Appendix D: Energy model

D.1. The UKDCM2

D.1.1. Background to the development of the model

The following is an explanation of the basics of the UKDCM2 (United Kingdom Domestic Carbon Model version 2), the philosophy behind the calculations and the input and output data.

The modelling undertaken for this study is from work undertaken as part of the Building Market Transformation (BMT) project funded by the EPSRC and Carbon Trust as part of the Carbon Vision Buildings programme[1]. BMT took as a starting point the UK Domestic Carbon Model (UKDCM), as used in the 40% House project[2]. However, there is a significant amount of development work ongoing on the model. It is intended that as part of BMT, the model, all the data and assumptions, and analysis work (*eg*. scenarios and sensitivity testing), be made available for users to explore and to construct their own scenarios with, in late 2006.

The UKDCM2 is similar to both BREHOMES (Shorrock *et al*) and the UKDCM (Boardman *et al* 2005). The UKDCM was written because BREHOMES contained data which was proprietary and was therefore unavailable. The UKDCM2 is a bottom-up IDL (RSI) implementation which applies a BREDEM-8 (Anderson *et al*. 2001) energy calculation to the entire of the UK housing stock in order to calculate electricity and gas usage as well as total carbon intensity of the UK domestic sector. The model incorporates all energy used in space heating, as well as cooking, water heating and domestic lights and appliances. The housing stock is taken forward on a year by year basis, applying demolitions, retrofits, new build, changes in heating systems *etc*. Energy calculations are made each month for each year from 1996 to 2050 (see Figure 1).

The bottom up modelling process combines known historical data and trends with projections about a range of possible futures and what might cause them.

The housing stock represents the UK housing stock in 1996 using data taken from the English Housing Condition Survey (EHCS) and the equivalents in Scotland, Wales and NI. The 24 million dwellings in 1996 are represented by 431 housing categories.

D.1.2. Context of the model

Section 3.2 of the main report describes the Socio-technical context within which the model is positioned, and the extent to which it takes into account demographics, climate, supply side changes, societal influences and behavioural change, technologies, and policy measures. It does not explicitly take into account economics, but it does take into account a more wealthy society with higher expectations of home ownership, comfort and energy services.

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[1] See http://www.eci.ox.ac.uk/lowercf/bmt.htm

[2] See http://www.eci.ox.ac.uk/lowercf/40house.html

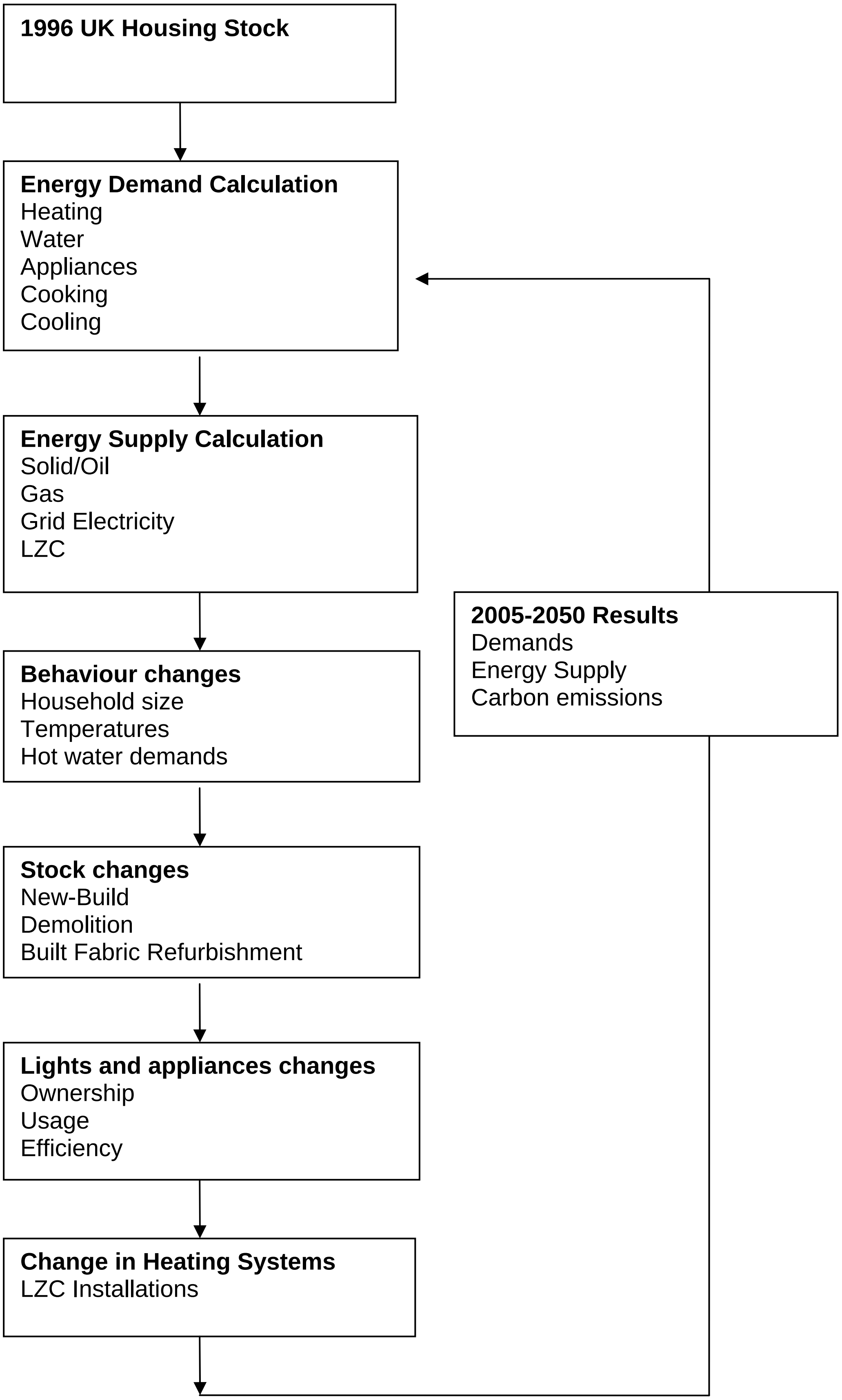

Figure 1 The Structure of UKDCM2

D.1.3. A heat flux model

When a home is at a steady temperature, heat losses equal heat inputs. Homes are heated through solar gain, bodies, waste heat from lights and appliances, and heat given off from the hot water tank and distribution system (although not all these inputs are considered useful because they can occur when no heat is demanded, eg. at night or in the summer). The remaining heat demand (the useful energy for space heating) is provided as the output from the main heating device. Heat is lost through walls, floor, ceilings, windows, from warm air vented to the outside, and through hot water to the drain.

BREDEM-8 is the Building Research Establishment tool for estimating energy usage in a specific house, and is a heat flux model. In UKDCM2, BREDEM processes are applied to a model of the whole housing stock. This is repeated for each month and for each year of the scenarios. The stock model is evolved forward at the end of each year by changing the rate of user defined retrofits, new build, demolition, U-values for retrofit elements, carbon intensity of electricity and gas, the mix of the heating systems and additional sources of energy (renewables, solar water heating etc). Thus gas use, electricity use, and carbon intensity can be calculated for each year for the UK housing stock to 2050.

In the current stock, typically 55% of the useful space heat comes from the boiler. The rest of the heat comes from what is described as ‘incidental gain’. In the low-energy homes in 2050, heat from the main system would fall to 25% (In scenario B) and 21% (in scenario C) of the useful energy required to heat the home (Figure 2).

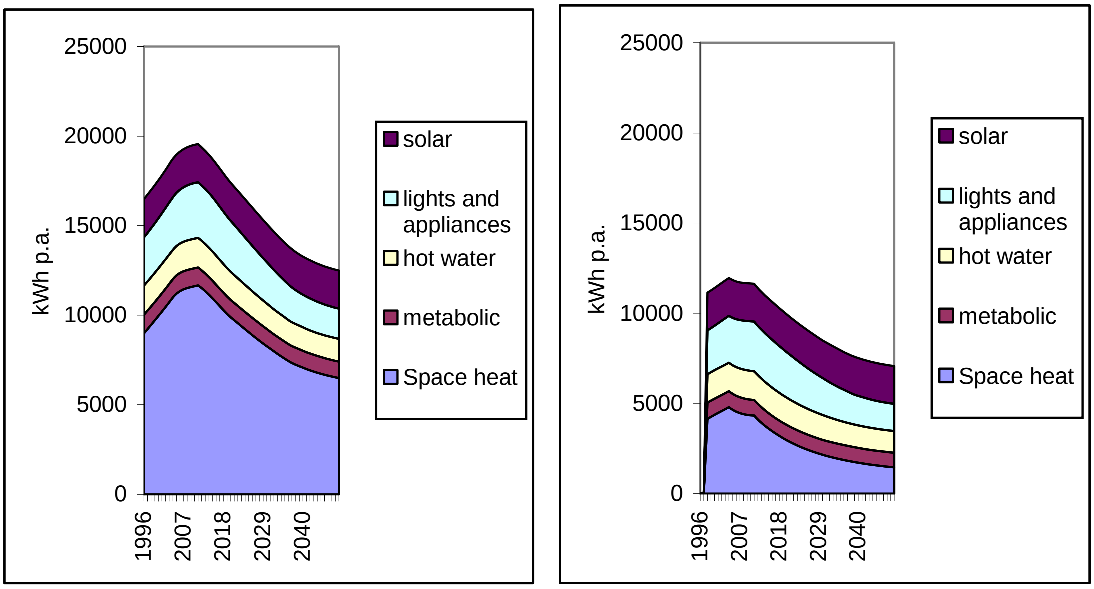

Figure 2 **Useful heat gains in pre 1996 (L) and post 1996 (R) homes, Scenario C**

In terms of percentage of heat loss, ventilation accounts for a significant loss in current homes, but this increases as a percentage as building fabric is improved through refurbishment (Figure 3). In post 1996 homes built to appropriate building regulations, the total heat loss is much smaller, with fabric heat loss and ventilation loss minimised, leaving windows and hot water as major sources of heat loss. Indeed, in the ultra low energy house, recovery of heat from waste hot water could be an attractive measure.

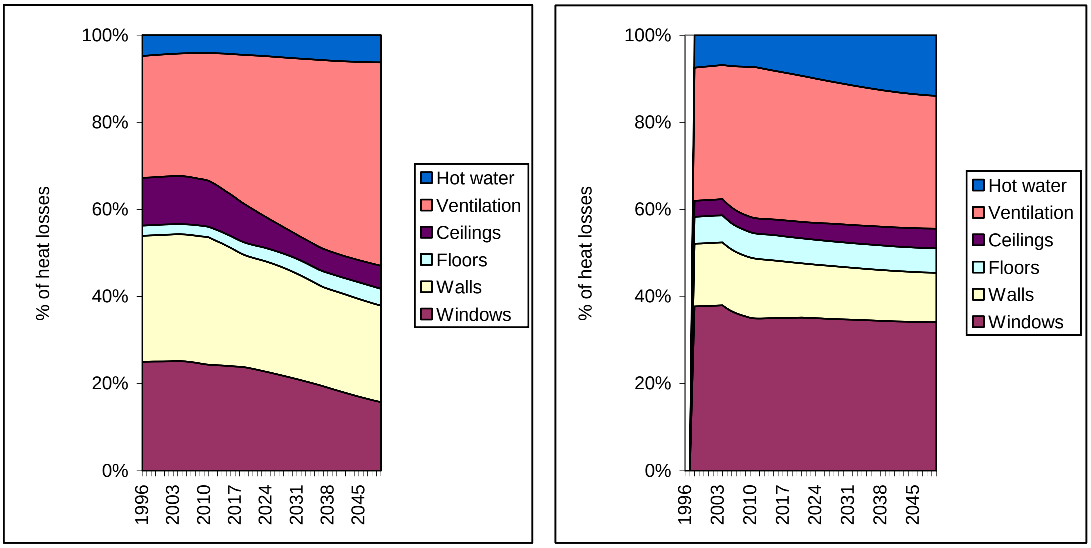

Figure 3 **Heat losses in pre 1996 (left) and post 1996 (right) homes, Scenario C**

D.1.4. The importance of useful energy

In order to understand the meaning of the results it is important to be clear on some definitions. The following definitions are adapted from DUKES (2005).

Primary energy is the total input of primary fuels and their equivalents including energy used or lost in the conversion of primary fuels to secondary fuels (for example in power stations and oil refineries), energy lost in the distribution of fuels (for example in transmission lines) and energy conversion losses by final users.

Delivered energy is energy from deliveries, by energy companies via pipelines for gas, or the public distribution system for electricity or via merchants for oil and coal.

Useful energy is the energy available after deduction of the losses incurred when final users convert energy supplied into space or process heat, motive power or light. Such losses depend on the type and quality of fuel and the equipment used and on the purpose, conditions, duration and intensity of use.

Using these definitions, there are a number of implications for this accounting process for the UKDCM:

- Based on the discussion above, **Lights and appliances and hot water**, are treated first for their service in terms of light, hot water out the tap etc, and second as a source of heat to heat the dwelling. To simplify the analysis it is assumed here that for all electricity use, all energy in is useful, i.e. total useful (light plus heat etc) is equal to delivered.
- A number of forms of **Low and Zero Carbon technologies** provide useful energy, but would not be included in DUKES as delivered energy, for example: energy from solar thermal; electricity generated in building integrated wind, PV, or CHP in the home (although electricity supplied from community based CHP outside the home would be considered delivered via the public network). This is consistent with methodology in DUKES for on-site generation (described as auto-generation) where fuel used in autogeneration (where gas oil, or coal) is counted as delivered, but not the electricity generated. To simplify the analysis it is assumed for electricity generated, that useful electricity from LZC displaces delivered electricity in a ration of 1:1.

For these reasons, the modelling is based on useful energy demand in the home, much of which would be met from LZC. However, in order to understand the impact on the supply industries, this has to be equated back to the impact on delivered energy.

The priorities in reducing the environmental impact of a dwelling are thus:

1. **reduce heat losses from the dwelling** so that energy in is provided from solar gain and bodies, and then decarbonise energy sources.
2. Lights and appliances are (in heat terms) a high carbon energy source equivalent to electric heating. **Improved energy efficiency of lights and appliances** means that the heat from them is replaced by a lower carbon source (the heating system)
3. **reduce the carbon content of space and water heating**. This could be via renewables, or by taking some of the energy in as electricity (CHP, wind or PV) for lights and appliances. The net effect of efficiency and LZC could be to reduce delivered electricity to zero.

D.2. Comparing the model with actual data

For the period 1996 to 2005 the model is compared with actual data. 1996 is taken as a starting point because the House Condition Surveys provide a detailed picture of the stock. From 1996 to 2005, data is reasonably accessible on evolution of ownership and condition, as well as on actual weather data from the Met Office[3] (note for a comparison with actual data, weather is used, but when projecting forwards, climate mean 1971-2000 is used). The outputs of the model can be compared to known actual energy supplied data from DTI over 31 quarters 1998 - 2005[4].

Within the model there are a number of variables which are not well known, such as the heating cycle and dwelling occupancy times, the thermal mass and responsiveness of the heating system as well as the actual mean internal temperatures. In this study, the internal temperatures were taken from the Housing Surveys and the internal temperature trajectory from BRE model data. This leaves a number of factors with which the model could be calibrated, factors which, however, are likely to change slowly over the evolution of the housing stock and lifestyles. The overall agreement between modelled energy and actual energy is less important in the model validation than the seasonal change and correlation with external temperature.

Modelled temperature may not equal actual temperature for a number of reasons, but an important one is that building regulations are a design standard, and because there is little enforcement, there may be a significant difference between a home as designed and a home as built. Anecdotal evidence suggests that workmanship on UK construction sites is poor, that buildings lose more heat in practice than in theory, and that the construction industry is ill-equipped to deliver airtight buildings. These conclusions are supported by a study on construction practices (Olivier 2001), one on building heat loss in real life (Doran 2000) and one on airtightness testing (EST 2004). Thus homes may in practice never reach the modelled internal temperatures. This could be a significant source of error in BREDEM, BRE Domestic Energy Factfile, this model, Government projections etc. More measured data is needed to validate policy.

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[3] See http://www.metoffice.gov.uk/

[4] See quarterly data on energy supplied to the residential sector at www.dti.gov.uk/energy/inform/energy_trends/index.shtml

Using this approach of validation and calibration, it can be seen from Table 1 that total energy modelled is within 0.25% of total energy actually supplied across the 31 quarters. The differences are 7TWh low for coal and oil, and 7TWh high for electricity out of 4224 TWh all fuels on an annual average year.

Table 1 Average annual energy, 1998-2005 (TWh)

	coal and oil	gas	electricity	total
DTI data	58.80	371.55	113.44	**4,214.40**
UKDCM2 modelled	51.65	372.39	121.03	**4,224.29**
% difference	-12.16%	0.23%	6.69%	**0.23%**

Figure 4 shows that by aggregating the monthly outputs from UKDCM2 into quarters, a close fit can be obtained with quarterly DTI energy data including seasonal variation in gas use. The seasonal variation in electricity use is less close, because BREDEM does not account for lights and appliances use being seasonal, though we know from previous work by ECI as part of the DECADE programme that households cook less in summer, and light use is inversely proportional to hours of daylight. The seasonality of electricity use is due to electricity use in space and water heating. Because there is no storage of gas and electricity, delivery and use of these commodities happen simultaneously. The relationship between seasonal modelled use, and actual deliveries of coal and oil (not shown) is poor, because coal and oil is delivered throughout the year (prices are lower in summer) and stored for use in colder periods. Figure 4 also shows a good fit between hot water use and space heating, on the basis that summer gas use includes little or no space heating.

It is interesting to note that most of the variation in delivered energy can be explained by factors within the model, - i.e. number of homes, ownership of appliances, and temperatures. It is not necessary to include price to explain the variation, though income (and to a lesser extent energy price) may explain variations in desired internal temperatures and ownership of appliances over the period.

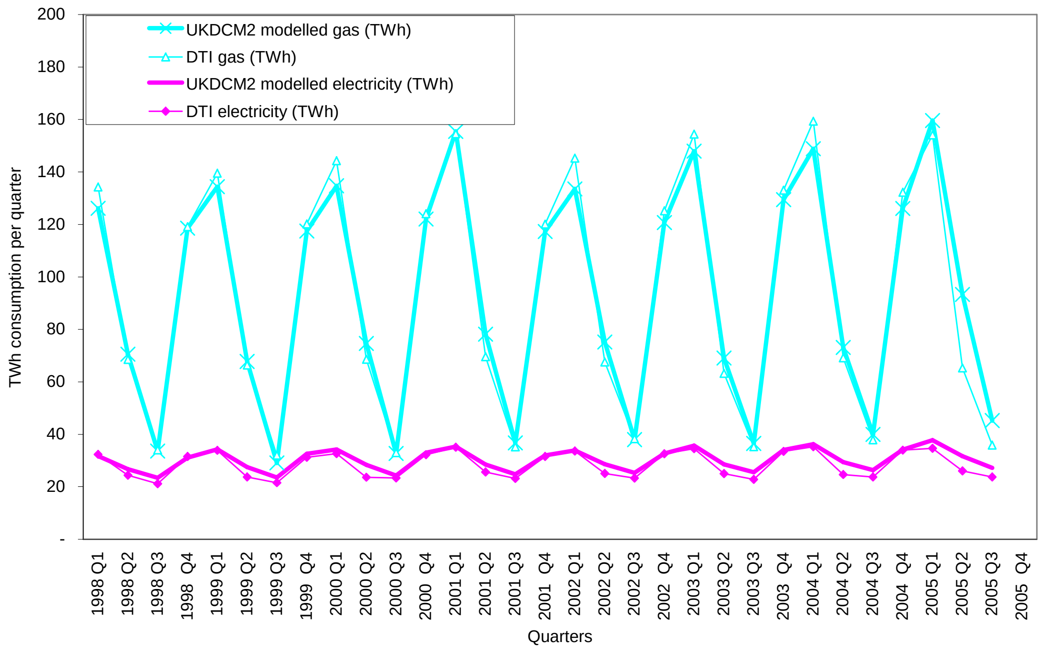


Figure 4 Predicted and actual gas and electricity use from homes

There does however, remain a risk of getting the right answers for the wrong reasons, for example, homes being heated to a higher temperature for shorter periods than we know of. High temperatures cause larger heat losses, but this factor could be influenced by policy. Occupancy is largely independent of policy and dictated by the age profile and social structure of society and work and leisure patterns. These factors could each be very different in 2050 than today, causing a different (higher or lower) result than today. The model becomes less reliable the further away from today. However, it is not a prediction tool, but a scenario analysis tool. Any modelling error is likely to be in each of the scenarios, and thus cancelled out. So whilst the absolute level of the scenarios may vary, the difference between scenarios is likely to be secure.

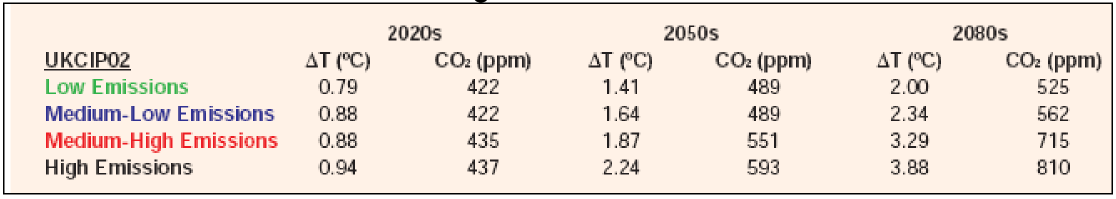
With these caveats, however, the model is as good a representation of reality between 1996 and 2005 as possible within the resources available. On this basis, household numbers, ownership, efficiencies etc are projected forwards to explore a range of possible futures.

D.3. Assumptions going forward

D.3.1. Climate

Our aim in this work was to comment on energy issues not to open a debate on modelling of climate. The conservative assumption was used of average climate between 1971 and 2000, together with a sensitivity test of +2ºC in 2050. This is a simplification of the UK Climate Impacts programme (UKCIP) Medium High and High Emissions scenarios (Table 2). The impact of a 2ºC temperature rise in 2050 during periods of heating would be a reduction in carbon of 8 to 10% across the scenarios (i.e. a reduction to 44% of 1996 levels becomes a reduction to 40% of 1996 levels). The effect of a 1C rise would be a 5% reduction (44% becomes 41.9%) etc.

Table 2 UKCIP climate change scenarios



	2020s		2050s		2080s	
UKCIP02	ΔT (ºC)	CO_2 (ppm)	ΔT (ºC)	CO_2 (ppm)	ΔT (ºC)	CO_2 (ppm)
Low Emissions	0.79	422	1.41	489	2.00	525
Medium-Low Emissions	0.88	422	1.64	489	2.34	562
Medium-High Emissions	0.88	435	1.87	551	3.29	715
High Emissions	0.94	437	2.24	593	3.88	810

D.3.2. Population and household formation

This subject is common to a range of analysis including energy, land-use and waste and has been written up separately, see Appendix I.

D.3.3. Emissions factors

Emissions factors from gas, coal and oil are uncontroversial, since there is a direct relationship with use of the product in the home. The most controversial emissions factor is electricity, because electricity use in the home comes from a mix of plant using different fuels at different efficiencies and running at different times. The emissions factor would vary going forward with changes in plant from retirements (eg of coal and nuclear) and new build (eg of gas fired stations and renewables).

MTP (2005) illustrates two approaches going forward (Figure 5):

- an emission factor for electricity consumption (the system average value), suitable for monitoring and reporting on carbon emissions based on actual or predicted energy consumption (Carbon Accounting). Historic values are taken from DUKES. The electricity consumption emission factors used for 2005 and beyond are based on DTI energy projections (central growth and the average energy prices) in

Energy Paper 68 increased by 13% to take account of transmission and distribution losses.

- an electricity saving emission factor (based on the average of the marginal generation plant and expected new generation plant) for assessing the carbon reduction that a particular (policy) action will achieve.

A third value in Figure 5 is illustrated. For the last few years, many programmes have assumed an average of 0.117 kg C[5], based on assumptions that new power projects would be gas based. These have become enshrined in DEFRAs reporting guidelines (DEFRA 2005).

Actual data based on DUKES shows, that in practice, emissions have never got as low as either DTI projections used by MTP or DEFRA's reporting guidelines. Since the implementation of new electricity trading arrangements in the UK, gas plant build has been virtually halted, nuclear output has been lower than previously, and coal has been higher. Emissions per kWh have gone up, not declined. Emissions factors assumed by Government seem rather wishful thinking, and importantly, undermine the value of energy efficiency and LZC by more than 20%.

From actual levels in 2004, MTP's 'savings' line seems the most realistic projection. And since network supplied electricity in each of these three scenarios decline markedly, an emissions saving approach based on marginal plant and avoided new plant is most appropriate. Given uncertainties and the lack of any projections beyond 2020, emissions levels from 2020 to 2050 are fixed at those given in 2020. It should be noted that in scenarios B and C, there are no net imports from the network in 2050.

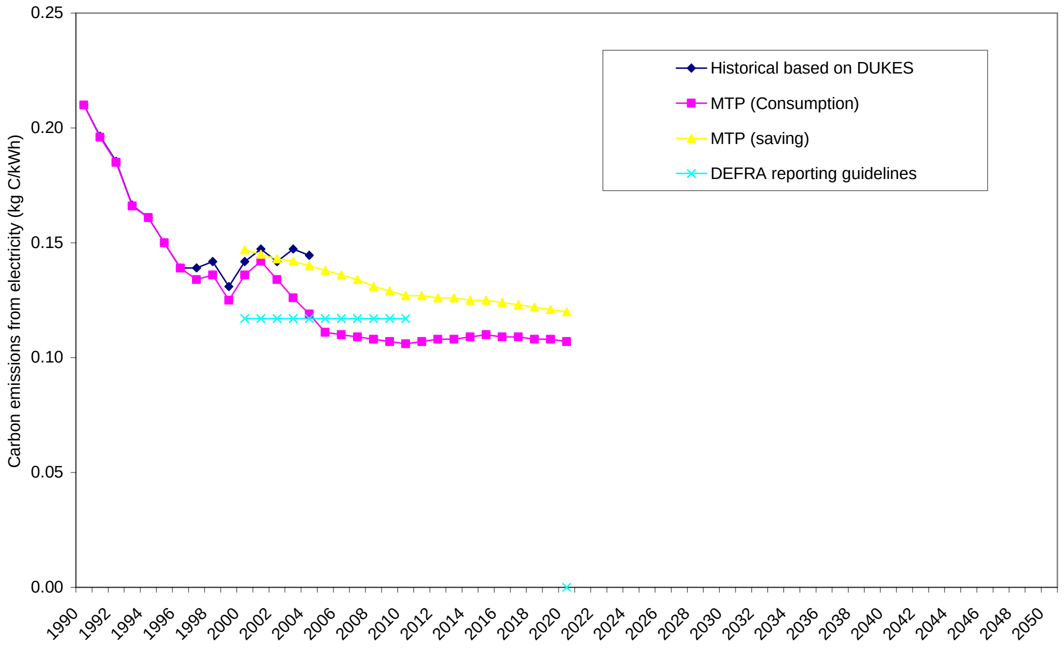


Figure 5 Carbon emissions from electricity (kgC/kWh)

D.3.4. Demands for space heating

Evidence for the starting point and for the trend in space heating is based on EHCS

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[5] Note, 0.43 kg Carbon expressed as CO2 is equal to 0.117 kg C expressed as carbon. The conversion factor is x44/12.

(1996) see Table 3. The problem is that temperatures are different in different parts of the home, at different parts of the day and year. Age and type of dwelling and presence of central heating all play a role, together with income group and occupancy level. Temperatures have not been measured consistently since the 1996 EHCS. Determining something representative of the stock at a given time, and then determining a trend is very difficult. Research by EST (2006) gives cause for concern: internal temperatures may be determined by a 'cohort effect', with younger groups setting thermostats at higher temperatures than older groups. Perhaps a sign of things to come?

Table 3 Evidence of temperatures over time

Source	Sector	Temperatures
Crichley (2001) based on 1996 EHCS energy report	All	In 1996, the average living room temperature was 19.5oC, an increase of 1.5oC over 1986 when the external temperature was almost identical. In the hall (used as a proxy for the remainder of the home) the average temperature was 17.9oC, compared with 16.3oC in 1986. The rate of increase is even higher than anticipated from research in 1980, that found in the previous 30 years temperatures had been rising at around 1oC a decade
Shorrock and Utley (2003)	All	Estimate a trend of 0.2C a year over the last 30 years (24 hr average internal temperature for the six winter months, so likely to be cooler than assumed in UKDCM)
Walker J and Oseland N (2000)	Social housing	19 to 23.5ºC
Alembic research (2002)	Social housing	25-30ºC.
Pett J and Guertler P (2004)	Social housing	23.3ºC in living room 22.8 ºC in hall 21.25 ºC in kitchen.
Oresczcyn T et al (2006)	Low income (HEES eligible)	Living rooms: pre-1930 dwellings 18.4ºC, and post-1930 19ºC. Living room by SAP: <41 17.5ºC and >70 19.8ºC; Bedrooms, pre-1930 16.7ºC; 1930-65 17.2ºC; post-1966 18.2ºC. Bedroom by SAP, <41 15.6ºC and >70 18.1ºC.
Isaksson C (2005)	Swedish low-energy homes	21-22ºC
EST (2006)	All	Nearly half of all homes have their thermostat set above the recommended average temperature of 18-21 degrees. 1 in 5 (19%) set temperatures above 25 degrees in their homes during the winter, with 25-34 year olds clocking up the highest average temperatures of all age groups

In UKDCM2 temperatures are the temperatures demanded by the householder for the duration of the heating cycle (46% of the time) (Figure 6). If the house is cooler than this in the morning, evening and weekends, the heating system is assumed to be called. The temperature is a whole house average. It is assumed that temperatures will continue to rise but saturate, and that as historically, improvements in efficiency in the existing housing stock are predominantly taken as increased warmth. With the levels of refurbishment envisaged, it is also assumed that the difference between old and new dwellings will disappear over time. It may also be assumed that they are lower in a more carbon aware world, eg because of better feedback on energy use and an understanding of the link between temperature and energy use and carbon emissions. The best than can be said is that temperatures modelled 1996-2005 and projected forward are not inconsistent with the available evidence.

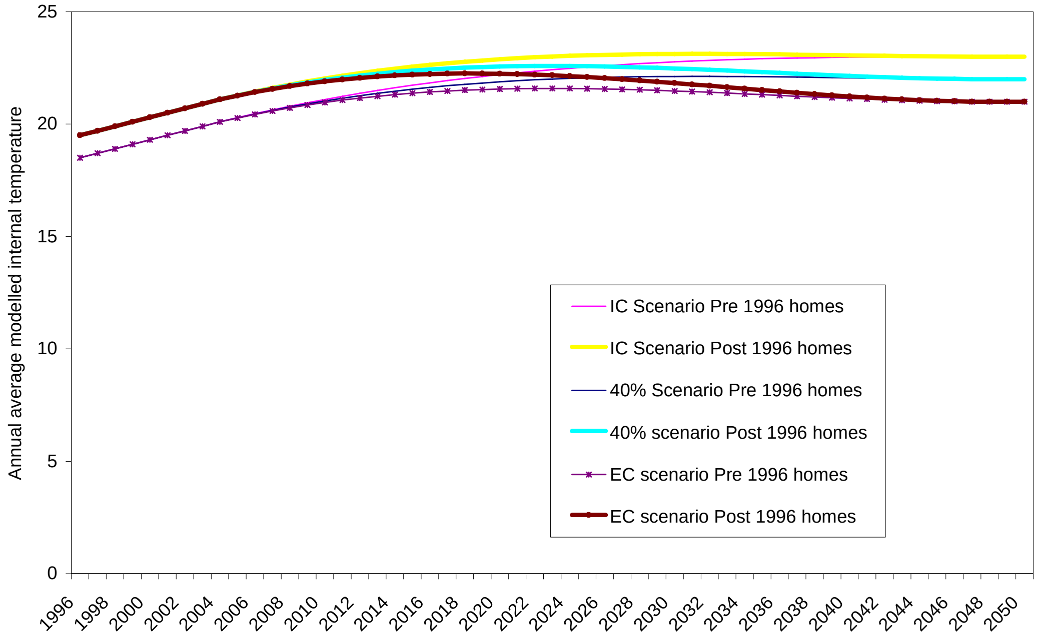

Figure 6 **Temperature trends in UKDCM2 (demanded during the heating cycle)**

D.3.5. Demands for water heating

‘Hot water’ means all water drawn from boilers or hot water tanks that is not used for space heating. This covers instantaneous water heaters (electric showers and immersion heaters) along with water for hot-fill appliances, but not the water that is heated internally by appliances such as dishwashers. In BREDEM, this is modelled separately by the BREDEM lights and appliances algorithm (BRE Housing, 2005). The consumption figures given here are taken to be volumes of water leaving the hot water tank and stored at the standard temperature of 60°C, unless stated otherwise. The literature is not always clear about whether measurements are of water leaving the tank or coming through the tap or shower head (after some heat loss in the pipe, and sometimes after mixing with cold water). For studies of bathing or showering, it will probably be the latter.

Domestic hot water demand stays more or less constant over the seasons, and is closely related to household occupancy: Until the findings of the current EST study of domestic hot water demand are published (possibly in 2006), we do not have any reliable up-to-date figures with which to model recent demand.

In the absence of these, hot water demand has been modelled starting from the figure of 41.2 litres/head/day (lhd) taken from the hot water tap derived from BREDEM-8 (2002). The limited data available show an upward trend in hot water usage over past decades. Hot water consumption is influenced by a range of socioeconomic factors and the projected figures can only be taken as a rough guide to possibilities. There could also be a increase in demand in response to climate change: 1% by 2010, 2% by 2025 and 4% by 2050 (Downing et al, 2003).

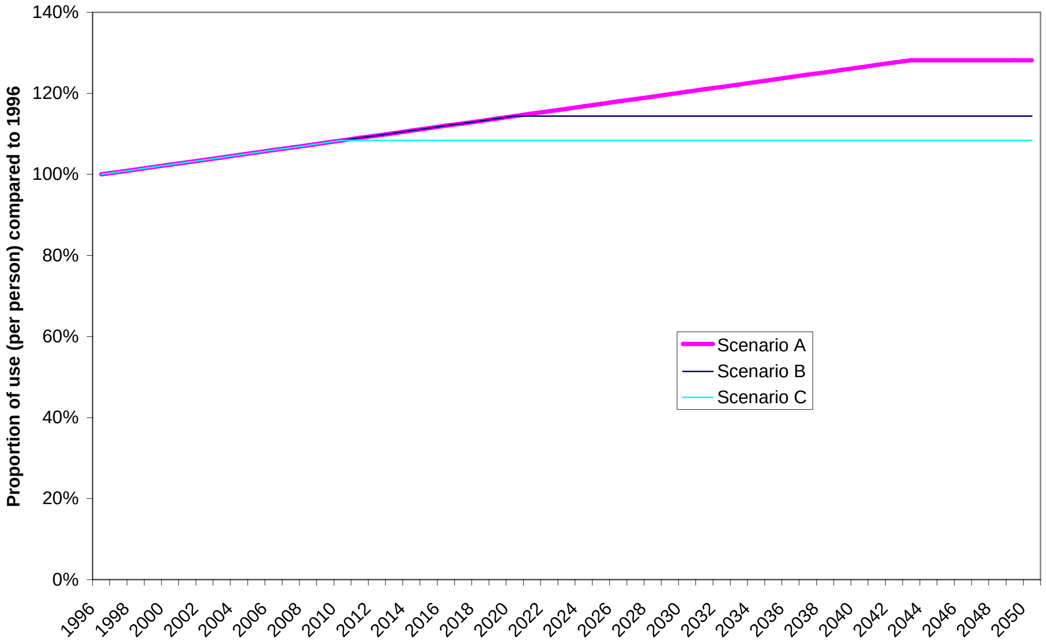

Figure 7 **Hot water demand per person, Scenarios A, B & C**

It is worth remembering that in 1976 the water used for personal washing each day was around 34 litres – a figure that had risen, 20 years later, close to 50 litres and was projected to continue rising to approximately 60 litres by 2020 (Herrington, 1996). Technologies are now widely available that offer enjoyable and affordable showers with increased flows of water. At the same time, perceptions of what constitutes comfort and cleanliness are shifting (Shove, 2003).

Hot water consumption is influenced by a range of socioeconomic factors and the projected figures above can only be taken as a rough guide to possibilities. One such factor is age: other things being equal, the elderly are likely to use less hot water than younger people (Sefton and Chesshire, 2005). The most likely explanation is that younger people are accustomed to a less frugal way of life than their parents. This obviously has implications for future demand.

The main single factor likely to push up demand is the increase in showering, coupled with the increases in flow that are possible with multiple-head showers and power showers. This more than compensates for the decline in bathing (MTP policy briefs; Hand and Southerton 2004).

Herrington takes the view that overall water use may for some purposes be most helpfully viewed as a mixture of ‘basic’ and ‘discretionary’ or ‘luxury’ usage. The former would be expected to be more or less constant across income bands (and is likely currently to be of the order of 100 lhd), but the latter may be expected to be positively associated with income. He cites Water Services Association (WSA) and Ofwat data that point in this direction. WSA statistics for 1991-92 suggested average per capita unmeasured household water demand was 10% higher in the south and east of England & Wales than that in the north and west, while Ofwat returns show that the demand for unmetered water has risen at a higher rate in the comparatively wealthy south and east of England & Wales than in the north and west over 1991-92 to 2003-04 (pers. comm.). Table 4 shows the difference between these regions; one that Herrington expects to grow over time (pers. comm.).

Table 4 Differences in consumption between metered and non-metered households, England and Wales, 2003/04

	Metered consumption (lhd)	Unmetered consumption (lhd)	Difference as % of unmetered
S&E England &Wales	144.5	169.3	15
N&W England &Wales	134.0	147.0	9
Total England and Wales	140.5	157.9	11

Note: South and east England is made up of the statutory water undertakers covering the Anglian, Southern, South West and Thames regions of the Environment Agency. North and west England covers the Midlands, North East and North West EA regions.
Source: Calculations undertaken using data published in Table 13 of *Security of supply, leakage and the efficient use of water: 2003-2004 report* (Office of Water Services, Birmingham, 2004).

The most promising single tool for demand reduction is water metering, which is likely to encourage householders to install lower-flow devices and to use hot water for shorter periods of time. Domestic water metering is introduced at varying rates under each scenario and reaches every household by 2050 under Scenario C (something that could however be achieved sooner, as demonstrated in other European countries).

When comparing the (wholly metered) Isle of Wight with neighbouring (largely unmetered) Hampshire, Ofwat conclude that ‘metering leads to the level of demand being some 10% lower than would otherwise be the case’ (Ofwat, 1999). Another analysis of 8,000 households between 1996 and 2001 found that the average reduction in consumption due to metering in the UK was 9%. The figure varied between 2% and 14% depending on the volumetric charge. There was evidence that water saving measures were self-reinforcing, with 0.2% reduction each month (Baker and Toft 2003, quoted by Sim et al 2005). An Environment Agency Study (2004, also quoted by Sim et al) supported this; it also noted reduced consumption during two years *before* switching, of 8 -11%.

At present, households have the option of installing a water meter, as laid out in the Water Industry Regulations 1999. In 2002, only 21% of properties in the UK and Ireland had water meters but this figure is forecast to rise to 36% by 2010. Water metering has been standard in all new build homes since 1989; therefore the proportion of homes in the stock with meters would gradually rise from now on, even if no further measures to introduce metering were to be taken. The only target the government has set is for 50% of households in the South East to be metered by 2020 (MTP BN WAT13). The Environment Agency has set meter penetration targets of 60-90% of households by 2030, but have some ‘concern as to whether water companies will be able to meet this’ (Sim et al 2005). This concern could be unwarranted: in the six years from 1997-2003, the number of homes with water meters increased by 14%, from 8-22% (ibid.). If this increase continues at the same rate, we could expect an increase of a further 63% in the course of the 27 years from 2003 – 2030, to 85%.

Social norms and behavioural issues are crucial to future hot water demand and at present these are moving in the wrong direction, towards ever-higher demand for washing and showering. These are not amenable to direct policy initiatives. But they are elastic and could adapt to an environment in which both water and energy were valued more highly than at present.

The development of high-flow shower heads and jets could have a significant effect on future hot water demand. Conversely, low-flow taps and shower heads can reduce flow over standard designs by as much as 50%. There are problems of definition about what constitutes high and low flow, but it clearly makes sense to promote the latter and to consider minimum standards for taps, shower heads and water jets.

Hot water storage losses too can be reduced (EVA 1998). Current losses with a foam covered cylinder are (under test conditions over 24 hours) about 2.5kWh per day (having reduced from some 12 kWh p.d. for an uninsulated tank). But the tank is full of hot water only part of the day, so in practice, losses are estimated at 68% (1.7 kWh p.d.) of this. Depending on future insulation thicknesses and the type of insulation used, consumption could come down as shown. Scenario A assumes the best on the EU market by 2050 becomes standard, (and indeed labels, voluntary agreements or standards under the Energy Using Products Directive may drive this) and Scenario C assumes vacuum insulated panels. An important factor in this, is that UK tanks are sold almost in kit form, because they are often combined with heat exchangers linked to hot water systems. They are hard to regulate except through building regulations. EU tanks are often electrically heated, operate at mains pressure and sine they are sold like an appliance (complete, and high value items) they are easier to regulate.

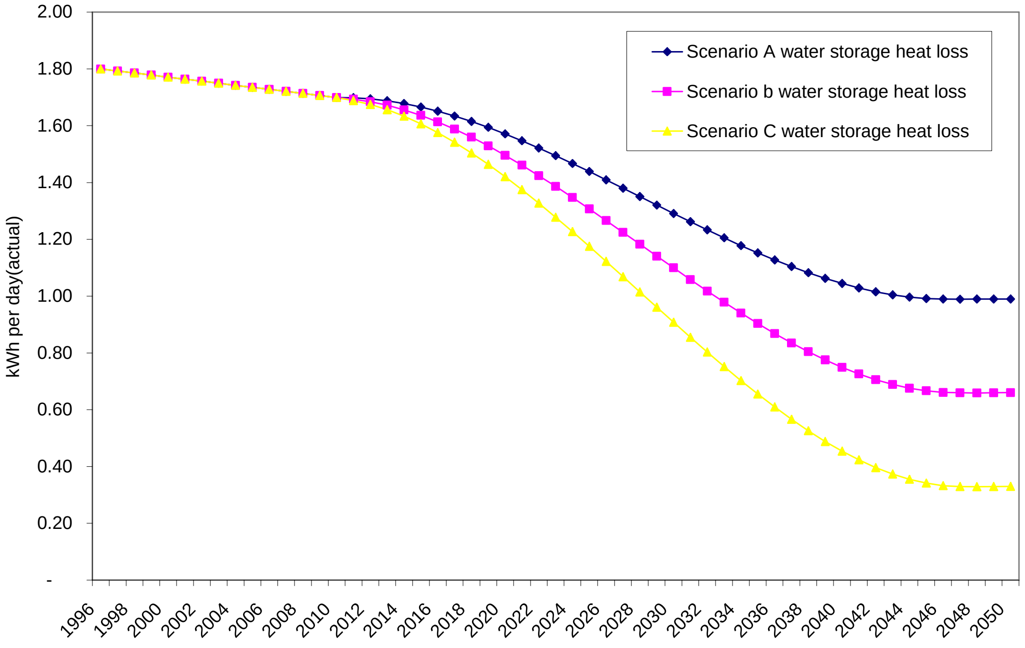

Figure 8 **Hot water storage losses, Scenarios A, B & C**

D.3.6. Refurbishment of the existing stock

The assumed refurbishment strategy within the modelling is outlined in Table 5. Scenario A follows (broadly) current policies, while scenario B accelerates the pace of change. Scenario C is yet more ambitious. The assumed uptake of measures is shown in Figure 9, and the ‘U’ Values for different measures in 2050 is shown in Table 6 (the ‘U’ value gives the rate of heat loss: a lower U value equals better insulation). The main difference between the scenarios is the uptake of measures. In terms of the performance of the insulation, most measures are the same across all scenarios by 2050, with the exception of wall insulation in scenario C.

Table 5 Refurbishment strategy, Scenarios A, B & C

	Scenario A	**Scenario B**	**Scenario C**
Currently cost-effective insulation measures	Increase in line with current trends: saturated markets by 2050	Slightly faster take-up	Faster take-up; cavity wall insulation up 300%, take-up saturates by 2020
More costly and/or disruptive insulation measures	Negligible take-up	15% of solid wall-homes with wall insulation	35% take-up of solid wall insulation plus 37% take-up of external cladding of previously insulated cavity walls
Air-tightness	Slight improvements	Slight improvements	Greater improvements
Windows	Mature market; replacements continue to improve	Mature market; replacements continue to improve	Mature market; improvements achieved slightly earlier

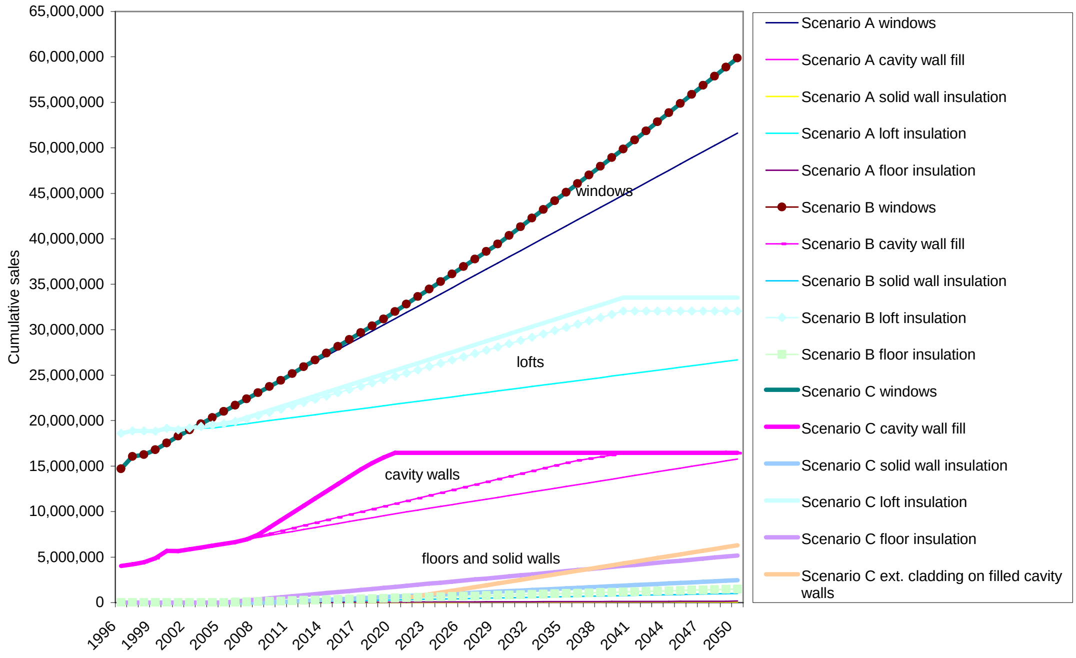

Figure 9 Uptake of refurbishment measures, Scenarios A, B & C

Table 6 U-values of retrofit measures in 1996 and 2050, Scenarios A, B & C

year	Window retrofit	Cavity retrofit	External wall retrofit	Loft retrofit	Floor retrofit
1996	3	0.6	0.5	0.2	0.2
Scenario A 2050	0.8	0.6	0.5	0.2	0.2
Scenario B 2050	0.8	0.6	0.5	0.2	0.2
Scenario C 2050	0.8	0.25	0.25	0.2	0.2

Figure 9 shows 3 scenarios for each of four groups of products: windows, lofts, cavity wall insulation and the final group of (much harder) measures, floors and solid walls. These measures are applied to the 23.8 M homes standing in 1996, around 21M of which will be standing in 2050, whilst some will be demolished. Homes post 1996 are assumed not to be upgraded.

- **Windows**: many homes have some double glazing, but not necessarily all windows in a house are double glazed. There is already a market for replacement double-glazed windows and it is assumed that many units which have already been fitted will be replaced one or more times in the next four decades or so (hence 60 million contracts for 23.8 million homes). The recent rise of uPVC windows, in particular, may lead to failures as the plastic becomes more brittle from UV radiation. The energy performance of windows can improve dramatically, from the current stock average of a U value of 3, current building regulations require less than 2, and the best on the market is already 0.7.

- **Lofts**: around 85% of homes have a loft and the loft is accessible. Repeat installation may be due to one of several factors: compression or water damage; renovation involving loft conversions, where old insulation is taken out and new and improved material installed; successive top-ups to achieve the levels recommended, or replacement with new and better materials (ie achieving a better insulation value with a smaller thickness).
- **Cavity wall insulation**: about 17 M homes have cavities. All scenarios achieve over 90% uptake in these dwellings by 2050. Scenario C sees saturation by 2020; scenario B achieves the same level by 2040.
- **Solid wall insulation**: about 7 million homes have solid walls. In scenario B about 1 million and in scenario C, 2.5 million are treated.
- **Floor insulation**: data is poor, but it is assumed that the potential for ground floor insulation is 85% of the total with the rest being flats with no ground floor. Floors can be suspended timber floors and concrete floors. The type of floor is not well known since it is not part of the house condition surveys, but an estimate based on construction type is that half of homes have timber, and half have solid concrete floors. The suspended timber floor is easier to insulate because of the depth of space available. Only a thin layer of insulation can be applied to concrete floors, unless they are dug up and relaid.
- **External wall insulation**: In scenario C, uptake of cavity wall insulation achieves saturation by 2020. Thereafter, external cladding of previously filled cavity walls is adopted as the best way of bringing those walls up to the necessary standard. Uptake of this additional level of insulation on cavity walls is relatively rapid, reaching over 7 million homes by 2050. Some 1970's properties are treated in this way as part of a whole house makeover which changes the character of the property, with the house clad, for example, in cedar.

A note is needed here on thermal bridges. Thermal bridges can be a significant fraction of overall heat loss, a fraction which would increase as major fabric elements are improved. The figures for insulation standards above are based on the average for each element including the thermal bridges in each element.

The key issue from moving from scenario A to scenario B and C would be to develop a policy approach which moves away from applying measures one at a time (eg through the Energy Efficiency Commitment EEC), and limited to only measures considered cost effective with current energy and equipment prices, to one which undertakes a whole-house refurbishment (often involving a considerable amount of work, eg the removal of a wall or floor). An example of this can be found in South Wales. Some council-owned solid walled homes in terraces have had the front solid wall removed along the whole terrace, and within its footprint, an insulated cavity wall constructed. With this level of intervention, it is possible to see near whole house and even whole-terrace treatment. This allows crawl space under the floors to insulate them, and windows and lofts can be done simultaneously. A similarly integrated approach has been achieved in a small number of 'flagship' privately-owned refurbishments, eg the Nottingham Ecohome. These pioneering approaches would need to become mainstream, driven by the need to reduce the risk of climate change or in response to higher energy prices. Such an approach would need the development of an installation industry focused not on one measure (cavity wall insulation or windows) but on appropriate and integrated whole house treatment.

D.3.7. Changes to the stock: demolition and new build

This subject is common to a range of analysis including energy, land-use and waste and has been written up separately, see Appendix H.

D.3.8. New build standards

Modern UK homes perform better than old ones (for which there were no thermal performance standards at all), but the standards in the 2002 Building Regulations still fall short of the best available practice using today's technology. BedZED and the Hockerton Housing Project are two examples of recent new housing schemes with zero net space heating demand. In addition, a number of theoretical standards have been proposed, including the Energy Efficiency Best Practice for Housing 'advanced' standard and the Association for Environment Conscious Building's 'gold' standard (Table 7).

Table 7 Comparison of BedZED, EEPH and AECB standards with 2002 Building Regulations (part L)

Elemental U value	BedZED	EEBPH 'advanced' standard	Proposed AECB 'gold' standard	Building Regulations 2002 part L1
Walls	0.10	0.15	0.15	0.35
Roofs	0.11	0.08	0.15	0.16-0.25
Floors	0.10	0.10	0.15	0.25
Windows, doors	1.2	1.5	0.8	2.0-2.2
Airtightness				
Air changes/hour	2.0 @ 50 Pa	-	0.75 @ 50 Pa	-

Sources: Twinn 2003, EST 2002, Olivier 2004, ODPM 2002

The energy consumption of developments such as BedZED and Hockerton is very low by conventional standards due to careful design to maximise useful solar gains, combined with an envelope of insulation about 300 mm thick in the walls, roofs and floors. From Table 7 it can be seen that the 2002 Building Regulations part L1 comes close to this standard for roofs, but not elsewhere. As mentioned above, the amount of insulation put in floors and walls during construction is particularly important, as retro-fitting extra material at a later date is practically very difficult.

The point of this discussion is not to argue which of these 'gold' standards is the best, but rather to underline the general principle that they all capture: with a thick layer of insulation in the building fabric (including high-performance windows and doors) and attention to airtightness, it is possible with existing technology to build homes with zero or close to zero space heating demand.

Low and zero carbon technologies in new build could be particularly important:

- In new building a certain level of heating needs to be supplied anyway, so the cost is the marginal up-front cost of LZC over conventional heating
- Housing developers could out-source the entire provision of energy infrastructure to an ESCo, who could design, build, finance and operate the system.
- Economies of scale can be achieved because of the size of new build projects
- Design of the local network can maximise income, eg by retaining ownership of electricity infrastructure, an ESCo could sell any electricity exported direct

to other households (and thus obtain something like three times the value compared to sale to a supplier)

D.3.9. Lights and appliances

Data for UKDCM was based on:

- 40% House (Boardman et al 2005)
- MTP analysis (see www.mtprog.com). MTP only goes up to 2020 at the present time, and is revised annually.
- Cadence Run 5 (Fawcett et al 2000) which went up to 2020.

There are a range of issues and drivers:

- **The basic driver** is expected to continue to be more households (23.9 to 31.8M homes in 2050, up 33%) and wealthier households. However, ownership of some appliances is expected to saturate in percentage ownership (eg ownership of washing machines already has), and even under the reference case scenario, the link between ownership and consumption is weakened through improved efficiency. Consumption too may begin to saturate, unless new technologies or products change this.
- **New product groups** could emerge with changes in technology, population structure and wealth create new marketing opportunities, for example:
    - **More and more kitchen appliances**. Though increased ownership does not necessarily imply increased consumption. For example, a coffee machine when used displaces a kettle, a sandwich toaster may displace an ordinary toaster. What it does mean is that the savings from improved efficiency are harder to capture.
    - **home security systems**. Often systems have communications and monitoring potential.
    - **Home control products**, security products with communications capability could be two way devices not just one way.
    - in a warmer climate with a wealthier population, **outdoor products** may become more significant, eg patio heaters, hot tubs, outdoor lighting and conservatories.
    - In a warmer climate there may also be more **cooling** in the home.
- **New technologies**. A key trend is increasing electronics in simple devices. Products are becoming more portable, with wireless communications and in future wireless power. This has several implications:
    - **Standby consumption:** making devices portable (like the landline telephone) implies increased ownership (at least in the short term) of batteries and chargers. Fewer and fewer appliances –even major appliances like washing machines- have an off-switch, because it isn't required at low power levels, and the control system of many appliances consumes under this level. Transformer based power supplies currently consume 1-7W, but electronic power supplies with losses of 0.1W are possible. Standby consumption could be a transitional technology.
    - **New power sources:** fuel cells may power new mobile devices such as phones, MP3 players, PDA's and laptops by 2007[6]. The input fuel would thus be gas rather than electricity, with much lower carbon emissions. In due course, PV may make a comeback for small electronic goods, if efficiency improves (from 6% to 20% and even 50%), and if costs come down (eg moving away from silicon based technologies, and using polymers rather than

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[6] Toshiba, NEC, Hitachi, and Casio have all announced protypes, see for example, http://www.engadget.com/2004/05/11/casios-laptop-fuel-cell/, and http://news.bbc.co.uk/1/hi/technology/3837585.stm

  glass as a substraight). PV will require back-up power sources either in the form of a battery or fuel cell, with both technologies making significant technical progress.
  - **Powerline Communication and Broadband**: Powerline communication uses the common electrical grid to carry an Internet digital signal to your home plug, and thence to an appliance. New products include Internet radios and televisions. New personal computers (PCs) are including a powerline chipset for automatic network communications.
  - **electronics design** aimed at improved portability, will drive down power consumption both of standby modes and of associated screens.
  - **LEDs for lighting**: incandescents are around 15-17 lumens per watt, CFLs around 60 lpw, and whilst LEDs are struggling to match CFLs currently, progress is expected to take them to 150 lumens per watt in future. Lighting consumption could fall to a tenth what it currently is.
  - **VIPs for refrigeration and hot water storage** could reduce consumption to a quarter of what it currently is.
- **Merging of technology groups** – The whole area of communications (TV, telephone, and PC's) is merging. In practice, this happening quickly and significant change could be seen before 2010. For example, Home entertainment products and PCs are likely to come together as a single group with televisions have writeable storage (currently DVDs) together with software capability for games playing. At the same time, phones are merging with portable computers, and even -with the advent of 3G- with televisions. So whilst main televisions are getting larger (eg plasma screens), second televisions could be pocket devices.
- **Shortening of product lifetimes** – If product lifetimes were once determined by product failure, they are increasingly determined by fashion (eg fitted appliances replaced in kitchen refurbishment) or economic redundancy or because they have been superceded by technical change (mobile phones, laptops and televisions). Little account of this can be taken without a full and detailed stock model.
- **Fuel switching:** could be a real opportunity to reduce carbon in clothes dryers, hobs and ovens.

Projections to 2020 are based on revisions to Cadence, and later projections are more top-line, not based on a full stock model. The sectors have been ordered with the most stable product groups at the bottom, and the most changing product groups at the top.

In Scenario A, consumption continues to rise to 120 TWh. The largest contributor to this is home electronics, but new 'outdoor products' also make a contribution. In Scenario B, consumption in 2050 is reduced to 63 TWh and in Scenario C to 54 TWh.

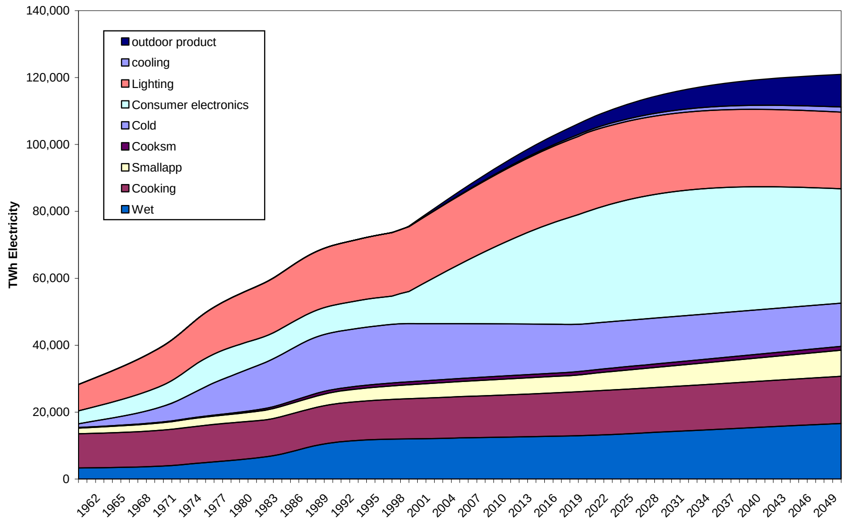

Figure 10 Electricity consumption from lights and appliances under Scenario A

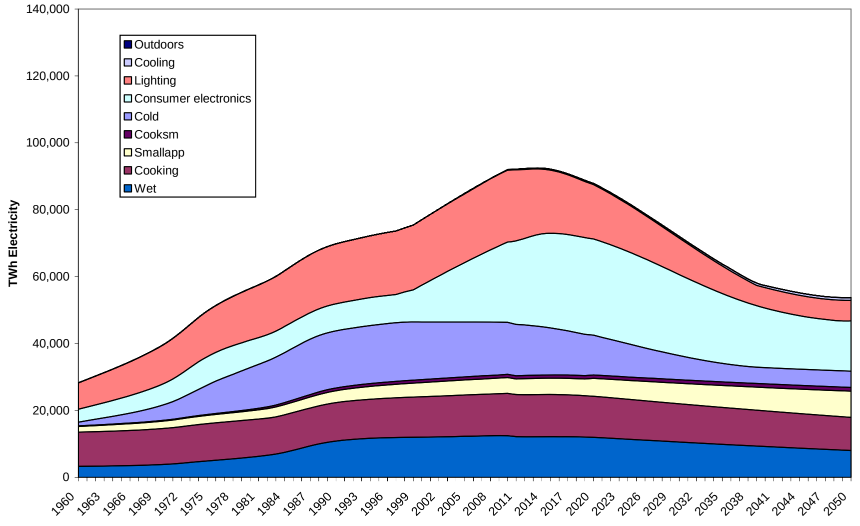

Figure 11 Electricity consumption from lights and appliances under Scenario C

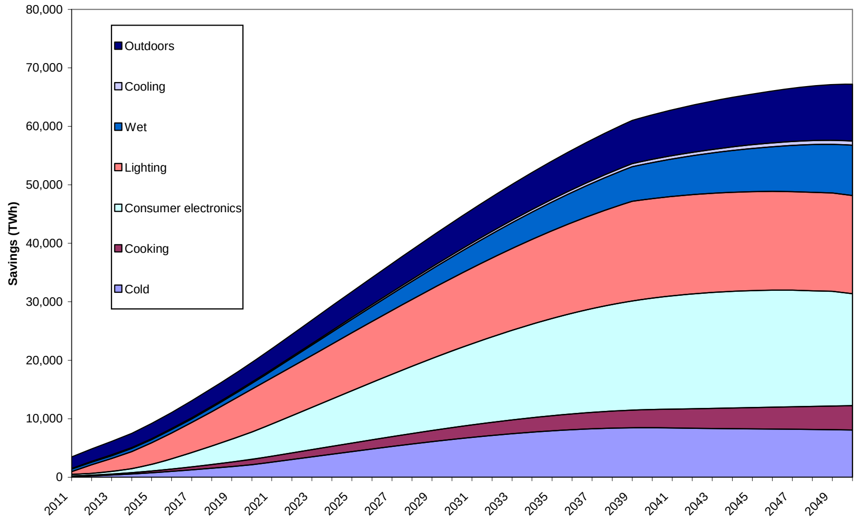

Figure 12 Electricity savings from lights and appliances (Scenario A minus C)

Figure 12 shows a 56% reduction in electricity can be achieved in Scenario C compared to Scenario A by 2050. Consumer electronics (solid state power supplies, better power management and better screens) and lighting (LED's) account for over half of savings. Fuel switching in cooking and wet appliances makes much more saving of electricity than does efficiency, and in outdoor products, fuel switching and avoided high energy consumers save 14% electricity. Vacuum insulated panels in refrigeration account for 12% electricity.

If policy agreement were forthcoming in time to implement measures by 2010, most of this could be achieved by 2030, given the current rate of stock turnover. A key issue is that because lights and appliances are traded good, agreement at EU level would be needed. However development of new technology is something that the UK could play a key role in.

D.3.10. Low and Zero Carbon Technologies

The potential can broadly be categorised into different types of schemes;

- **Combustion based opportunities** - those that generate heat and may in the process generate electricity. They would replace a conventional (gas electricity coal or oil) heating system at the end of its life, typically every 12-18 years. These again divide into group systems (community heating) or individual systems (micro CHP, or biomass). Community heating is predominantly a technology for dense urban communities. Micro CHP is essentially a suburban or rural technology.
- **Rooftop opportunities** – these capture wind or sun and may be competing for roofspace. A low cost replacement opportunity occurs in new build when a roof is installed anyway, or when a roof is replaced, which may be every 50-100 years, or when a roofspace is converted for living space.
- **Rural opportunities** – where location dictates availability such as biomass, or heat pumps which need space and are only really cost effective when a home is not on the gas network.

Table 8 Assumptions for LZC, Scenarios A, B & C

	Scenario A	Scenario B	Scenario C
Dirty fuels (direct electric heating, solid fuels)	• Electric heating is around the same level, • Coal and oil slow to decline	• Electric heating is around the same level, • Coal and oil slow to decline	• Electric heating is around the same level, • Coal and oil slow to decline
combustion based opportunities (gas and urban biomass, heat only and CHP)	• Total uptake similar to condensing boilers, so by 2050, 5% Stirling engine 5% fuel cell, 5% district heating • % biomass in micro is 5%, and in DH is 20%	• 7m homes have zero space heat • Uptake of each technology similar to condensing boiler uptake, so by 2050 half of homes having some form of CHP (15% Stirling engine, 20% fuel cell, and 15% district heating) • biomass is 15% of stirling engines and 25% of Community Heating	• 7m homes have zero space heat • Uptake of each technology similar to condensing boiler uptake, so by 2050 just over half of homes havesome form of CHP, but higher electrical efficiency of fuel cells, and more biomass /energy from waste (5% Stirling engine, 30% fuel cell, 20% district heating) • large scale intervention means CH good in early years, with 50% being biomass or EfW
rooftop opportunities (PV solar thermal, BIW)	• Ownership grows at half the recent growth of condensing boilers until a fifth of roofs have a device • 10% Solar Thermal • 5% PV • 5% solar thermal • No increase in output from roof devices	• Ownership grows at the same rate as condensing boilers over the last 15 years, until ownership saturates with a third of roofs having installations – eg • 12% solar thermal • 10% PV • 7% Building Integrated Wind • Some increase in output	• Ownership grows at the same rate as condensing boilers over the last 15 years, until ownership saturates with half of roofs having installations • 25% Solar thermal • 15% PV • 10% Building Integrated Wind • Significant improvements in outputs over incremental
rural opportunities (biomass and heat pump)	• 3% Heat pumps • 3% biomass	• 5% heat pumps • 5% biomass	• 5% heat pumps • 5% biomass
Total	• Gas boilers (heat-only) are still the dominant technology for space & water heating with low uptake of LZC (**38**% ownership in 2050)	• Uptake of LZC is higher, reaching **89**% ownership in 2050	• Uptake of LZC reaches **115**% ownership in 2050, but with a higher proportion of renewables relative to Scenario B

No improvements in output of rooftop devices were assumed in Scenario A, but significant 30%-100% were assumed in Scenario C, from a combination of more efficient devices, and larger installations (Figure 13)

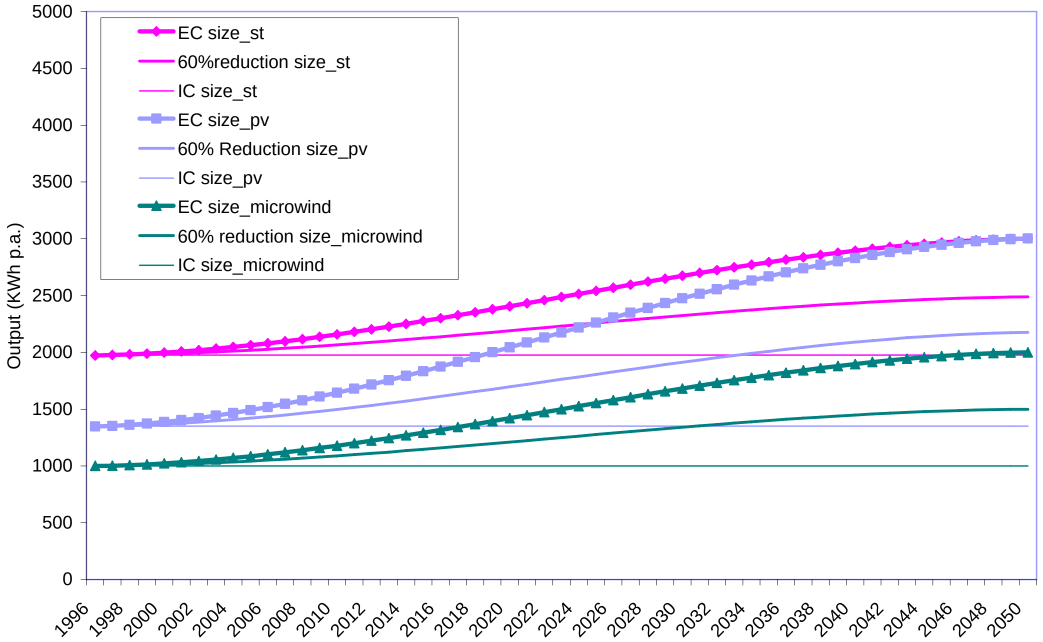

Figure 13 **Changes in output from rooftop based devices to 2050**

The mix of technologies is indicative. The total proportion of heat and electricity supplied under each scenario is shown in Figure 14.

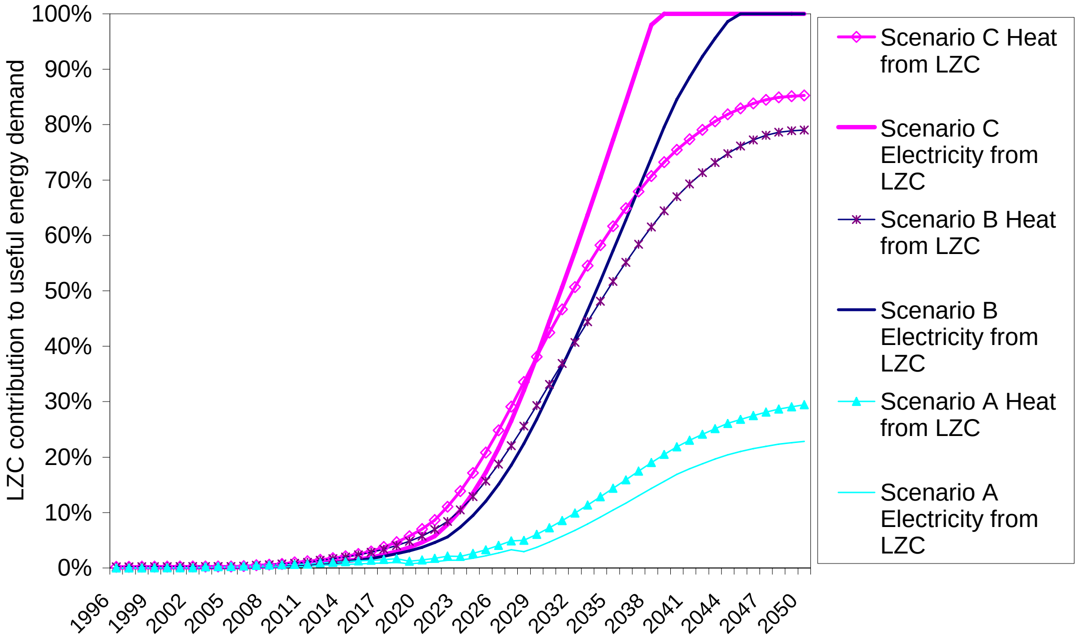

Figure 14 **Percentage of heat and electricity from LZC, Scenarios A, B & C**

From a socio-technical perspective, the installation of LZCs presents arguably the greatest challenge, requiring a major shift in the nature of the supply industry and network operators, with consequences for the investment of capital (See Figure 15). The industry has significant investment in the existing infrastructure and their interest is in retaining an income stream from electricity flowing through the network rather than managing a large number of small scale exporters of power.

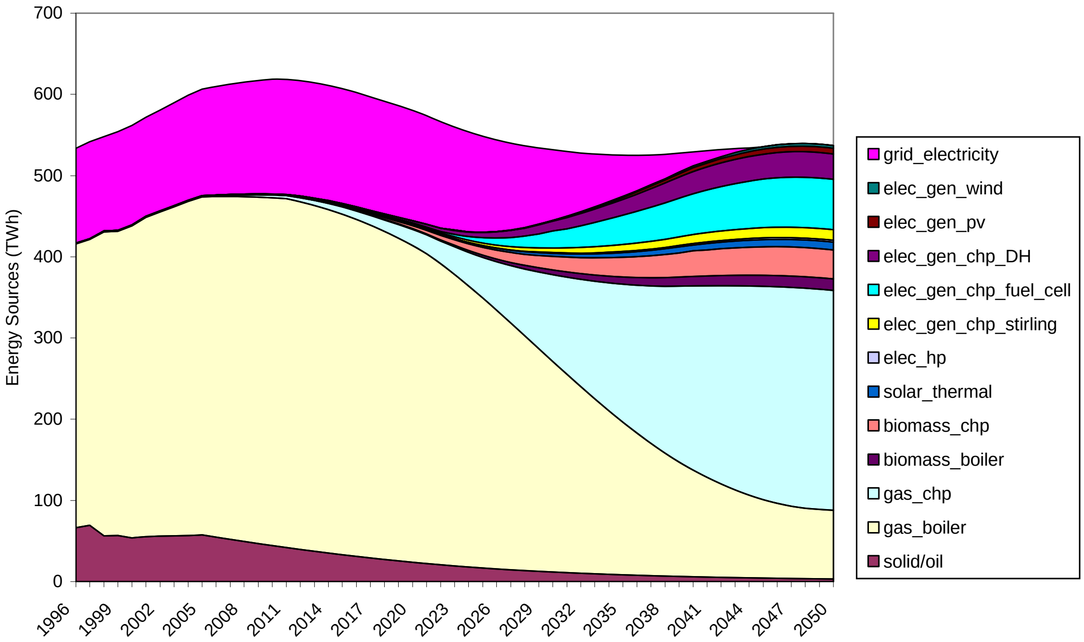

Figure 15 Low and Zero Carbon technologies, Scenario B

Note: energy in the above is not additional: gas is an input into CHP, and electricity is an output. The aim is to show the relative contributions of different technologies to replacing conventional sources of gas and electricity.

The potential for each technology has been based on a range of existing studies, eg

- for **Community heating**, more than 20% of UK homes could be served by Community Heating with 27% of the potential for CHP in London, and 66% in half a dozen major cities (EST 2003). Another study explored the potential for LZC in London. PB Power, in a study for the London Mayor and Greenpeace, found that LZC could reduce carbon emissions by 28% by 2025. Of these savings, district heating made around 90% of the savings because of the density of build in the capital, and utilising a mix of natural gas, biomass and energy from waste (PB Power 2006). In the report, Solar thermal, PV, and micro CHP together saved around 10% of this total. There is nothing new in the potential for district heating in large UK cities. The Department of Energy 'Energy Paper' series explored the theme several times. Energy papers 20 (DoE 1977), number 35 (DoE 1979), and number 53 (DoE 1984) together identified significant potential in 9 major conurbations. So whilst Denmark changed its planning regime in the mid-1970s to stimulate CHP and now supplies around half of homes with CHP, the UK merely talked about it.
- The potential for **biomass** heat only and in larger CHP applications has been explored by Bauen Woods and Hailes (2004), RCEP (2004), and Carbon Trust 2005). The potential for **Energy from Waste** in large CHP applications is separate (Institute of Civil Engineers 2005).
- The potential for **microCHP** was estimated to be around 12million homes (FaberMaunsell et al 2002). Little overlap was found with community heating because Community heating is a dense urban technology, and microCHP is a suburban technology, where density is too low to make a heat network cost effective.
- The potential for **heat pumps** was identified by Hitchen (2004). The potential is limited to homes without access to gas, and where the disruption could be tolerated, such as new build or significant refurbishment (eg installation of underfloor heating and trenches outside)
- The potential for **Building Integrated Wind** was estimated as being up to 5TWh by around 2020 (Dutton, Halliday and Blanch 2005). This is of the order of 5% of

residential electricity demand, depending on year and scenario.
- An integrated study of **microgeneration** including Building Integrated Wind, PV and solar thermal as well as CHP below 50 kW was published by DTI (2005).

Many of these studies do not take account of the reductions in energy demand through efficiency improvements, or increased number of dwellings to 2050 (usually only existing build) or changed energy prices or reductions in cost through technology learning. Hinnells (2005) in a paper to BIEE paper attempts this, and shows that taking all these factors into account, under the 40% scenario, paybacks could fall to less than 5 years at these rates of uptake. Thus this scenario has plausibility.

A key point is that the UK lags behind many other OECD countries, for example:
- **District heating** with CHP serves less than 0.1% of UK households. IN EU-15 23 million people live in homes served by district heating. In Finland and Denmark around half the population live in schemes served by district heating.
- **Heat pumps**: Sweden has just under 10% of homes have a heat pump (as well as more than a quarter of households on district heating).
- **PV**: the UK has supported installation of just over 1000 completed for the UK (EST 2005). Germany has recently completed a programme of 100,000 solar roofs (IEA 2003). Japans PV programme is four times the size of Germany's. Japan has a subsidy program goal of increasing PV demand by 400 MW per year through 2010 and Germany has a goal of 100 MW per year through 2005. (EIA undated)
- **Solar thermal**: around 80,000 solar thermal systems are installed in the UK, but over 1m are installed in the US (Crest Website)

Many of these countries already have higher installations than is foreseen in Scenario C for the UK in 2050. The technology is available, it simply needs the right market framework.

D.4. Model Results including scenario and sensitivity analysis

The model output consists of a large amount of energy demand and supply data at yearly intervals from 1996 to 2050. The main data extractions from this are

1. Energy demands (total and mean kWh per dwelling)
2. Energy supplied by fuel source (total and mean kWh per dwelling)
3. Carbon intensity from fossil fuels (MTC)

The outputs of the model are summarised in Chapter 3 of the main report. In addition to these main outputs, the flexibility of the model is such that a range of scenario analysis and sensitivity testing can be performed to examine the relative importance of individual assumptions.

D.5. Next steps with the model

The work presented here is work in progress. Further work will focus on
- Further disaggregation of the potential by dwelling type
- Examination of the costs and benefits look at carbon and cost (NPV) for 1000 scenarios
- Implications of scenarios in terms of embodied carbon, and thus total carbon.
- The model, all assumptions, and scenarios will be made available on a

fileserver around the end of 2006 from ECI. Users will be able to set up their own scenarios and cost assumptions, to test impacts on carbon emissions. This tool will be a powerful tool to assess individual programmes within the context of other approaches.

- Beyond this, further work is needed to assess possible improvements to BREDEM, which is used as the basic calculation engine here, although, as previously stated, it has significant weaknesses in assessing more efficient dwellings.
- Further work could be done to identify a spatial dimension for potentials. This would, in particular, guide planning decisions on homes (as destinations for heat) and power stations and energy from waste facilities (as sources for heat).
- Key technology changes which need more examination later include opportunities to maximise solar gain, daylighting, thermal bridging, and deterioration in performance with time associated with insulation and LZC measures.

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