Low and zero carbon homes: understanding the performance challenge

Informing the debate

NHBC Foundation
Housing research in partnership with BRE Trust

ZERO CARBON HUB

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Acknowledgments

This publication was written by Cutland Consulting Limited
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We would like to thank the following for providing photographs and images:

Box 1	Co-heating test, BRE
	Thermography, Energy Saving Trust
	Heat flux measurement, BRE
	Smoke pencil investigation, BRE
	Air leakage test, NHBC
Box 2	Stamford Brook, Leeds Metropolitan University
	Elm Tree Mews, Leeds Metropolitan University
	Avante, Crest Nicholson
Box 3	Aerial photo, Infoterra Ltd and Bluesky
	Space heating graph, BRE
	Salford low energy housing, Salford University
Box 4	House, Milton Keynes Development Corporation
	Sketch, Neil Cutland
Figure 1	NHBC
Figure 2	Energy Saving Trust
Figure 3	BBA
Figure 4	EcoDesign Consultants
Figure 5	Neil Cutland

NF 41
Published by IHS BRE Press on behalf of the NHBC Foundation
February 2012
ISBN 978-1-84806-255-9

Foreword

With just four years remaining until the zero carbon homes policy comes fully into effect it is only right to dwell on the issue of whether new homes built from 2016 will deliver in practice their promise of zero carbon performance. Evidence emerging as the industry gears up for the challenge shows that homes can under-perform in terms of their energy efficiency and carbon dioxide emissions, sometimes by a wide margin. While some may rush to blame house builders and/or building control for the apparent failings, in reality there are likely to be many factors that contribute to the 'CO_2 performance gap' and this report begins to document the range of potential factors.

One of the recommendations of the Zero Carbon Hub report *Carbon compliance – setting an appropriate limit for Zero Carbon New Homes*, published in February 2011, was that from 2016 compliance should be based on 'as-built' (as opposed to 'as-designed') performance. This NHBC Foundation report, guided by industry, lays a foundation for future work in this important area from which the industry can begin to develop solutions to the issues identified.

The Zero Carbon Hub and NHBC Foundation are already supporting further work in this area: a BRE-led project with colleagues from academia and testing agencies that is exploring the issue of co-heating testing in detail and which may help to develop standard test methods; another with BBA and insulation manufacturers that is laboratory testing insulation materials in a 'dynamic hot box' that replicates real-life conditions better than current established standard test methods. Both of these projects are scheduled to conclude in the first half of 2012.

Addressing the CO_2 performance gap will be critical to the delivery of the zero carbon homes policy and maintaining confidence in new homes. The new homes we are building will form part of the UK's existing stock for many decades, even centuries, to come and so it is important that they are designed and built well so that they deliver benefits over their whole lifetimes.

Neil Jefferson
Chief Executive, Zero Carbon Hub

About the NHBC Foundation

The NHBC Foundation was established in 2006 by the NHBC in partnership with the BRE Trust. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, the NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of the Government's 2016 zero carbon homes target.

The NHBC Foundation is also involved in a programme of positive engagement with Government, development agencies, academics and other key stakeholders, focusing on current and pressing issues relevant to the industry.

Further details on the latest output from the NHBC Foundation can be found at www.nhbcfoundation.org.

NHBC Foundation Advisory Board

The work of the NHBC Foundation is guided by the NHBC Foundation Advisory Board, which comprises:

Contents

Executive summary

If the energy consumption of an occupied home is greater than its designer predicted, then its carbon dioxide emissions will also be higher than predicted – this is the 'CO_2 performance gap'. There appears to be a growing body of research evidence that new housing is failing to deliver the anticipated levels of CO_2 emissions, although there is relatively little understanding within the wider industry of what might be causing this.

Studies of housing schemes over the last 30 or more years have provided many useful insights, although they do not agree on the precise causes or the scale of the problem. For example, the design predictions for space heating energy at Milton Keynes Energy Park in the late 1980s showed extremely close agreement with measured consumptions. When low energy housing in Salford was revisited, the average energy consumption was found to be almost exactly the same as had been measured 20 years previously. More recently, co-heating tests at Stamford Brook, Altrincham, revealed that party walls did not have the zero U-value assumed in the standard design calculations; homes at Elm Tree Mews, York, had a higher heat loss than had been predicted, due to additional structural timber in the manufactured frame; and latterly a co-heating test on the Avante development in Maidstone measured the fabric heat loss as slightly better than predicted.

There are seven key questions that need to be considered in order to understand how a performance gap could arise:

1. Is the **assessment model** that was used to make the prediction accurate, and has it been correctly implemented in the software used by the designer?
2. Is the model's **input data** correct (and if not, is that due to the conventions or the user)?
3. Is the home's **design** overly complex, presenting unreasonable challenges to the construction team?
4. Are there fundamental **construction quality and skills** issues?
5. Do **building materials and mechanical and electrical (M&E) systems** perform as well in practice as laboratory tests predict?
6. Do changes in specifications get properly **communicated**?
7. Are the **post-construction tests and checks** appropriate and adequate?

There are ways of mitigating the effect of all of these possible causes. For example:

1. **The assessment model.** BRE periodically validate the accuracy of the UK's Standard Assessment Procedure (SAP) and re-calibrate the calculations. The Zero Carbon Hub has concluded that, subject to a number of technical enhancements, SAP should continue to be used as the carbon compliance tool for new homes.
2. **Input data.** User errors can be reduced by employing an accredited On-Construction Domestic Energy Assessor (OCDEA). If monitored data on the performance of products or systems is not available, mandatory 'safety factors' could be introduced. The SAP conventions should continue to be regularly reviewed by BRE.

3. **The design**. There are numerous benefits to making designs simple and buildable, and even low or zero carbon homes can be simple in principle. Designers should aim to produce designs which encourage site operatives to get the detailing right, which aim to eliminate the need for improvisation on site, and which make it easy for installers to route pipes and ducts. If challenging details cannot be avoided altogether, small sample sections could be built onsite and the workforce educated in new techniques.
4. **Construction quality and skills.** Passivhaus-like approaches, which include an airtightness champion, clerk of works, photographic recording, etc, could clearly reduce the performance gap, but are unlikely to be workable in the mass market. Increased use could be made of existing industry publications, training schemes, good practice guides, etc, and new training techniques might also be tried.
5. **Building materials and M&E systems.** New laboratory test methods could be used which better simulate real-world conditions. The performance of M&E systems could be tested as an installed whole rather than as a kit of parts.
6. **Communications.** Simple systems could be put in place to improve inter-team, as well as intra-team, communications. Approved Document L1A now includes the requirement that SAP calculations are lodged before work starts as well as on completion. There is some interest in using building information modelling (BIM) for housing, as well as for larger projects, to improve communications.
7. **Post-construction tests and checks.** It could be unwise to regard Building Control as an instant panacea. A greater emphasis on mass-scale monitoring would enable the performance gap to be systematically diagnosed, and the learnings to be fed back to the housebuilding community. Any prescribed methodology must be pragmatic – for example, simple fuel consumption monitoring via smart meters may be more workable at scale than, say, co-heating tests.

A move towards simpler built forms and design features would not necessarily lead to architecturally uninteresting homes. Balconies, bays and projections can be designed as free-standing features which do not create thermal bridges. Simple built forms, if well-proportioned and detailed, can be visually pleasing.

It is clear that there are a multitude of possible causes of the performance gap, which between them span the period from the initial modelling through to the occupation and operation of the finished home. In principle there are ways to mitigate the effect of each of the possible causes, and by applying a combination of these solutions a significant reduction in the size and extent of the performance gap could be achieved.

1 The CO_2 performance gap

Introduction

There appears to be a growing body of research evidence that new housing is failing to deliver the anticipated levels of CO_2 emissions. But there is relatively little understanding within the wider industry of what might be causing this.

It seems that somewhere between a home's design and its occupation, a gap can develop between the expected and the actual energy consumption. If the energy consumption of the occupied home is greater than its designer predicted, then its carbon dioxide (CO_2) emissions will also be higher than predicted – this is the 'CO_2 performance gap'. It is recognised that a CO_2 performance gap could be a major stumbling block for the housebuilding industry on the way to delivering zero carbon homes in the mass market*.

The UK is in a period when performance standards for new homes are rising rapidly. The Zero Carbon Hub report *Carbon compliance – setting an appropriate limit for zero carbon new homes*, published in February 2011, recommended that, from 2016 compliance should be based on 'as-built' (as opposed to 'as-designed') performance[1]. If it is true that there is already a performance gap, then (if nothing is done about it) as time goes by the gap will increasingly affect the reputation of the industry, will become a source of consumer complaints for housebuilders and landlords, and will undermine confidence in government figures and policies.

Unsurprisingly therefore, interest in the performance gap is growing within both industry and government. This report will consider the evidence for the gap, what factors might be contributing to it and how their effect could be mitigated.

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* In the context of climate change and greenhouse gas emissions, the phrases 'carbon' and 'carbon dioxide' tend to be used interchangeably. Academia and industry more commonly refer to the 'energy performance' or 'energy consumption' of a building rather than its 'carbon performance'. In this respect, when discussing the performance gap it is acceptable to think of energy, carbon and carbon dioxide as effectively the same thing.

Evidence for a performance gap

There are various ways of measuring aspects of a completed home's energy performance. Some of the commonest methods are described in Box 1.

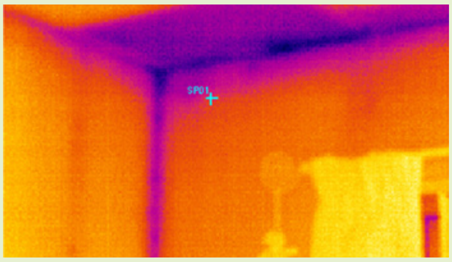
Box 1 Fabric-related measurement methods

There is a wide range of measurement and test methods in use today. Some provide very detailed data about specific elements of the fabric. Others provide broad data about whole-house performance (notably the air leakage test, which is a mandatory part of the compliance process required by Approved Document L1A 2010[2], and the co-heating test, which is widely used in research projects). Between them, such methods can provide a comprehensive view of a home's performance, but taken in isolation the results need to be treated with more caution.

Co-heating test: a method of measuring the steady-state heat loss from fabric and air infiltration together. The building is heated using electric heaters to typically 25°C during cold weather (or to higher temperatures if conducted during warmer weather) and kept at that temperature for two to three weeks. By measuring the amount of electrical energy that is required to maintain the internal temperature, the approximate heat loss of the home can be calculated.

Co-heating test

Thermography: a thermographic camera, sensitive to infrared radiation, is used to take a picture that shows the relative temperatures of the different external elements of the home. The different temperatures are represented by different colours, and can be used to identify missing insulation, cold bridges and significant air leakage paths.



Thermographic image

Heat flux measurement: the heat flow rate through specific building elements (for example a wall) is directly measured using heat flux sensors, and the as-built U-value of the element can then be estimated.

Heat flux sensors in situ

Air leakage test: a large electrical fan is used to alternately pressurise and depressurise the completed home. By recording the electrical energy used by the fan, the flow rate required to maintain the pressure difference can be estimated. Hence the air infiltration rate of the home can be calculated.

Air leakage test

Smoke pencil investigation: conducted during an air leakage test. Detailed leakage paths can be found by moving a smoke pencil around the key construction details inside the home and observing the direction of the smoke flow.

Smoke pencil

There are rather fewer recognised techniques for measuring the performance of building *components* in completed homes, although there are established methods for testing components under laboratory conditions (eg hot-box testing of insulation products, efficiency measurements of boilers and heat pumps, fan power measurements and performance measurement of microgeneration technologies).

There have been many academic studies of the as-built energy performance of housing schemes, going as far back as the 1970s. A detailed review of the studies has been presented elsewhere[3] and is outside the scope of this report, but three more recent studies are summarised in Box 2. Two older studies of low energy housing schemes are also presented in Box 3; both of these schemes were subsequently revisited in order to investigate how their energy performance had changed over 20 years.

Box 2 Recent case studies of energy performance measurement

Stamford Brook, Altrincham

Co-heating tests carried out between 2004 and 2007 on six completed homes showed that the measured heat loss was greater than the design value, in one case by 100%. This was largely attributed to a previously undiscovered 'thermal bypass' effect, where unexpected heat losses were occurring due to external air circulation within cavity party walls. As a result, the party walls had an effective U-value of 0.5–0.6 W/m^{2}K, rather than a U-value of zero as assumed in the standard design calculations[4]. This effect was subsequently addressed in Approved Document L1A 2010[2], which now requires cavity party walls to be sealed (or a higher default U-value to be assumed).

Elm Tree Mews, York

Measurement of the building fabric of six homes between 2007 and 2009 showed considerably higher heat loss than had been predicted at design stage. This was found to be largely the result of additional structural timber in the manufactured timber frame, which had not been included in the original U-value calculations for the walls and roof; in essence, what was built was not actually what had been modelled. This could be thought of as an error in the design model's input data, or as a failure in the communication processes, but not as a construction-stage failure as such. Unexpected thermal bridges and cavity wall bypass effects were also discovered, heat pumps were found to be under-performing, and substituted windows did not have the same performance as assumed at the design stage[5].

Avante, Coxheath, Maidstone

During the winter of 2011 Crest Nicholson with Oxford Brookes University carried out a co-heating test on a home constructed using structural insulated panels (SIPs), as part of their assessment of the SIPs product. The measured fabric heat loss was 9% better than predicted, even though the air leakage result was slightly worse than the design target. This study highlighted the importance of attention to detailing, and of understanding the effect of the design model's conventions (in this case the requirement to use a default value for the thermal bridging at junctions which was worse than the actual bridging in reality).

The party wall thermal bypass effect (which was not required to be addressed under the Building Regulations at the time) was also measured, and accounted for 8% of the home's total heat loss.

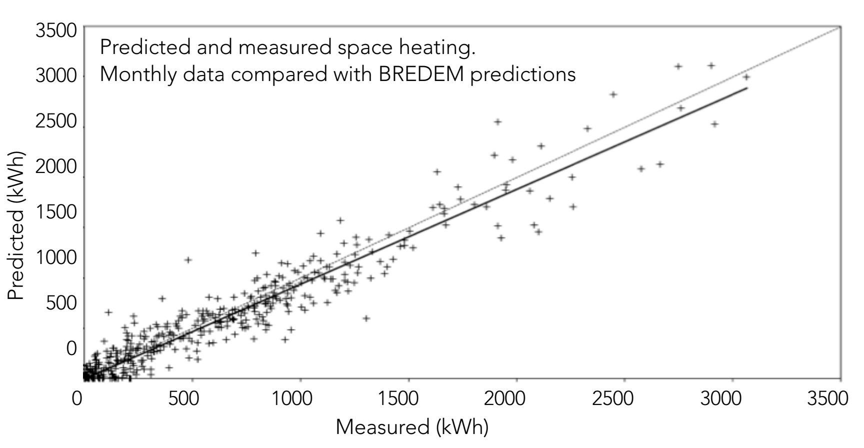
It is important to note that, while the results have provided many useful insights into some very important issues, the number of recent studies of low carbon homes is too small to be statistically significant[6]. It can also be misleading to represent the discrepancies as percentages; a small absolute difference in the heat loss or energy consumption may in some cases be unimportant but can still, in a low energy home, be a relatively large percentage of the total.

Box 3 Historical case studies revisited

Milton Keynes Energy Park

Milton Keynes Energy Park is a mixed development which includes 1200 homes built between 1986 and 1999. The homes' energy performance was designed to be 30–40% in advance of the Building Regulations of the day. Some 250 homes were monitored over two heating seasons, with detailed readings taken of electricity and gas consumption, internal temperatures and humidities. The design predictions for space heating energy are compared with the monitored results in the figure below, which shows extremely close agreement between theory and practice over a wide range of space heating energy consumption[7].

University College London re-monitored 33 of the Milton Keynes Energy Park homes between 2005 and 2006, and found that, 20 years on, the homes' overall gas consumption had increased by only around 10% (some of which was due to increased internal temperatures and hot water usage rather than deterioration of fabric or services) [8].



Salford low energy housing

In 1980 Salford Council built eight highly insulated well-sealed homes. After successful detailed monitoring they went on to build a further 200 homes. Between 1980 and 1982 a monitoring study recorded temperatures and fuel use at half-hourly intervals, and produced results which showed that space heating consumptions averaged just 25% of the traditional housing stock.

The homes were revisited in 2010, and space heating energy consumption was calculated from the heating season length and heating costs reported by the residents. The calculated average space heating energy consumption was found to be almost exactly the same as was measured for the 1980–82 seasons[9].

2

Causes of a performance gap

Possible causes of a performance gap

The studies described in Box 2 above discovered some specific issues that contributed to the observed performance gap in those particular cases. The full list of possible issues is somewhat larger; in the sequence design–build–occupy, the key questions are as follows:

1. Is the **assessment model** that was used to make the prediction inherently accurate enough, and has it been correctly implemented in the software used by the designer?
2. Is the model's **input data** correct (and if not, is that because of unrealistic conventions or because of user error)?
3. Is the **design** overly complex, presenting unreasonable challenges to the construction team on site?
4. Are there fundamental **construction quality and skills** issues?
5. Do the **building materials and M&E systems** perform as well in practice as laboratory tests predict?
6. Do changes in specifications during manufacture or construction get **communicated** back to the designer (and vice versa)?
7. Are the **post-construction tests and checks** appropriate and adequate?

There is a temptation amongst people in the housebuilding world to arbitrarily blame one of these seven possible causes, depending upon the standpoint of the person or organisation concerned. It would fundamentally help our understanding of the CO_2 performance gap, and improve our ability to reduce its size, if a more systematic approach were taken to deciding which of the causes are really responsible in each instance.

The causes in detail

The possible causes of a performance gap initially need to be understood before deciding how to mitigate their effects. The causes are discussed in more detail below; some of them *are* well understood, but the picture is far less clear for others. Some of the ways to mitigate the effect of these causes are then discussed in Section 3.

1 Is the **assessment model** that was used to make the prediction inherently accurate enough, and has it been correctly implemented in the software used by the designer?

The main model used in the UK for carbon/energy performance compliance is the government's Standard Assessment Procedure, SAP[10] (otherwise known as version 9 of the Building Research Establishment Domestic Energy Model, or BREDEM-9). BREDEM is a 'variable base degree day model'. This type of space heating model is capable of producing accurate predications with relatively little effort on the part of the user. However, one of its less helpful characteristics is that, for a well-insulated home, the predicted space heating energy demand is very sensitive to small variations in the input data*.

The fundamental space heating calculations within BREDEM have been extensively validated over the years, notably using statistically significant data from hundreds of homes in Milton Keynes Energy Park in the early 1990s as described in Box 3 on page 4. Because this part of BREDEM is largely theoretical, and is not dependent on changes in building practices and standards, the calculations (and their validation) remain valid even into the 2010s.

In addition to the degree day method which lies at its heart, SAP contains a number of separate 'auxiliary' calculations which predict air infiltration, internal gains, hot water energy use, energy consumption by lighting and fans and energy produced by microgeneration technologies, etc. By and large these calculations are empirical (ie the predictions are simply deduced from field data), and so they need re-calibrating on a regular basis as societal and technological changes occur – increased use of showers, more efficient light bulbs, etc.

BRE, who are responsible for maintaining SAP, re-calibrated the auxiliary calculations as recently as 2009 and are confident that they adequately reflect reality[11].

SAP is sometimes criticised for producing inaccurate results because it assumes a standard occupancy pattern (the number of people and their heating regime) which does not reflect reality. It is important to realise that this is not an inherent inaccuracy in the model, for two reasons:

- the standard occupancy pattern is empirically derived from national average figures that were updated in 2009[12,13] and so does in fact reflect reality on a statistical basis (even though it may not be correct for a specific individual household), and
- in any case, occupancy patterns strictly fall into the category of input data – see (2) below.

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* However, where good energy performance has been achieved mainly through the use of low and zero carbon services rather than fabric, variable base degree day models are far less sensitive to changes in the input data.

Whenever a model is implemented in software, quite aside from any inherent inaccuracies in the model itself, there is the possibility that the programming process will introduce errors (or 'bugs'). As a result, there is inevitably some variability in the quality of commercially available software which is generated in this case by a number of different suppliers.

2 Is the model's **input data** correct (and if not, is that because of unrealistic conventions or because of user error)?

A certain level of errors will always occur when a user enters data into any software package, ranging from simple keying mistakes to a misunderstanding of core concepts. The more technical the package the higher the error level is likely to be, and when an assessment process is cost-driven (as in the housebuilding market) there might be less incentive for rigour or accuracy.

Another kind of error in the model's predictions can be caused by the automatic assumptions which the model makes (for example the fraction of timber in a frame, as happened at Elm Tree Mews – see Box 2 on page 3) and the conventions which the users are required to adopt (for example, with SAP 2005, On-Construction Domestic Energy Assessors (OCDEAs) were required to assume the existence of a secondary heating system even if one did not exist; this convention was changed with SAP 2009).

As discussed previously, SAP's standard occupancy pattern is strictly part of the input data rather than the model itself.

3 Is the **design** overly complex, presenting unreasonable challenges to the construction team on site?

Architects and designers make numerous decisions, which ultimately result in a home being 'simple' or 'complicated', in terms of both building and operating it. If it is overly complex to build then there is an increased chance that the construction team will make errors (or deliberate simplifications) on site; both of these might cause the actual performance of the fabric or services to be worse than predicted. If the services in the home are so complex that the occupants struggle to operate them correctly, then that too could cause higher than predicted energy consumption.

4 Are there fundamental **construction quality and skills** issues?

There is much anecdotal evidence of poor construction practice, for example the cavity wall with poorly installed or missing insulation (Figure 1), the physical gaps around a reveal detail, or the maze of flexible pipework attached to a mechanical ventilation system (Figure 2). There are also many examples of a home's performance being reduced by product substitutions or excessive improvisation on site.

It is very common for the construction process to be blamed for a performance gap. However, there is a common lack of basic knowledge and understanding that runs through the supply chain over how to address certain issues – for example, the lack of a clear resolution to the risk of cold bridges at junctions and corners.

The solution to this should be acknowledged as a major challenge for manufacturers, designers and constructors. In order to better understand and rectify the performance gap in the mass market it is vital that a systematic approach is taken and that the origin(s) of any gap are identified accurately.

Figure 1 Poorly installed cavity wall insulation

Figure 2 A complex arrangement of ductwork connecting to a mechanical ventilation and heat recovery unit

5 Do the **building materials and M&E systems** perform as well in practice as their laboratory tests predict?

Laboratory approvals processes such as hot-box testing of insulation may not always give results that correspond to in-situ product performance, where factors such as wind and dust play a part. A similar problem exists with M&E services, where systems are commonly tested as a kit of parts rather than as an installed whole. In the case of mechanical ventilation with heat recovery, for example, it is normal to certify the heat recovery efficiency of the fan unit in isolation in the laboratory, and not to examine the quality of the installed ductwork.

These problems can have a very significant effect on the overall performance of the as-built home.

6 Do changes in specifications during manufacture or construction get **communicated** back to the designer (and vice versa)?

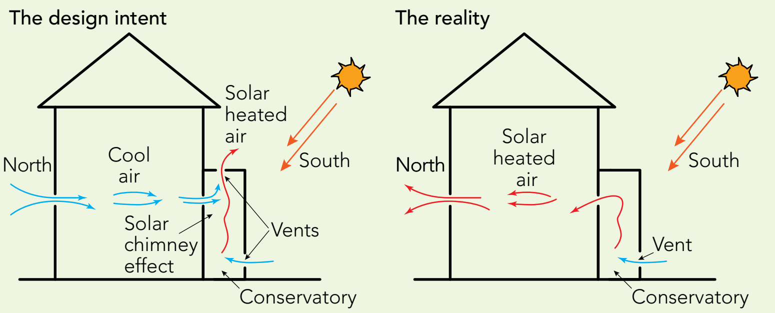
It is almost inevitable that, during the construction stage, changes will need to be made to a design or specified products will need to be substituted. There is a requirement in Approved Document L1A 2010[2] that such changes must be fed back to the designer who must then re-calculate the predictions. However, if this does not happen there will be a perceived performance gap and possibly other unexpected consequences (see example in Box 4).

There can also be communication failures in the other direction, for example where a designer makes a change to a design or specification but omits to inform the contract manager or site manager. Communication failures do not always occur at the interface between teams; they can sometimes occur between members of the same team.

Box 4 An example of unexpected consequences

The architect for a social housing scheme in Milton Keynes designed a simple solar space cooling system, which included a small lean-to conservatory and a system of ducting to allow cool air to flow through the house from the North side into the conservatory. The design relied on a 'solar chimney' effect for which high- and low-level vents were needed in the conservatory. At the construction stage the supplier did not include the high-level vents for cost reasons. As a result the conservatory pushed solar-heated air into the house during the summer rather than pulling cool air through it.

Had the omission of high-level vents been communicated to the designer prior to the delivery to site of the conservatory, the situation could have been averted.



7 Are the **post-construction tests and checks** appropriate and adequate?

Arguably the UK's Building Control process has to date paid insufficient attention to Part L, and there is a case for a greater emphasis on enforcement in this area. However, Approved Document L1A 2010[2] introduced a number of new compliance requirements aimed at addressing this criticism[14].

Some research institutions have called for enhanced mandatory performance measurement, such as introducing a co-heating test requirement into Approved Document L1A in addition to the current regime of air leakage testing. There are, however, questions over the practicality of such tests.

The UK currently has no large-scale programme of basic monitoring of fuel consumption on a disaggregated basis. Other European states have found this to be an effective way of quantifying housing performance in a statistically significant way.

Some housing providers contend that the performance of a low energy home is compromised unless the occupants are formally educated in the operation of the home (eg how to programme the heating system for maximum savings, and the need to change the filter of the mechanical ventilation system). Without education on fabric-related issues too, homeowners may use inappropriate wall fixings that puncture the airtight barrier or create thermal bridges.

3 How to mitigate the effects

Any systematic approach to understanding the performance gap should firstly accept that there will always be a certain level of 'scatter' on the graph of actual versus predicted performance, because housebuilding, like many manufacturing processes, can exhibit statistical phenomena. Naturally, however, the aim should also be to reduce the amount of scatter.

It is also important to be aware that a performance gap expressed as a percentage of the design prediction can be misleading; as previously discussed, with low and zero carbon homes the absolute value of the gap can be very small even though the percentage is large.

1 Consider using a different **assessment model**, and choose your software with care

Strictly speaking, there is currently no option to use a different model because SAP is mandated by government for Part L compliance. It is nevertheless regularly proposed by academics and low energy enthusiasts that SAP should be replaced by a different model, one which can produce predictions closer to reality. It is outside the scope of this report to discuss those issues in detail; a comprehensive review was carried out by the Zero Carbon Hub in 2010 which concluded that, subject to a number of technical enhancements, SAP should continue to be used as the carbon compliance tool for new homes[15].

Software can be of variable quality, but purchasers can be sure that a SAP product has been through a comprehensive testing and accreditation process by obtaining it from one of the DCLG-approved SAP software providers, of whom there are currently eight[16].

2 Ensure that the **input data** is correct

The incidence of user errors is likely to be reduced by employing an accredited OCDEA rather than an uncertified SAP assessor. The Zero Carbon Hub has also made a case for introducing a separate accreditation scheme specifically for designers of low energy homes[3].

The SAP conventions and the internal assumptions made by the model must be regularly reviewed by BRE, and changed whenever robust evidence emerges that indicates a need to do so.

Mandatory 'safety factors' could be introduced, where the performance of a material or system is assigned a conservative default value in the absence of monitored data. The procedure in SAP Appendix Q goes some way towards this, and there are also precedents in the thermal bridging and airtightness sections of Approved Document L1A 2010[2].

The existence of a standard occupancy pattern should be accepted as a compliance necessity. The occupancy pattern built into SAP is statistically robust, and it is hard to see how it could be improved upon in the context of a national compliance tool. When appropriate (eg for research studies) there are various ways by which the results can be calibrated for the actual occupancy.

3 Make the **designs** simple and buildable

There are numerous benefits to making designs simple and buildable, and even low or zero carbon homes can be simple in principle. The aim of the designer should be to produce straightforward designs which:

- encourage site operatives to get the detailing right – and which ideally make it *inevitable* that they will get it right
- aim to eliminate the need to improvise on site
- include a thermal bridging avoidance strategy and present fewer opportunities for inadvertently introducing thermal bridges on site
- include an airtightness strategy and reduce the risk of compromising the airtight barrier:
    - by the site operatives (eg by making it obvious where and how to seal the joints),
    - by the occupants when hanging pictures etc (eg by using block and wet plaster construction, or framed construction with the barrier physically remote from the plasterboard),
    - by third parties such as satellite dish installers (eg by designing-in a cable void, and providing documentation for the occupiers)
- make it easy for the services installers to decide where to route pipe runs, flue positions, etc.
- have well-integrated building services so that both the installer and the occupiers find it easy to understand the operation of the system.

An added benefit of a simple design is that fewer drawings will be required, which will also reduce costs.

If, despite a shift towards simplicity and buildability, there are still some challenging details within the design, it may be useful to build some small sample sections on a remote corner of the site. The samples would be left in place for the duration of the build-out, and the site operatives would be able to examine the samples whenever they encounter one of these details.

There may be a need to educate key personnel in new issues or techniques. For example, the importance of having both an airtightness and a ventilation strategy from the outset may not be understood by the architect; the need to fully specify M&E systems may be a new concept (eg fan power as well as heat recovery efficiency should be specified for a mechanical ventilation system); site managers should be instructed not to accept substitutions without prior consultation with the designer.

'Blue sky thinking' should also be encouraged. It may be a step too far for a house builder to switch to an alternative method of construction, but it is worth at least reviewing the alternatives to ascertain whether they might deliver benefits. (For example, many builders who otherwise use traditional methods now create well-insulated rooms in the roof using SIPS.)

4 Tackle **construction quality and skills**

Many low energy housing enthusiasts advocate an entirely new approach to the design–build–commissioning process. The Passivhaus approach[17], for example, has a formal design certification process and often includes a dedicated airtightness champion, a full-time clerk of works, photographic recording of the build, and specific contractual arrangements. Such an approach clearly has merit in reducing the performance gap, but it is arguably unrealistic to expect volume housebuilders to change their practices so radically.

The Zero Carbon Hub has made a case for a government accreditation scheme for builders of low energy homes[3], although it is unclear how this would work with large-scale subcontracting of labour.

In the mass market, and in keeping with the philosophy of keeping things simple, increased use should be made of what is already available. There are numerous industry publications, training schemes, good practice guides, etc, the potential of which for closing the performance gap is far from exhausted.

In conjunction with these established resources, new techniques might be tried – for example, a new type of toolbox talk which does not go as far as trying to educate site operatives about the finer points of airtightness detailing, but does emphasise the absolute basics ("This bit here is the airtight barrier…", "Don't drill any holes after today because the airtight barrier has gone up…", etc).

As previously mentioned, site managers should be regularly reminded of the implications of accepting substitutions without approval.

5 Review **building materials and M&E systems** testing methods and installation procedures

Manufacturers' performance claims are based on laboratory data which may give designers unrealistic expectations of real-world performance. For example, insulation performance is influenced by wind blowing across its surface or into the joints between sheets, and these effects are not included in standard laboratory hot-box tests. The BBA is currently investigating these effects using large-scale modified hot-box testing which better simulates real-world conditions for typical constructions (see Figure 3). The outcome of this research should enable improved accuracy of the data used by SAP to predict energy performance.

The Zero Carbon Hub has made a case for a government accreditation scheme for suppliers/installers of low energy M&E systems[3]. This would help to address the situation described in Section 3 where the performance of a mechanical ventilation unit is affected by the use of flexible and badly sealed pipes with tight radii rather than rigid ducts with smooth bends.

Approved Document L1A 2010[2] contains a requirement for fixed building services to be commissioned by an appropriate person, and for the Building Control Body to be notified that the commissioning has been completed. This should ensure that systems are properly tested and adjusted (although it would not alleviate the ductwork issue described above).

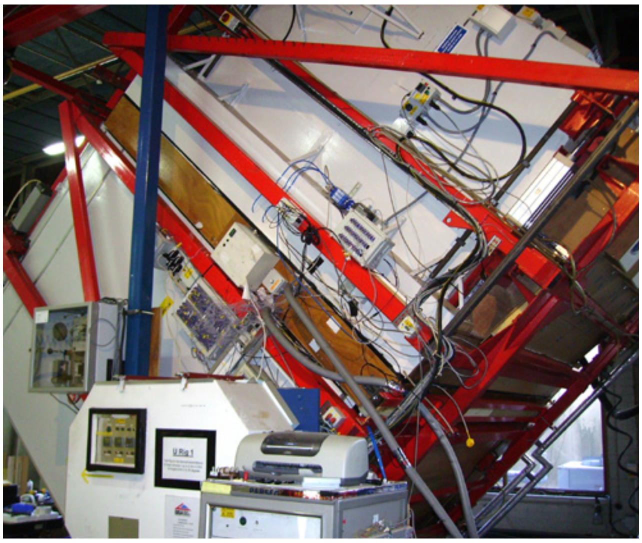


Figure 3 Large-scale dynamic hot-box testing

6 Improve the **communications**

Better communications in general would inevitably reduce the effect of many of the causes of the performance gap, as well as reducing the number of unexpected consequences. Manufacturers, designers, specifiers, installers and builders all have different roles and work in different locations, but it should be straightforward to put in place simple systems to improve the inter-team as well as intra-team communications.

Approved Document L1A includes the requirement that SAP calculations are submitted to the Building Control Body before work starts on site as well as on completion of the works; this addresses some of the issues of substitutions and design changes on site.

In July 2011 the government published its Building Information Modelling (BIM) Working Party Strategy[18]. Amongst other things, BIM is intended to improve communications between all members of a construction project. BIM is in its infancy and is controversial – in particular because it is said to increase project costs. There is nevertheless some interest in using BIM for housing as well as larger projects, and it would clearly contribute to reducing the performance gap were BIM to achieve widespread take-up in the housebuilding industry.

7 Ensure that **post-construction tests and checks** are fit for purpose

Building Regulations enforcement has its challenges. Notably (i) the resources devoted to Part L are limited given the (quite appropriate) focus on structure, fire and safety etc. and (ii) some construction details will be concealed by subsequent work by the time an inspection is carried out. Since there are so many causes of the performance gap it could be unwise to regard Building Control as the instant panacea; any changes to the enforcement regime must be made systematically and gradually over time.

Approved Document L1A 2010 introduced several requirements aimed at improving compliance generally, and it appears that successive revisions to the Building Regulations will continue to address the issue.

Post-construction testing and monitoring also has an important part to play, and this is discussed in Section 5.

4 The architectural challenges

Aesthetic considerations are important, and local planning policies can also include requirements for specific design features such as dormers, and steps and staggers. However, the implications for the thermal performance of the resulting homes is often not fully considered by designers or planners. Simple built forms are inherently more energy efficient due to their more favourable surface area to volume ratio and their relative lack of thermal bridges at junctions. Moreover, design features which involve complex detailing are at higher risk of incorrect implementation on site.

A move towards simpler built forms and design features would not necessarily lead to architecturally uninteresting homes. Balconies, bays and projections are regularly seen on Passivhaus low energy homes, where the thermal bridges can be eliminated by supporting the features externally rather than cantilevering them off the structure. Simple built forms, if well proportioned, can be visually pleasing – especially when combined with imaginative features such as contrasting panels, coloured details and part-cladding (see Figure 4).

Some very interesting designs can also be implemented with minimal complexity at the site level using modern methods of construction. The highly industrialised Japanese housebuilding process, for example, offers housebuyers a wide range of design options that can be selected from a computer screen in the showroom when purchasing.

Investing more in the design stage will not only result in better as-built performance but can also achieve savings in training, supervision and re-work at the construction stage.

Figure 4 Low energy homes at Howe Park Wood, Milton Keynes

5 The role of testing and monitoring

Without routine testing and monitoring of completed homes there is no way of determining the true extent of the performance gap in the mass market, either in terms of its size or how widespread the problem is. A greater emphasis on testing and monitoring will enable us to diagnose the gap, systematically determine which of the many possible causes are to blame, develop solutions and feed back the learnings to the housebuilding community – from the developers of the calculation tools to the manufacturers, designers, builders, installers, researchers and policy makers.

As a result, ultimately the predictions will be more accurate and the homes will be higher quality, closing the performance gap from both ends and reducing the UK's CO_2 emissions accordingly.

Assuming that *mandatory* testing/monitoring is introduced, it is essential that the prescribed methodology is pragmatic. The co-heating test, for example, is an excellent diagnostic research tool for a prototype home, but is unlikely to be workable at scale. As one major developer has said, *"When you factor in the time the homes are taken off the market (with associated loss of cashflow), the cost of equipment, the analysis and making good, the co-heating test itself is a prohibitively expensive tool, and not a practical way to test housing at volume. But as a research process, this study has been an invaluable piece of learning."*

Not since the early 1990s has any large-scale post-occupancy monitoring of the fuel consumption of homes been undertaken in the UK. Such monitoring would be statistically significant, which means that any distorting effect of standard occupancy assumptions would disappear, revealing the true extent of the performance gap. Statistical significance also gives confidence that the results are not just random occurrences or 'one-offs'. With the advent of smart metering at a national scale (Figure 5), it should become technically straightforward and economically feasible to carry out mass monitoring of this nature. This could then provide a method for routinely measuring energy performance in the volume housebuilding market.

Importantly, the learnings that arise from any programme of testing and monitoring must be fed back in a spirit of openness and honesty. This means that the framework for the process must be supportive and nurturing, and practitioners who report valuable 'negative' findings are not denigrated as failures but are praised for their integrity.

Figure 5 Smart gas meter

6 Conclusions

The as-built energy performance of homes and its effect on the UK's CO_2 emissions are of increasing interest as the zero carbon milestone of 2016 approaches. There is currently some evidence of the existence of a CO_2 performance gap, where the measured emissions of a completed home do not agree with the prediction that was made at the design stage.

The tendency in the UK has been to blame the housebuilders for this gap, rather than trying to understand the wider issues which could be interacting. Recent evidence for the gap comes from a very small sample of homes (albeit rigorously researched), and some older studies did not reach the same conclusions. It is clear that a more systematic approach to (a) understanding and (b) solving the performance gap would have major benefits.

This report has identified and discussed a multitude of possible causes, broadly grouped into seven categories, which span the period from the early predictions through to the occupation and operation of the finished home.

Section 3 has discussed ways to mitigate the effect of each of the possible causes. It is likely in practice that a **combination** of solutions will be necessary, and between them a significant reduction in the size and extent of the performance gap could be achieved.

Finally, Section 5 has discussed the role of post-construction testing and monitoring, in particular the need for it to be practical in the mass market, and the importance to UK emissions reductions of nurturing an open and honest learning culture.

References

1. Zero Carbon Hub. Carbon compliance – setting an appropriate limit for zero carbon new homes. London, Milton Keynes, February 2011. Available at www.zerocarbonhub.org
2. Department for Communities and Local Government. The Building Regulations (England and Wales) Approved Document L1A 2010. Conservation of fuel and power in new dwellings. London, TSO, 2006. Available at www.planningportal.gov.uk/uploads/br/BR_PDF_ADL1A_2010.pdf
3. Carbon compliance for tomorrow's new homes; Topic 4: Closing the gap between design and built performance. London, Milton Keynes, Zero Carbon Hub, August 2010. Available at www.zerocarbonhub.org

4 Wingfield J, Bell M, Miles-Shenton D, Lowe R and South T. Evaluating the impact of an enhanced energy performance standard on load-bearing masonry domestic construction, Partners in Innovation project CI 39/3/663, Final Report. Leeds Metropolitan University, 2007. 91pp. Available at www.leedsmet.ac.uk/as/cebe/projects/stamford/index.htm

5. Bell M, Wingfield J, Miles-Shenton D and Seavers J. Low carbon housing: lessons from Elm Tree Mews. 118pp. York, Joseph Rowntree Foundation, 2010. Available from www.jrf.org.uk
6. However, new studies are now beginning to appear with increasing frequency – for example: GHA Monitoring Programme 2009–11: Technical Report. Results from Phase 1: Post-construction testing of a sample of highly sustainable new homes. London, Good Homes Alliance, December 2011. 45pp. Available at www.goodhomes.org.uk
7. The performance of BREDEM/SAP in predicting the energy use of actual dwellings and in comparison with other models, BRE, April 2010. The BREDEM model is discussed further in Section 2.
8. Summerfield AJ, Lowe RJ and Bruhns HR et al. Milton Keynes Energy Park revisited: changes in internal temperatures and energy usage, Energy and Buildings, July 2007, 39 (7) 783–91.
9. Brown P, Burke ME, Morris G and Webster PJ, The Salford low energy house: learning from our past, University of Salford, Salford Housing & Urban Studies Unit, 2010. 19pp. Available at www.shusu.salford.ac.uk
10. The government's standard assessment procedure for energy rating of dwellings, 2009 edition. Published by BRE on behalf of DECC. 208pp. Available at www.bre.co.uk/filelibrary/SAP/2009/SAP-2009_9-90.pdf
11. Henderson J. Review of auxiliary energy use and the internal heat gains assumptions in SAP. Garston, BRE, 2009. Ref. STP 09/AUX01. Available at www.bre.co.uk/sap2012/page.jsp?id=2768
12. Shorrock L. Analysis of the EST's domestic hot water trials and their implications for amendments to BREDEM and SAP. Garston, BRE, 2008. Ref. STP 09/DHW01. Available at www.bre.co.uk/sap2012/page.jsp?id=2768
13. Henderson J. A review of the relationship between floor area and occupancy in SAP. Garston, BRE, 2008. Ref. STP 09/NOFA01. Available at www.bre.co.uk/sap2012/page.jsp?id=2768
14. For a summary of the changes, see Technical Extra, Issue 3, NHBC, September 2011, pp3–4. Available at www.nhbc.co.uk/Builders/ProductsandServices/TechnicalExtra/TechnicalExtraIssue3
15. Zero Carbon Hub. Carbon compliance for tomorrow's new homes – a review of the modelling tool and assumptions. London, Milton Keynes, July 2010. 52pp. Available at www.zerocarbonhub.org
16. See www.bre.co.uk/filelibrary/SAP/2009/SAP2009_9-90_software.pdf
17. See www.passivhaustrust.org.uk/what_is_passivhaus.php
18. Department of Business, Innovation and Skills. A report for the Government Construction Client Group Building Information Modelling (BIM) Working Party Strategy Paper. Ref. URN 11/948. 107pp. July 2011. Available at www.constructingexcellence.org.uk/pdf/BIS_BIM_Strategy_2011.pdf

All URLs accessed 10 January 2012.

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This report reviews the evidence that supports the existence of a CO_2 performance gap and explores its potential causes. It establishes that, contrary to some of the views expressed on the topic to date, there is no single cause. Instead the report identifies a multitude of possible causes and issues that may contribute, from the earliest stages of design through to post-construction checking. All of these issues need to be understood and dealt with if the CO_2 performance gap is to be minimised.

The NHBC Foundation has been established by NHBC in partnership with the BRE Trust. It facilitates research and development, technology and knowledge sharing, and the capture of industry best practice. The NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the UK's wider housing needs. The NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports house builders in developing strong relationships with their customers.

Published by IHS BRE Press on behalf of the NHBC Foundation
ISBN 978-1-84806-255-9

Housing research in partnership with BRE Trust