised) available on the Market Transformation Programme website (www.mtprog.com).

[9] Personal communication. Controls data provided by Jack Hulme, BRE.

[10] ETSU (now FES) report for DTI *New and Renewable Energy: Prospects in the UK for the 21st Century, Supporting Analysis.* March 1999.

[11] Personal Communication. Clear Skies grant application data provided by Chris Roberts, BRE.

[12] Solar Trades Association figures provided via Defra.

[13] Generating the Future: An analysis of policy interventions to achieve widespread micro-generation penetration. Energy Saving Trust. November 2007. (Figures from the report actually provided by Victoria Willis, EST)

[14] National Survey Report of PV Power Applications in the UK, 2005. July 2006. Prepared by IT Power and published by the Department of Trade and Industry. http://www.iea-pvpsuk.org.uk/exchange/infoexch_nsroverview.shtml

[15] Sheffield Hallam University, Energy use in the non-domestic building stock: 2000 catalogue of results, Draft report no. SCP 4/12.

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[16] Brown F, Rickaby P, Bruhns H, Steadman P, Surveys of non-domestic buildings in four English towns, Environment and Planning B: Planning and Design, Vol. 27, p. 11, 2000.

[17] Updated Partial Regulatory Impact Assessment: Carbon Reduction Commitment, DEFRA , June 2007 http://www.defra.gov.uk/corporate/consult/carbon-reduc/partial-ria.pdf

[18] BERR, Gas and Electricity generation and supply figures for Scotland, Wales, Northern Ireland and England, 2004 and 2005, http://www.berr.gov.uk/files/file43902.pdf, http://www.berr.gov.uk/files/file42926.pdf

[19] 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 – However, this would only affect air conditioned buildings which account for a relatively small proportion of the existing building stock.

[20] MTP, Briefing Note 1: Underlying Assumptions for Information and Communication Technology, www.mtprog.com

[21] GPG241, Energy savings in the selection, control and maintenance of air compressors. 1998.

[22] Eurovent Certification Company, Directory of Certified Products: Air Conditioners, Paris, 1999.

[23] Hill, Pearsall and Claiden, The Potential Generating Capacity of PV-Clad Buildings in the UK: Volume 1, Newcastle Photovoltaics Applications Centre, University of Northumbria, 1992.