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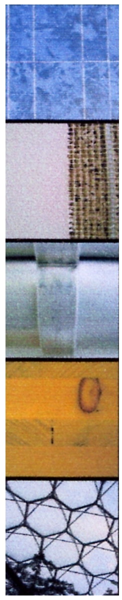


the sustainable building association

MINIMISING CO2 EMISSIONS FROM NEW HOMES

A review of how we predict and measure energy use in homes

2nd edition

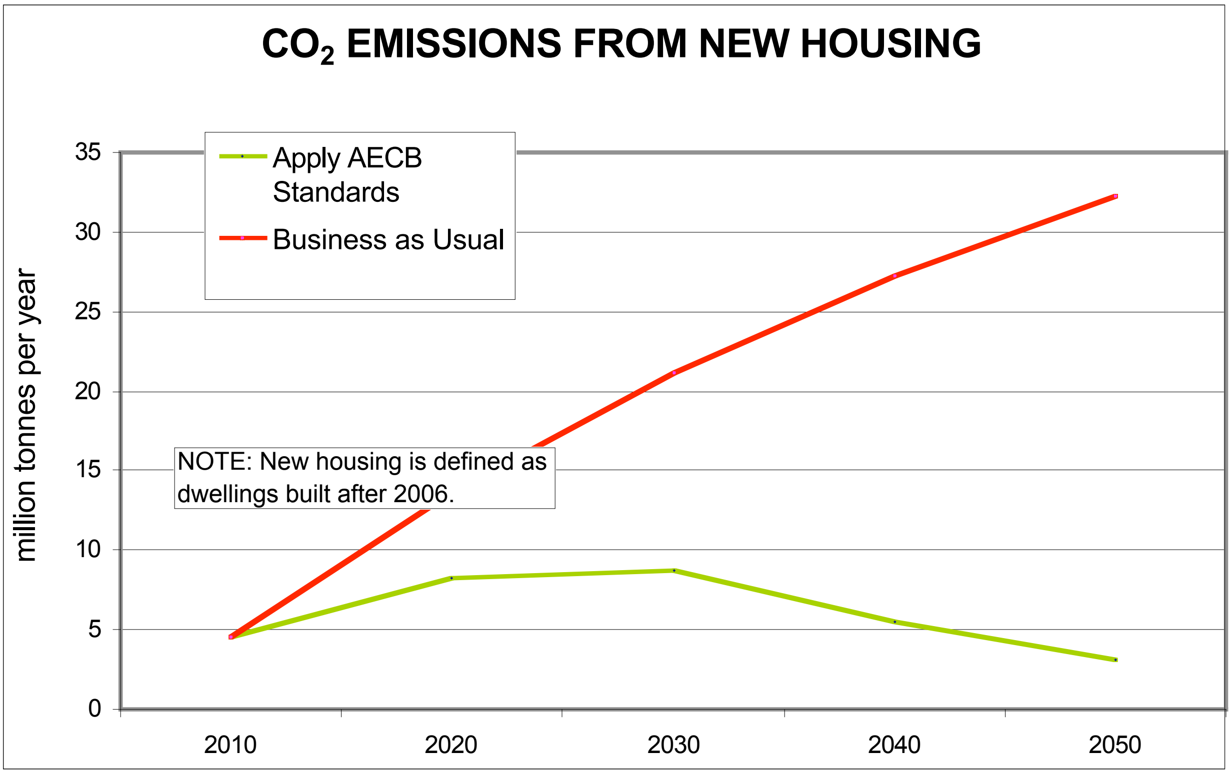
May 2006

EXECUTIVE SUMMARY

Domestic energy demand is rising. The AECB's research demonstrates that we are:

- significantly underestimating future energy use in new homes;
- passing up once-in-a-generation opportunities to make large low-cost savings in CO2 emissions from new homes;
- one-third of the homes which will exist in 2050 will be built between now and then so that storing up large and avoidable rises in CO2 emissions -

An integrated programme of high energy performance standards for new homes would save cumulatively the emission of 600 million tonnes of CO2 by 2050 compared to business as usual. This is around four years' total emissions from the domestic sector at current levels.



The proposed programme applies to new dwellings only. The application of the Standards to non-domestic buildings, or to existing buildings of either category, would further increase the saving.

The report demonstrates that the UK appears to be underestimating the potential savings from improved thermal envelope standards in particular, and improved energy efficiency standards in homes in general. More importantly, our research shows how energy and climate change policies are in danger of being distorted by failures to correctly predict and measure energy use in homes.

Main conclusions

1. The UK has not had an adequate programme of monitoring the performance of new homes built under successive improvements to the Building Regulations. As a result, it may be that we are underestimating the potential savings from improved thermal envelope standards in particular and improved energy efficiency standards in general. This discrepancy risks distorting UK energy and climate policies.
2. The limitations of current methodologies include the fact that they exclude around 30% of domestic CO_2 emissions - electrical appliances, electronic goods and cooking - and the fact that the simple, cheap energy efficiency measures which have not yet been implemented in the UK are not considered before considering the addition of expensive solar technologies.
3. In a carbon-constrained world, we need methodologies which account for all energy uses and all low energy options rather than those employed for Building Regulations which are masking opportunities for real reductions in emissions which could go beyond the 60% target to 90% or more.

Main recommendations

1. If we are to meet our climate change targets, the proposed standards need to account for all energy use in homes.
2. The calculation methods need to be reviewed to ensure that they are appropriate for the design of low energy buildings. We need to count *everything*, if we are to succeed in building what we think we are building!
3. We need to publish a pattern book of simple, high-performance solutions.
4. We must gather and publish more much information on what actually happens in practice.
5. We should concentrate on getting the passive energy measures right before we add expensive kit – build in, not bolt on.

MINIMISING CO2 EMISSIONS FROM NEW HOMES

Recommendations are made for the development of a national approach for constructing high-performance homes with low energy use and low CO2 emissions[1]

A paper from the AECB

Authors: Liz Reason, David Olivier

Introduction

1. During the course of 2005, the AECB was in discussions with EST about the Trust adopting as its revised Energy Efficiency Best Practice standards, the AECB's own Silver and Gold Standards for building energy performance. These standards, if implemented in full, would lead to a reduction in CO2 emissions of 70% and 95% respectively against emissions from an average home. The EST and AECB were developing an ambitious programme of rapidly improving standards, leading to the Gold Standard being integrated into Building Regulations for all new homes possibly as soon as 2016.
2. The EST then asked its Programme Manager, BRE, to prepare a consultation document on the standards. When the document was complete, the Silver and Gold Standards represented headline CO2 emissions savings of just 40% and 65%. The AECB was surprised by this development so undertook detailed analysis of BRE's proposals.
3. The aim of this paper is to set out what the AECB's research showed and to demonstrate why the AECB Gold and Silver Energy Standards differ significantly in their energy and CO_2 performance from the "Silver" and "Gold" Standards developed for EST. More importantly, our research shows how energy and climate change policies are in danger of being distorted by failures to correctly predict and measure energy use in homes.
4. The paper is written by a non-technical author for non-technical readers.

Background

5. Climate change is becoming the over-riding imperative of energy policy. Climate change is the main reason for the government's latest Energy Review[2], the principal aim of which is to explore the case for a new generation of nuclear power stations. The review also aims to assess other policy options for reducing CO2 emissions. It is taking place in a context of rising emissions and concern that the UK will not meet its self-imposed target of 20% reductions over 1990 emissions by 2010 or even its 12.5% Kyoto target.

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1 This paper is the first of three. The other two are: 1. 'How much energy do the Building Regulations save?' and 2. Response to the EST consultation on its proposed new Best Practice standards.

2 Announced on 23rd January 2006

6. If we are to deliver real CO_2 reductions, every technology that can reduce emissions needs to be rigorously analysed for its effectiveness, assessed for the cost of saving each tonne of CO_2, and policies must be carefully designed and implemented to ensure that theoretical savings are matched in practice.
7. Policy development – like any development in science – is a three-part process:
    - a hypothesis - a theory to be proved or disproved by reference to facts
    - experiments - undertaken to test a theory
    - measurements – derived from the tests to provide the facts against which to prove or disprove the theory
8. This three-part process can be likened to a three-legged stool. If one leg is missing, the stool is not fit for purpose.
9. If we are to manage our emissions down to the target set by government (currently 60% by 2050), we need to predict future emissions accurately. If we underestimate emissions from any sector, emissions will be higher than expected, and we will not meet the target, with all the risks inherent in that outcome.
10. The domestic sector is responsible for over 25% of emissions. Domestic energy demand has been growing faster than demand from the transport sector, CO_2 emissions are starting to rise again, and they are predicted to rise further - particularly due to plans to build millions of new homes over the next decade to meet growing demand for new households and population growth.
11. This paper explores some of the reasons why domestic energy demand is rising and summarises work which demonstrates that we are:
    - significantly underestimating future energy use in and emissions from homes
    - passing up opportunities to make large low-cost savings in emissions from new homes
    - storing up large and avoidable rises in CO_2 emissions.

The art (or science?) of estimating emissions from new homes

12. Building homes is becoming an increasingly scientific process. Where houses may have been built to provide shelter from wind and rain, they are increasingly required to keep us at a comfortable temperature when outside temperatures are either hot or cold. They provide the space that supports many elements of our lifestyle including high standards of hygiene, entertainment, communications and work.
13. The objectives of Building Regulations were originally related to health and safety issues; the energy performance of buildings was not introduced until the 1970s. BREDEM[3] was developed in the early 80s as a tool for modelling energy use in homes and has since been used to estimate energy savings from higher standards

[3] Building Research Establishment Domestic Energy Model

of energy efficiency in buildings. SAP[4] was developed in the 1990s as a tool for architects and builders to calculate whether their designs meet the energy and CO2 performance targets set by the Building Regulations. It will also be used for the awarding of energy labels for homes.

14. The underlying data for BREDEM was gathered during the course of government-sponsored programmes for monitoring energy use in homes in the late 70s and early 80s. These included half-hourly monitoring of indoor and outdoor temperatures, detailed records of heating and water use and controls, and social studies of how people lived. These programmes have not been repeated since, so over the last 20-25 years and five successive amendments to the Building Regulations, the data on which BREDEM is based have gradually moved away from real measurements to theoretically calculated data. Emissions reductions which are expressed as a saving of one set of Building Regulations over another, e.g ADL1-2006 over ADL1-2002, are in effect comparing theory to theory.

15. Does this matter? Yes it does, and for three key reasons. First, lifestyles have changed dramatically in the intervening years with behavioural changes (e.g. expectations of higher indoor temperatures and daily showers) and the monitored data gathered in the early 80s was based on homes with relatively little insulation. (For example, homes built under the 1976 regulations had no cavity wall insulation.)

16. Second, it is now widely understood that many new homes do not comply with Building Regulations. This is due to design errors, building defects and failures in enforcement, all largely based on a poor understanding on the part of those implementing the regulations as to how energy is used by and in buildings. Two short studies by the Energy Efficiency Partnership for Homes have provided evidence for this. SAP has been modified to take account of some defects, but the impact of all thermal bridges on energy use are still not fully covered.

17. Third, while Building Regulations to improve the thermal performance of building fabric are an important policy tool, they need to be supplemented if they are to be appropriate for our needs in an increasingly carbon-constrained world. For example, energy use by cooking and appliances is currently omitted from the model. There has also been a rapid growth in the use of electronic goods which is also omitted. What all this means in practice is that the model has been gradually departing from reality. To take our earlier analogy, the third leg of the stool has been taken away.

18. We provide examples below which demonstrate that energy use in new homes and the savings available from improved insulation and airtightness could be being underestimated significantly. Further savings could be made by accounting for other energy-saving measures which are not currently included. And, if government is to enlist the support of consumers in reducing climate change emissions, we need to count all energy uses. This is because consumers' main link with their energy consumption is their fuel bills which do not distinguish

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4 SAP (Standard Assessment of Performance) is a multi-layered spreadsheet with assumptions based on an underlying computer model – BREDEM – and on results from past building research.

between the uses to which fuels are put[5]; and they will need to understand and manage their emissions from all sources, not just some of them.

19. So, in a carbon-constrained world, the methodologies employed for Building Regulations are masking opportunities for real reductions in emissions which could go beyond the 60% target to 90% or more.

The AECB's Gold and Silver Standards

20. The standards proposed by AECB, if implemented in full, would reduce emissions from new homes built to the Silver Standard by 70% and from homes built to the Gold Standard by 95%. The standards have two key characteristics. First, they account for all energy use and CO2 emissions from new buildings. Second, they prioritise heat loss and and re-think every building detail to achieve airtight, highly-insulated buildings where each penetration of the warm fabric is carefully designed and constructed.

21. How did the AECB arrive at its standards for the energy and CO2 performance of homes? They applied their experience of building low energy homes, of how to calculate energy use from different design elements, as well as what can be achieved with high standards of construction. With their Silver Standard, they looked closely at what had been achieved abroad in, for instance, Canada and Switzerland. They based their Gold Standard on the German Passiv Haus standard, the energy and CO2 performance of which is validated by measurements from hundreds of homes. Then they took a baseline of real data from which to calculate their estimated emissions reductions.

22. The baseline data used were derived from DTI statistics for delivered energy to the domestic sector for 2003. This was done for convenience, but any baseline data could be used - provided they are real, monitored data.

Comparing EST's and AECB's Gold and Silver Standards

23. At present, the base case adopted by EST for its consultation document on the EEBPH standards is the predicted energy consumption of a dwelling built to ADL1-2006. Compared to this baseline, EST's predicted savings for Bronze, Silver & Gold are respectively 0-10%, 40% and 65%. *However, these reductions are based on the TER[6]; they are **not** reductions in total energy use or CO2 emissions.*

24. AECB Silver and Gold are required to deliver around 70% and 95% CO2 reductions versus the average dwelling stock. We know how much energy the dwelling stock consumes and how much CO2 it emits. So by comparing Silver

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5 Gas consumption will roughly equate to space and water heating in homes heated by gas, with probably some additional usage for cooking. But in dwellings which are electrically-heated, it is not possible to distinguish between space and water heating, lighting and appliances consumption

6 Target Carbon Emissions Rate (or TER) is a CO2 emissions rate for the dwelling's space and water heating and lighting, measured in units of kg CO2/m2.yr. (It excludes energy used for cooking and appliances.) The TER for the 2006 Building Regulations is set at 20% below the CO2 emissions rate of a 'reference dwelling', whose characteristics are provided by ODPM in an Appendix to Part L.

and Gold to this baseline, AECB is able to compare fact to fact. The methodology adopted by EST/BRE compares theory to theory, but theories which are increasingly departing from reality.

25. For the purposes of developing a joint set of standards, it would be necessary for all parties to adopt a common base case for comparison. The AECB is using the average delivered energy per unit area for the existing UK dwelling stock in 2003 of 278 kWh/m^2yr and the associated CO2 emissions. An alternative would be to use the figure which applied to the dwelling stock in 1990 - the base year for the Kyoto Treaty. The principle is that, *in the absence of monitored data*, other broad national statistics provide the nearest substitute.

26. It was trying to understand what had driven these different outcomes that prompted the AECB to undertake the detailed analysis of which a summary is provided below.

Results for BREDEM and SAP

27. So far as we can tell, SAP seems to be giving imprecise predictions (especially for space heating energy) in the following circumstances albeit for a variety of different reasons:

    1. *Old dwellings*: it can over-predict space heating energy if one uses the standard SAP heating pattern because old dwellings are often heated to a lesser standard than modern ones; this is an understandable compromise between running costs and thermal comfort on the part of the occupants of older dwellings;
    2. *Contemporary dwellings*: it under-predicts space heating energy because:
        a. actual U-values are poorer than assumed due to the presence of substantial additional thermal bridges (design and construction details that provide opportunities for cold/heat to travel through the thermal envelope);
        b. actual air leakage is worse than the algorithm suggests;
        c. workmanship is imperfect, leading to some air movement within and around the insulation layer;
        d. mean 24-hr daily internal air temperatures in modern houses exceed the level assumed;
        e. other thermal defects are present;
        f. and so on.
    3. *"Future" dwellings such as Silver or Gold*: some energy efficiency measures,which are included in the AECB Silver Standard are not listed or available in SAP-2005. Some settings for lighting or ventilation system efficiency which would be appropriate to Silver or Gold are not available, causing SAP to over-predict electricity consumption. Passive solar design is poorly dealt with, causing SAP/BREDEM somewhat to over-predict gas or oil demand if a dwelling has generous south-facing glazing and high thermal capacity. Geometric thermal bridges become more significant in well-insulated dwellings, causing SAP to under-predict space heating energy.

28. Figure 1, which shows our preliminary results, demonstrates the differences in predicted energy use for the different standards compared to the average for the UK dwelling stock.

29. Figure 2 shows the resulting CO2 emissions compared to the average for the UK dwelling stock.

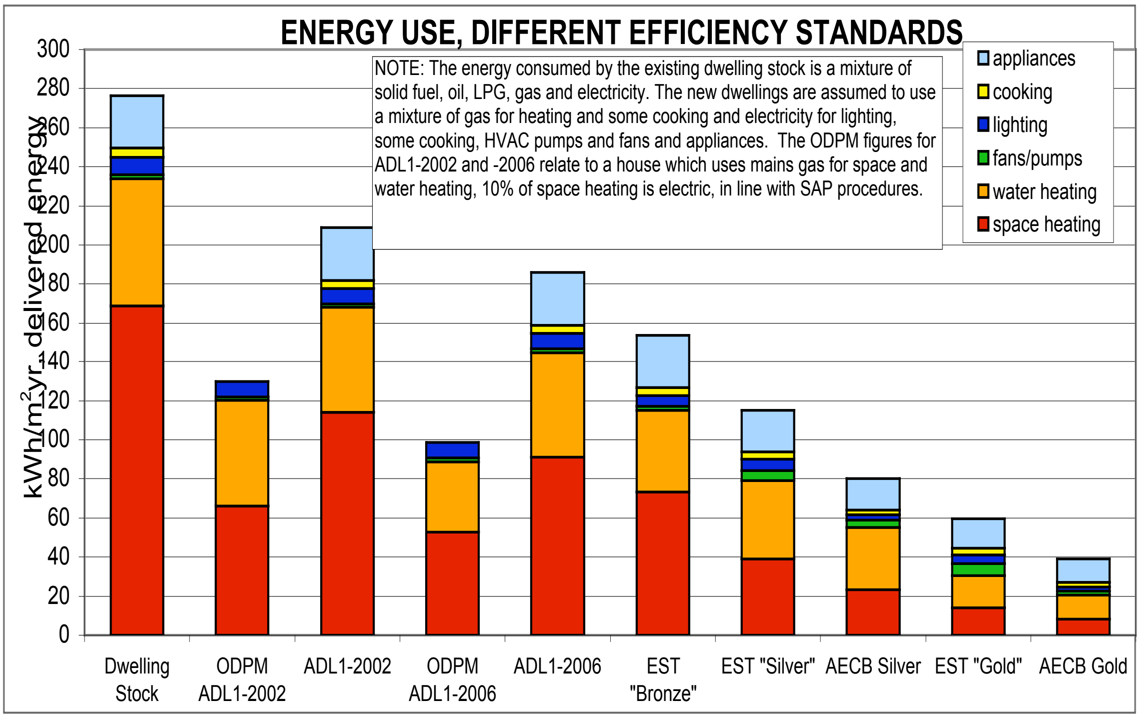

Figure 1. Comparative Energy Use, Different Energy Efficiency Standards

NOTES:

1. Whole home emissions for a typical home built to each standard are AECB estimates of likely 'real world' emissions, based on results from AECB research. AECB standards cover ALL energy. EST standards and Building Regulations exclude cooking, electrical appliances, a proportion of lighting etc. The table compares total domestic emissions for homes built to each standard. See AECB Paper 3: 'EST AECB and Building Regulations Standards 17/02/06' and Paper 1: 'Minimising CO_2 emissions from new homes'16/02/06 at www.aecb.net/energyinbuildings.php

2. Emissions relating to average dwelling stock in 2003 are taken from the measurements in DTI Digest of UK Energy Statistics, 2004 coupled with housing stock floor area data collected by Dr. D. Johnston, Leeds Metropolitan University.

3. New dwellings to ADL1-2002, ADL1-2006 and EST Good Practice are assumed to use a mixture of gas, LPG, oil and electricity for heating, electricity or gas for cooking and electricity for lighting, HVAC pumps and fans and appliances. The ODPM figures are obtained for a house with mains gas heating, using all the standard SAP procedures.

4. All figures are modeled on a typical home, an 80 m^2 semi-detached house.

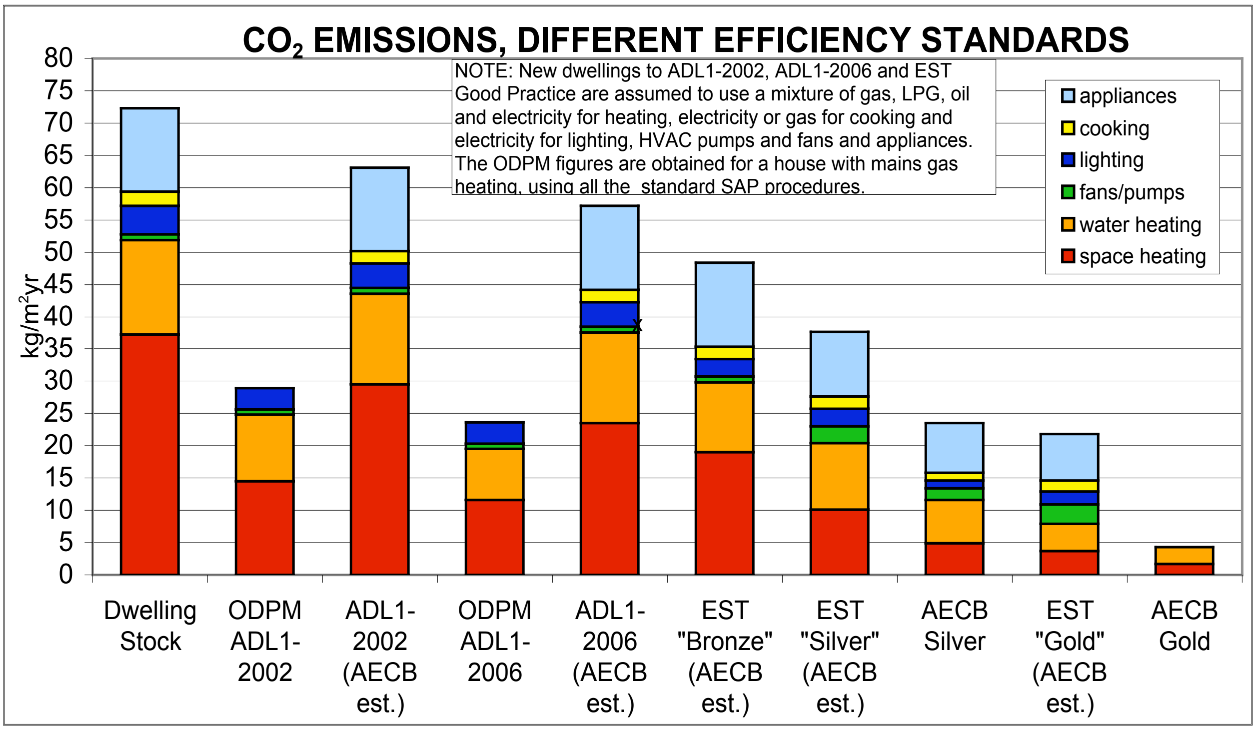

Figure 2. Comparative CO2 Emissions, Different Energy Efficiency Standards

30. When the energy saving between the EST and AECB standards is translated into CO2emissions, the AECB Gold and Silver Standards would lead to CO2 emissions 35% and 30% lower respectively than the EST Gold and Silver standards.

31. The above programme would save cumulatively the emission of 600 million tonnes of CO2 by 2050 compared to business as usual. This is around four years' total emissions from the domestic sector at current levels.

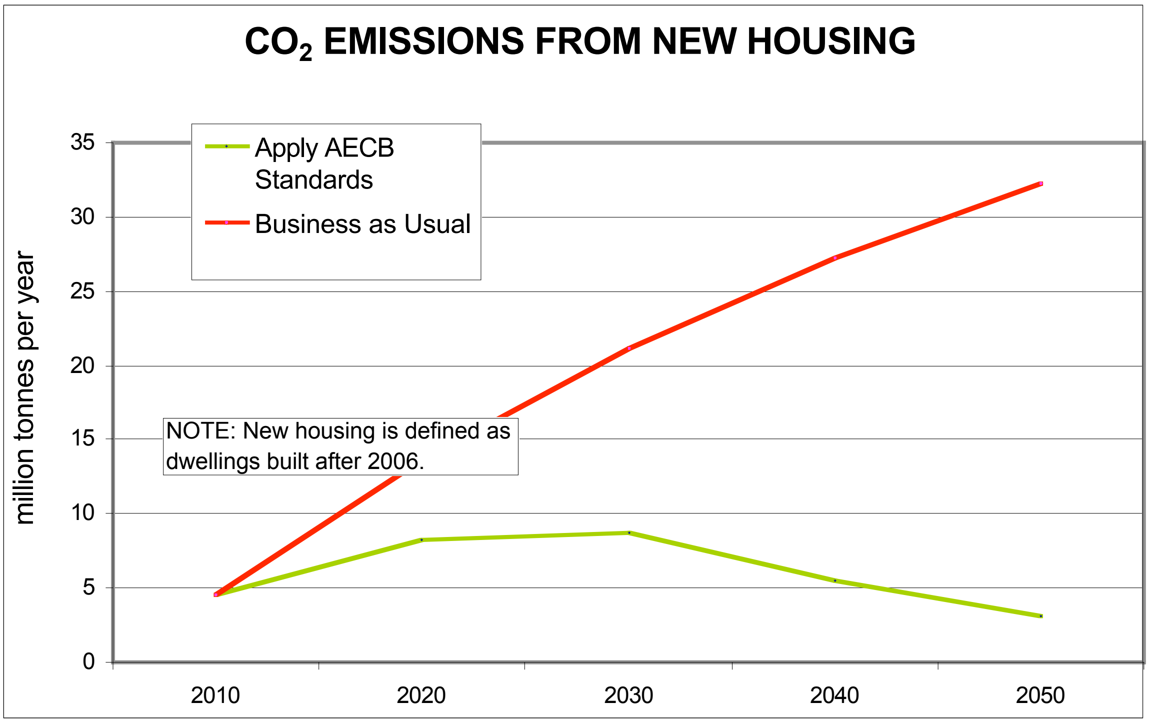

Figure 3. Cumulative CO2 savings from implementation of AECB standards from 2010 to 2050

32. This figure refers to new domestic buildings only. The application of the Standards to non-domestic buildings, or to existing buildings of either category, would further increase the saving.

Main conclusions

33. The UK has not had an adequate programme of monitoring the performance of new homes built under successive improvements to the Building Regulations. As a result, it may be that we are underestimating the potential savings from improved thermal envelope standards in particular and improved energy efficiency standards in general. This discrepancy risks distorting UK energy and climate policies.

34. The limitations of current methodologies include the fact that they exclude around 30% of domestic CO2 emissions - electrical appliances, electronic goods and cooking - and the fact that the simple, cheap energy efficiency measures which have not yet been implemented in the UK are not considered before considering the addition of expensive solar technologies.

35. In a carbon-constrained world, we need methodologies which account for all energy uses and all low energy options rather than those employed for Building Regulations which are masking opportunities for real reductions in emissions which could go beyond the 60% target to 90% or more.

Main recommendations

1. If we are to meet our climate change targets, the proposed standards need to account for all energy use in homes.
2. The calculation methods need to be reviewed to ensure that they are appropriate for the design of low energy buildings. We need to count *everything*, if we are to succeed in building what we think we are building!
3. We need to publish a pattern book of simple, high-performance solutions.
4. We must gather and publish more much information on what actually happens in practice.
5. We should concentrate on getting the passive energy measures right before we add expensive kit – build in, not bolt on.

Detailed recommendations

i) We need to agree a base case against which the energy and CO2 performance of these standards is expressed.

ii) We need to resolve the flaws in current methodologies by agreeing realistic conventions and methods which accurately describe the physical reality of how a dwelling is designed and built.

iii) We should start immediately a programme of monitoring, on a simplified basis, to establish real fuel and electricity use in a random sample of modern homes.

iv) The main documents needed to support a higher standard include a technical specification and extensive guidance on suitable details.

v) SAP-2005 worksheets need to expand their coverage of energy efficiency technologies in order to give realistic results for international good or best practice standards; e.g., AECB Silver and Gold™, also EST "Gold" and possibly "Silver" Standards.

vi) The AECB proposes defining the standards as:

a. Prescriptive versions of AECB Silver and Gold

b. Performance versions of AECB Silver and Gold expressed as

i. maximum kWh/yr of gas (or other fuel) and electricity, and

ii. maximum kg/yr of CO2 and possibly primary energy

iii. both i. and ii. need to quote the size of the dwelling in m^2.

iv. the standards would retain the maximum fabric U-values quoted in the prescriptive versions of Silver and Gold, because the fabric cannot be retrofitted later[7].

vii) A Bronze standard could be positioned midway between the savings that will be achieved by ADL1-2006 and by Silver. So if ADL1-2006

[7] The AECB has listed since 2004 several documents which would need to be produced to support users of the standards, plus other actions.

saves, say, 25% versus the dwelling stock, and AECB Silver saves 70%, Bronze should aim at saving 45%, again using realistic assumptions and calculation methods.

viii) The AECB standards and delivery programme would deliver the CSH levels 1-5 in line with the existing methodologies and, in addition, could pilot a carbon budget based whole home emissions standard; this will trial the effectiveness of a new methodology which might assist UK householders to fully realise the maximum CO2 savings theoretically possible.