ZERO CARBON HUB

NHBC FOUNDATION
Housing research in partnership with BRE Trust

CARBON COMPLIANCE FOR TOMORROW'S NEW HOMES

A REVIEW OF THE MODELLING TOOL AND ASSUMPTIONS

TOPIC 4
CLOSING THE GAP BETWEEN DESIGNED AND BUILT PERFORMANCE

August 2010

Zero Carbon Hub

The Zero Carbon Hub was established in the summer of 2008 to support the delivery of zero carbon homes from 2016. It is a public/private partnership drawing support from both Government and the industry and reports directly to the 2016 Taskforce.

Zero Carbon Hub has developed five workstreams to provide a focus for industry engagement with key issues and challenges:

- Energy Efficiency
- Energy Supply
- Examples and Scale Up
- Skills and Training
- Consumer Engagement

To find out more about these workstreams, please visit www.zerocarbonhub.org.

If you would like to contribute to the work of the Zero Carbon Hub, please contact info@zerocarbonhub.org.

NHBC Foundation

The NHBC Foundation was established in 2006 by 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 Government's 2016 zero carbon homes target. Research has included a review of microgeneration and renewable energy techniques and the groundbreaking research on zero carbon and what it means to homeowners and housebuilders.

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.

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FOREWORD

In setting its target for all new homes to be zero carbon from 2016, the Government have presented the greatest challenge the house building industry has ever had to face. Emerging evidence of a potentially large gap between performance of homes 'as designed' and that achieved 'as constructed' makes the task even more challenging. It would make no sense to achieve zero carbon housing in theory only. Meeting the challenge is the responsibility of the industry as a whole, from designers, developers and the supply chain to the supporting infrastructure of government, professional and trade bodies, educators, trainers and the research community. The role of the Zero Carbon Hub in facilitating change will be crucial.

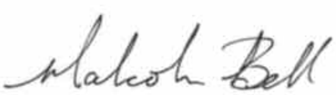
The work of my research group at Leeds Metropolitan University and evidence from elsewhere makes it quite clear that the performance gap referred to above can be very large with some measurements of whole-house heat loss being around double that calculated at design stage. This is not to say that all homes fail to meet their carbon target and more work is required to establish the full scale of the problem, but the evidence is sufficiently strong to set alarm bells ringing.

Analysis by this Topic Work Group lead us to conclude that change is required in the way design and construction is undertaken, building on existing performance testing requirements and schemes such as the industry's robust detail scheme for sound insulation. In order to effect change, practical guidance and tools are required, coupled with clear feedback based on routine performance measurement, so that all new homes perform to the required standard. The Work Group recognised however that the necessary change will require investment across the industry and that the regulatory framework is of crucial importance in setting a level playing field for all. The key message to government is that the regulatory framework, post 2016, should provide advantage to those who invest in closing the performance gap and disadvantage to those who do not.

In proposing a way forward we were mindful of the need to address a number of matters of detail. Also that there is much work to do in providing guidance and support, from blueprints for improved design and construction processes to improved production performance testing methods for dwelling fabric and services. Time is short and a clear statement from Government, within the next few months, setting out their determination to close the performance gap will be crucial to success. Such a statement would be the precursor to a strong partnership in which Industry and Government work together to develop a detailed regulatory and policy framework as well as setting in train other work streams, all focused on the ultimate goal.

The report of the Topic Work Group has involved a great deal of hard work by people from across the industry. Our exploration of the issues has been robust and invigorating and I would like to thank Topic Work Group members for the enormous contribution they have made. It has been a privilege to work with such a committed and enthusiastic team.

Over the last 5 years I have asked myself on numerous occasions whether the industry can produce homes that meet zero carbon standards robustly and reliably every time. My experience in this Topic Work Group and the wider Zero Carbon Hub Task Group has increased my optimism. The wider house building industry is capable of great things and with the right leadership and support, low energy / zero carbon housing (for real) is well within our grasp.



Malcolm Bell
Chair Topic Work Group 4 – Centre for the Built Environment, Leeds Metropolitan University.
August 2010

TASK GROUP TERMS OF REFERENCE AND REVIEW STRUCTURE

This forward-looking review reports the findings of an expert Task Group, facilitated by the Zero Carbon Hub, to consider whether the existing carbon compliance tool, the assumptions on which it is based and the regulatory framework surrounding it are appropriate for low energy/zero carbon homes. It has been prepared primarily to inform government and the 2016 Task Force, the Senior Government/Industry steering group overseeing the implementation of the zero carbon new homes from 2016.

The work had three objectives:

1) To define an appropriate compliance (and design) tool for low carbon/energy homes from 2016
2) To recommend a way by which industry can have an indication of how the 'likely' future changes to the compliance model might impact the predicted dwelling performance
3) Propose a transition and implementation plan for the 2016 compliance tool

Five Topic Work Groups, reporting to the main Task Group, were established in Autumn 2009 to explore in detail the key issues and ensure wide input into recommendations. The Topic Work Groups reported in Spring 2010 and their work is presented as a series of separate Topic reports, listed below. The Task Group considered these reports and prepared an introductory Overview report summarising the main findings and recommendations.

OVERVIEW	**Overview of findings and recommendations** The Task Group's summary of the Topic Work Group reports
TOPIC 1	**Carbon compliance tools considerations** Looking at modelling tools currently available both here and abroad and considering key characteristics, what they assess and the trade off between accuracy and ease of use.
TOPIC 2	**Carbon intensity of fuels** Considering the implications of, and an appropriate response to, the changing carbon intensity of electricity and other fuels.
TOPIC 3	**Future climate change** Setting out how projected national and local climate changes could affect energy demand. Exploring for example how the compliance tool should embrace overheating risk.
TOPIC 4	**Closing the gap between designed and built performance** How the compliance tool should accommodate (and help reduce) any performance gap between design performance and what is achieved on site. (THIS REPORT)
TOPIC 5	**How the performance standard should be expressed** This looks at whether carbon compliance should be expressed as an improvement versus a notional building (as now) or in absolute terms (kg CO_2 emissions per unit area).

The work of the Topic Groups was informed by modelling commissioned on a range of house types, climate assumptions and compliance tools. The aim was not to provide accurate predictions, but rather to identify which, of a range of factors, have the greatest impact on the carbon performance of a new home.

MODELLING	**The modelling supporting this review** Sets out the modelling undertaken to support this programme of work.

CONTENTS

ACKNOWLEDGEMENTS

The Zero Carbon Hub is extremely grateful to all participants who contributed to Topic 4 Work Group and gave generously of their time and expertise.

To enable it to carry out the necessary in-depth review work that underpinned the recommendations in this Report, Topic 4 Work Group is grateful for the funding support it received from Communities and Local Government (CLG), the Department of Energy and Climate Change (DECC) and the Zero Carbon Hub.

The Work Group also gratefully acknowledges the NHBC Foundation for generous sponsorship of the dissemination phase of this work, including this report series.

The members of this Topic Work Group were:

Malcolm Bell (Topic Work Group Chair)	Centre for the Built Environment, Leeds Metropolitan University
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Michael Black	Bovis Homes (on behalf of the Home Builders Federation)
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Observers:

Mark Davies	CLG

EXECUTIVE SUMMARY

Building zero carbon / low energy homes reliably and robustly across the whole of its production is, probably, the most challenging goal any house building industry anywhere in the world has been asked to achieve. What is more, to achieve such a goal by 2016 is doubly challenging and will place considerable strain on every part of the industry, including house builders, their professional advisors and the product and labour supply chains. The strain on the building control system and the supporting infrastructure such as government policy initiatives, education and training and research and development will be equally demanding.

Set against this extremely difficult challenge, is an emerging concern that energy consumption and carbon emissions from new housing can be above that modelled at design stage. To ignore such concerns would risk undermining the zero carbon policy and would carry considerable commercial risk for the industry as a whole. Post 2016, customers will expect extremely low fuel consumption as well as comfortable dwellings. If this expectation is put in jeopardy by poor performance of insulation and services, resulting in higher fuel bills and poor levels of comfort, the loss of confidence in the industry and the regulatory system would be considerable. Also there would be an increasing risk of demands for compensation and expensive rectification work.

In view of these concerns, this Topic Work Group was tasked to evaluate the available evidence relating to realised energy and carbon performance, investigate the issues involved and propose a way forward.

In our review of the evidence we looked at work on the performance of new housing in general as well as more specific studies of fabric heat loss, airtightness and efficiencies of services such as space and water heating. In broad terms we concluded that there is, indeed, grounds for concern, with some studies of whole house heat loss suggesting that heat loss can be double what it was calculated at design stage. However, we became acutely aware that the number of detailed studies of energy and carbon performance is very small and there is an urgent need to strengthen the evidence base, both in terms of the extent of the problem and our understanding of the technological issues involved.

The difficulties of ensuring that the vast majority of new dwellings meet the required energy efficiency and carbon compliance standard are considerable. Our investigation of the problems revealed a large array of issues that involved every facet of the industry and its supporting infrastructure. These can be summarised as follows:

- The general state of technological understanding is insufficient for the production of low and zero carbon housing on a mass scale. The industry has many people who understand the principles involved and the underlying building science is well established but there is very little detailed understanding of as-constructed performance in relation to specific technologies and ways of building. Similarly, methods of measuring performance both during and after construction are seriously underdeveloped. The level of detailed understanding needed to build dwellings that perform as expected is considerable and much more needs to be done to both develop the detailed understanding and diffuse it throughout the design and construction community.
- Industry cultures are not sufficiently well focused around the energy and carbon performance of the product. Until the advent of the zero carbon homes policy, the saliency of energy and carbon performance was very low. In short, the industry has never been faced with a demanding carbon target, nor has it been

asked to prove, objectively, the energy/carbon performance of its product. Achieving zero carbon standards will require a significant shift in culture as well as industry expectations and practices.

- Energy and carbon performance is not well integrated into the design process, nor is there sufficient control of low energy/carbon design. Calculations and modelling are often divorced from design and the mechanisms for ensuring that modelling is an accurate reflection of what is built are weak. Similarly, the amount of detail design undertaken and detailed information provided for site staff and operatives is small. This leads to an expectation that those on site will make up the detail, working round the problems based on their previous experience. With the advent of exacting zero carbon standards this cannot continue.
- It is clear that construction suffers from insufficient design information but, equally, the construction processes adopted do not operate at a sufficient level of detail to ensure that the required performance is achieved. Construction sequences are flexible but often result in one operation being hampered by a previous one. Similarly, processes are not well geared around robust inspection and performance measurement, nor are product substitutions fully evaluated against the required performance standard.
- Feedback mechanisms on energy/carbon performance are not well developed and this hinders improvement in design and construction. There is a tacit assumption that what is modelled is achieved in practice. As a consequence there is very little understanding of what works and what does not, and very little continuous improvement in energy/carbon performance.
- As well as supplying product, the supply chain is an important provider of design and construction information, which is used in the compliance model. However, many of the performance claims are based on 'nominal' assumptions, theoretical models and laboratory performance tests and do not correspond with as-constructed performance. There is a need for the supply chain to work closely with house builders and their designers to establish robust estimates of as-constructed performance and to ensure that the estimates are used appropriately in design. Also considerable support is needed from the research community to establish methods and develop understanding.

In developing a solution to the problem of underperformance it is clear that the focus should be on improving the robustness of design and construction, a task that will involve the whole of industry, not just those designers and developers in the front line. However, the existing approach to building regulation and control provides little incentive for developers and the supply chain to invest in making the process improvements that are necessary.

In our view, an improved regulatory framework is required. Such a framework would provide a level playing field for house builders, ensure that standards are verifiably met and build an incentive and penalty structure that mobilises the commercial imperatives so as to drive the industry towards robust performance.

We propose that work should begin almost immediately to develop the existing regulatory framework based on the following key principles:

- **Clear performance parameters**. – The key physical performance parameters that are the basis of the Dwelling Emission Rate (DER) calculation should be made more explicit and used to evaluate as-constructed performance. Although the DER should remain the principle regulatory parameter for assessing the overall standard achieved, developers can only be held responsible for the physical characteristics of the dwelling and for the provision of the supporting operational information for households. They cannot control the way any particular household chooses to use the dwelling.

- **Confidence factors** – As a means of providing an incentive for designers and developers to improve the control they exert over design and construction, a series of factors should be applied to the relevant physical performance parameters in the DER calculation. The factors would reflect the level of control in design and construction. For those who invest in providing a high level of control, the factor would be negligible but for those who were not able to apply the necessary control, a large factor would be applied, resulting in significant over-design by way of compensating for the lack of control. The application of high confidence factors would result in increased costs and provide an incentive for investment in process control so as to avoid the imposition of what could be a large factor.
- **Accreditation of design and construction** – In order to be able to claim very low or zero confidence factors, developers and designers would have to demonstrate that their control processes are robust and deliver robust performance. This principle would require a well designed accreditation process that was recognised and audited through the building control or other national system.
- **Accreditation of fabric and services systems** – One route to robust performance could be to make use of particular construction or services systems that have been type tested in the field and are supplied and incorporated into the dwelling under certain supervision arrangements. Such systems could be accredited and incorporated into a developer's own processes.
- **Post completion testing** – Post completion testing is vital to ensuring that the system as a whole is delivering the performance required. This would be undertaken on a sample basis and the results fed back to the developer and their designers. Where failures occur these would be subject to further investigations and corrective actions which could include increased testing and/or the application of confidence factors until improvements are demonstrated.
- **Audit arrangements** – In auditing and testing of accredited design and construction organisations it will be important to avoid overly bureaucratic processes. The most appropriate test of any system is to verify its outputs such as the quality of design information used on site or the test results from in-production testing. We believe that by applying the principles of output audit a workable system can be developed.

We fully recognise the need to develop the proposals in much greater detail so as to produce a framework that not only achieves the desired performance outcome but also is practical, proportionate and minimises commercial risk. To this end we further propose that detailed proposals are developed by a joint industry – government group with priorities set using risk assessment processes and informed by the experience of, amongst others the NHBC, Robust Details Ltd, air pressure testing organisations and the research community.

Delivering low energy homes that perform in practice has considerable implications for developers, in particular and the industry in general. In developing the above proposals it will be important to ensure that the final framework does not become a burden in its own right. We are particularly aware of the different impacts that the proposals could have on developers of different types and output volumes and the need to accommodate the needs of all sectors of the industry. Similarly we are mindful of the likely impact on the supply chain and the opportunities that could be provided for innovation, much of which is undertaken by small as well as large companies.

The move from predicted performance to actual performance represents a significant change. The notional 70% carbon compliance reduction in emissions that has been assumed in policy modelling could result in a larger actual shift as the performance gap is closed. This should be taken into account when reviewing the 70% Carbon Compliance level and the impact of changes as a result of an enhanced compliance approach.

The impact of our proposals on the building control system are likely to mean a significant shift in the nature and role of building control personnel. In the field of energy and carbon performance, their existing role as checkers of plans and inspectors of construction on site is likely to diminish. In its place will be an increasing requirement to assess performance data and audit process outcomes. This will require a change in skill sets and there will be implications for the operation of other parts of the regulations.

It is envisaged that the implications for building control and the industry together with other relevant issues will be explored during the detailed framework design phase suggested above.

Throughout our discussions we have focused on what we believe to be the fundamental issues in ensuring that what is designed is what is built and that as-constructed performance meets whatever standard is required. This has led us to focus much more on the industry and its processes than on the modelling tool itself. Although we have identified a number of implications for the modelling tool, principally for the accuracy of its inputs and the usefulness of its outputs in assisting the evaluation of performance, we consider our conclusions to be applicable whatever tool is used. The most important requirement is that the tool and its surrounding regulatory framework encourages and supports the industry in delivering housing that performs in reality as well as in theory.

The transition to a future in which over 95% of housing production not only meets exacting low energy / zero carbon standards in theory but is able to demonstrate unequivocally that the standards are achieved in reality, will be difficult and, in our view, will take longer than the six years that remain between now and 2016. A much more realistic target date for full operation of a reliable system would be 2020. There is much to be done and much to consider and even 10 years may be too short a time frame. As such, announcing the intent for a modified regulatory framework which enables this to take place is necessary within the next 6 months.

In addition to the detailed design of a new regulatory framework, the transition period would need to seek the development of the research base and of the education and training infrastructure so that greater understanding is achieved and the appropriate skills are developed. We make recommendations in all these areas. However, the most important requirement is for a series of fully evaluated pilot schemes that explore the workings of the regulatory framework and provide feedback well in advance of implementation so that lessons learnt can be incorporated into final proposals. Similarly, the pilot schemes could serve to provide a set of process improvement blueprints tailored to the needs of different types of developer and designer and that help the supply chain provide what the industry needs.

It is now well accepted that carbon emissions from the housing stock need to be radically reduced and that achieving low energy / zero carbon new housing standards post 2016 will have an important part to play. However it is vital for the Government and the wider house building industry that such standards are actually achieved in dwellings as-constructed. This represents a considerable challenge but one which we believe the industry can meet given the right leadership, guidance and support. It is clear that tackling the problems we have identified will require considerable investment in improving the way we design and the way we build. There is much to do but the most important first step will be for Government to provide a clear statement that it is determined to achieve the necessary reform, using the findings of this report as its starting point. Such a strong signal is crucial since it will provide the confidence the industry needs to invest in improvement and drive the research & development and training effort that is required.

INTRODUCTION

There is a growing concern that the predicted energy/carbon performance of housing (and other buildings for that matter) is not matched by that realised in practice. Although relatively small, the evidence base suggests that the concern is well founded. This raises particular difficulties for Government and the house building industry. For the Government, reducing carbon emissions in housing (both new and existing) is a central plank of its climate change strategy. For the house building industry, there are additional concerns relating to their commercial and legal responsibilities to their customers. In the current regulatory climate, energy and carbon underperformance goes largely undetected by house buyers and tenants but with the advent of zero carbon standards, underperformance is likely to become much more salient and it is likely that developers could be exposed to significant commercial risk.

The recent consultation document on proposals for the Building Regulations (England & Wales)[1] Part L2010 (CLG 2010) devoted a whole chapter to the issue and its implications for regulatory compliance. The consultation echoes a previous report from the National Audit Office (NAO, 2008) in which they made the following comment:

'There is a growing recognition that non-compliance may undermine the effectiveness of Building Regulations, especially as they become increasingly stringent. But as yet there is little concrete information on the extent of non-compliance or how best to tackle it.'
(NAO 2008)

Similarly; the House of Commons Public Accounts committee (PAC 2009) reinforced the concerns, highlighting;

- the crucial importance of the building industry, its skills and processes,
- the need to strengthen the building control system and
- the ongoing requirement for rigorous and objective measurement of performance so as to establish the extent to which standards are being achieved.

A recent study for the Department for Communities and Local Government (CLG) of the implementation of the 2006 revision to Part L of the Building Regulations, which included some 11 workshops with the building control community, developers, clients and their consultants. indicated that there is considerable uncertainty surrounding the as-constructed energy/carbon performance of buildings (both dwellings and non-dwellings) when matched against the input parameters to the national calculation methodologies (Bell et. al., 2010)[2].

The financial and commercial risks for developers, post 2016, are likely to be considerable if they are not able to demonstrate, objectively, that the dwellings they produce meet the stringent requirements of zero carbon housing. If, as a result of government statements about zero carbon legal standards, reinforced by sales material, customer expectations rise, the industry could be faced with a significant increase in claims. In addition, public confidence in new house building could fall and the value of home builder brands decline.

This report explores the available evidence on the existence and underlying nature of the performance gap, makes proposals on how the problem could be addressed and draws out the implications for the zero carbon homes compliance system in general and the modelling tool in particular.

[1] Throughout this report all references to the Building Regulations and its different parts refer to the Building regulations for England and Wales unless otherwise stated.

[2] It is important to distinguish between the physical input parameters to the model and the Dwelling/ Building Emission Rates (DER or BER) as produced by the national calculation methodologies (SAP and SBEM). Parameters such as fabric heat loss and services efficiencies are combined with occupancy and standard use assumptions to produce the DER/BER. However when assessing as-constructed performance, it is the physical input parameters that are relevant to assessing the extent of any performance gap, since they are not influenced by occupancy and use assumptions.

THE PERFORMANCE GAP: A REVIEW OF EVIDENCE

Although direct evidence on performance is derived from a relatively small number of studies, those whole-house measurements that have been undertaken have considerable depth and rigor and provide not only a final measure but also explore the design and construction factors that have contributed to the performance measured. Most of the detailed evidence of whole house fabric performance is based on detailed case studies, supplemented with specific investigations of envelope U values and more broadly based cohort evidence on airtightness from a large number of pressure tests undertaken post 2006. Evidence from studies that have measured gas boiler efficiencies is also available and other studies are ongoing that seek to assess other systems. It is, perhaps, lamentable that there is no statistically representative data on whole dwelling performance from production cohorts post 2002 or post 2006. This means that it has not been possible to derive a performance distribution curve that can be used to identify the full extent of the gap and the scale of the problem. However the case material has given cause for considerable concern within government, industry and the academic community.

In reviewing the evidence we do not distinguish explicitly between those aspects that have their origins in design and those that are primarily construction related. Indeed, in many cases it is not possible to disentangle the two. Buildability arguments present a good example since the designer could argue that the design was not constructed as-drawn and the constructor that the design could not have been built as-drawn so they had to find a way round the difficulty. Similarly, if the designer has not provided sufficient detail (sometimes because they were not commissioned to provide it) and the operatives on site are expected to add the missing details, where does responsibility lie for underperformance? Clearly both design and construction play their part and it would be counter productive to apportion blame and responsibility. Addressing the problems of underperformance and developing a system in which performance is verifiably achieved consistently is the responsibility of the whole industry[3], working within a supportive regulatory environment, not just those designers and developers who are on the front line.

The performance of new housing in general

Quality and the performance of construction in general has been a recurring them of a number of reports on the construction industry going back to the 1960s at least, for example Banwell (1964) Egan (1998), Barker (2004) and Callcutt (2007). Given that most of these concerns were in relation to quality factors that could be observed directly, it would be surprising if energy and carbon performance, which is not so amenable to direct observation, was immune to problems of underperformance.

The first detailed study of defects in traditional housing was undertaken in some 12 public sector and 3 private sector schemes from around 1978 to 1982 (Bonshor and Harrison 1982a, Bonshor and Harrison 1982b). A follow up study was undertaken in the early 1990s (Harrison 1993) that focused on 18 private sector and housing association schemes with an additional 8 'energy efficient' schemes inspected for quality of efficiency features such as fitting of wall insulation. These studies, conducted between 30 and 20 years ago, produced a large catalogue of significant defects. In the case of the

[3] Throughout this report our references to the industry are meant to have the widest possible interpretation within the context of the discussion. This would include the supply chain, the professional bodies, trade associations, and building control and, in many cases, the industry's supporting infrastructure, which is made up of education & training (at all levels), research, government policy and industry support through such organisations as the Technology Strategy Board.

8 energy efficient schemes some 88 insulation and airtightness type defects were recorded. The qualitative analysis of causes of defect in the 1982 study suggested that there was an equal split between design and construction. More recent work focusing on energy efficiency and the application of the 2002 Part L robust details (Bell et. al. 2005) suggested that nothing much seemed to have changed since the early 1990s with a similar range of defects in such things as the fitting of insulation, thermal bridging and airtightness.

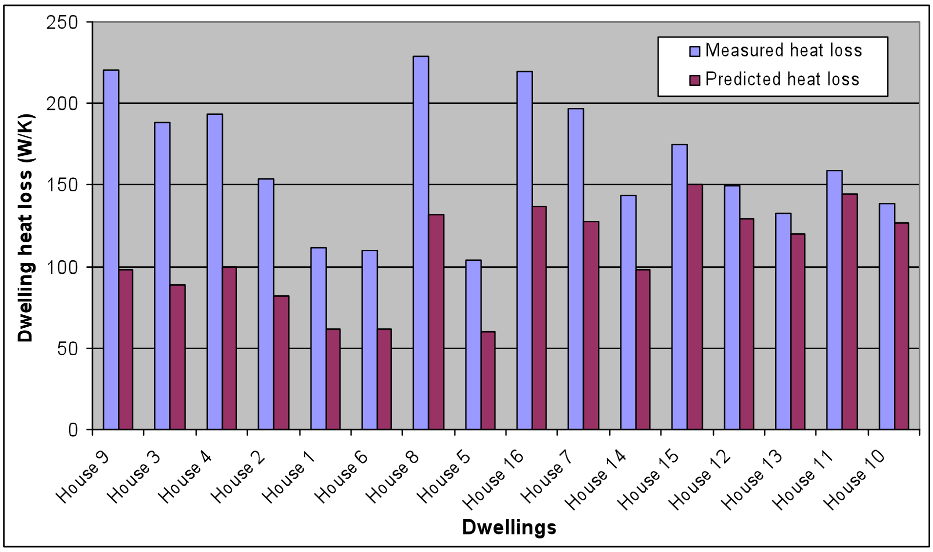

Figure 1 Measured v Predicted whole house heat loss for 16 dwellings[4]

Fabric performance (fabric heat loss)

The body of evidence on whole-house heat loss is increasing. Figures 1 and 2 provide evidence of the discrepancy in whole house heat loss between what was predicted at design stage and what was realised in practice. The results are for 16 measurements of whole house heat loss (using the coheating test method – Wingfield et. al. 2010[5]) from new dwellings[6]. Each of the measured values is compared with its companion predicted value as determined from design documentation. All tests, with the exception of house 14[7] were carried out by the Buildings, Energy and Sustainability group at Leeds Metropolitan University. The results are for a mix of house types and sizes. All are between 2 and 3 storeys with the exception of one house, which was 4 storeys. Only 2 houses were detached, the rest were a mix of semi-detached, mid and end terrace and in most non detached cases the existence of a party wall thermal bypass was noted[8].

The dwellings measured were designed to standards that ranged from the Part L 2006 Building Regulations to energy/carbon levels 4 and 5 in the code for sustainable homes (CLG 2008). The most striking picture is one of a large performance gap, which can be over 100% in some cases. Only 5 out of the 16 houses demonstrate even a reasonably close match at between 10 and 15%. None of the dwellings had a measured value that was less than the predicted value.

[4] Sources – Bell et. al. (in-press), Wingfield et. al. (2010), Wingfield et. al. (2009), Wingfield et. al. (2008), Stevenson and Rijal (2008)

[5] This method involves testing an unoccupied dwelling during the heating season. During the test period (usually 2 to 3 weeks), the amount of energy required to maintain a constant internal temperature (typically 25°C) is measured and related to external temperature. The data obtained are then used to plot power input against temperature differenced over a series of averaging periods (usually 24 hours) to give a whole house heat loss coefficient in W/K which can be compared with a theoretical value derived from standard heat loss calculations.

[6] Measurements were carried out between various winter periods from 2005 to 2010.

[7] This result was taken from a test undertaken on the Sigma house on the BRE innovation park (Stevenson and Rijal, 2008)

[8] A thermal bypass exists whenever clod external air is able to circulate between an insulation layer and the air barrier thus cooling the void and bypassing the insulation. The most notable example is found in party wall cavities between dwellings.

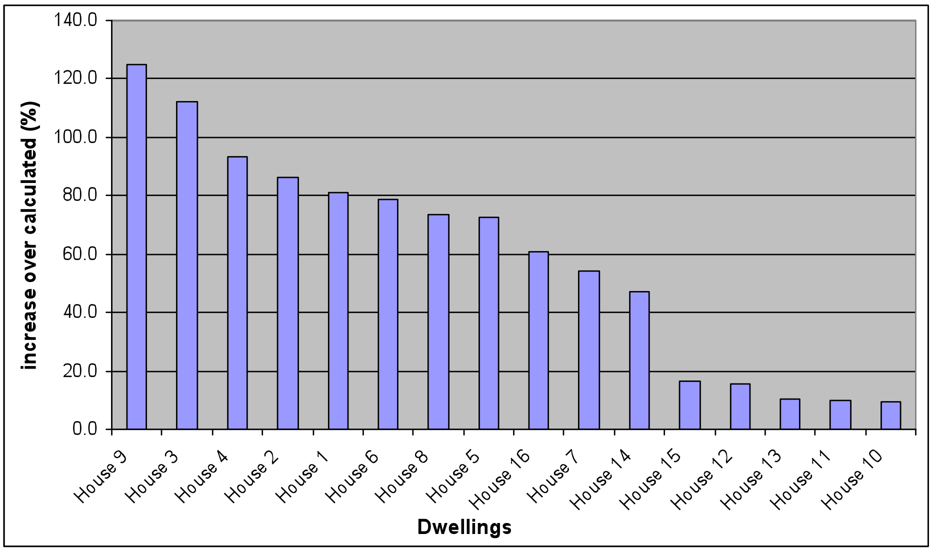

Figure 2 Measured v Predicted whole house heat loss as a percentage of the predicted value

Although the sample can not be described as representative of dwelling production, it is surprising that so few are even remotely close to the predicted value and none are lower than predicted. This is of particular concern when one considers the fact that in all but 4 cases, which relate to a 2006 compliant commercial development, the data are taken from schemes that had a particular focus on improved energy performance. Given this focus, it is unlikely that the sample of values are just the unfortunate workings of chance. It is worth remembering also that in the proposed regulatory context of zero carbon performance standards, even very small failure rates could be critical.

Further evidence of underperforming dwelling fabric is provided by a number of studies that measured in situ envelope heat flux, from which indicative U values were derived. The evidence available in the UK is derived from work by Siviour (1994) and Doran (2005) and measurements made during coheating tests undertaken by the Leeds Met team. Siviour's work on cavity masonry suggested that wall U values could be higher by over 50%, Doran's work on a number of different elements provided results showing a gap ranging, on average, from zero in a number of timber frame walls to over 20% for other wall constructions. However, the averaging of the cases belies a large range in the discrepancies observed with some measurements more than double the calculated value. The work of the Leeds met team on an off-site, closed timber I beam panel scheme indicated measured U values over 50% higher than predicted at the design stage and that much of this increase was more likely to be the result of a significant underestimation of timber fraction. This illustrates the importance of rigour in design calculations, which are a critical input to the Standard Assessment Procedure (SAP), as well as actual construction (Bell et. al., in press). Other work by the Leeds Met team on partial fill masonry with room-in-the-roof (Wingfield et. al. in press) showed external wall U values (calculated value 0.3 W/m2K) ranging from 0.5 W/m^{2}K (+66%) to 1.09 W/m^{2}K (+260%).

Work in Belgium on cavity masonry, much of which is consolidated in Hens et. al. (2007), has sought, among other things, to assess the likely impact of insulation placement and goodness of fit in fully filled and partially filled cavity walls with nominal U values of between 0.22 and 0.2 W/m^{2}K. The potential for very large increases in U value, particularly when using rigid insulation, would appear to be very large with increases ranging from 80% in the case of full fill mineral fibre to over 350% in the case of rigid board partial fill.

Attempts to investigate the reasons for the discrepancies have identified the following aspects:

- Degradation of element U values from ill fitting wall insulation, which allows air movement around and through insulation layers.
- Higher than anticipated thermal bridging at junctions and around openings.
- Significant thermal bypassing through party wall cavities and in other positions where the envelope air barrier is separated from the insulation layer[9].

Fabric performance (background ventilation heat loss – air tightness)

Figure 3 presents pressurisation test data sets from samples of dwellings post 2002 (Grigg 2004), post 2006 (NHBC 2006) and the Stamford Brook Development (Wingfield et. al. 2008). These data indicate a reasonable improvement in airtightness following the introduction of a limited testing requirement post 2006. The proportion of dwellings failing to meet the regulatory limiting value of 10 $m^3/(m^2.h)$ was reduced from 33% to only 3%, with a shift in the mean from 9.21 post 2002 to 6.21 post 2006.

The Stamford brook data illustrate the impact of a lower airtightness target with a mean of 4.45 $m^3/(m^2.h)$ set against the target of 5 $m^3/(m^2.h)$. However it is important to note that although the Stamford Brook mean was below the target value, over 30% had permeability values greater than the target. There is still some way to go to meet the airtightness requirements of zero carbon homes but these data present a reasonably encouraging picture and illustrate the impact on performance of even a relatively light touch testing regime. The introduction of a testing requirement for sound insulation (Part E of the building regulations) has had a similar impact, notably the development by the industry of a set of registered robust details managed by a self funding organisation (Robust Details Limited). The scheme verifies performance levels through a programme of inspection and sample testing. The latest annual report indicates a very high proportion of tests (93%) meeting the required standard (Robust Details Ltd 2007).

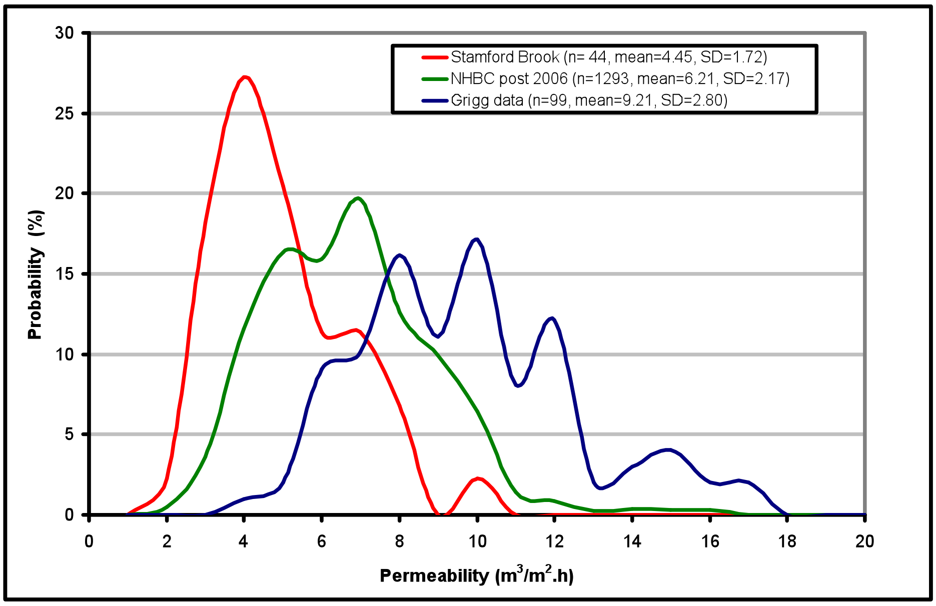

Figure 3 Air permeability distributions; post 2002 (Grigg 2004), post 2006 (NHBC 2008) and Stamford Brook 2005/06 (Wingfield et. al. 2008)

[9] For a discussion of thermal bypassing, see Wingfield et. al. (2009) and Lowe et. al. (2007).

Heating and hot water services

Emerging evidence from measurements of some 27 gas condensing boiler installations is demonstrating that efficiencies, as installed and in use, are likely to be some 5 percentage points below their SEDBUK rating (Carbon Trust 2007). Some corroboration of these data has emerged from more recent work done on behalf of the Energy Saving Trust (Orr et. al.,2009), which indicated efficiency values for the 10 regular boilers measured that were around 5 percentage points lower than their rated SEDBUK value. The range of the discrepancy was from about 2 percentage points to 9 points. Carbon performance is also considerably variable. Findings from baseline measurements of condensing boiler performance for the Carbon Trust's research into micro CHP indicate that electricity consumption for controls, fans and pumps can vary by around a factor of 2. This has considerable implications for standards based on carbon, since boilers of the same thermal efficiency could emit significantly different amounts of carbon (Carbon Trust 2007). Evidence from Stamford Brook provides a similar picture with estimated boiler efficiencies of the order 86% compared with a SEDBUK rating of 91% in the small number of cases monitored (Wingfield et. al. 2008).

In addition to boiler performance it is important to remember that efficiency will be heavily influenced by whole system effects (boiler plus pipework and inline components). In the monitoring work at Stamford Brook the whole system efficiency (boiler plus pipework) in one dwelling fell as low as 55% in the summer months. Some of the cause of the low system efficiency was related to very long and uninsulated flow and return pipework. Despite the fact that SAP takes account of pipe work heat loss it cannot be expected to cover the full range. The crucial point is the need to find ways of representing systems performance, as-installed in a particular scheme, rather than rely on theoretical generalisations.

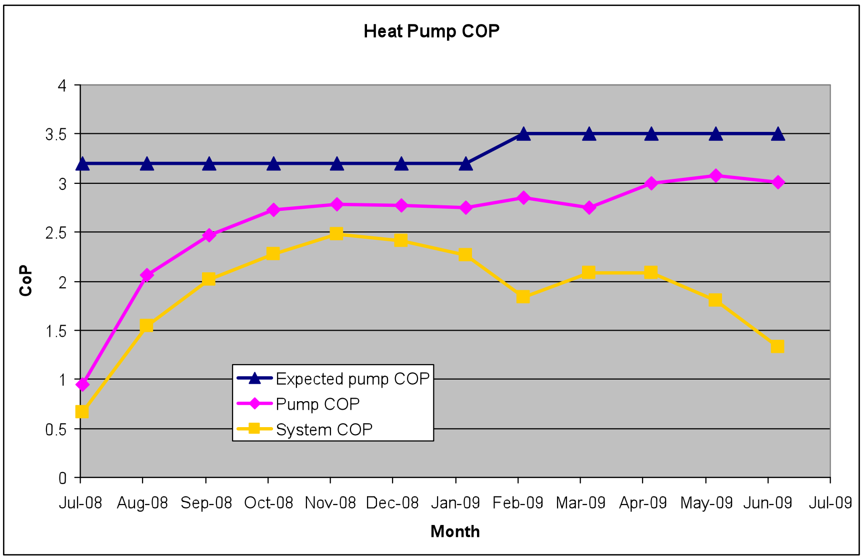

Figure 4 Coefficient of performance curves for a communal ground source heat pump system. (Bell et. al, in-press)

Increasing reliance on low and zero carbon (LZC) systems will further reinforce the need to understand systems impacts. Figure 4 shows coefficient of performance (CoP) curves based on monitoring data for a communal ground source heat pump, designed to run heating and domestic hot water for a terrace of 6 dwellings. Following a number of improvements to the control system and the design of the water pumping arrangements (resulting in the shift in the expected CoP in Feb 09), the measured heat pump CoP stabilised at a level close to the design assumption of 3.2. However the overall system performance, which included heat losses from the communal main and other design and control factors, is well below what would be required to achieve the standards set during design.

As with underperformance of fabric, the underperformance of systems is a complex area since performance is a function of whole system impacts. Ensuring a given level of performance requires considerable effort and understanding of the systems themselves and the interactions between the hardware and the people who use it. Controlling performance in the longer term will need to understand these issues and ways must be devised to minimise them and take the residual factors into account. The application of LZC systems will complicate this task even further and place a premium on sound science and understanding of system interactions.

Although outside the scope of this report, it is worth noting that similar concerns of underperformance have been noted in the non-dwelling sector. A range of important studies undertaken in the late 1990s and early 2000s demonstrated significant problems of underperformance (Bordass et. al. 2001).

Key conclusions and recommendations on the performance gap

Our review of the available evidence on the performance gap leads us to the following conclusions and recommendations:

- That the evidence points to the likely existence of a performance gap between design predictions and as-constructed performance.
- That the full extent of the problem is not known but that the evidence that does exists gives cause for concern across the house building industry.
- That more research should be undertaken to strengthen the evidence base both in terms of the extent of the problem but, more importantly, to improve understanding of the technological issues involved.
- That the achievement of policy objectives must be clearly demonstrated and mechanisms need to be put in place to provide a high level of confidence that as-constructed performance achieves the required standard in the highest proportion of dwellings possible (circa 95%).
- That there are important systems effects that reduce the theoretical performance of fabric and services.
- That systems effects should be explored and guidance provided so that systems effects can be taken into account in design and construction so as to improve as-constructed performance.

THE NATURE OF THE PROBLEM

The underlying problems are complex and extremely difficult to solve. The construction industry is highly fragmented and its processes both varied and difficult to define with clarity[10]. A particular characteristic of house building is the considerable variation in scale and structure. Callcutt's analysis of the industry in 2006/2007 (Callcutt, 2007) concluded that (ignoring self builders) some 83% of dwellings (116,000 units per year) were produced by fewer than 1% of house building companies with the remaining 17% (24,000 units per year) built by the remaining 99%, many of whom (78%) build fewer than 10 units per year[11]. However it would be a mistake to assume that the different types and scale of company are independent and that many of the underlying issues do not apply across the board. Many small companies work with larger companies as sub contractors and are influenced significantly by the contact. Also they all rely on the same supply chain for materials and components and for professional and site skills, albeit through different channels and with differing buying power. In this report we focus our attention on the generic issues rather than seek to differentiate to any significant degree between types of company. Clearly, further work will be required to address the more specific questions that arise in the different types of company but such work must be informed, in the first instance, by the broad analysis undertaken here.

Performance objective

In setting performance requirements, it is important to acknowledge that there are two distinct processes in house building. The first is the design process, which, among other things, seeks to demonstrate compliance with regulation. The second is the construction process, which seeks to translate the design into the built form that must comply with regulatory standards. It is important to differentiate the two aspects in order to understand the different roles and responsibilities involved and ensure that effective remedies are prescribed. If design inputs and, design decisions are accurate and reliably reflect reasonable expectations about as-constructed performance then the construction phase will be restricted to ensuring that the design/specification requirements are met. However the design process needs to reflect the tolerances involved and be mindful of what can be achieved at site level. Equally, the construction process needs also to be mindful of the tolerances expected and ensure that they are achieved. In practice, although distinct, the two processes need to be fully integrated so that each inform the other to achieve the same goal.

If the ambitious zero carbon homes policy is to be effective it is important to be clear about what success would look like in terms of the performance range to be expected from housing production in a mature zero carbon market. Inevitably, not all dwellings will perform at the same level but will form a distribution of carbon performance driven to a large extent by the carbon compliance standard, and the tolerances inherent in construction. Similarly, it would be naïve to expect that 100% of homes will achieve the standard. In our view the aim should be to ensure that 95% of new dwellings meet or exceed the carbon compliance standard. This objective is illustrated in Figure 5, leading to the conclusion that for the objective to be achieved, it is likely that carbon emission levels will be better than the standard in the majority of cases.

[10] Many of the underlying problems with the construction industry in general have been reiterated in a long history of official reports dating back to the 1960s (see for example, Banwell 1964, NAO 2001, the Egan report - Egan 1998 and the Latham report - Latham 1994)

[11] Callcutt (2007) assumes a net figure of 140,000 for the number of units produced by the industry after an allowance for the self-build sector (over 50,000 units). (see Callcutt, 2007 pp. 110-112).

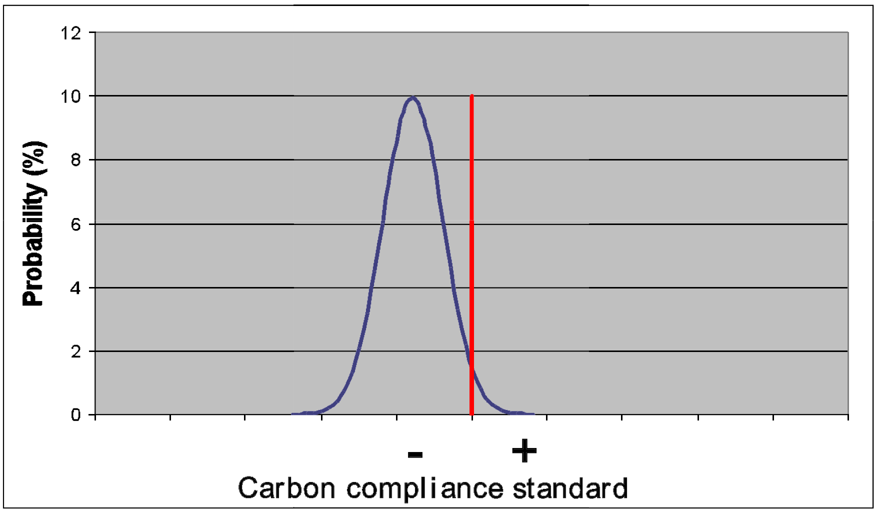

Figure 5 indicative performance distribution - 95% of dwellings with carbon emissions at or below the carbon compliance standard

The state of technological understanding

The underlying building science of low energy envelopes and efficient systems is well understood and, at least as far as space heating and conventional services efficiency is concerned, it is reasonably well modelled by a steady state approach such as BREDEM, the underpinning engine of SAP. However in applying the science and making effective use of the model, three important difficulties arise.

a) There is relatively little understanding of the impact of technological tolerances and other factors on realised energy and carbon performance – 'as-constructed performance'.

b) The development of understanding about as-constructed performance is hampered by a lack of practical methods that can be used to obtain feedback on performance in a production context – 'measurement methods'.

c) The knowledge and understanding about as-constructed performance that does exist is not well embedded within the design and construction community – 'diffusion of understanding'.

As-constructed performance

The degradation of insulation as a result of such things as air movement through and around insulation layers is well known and easily demonstrated with reference to established theory. However, to predict as-constructed performance in a particular situation is not so straightforward. The same is true of the related issue of thermal bypassing whereby external air infiltration into construction cavities creates an indirect heat loss path that bypasses insulation layers. Although the theory and principles of thermal bypassing are rather unremarkable in scientific terms, they have gone largely unrecognised both in the UK and elsewhere[12]. The particular case of the party wall bypass is a good example of a bypass mechanism that, although pointed out some 30 years ago in the USA, was not incorporated into UK building regulation guidance until 2010 (CLG 2010)[13].

Further scientific work on the as-constructed performance of fabric would be of benefit, particularly in the development of Computational Fluid Dynamic (CFD) models that can predict the effect of thermal bypassing. However, the ability to recognise bypasses and to eliminate them through appropriate design and construction is of much greater importance since they are much easier to design out than to calculate. Rather

[12] Thermal bypassing is a good example of something that, when explained, becomes so obvious that one wonders why no one took it seriously before.
[13] Although a small group of experts knew of the likelihood of heat los through party walls and there were a number of scientific papers available, it was not until the scale of the problem was, rather serendipitously, identified in the Stamford Brook project (Wingfield et. al., 2008 and Lowe et.al.,2007) that anyone took notice.

than sophisticated calculation tools, the most important need is for the efficacy and robustness of generic solutions to bypassing be verified in the field through rigorous type testing. A small number of such tests have been carried out to date (see for example Wingfield et. al. 2008 and Wingfield et. al 2009), the results of which were incorporated into recent Part L guidance (CLG 2010). The need for such practical development applies also to other aspects of thermal envelope design, and should be tackled as a matter of priority.

Further work is required also on improving our understanding of the as-constructed (or as-installed) performance of services. Again the difficulties do not lie with the basic science but in the performance of whole systems as they are applied. As was illustrated above with respect to a heat pump installation, systems performance can be significantly lower than that of its principal component, yet modelling often ignores or deals inappropriately with such impacts. Even in the case of more conventional systems such as gas boilers, emerging work in the last few years has recommended that the modelled (SEDBUK[14]) boiler performance be downgraded to reflect performance in use (Orr et. al., 2009).

The difficulty for designers and constructors lies in the availability of tools and guidance that would enable them to both design efficient fabric and services and make a robust prediction of system performance. We are of the view that it will be difficult for designers and constructors to meet the required standards in a reliable manner unless there is more robust guidance on as-constructed performance of fabric and services and the key design and construction conditions that must exist for such performance to be achieved.

Measurement methods

The capacity to measure and obtain useful feedback on key performance characteristics is central to any manufacturing system. Without effective feedback it is difficult to assure any particular performance level and almost impossible to improve. In house-building (and in the construction industry in general) very little performance measurement takes place and there is heavy reliance on visual inspection. In many areas, visual inspection is perfectly adequate and will always be an important mechanism for checking and feeding back on performance. However, in the field of energy and carbon performance, inspection alone is not able to control and verify that the level required has been met. This will be increasingly so as dwelling standards are tightened.

The impact of measurement is evident from the experience of mandatory air tightness testing following its introduction in 2006 (see Figure 3). Although there is still a long way to go, the proportion of dwellings meeting the maximum leakage rate and the availability of performance data has improved dramatically. The difficulty for the industry is that although a production test is available for airtightness, the measurement of fabric heat loss remains in the research domain and is expensive to undertake. Similarly, the performance of services remains something done as part of a monitoring project by researchers and not as part of commissioning or routine performance measurement prior to handover.

There remains a considerable body of work to do in the next 5 to 10 years to establish appropriate testing methods that are both effective in measurement terms and yet practical and applicable both within and at the end of the construction process. In undertaking this work a considerable effort is required in the next 3 to 5 years so that feedback can be provided in time for the framing of regulations for 2016.

In the case of services, much could be achieved by building into the design of systems a diagnostic and performance measuring capacity. Such capacity would assist not only in verifying that the required as-constructed performance had been met but would be of

[14] SEDBUK (Seasonal Efficiency of Domestic Boilers in the UK) refers a standard calculation designed to estimate seasonal efficiency of gas and oil boilers in the UK. A national database of SEDBUK values for different boiler models is referred to by SAP assessors when entering the boiler efficiency. However the calculated efficiency is based on bench performance adjusted in line with part load performance measurement and assumptions about load conditions over an annual cycle.

considerable value in maintenance. A considerable amount of self diagnostic capacity is currently built into components such as condensing boilers. To extend the philosophy to whole systems would be an obvious next step since it would enable developers to verify and demonstrate to customers that systems were well commissioned and delivering the performance expected.

Perhaps the most difficult area of methodological development will be in whole house heat loss measurement. Despite recent development work, as a result of the Stamford Brook and other projects, the central method (co-heating) has remained essentially the same as when it was first developed some 30 years ago. This and other methods are in need of urgent development. Such development will require close collaboration between building scientists, designers and constructors so as to ensure scientific rigour and applicability within the production context.

Diffusion of understanding

Evidence from a small number of detailed field studies (Wingfield et. al.,2008 & Bell et. al., in press) and feedback from the industry (Bell et. al. 2010) points to a general lack of understanding of many of the detailed design and construction issues in the production of low carbon housing. Although the general principles of efficient design and construction are well known throughout the industry, the detailed knowledge and understanding that is required to ensure robust as-constructed energy and carbon performance is not. This problem has at least two aspects. One relating to the general education and training systems and one relating to the extent of learning that goes on day-to-day in the workplace. Both will be important, the formal education system providing the principles and general skills and the workplace environment the detailed feedback on the problems with specific dwelling types and technologies.

In developing the range of formal education and training programmes, the role of professional and trade bodies will be crucial as well as the more obvious institutions such as colleges & universities, the skills councils and Government Departments[15]. Many of the courses run in the colleges and universities are shaped by the requirements of the professional bodies who accredit their courses. We believe that there is an urgent need for the professions, skills councils and education establishments to review and re-engineer education and training provision for both new entrants and established professionals. This should be done in such a way that it enables existing understanding to be diffused much more thoroughly and widely amongst all those involved in the development, design and construction of housing

Learning in the workplace is probably the most powerful learning of all since it is constant, immediate and meaningful. However, the lack of feedback on energy and carbon performance means that learning is more likely to reinforce existing performance norms, characterised by little capacity or enthusiasm to verify energy performance, rather than develop understanding of what it takes to produce low carbon housing. Also any learning, particularly by new entrants, generated within the formal system will be dissipated as the skills students learn while at university or college will rust through lack of use in their day-to-day activity. Ultimately, the required diffusion of understanding can only take place if coupled with improvements in the design and construction process and informed by feedback.

Industry cultures

Until the advent of the zero carbon housing policy in 2006, the awareness of the need to make drastic reductions in carbon emissions from housing has been very low. There has been neither regulatory pressure nor widespread 'demand side' appetite for low energy design or delivery. Research into the display of SAP certificates post 2002 and the use of energy efficiency in marketing materials revealed almost no enthusiasm for

[15] Currently education is divided between the Department for Education (schools) and the Department for Business, Innovation and Skills. If such a separation is not to have a detrimental effect then the needs of a low carbon built environment will need to be reflected in an integrated approach in which funding is coordinated.

promoting the energy efficiency of a home (NEF & De Montfort University 2003).

Since 2006 the industry has been coming to terms with the prospect of significantly higher performance demands than it has had to meet in the past and will need to respond accordingly. The evidence of underperformance, discussed above, points to the need to reengineer the design and construction process and to reorientate industry cultures around product performance objectives as well as commercial considerations. Indeed, in a world where the production of 'zero carbon' dwellings will become a touchstone for home buyers, commercial performance of companies may well be inextricably bound with the ability of developers to demonstrate that the required standards have been achieved and even exceeded.

There are many aspects of culture that impact on the delivery of zero carbon homes but perhaps the most critical is the lack of focus on integration of processes based on the performance of the product. This was an important theme of the study by Sir John Egan some twelve years ago. Although, in the following quotation, Egan was referring to the industry in general and was not specifically addressing the problem of carbon performance, it sums up this set of cultural issues (emphasis is as in the Egan report).

*"**integrate the process and the team around the product**: the most successful enterprises do not fragment their operations - they work back from the customer's needs and focus on the product and the value it delivers to the customer. The process and the production team are then integrated to deliver value to the customer efficiently and eliminate waste in all its forms.*

"The Task Force has looked for this concept in construction and sees the industry typically dealing with the project process as a series of sequential and largely separate operations undertaken by individual designers, constructors and suppliers who have no stake in the long term success of the product and no commitment to it. Changing this culture is fundamental to increasing efficiency and quality in construction." (Egan 1998 p13)

Significant cultural change will be vital to success but it must take place on a broad front. Without the integration of the process and the team around the product, the development of the knowledge base, cultural shifts within the supply chain, change in the regulatory environment and improvements in the supporting infrastructure, the transition to zero carbon housing will be almost impossible. Making the necessary shift is the responsibility of the industry as a whole and can not be left to those designers, developers and construction contractors who are on the front line. In framing the legislative environment it will be crucial that government ensure that those on the front line are able to rely on a supply chain that is realistic about as-constructed product performance, has access to a steady stream of competent people, is supported by national R&D programmes and have the necessary incentives to invest in their own performance improvement programmes.

Design Process

As with any complex product the performance of zero carbon dwellings will be determined by the process that produces them. Of course there is no single process of design and construction and there will be important differences between different types of client and developer, particularly between social and commercial sectors and between developers of different output volumes. However, whatever the differences there are a number of important principles and sub processes that are common to all.

Inception stage

At the inception phase, important design decisions are made for the whole development, often involving protracted planning negotiations. However, in most cases, the performance of the dwellings is taken for granted as negotiations take place over aesthetics, access, layout and planning gain. All of these issues are important and have a major impact on development appraisal calculations in which the costs of construction are squeezed. The process is not an exact science and, since land is often purchased years in advance of development, there is a great deal of uncertainty. However, the process needs to be able to take account of the costs of production, which are likely to be incurred a number of years in the future. In the context of the 2016 time scale developers are already making development decisions for schemes to be constructed post 2016.

Closing the performance gap will involve a significant investment by designers, developers and contractors in improving their processes and these will need to be taken into account in development appraisals that are being undertaken now for zero carbon developments post 2016. There is an urgent need for government to provide an early indication of the steps to be taken to close the performance gap and the transition timescales involved.

It is hard to see how any developer can make a significant investment in improvements without a clear signal from government about the actions to be taken to close the performance gap. The difficulty for any particular designer or developer in the present is that, unless everyone is required to take steps to close the performance gap and demonstrate that the required standard has been achieved, that designer or developer will be at a significant disadvantage. Clearly, the regulatory structure and commercial imperatives need to be set in such a way as to ensure that all developers are operating under the same constraints. It will be of particular importance that the commercial risks of underperformance are sufficiently salient as to reward those designers and developers who invest in improvements and penalise those who do not.

Dwelling design

Design processes vary and in most cases are ill-defined. Designers are regarded as 'suppliers' of a particular service meeting specific outcomes for fixed costs. On the whole they are not regarded as participants in a process but merely suppliers of a component at a specific stage, for example, a SAP assessment for building regulations compliance; a floor area measurement for an appraisal or a minimal set of details for a building regulations submission. This often means that design responsibility is diffused and fragmented and the different actors have little opportunity to cross check or verify important design inputs. This is particularly true of SAP assessments since they are treated as a specialist activity provided by a supplier who is judged on cost and timeliness of delivery rather than accuracy or contribution to design decision making.

In a typical process, the master planning, concept and detailed design phases are separate and often undertaken by different organisations yet they all contribute to carbon performance. For example, some of the difficulties of minimising thermal bridging or ensuring a high level of airtightness have their origins in envelope complexity brought about by aesthetic and other requirements that are determined at master planning and concept stages. Also house types are often designed with one form of construction in mind, such as cavity masonry but then changed at detailed design stage to timber frame, giving rise to a different set of design problems. All these changes will in turn affect the SAP rating and carbon performance. This is not to suggest that legitimate aesthetic or construction flexibility criteria should not be met but that there needs to be much more integration between the different design phases.

Realising robust carbon performance is highly dependant on detailed design, yet this aspect does not receive a great deal of attention, at least as it impacts on carbon performance. Observations of design and construction of low energy housing reveal many instances of details being made up on site, working from, at best, general arrangement drawings (Bell et. al. 2005, Wingfield et. al. 2008). Detailed design is highly complex and involves the coordination of input from many different sources from materials and services suppliers to the provision of design calculations and SAP modelling. Very often, the required coordination is not focused around achieving the performance standard but on meeting a required cost target. Of course, both are important and the challenge will be to ensure that the performance standard is met while minimising cost. Our analysis of the problems of detailed design would suggest that the following general issues need to be addressed.

a) **Understanding** – The understanding of effective thermal envelope design, particularly, the detailed design of thermal insulation layers and the air barrier needs to be improved significantly. Such understanding needs to be embedded in the design process and reinforced within the organisational culture. The same need for understanding applies to the principles of efficient systems design, particularly as they relate to pipe runs, accessibility and usability. The issues raised apply to design at every level but are particularly acute in detailed design.

b) **Design calculations** – In the majority of cases detailed energy calculations of such things as U values and Ψ values[16] are not undertaken by detailed designers as an integral part of the design process. Instead they rely on calculations provided by SAP assessors, materials and component suppliers and the default values contained in SAP to demonstrate compliance. Such an approach does not allow for many (if any) design iterations or optimisation. It also tends to encourage the acceptance, without question, of third party calculations, a significant reliance on nominal or default values and a reduction in the understanding of energy and carbon performance issues within the design community. There is an urgent need to reintegrate design calculations into detailed design process and use them to inform solutions rather than simply confirm, or not, compliance with regulatory standards.

c) **Accuracy and error checking** – The use of formal error and accuracy checking processes in detailed design calculations are rare. Input errors, particularly with respect to U values, areas and volumes, in SAP models can go undetected yet have a significant impact on the calculation of dwelling emission rates. Trinick et. al. (2009) reported that 52 out of 82 SAP assessments had an error and that when corrected 20% of dwellings failed to meet the emission rate target by around 10% on average.

d) **Design responsibility** – Responsibilities for the accuracy of design calculations, SAP inputs and the SAP calculation itself are very confused. A supplier may quote a nominal U value for their material as used in a certain type of construction, which they provide to the developer's technical team, the value along with lots of other 'nominal' values is provided to the SAP assessor who is not involved in the design process. Such a sequence is typical and leaves a trail of potential responsibility that is impossible to unpick. Under the current regime, the question does not arise since there is very little verification of as-constructed performance. However, this could change dramatically with a tighter carbon standard and an improved approach to verifying performance.

e) **Design for construction** – Detailed design needs to consider to a greater extent the requirements of construction in terms of buildability, sequencing, minimisation of complexity and robustness. This requires designs to be tolerant of construction variation or to be designed in such a way as to minimise the potential for variations to occur through the use of appropriate materials, components and build sequences. The use of standard detailing may help this process but the use of standard or accredited details should not be seen as a

[16] A Ψ Value (W/mK) is a measure of linear thermal bridging.

substitute for a solid understanding of thermal design principles and appropriate calculation.

f) **Design for inspection** – In order to achieve the desired final performance characteristics, designs need to take account of inspection requirements and performance checks during the construction phase to ensure that the various elements have been built in accordance with the original design specifications.

g) **Communications** – Communication between design and construction teams should be improved especially in terms of the detailed design information that is provided to site. In the vast majority of cases, the level of detailed design information is not sufficient to ensure that thermal performance is assured. One consequence of a general lack of detail design drawings and specifications is that construction teams have low expectations of the documentation provided. Construction teams expect to fill in the gaps themselves and are unlikely to consult design information even if it is provided. In an improved process not only will design drawings need to be more comprehensive and be supported by detailed construction and sequencing information, construction teams will have to be convinced that the information is worth consulting and that they are expected to use it.

h) **Change control** – The design process requires some form of change control procedure that can monitor and evaluate the implications of any modifications in design or any material or product substitutions to ensure that such changes do not negatively impact on carbon performance. Such a change control process will need to link with both the construction process and also to the procedures used by the supply chain.

i) **Continuous improvement** – A culture of continuous improvement in design should be adopted that actively seeks feedback into the design process. This will require a higher level of integration and cooperation between design and construction in general and between developers, their sub-contractors, suppliers and design consultants in particular.

Construction processes

Most developers have a construction process involving a general programme that includes a series of contract and hand over meetings at which key documents and design and construction information are communicated. Many also have a series of predefined site inspection points at certain stages. Such general processes tend to be reasonably well ordered and logical. However, at much lower levels of detail, there is considerable variation in the way that tasks are organised. Detailed monitoring or checking of construction against design details is almost impossible because of a lack of design detail or well understood performance criteria that can be built into inspection and testing processes. Site teams have to cope with insufficient detailed design and sequencing information and this results in the need to work round problems as they arise and to engage in on-site detail design without access to the necessary knowledge, understanding or modelling tools.

Rethinking construction processes is inextricably linked to changes in design processes and improvements in both design solutions and the provision of high quality design information. However, construction processes need to be capable of ensuring that what is designed is constructed. Of course, this presupposes that what is designed can be constructed robustly. However, hampered as it is very often by inadequate design information, there remains much that can be done to improve the production process. The issues that should be addressed are set out below:

a) **Understanding** – As in the case of design, the understanding within the construction process of the important principles of low energy/low carbon design and construction is not sufficient to enable robust construction. Work needs to begin to find ways of developing the knowledge base through on-the-job training and the use of performance feedback as well as more formal training.

b) **Production control** – Existing production control processes do not operate at a detailed level. In most cases, the order in which detailed operations are carried out is not described and much is left to the discretion of site management and construction operatives. Although such an approach is flexible and allows for the switching of resources, almost at a moments notice, it is not conducive to robust and repeatable performance of fabric and services. Site observations often reveal work that has to be opened up and reconstructed because something has been forgotten or an obstruction is created that prevents or makes awkward the installation of insulation, services pipes or air barriers. Not only does this lead to production inefficiencies, it also impacts on energy and carbon performance. The overall construction process may be reasonably well set out but much more needs to be done to provide control at a much lower level of detail.

c) **Standardisation** – One inevitable result of limited production control and detailed planning is a general lack of standardisation of process. It is common to observe the same house types built with different operation sequences and with differences in some of the hidden details. These differences occur from one site to another within the same organisation and even from one dwelling to another on the same site. Usually they occur because of different approaches taken by different site managers and different operative gangs. Services pipe and cable routes provide a typical example of a lack of standardisation. This is partly a result of limited design detailing but is also symptomatic of an approach that leaves a great deal to the discretion of lots of individuals, most of whom are unaware of the wider performance consequences of their actions.

d) **Construction sequencing** - Improved sequencing of construction tasks and more comprehensive documentation of preferred construction sequences would be expected to result from improvements in control and standardisation. This is both a design and construction problem and is likely to lead to much greater robustness of performance. It is worth remembering that the very act of deconstructing existing construction sequences and designing new ones on a house type by house type basis would help to point out production inefficiencies and potential cost savings as well as ensuring more robust energy and carbon performance.

e) **Resource logistics** – Marshalling the required resources for dwelling production is a very complex task and although the lack of standardisation of process and a very flexible approach to production control may seem attractive, it provides very little structure and undermines the discipline of ensuring that resources are planned well in advance. Similarly, the problem of inappropriate product substitution, which often undermines performance, is a symptom of this wider malaise in which construction can be modified at short notice with little thought for the performance consequences.

f) **Change control** – As part of a more standardised approach, robust procedures are needed for the control of changes to detailed construction and for product and material substitutions. This will ensure that any changes are identified and that the potential effects of such changes on performance are assessed before being implemented. The precise nature of control will vary but ,in principle, the key performance characteristics of all materials and components need to be very clearly specified and available to those who are responsible for decision making.

g) **Inspection processes** – Existing control methods rely heavily on visual inspection. However, effective inspection is hampered by the problems of process control and standardisation noted above. Under current practices the flexible and individualistic approach to detailed construction makes an effective inspection routine very difficult to implement. In a modified process, inspection planning would become much easier to undertake and if backed up by objective performance measurement would become much more effective.

h) **Performance measurement** – Performance measurement methods, which are able to verify as-constructed performance in a production context, are significantly underdeveloped. Even in areas such as services, where testing of such things as air or water flow is relatively straight forward, it is not done sufficiently thoroughly to be able to verify installation performance. Given the level of energy performance being aimed at post 2016, effective testing will become a crucial aspect. Not only will the results of testing provide confirmation that processes are effective but will also provide feedback so that both design and construction is improved. Existing testing regimes such as airtightness pressurisation may have to become routine, carried out before the air barrier is covered by finishes and more comprehensive than that required merely for regulatory compliance checks. Similarly systems commissioning processes will need to include aspects of energy performance as well as operation. However, it must be recognised that the battery of tests available is not very extensive and considerable effort will be required to provide developer and contractor organisations with the support they will require. Central to providing the necessary support will be the development of the performance measurement skill base within the industry at all levels.

i) **Continuous improvement** - A culture of continuous improvement is needed to ensure that process problems are identified and fixed during construction, and that there are procedures to record and capture this information to feedback into the design and construction processes.

Handover and aftercare

Handover processes are extremely variable. Observations at Stamford Brook and on other housing sites monitored by the Leeds Met team suggest that very often the people introducing occupiers to their new home have little detailed knowledge of the dwellings and their energy systems. Although information is left in dwellings (as is required by the Building Regulations) it is usually in the form of manufacturers' literature about the boiler and controls with little in the way of induction or energy.

Over the last 20 years various small studies have suggested that energy advice could reduce consumption but the evidence is mixed. More specific material on the provision of feedback reviewed by Derby (2006) would suggest that giving users information on energy consumption via displays is an important tool in helping occupants to learn how to reduce energy consumption. However, the nature of the feedback and the context into which it fits is an important factor in encouraging appropriate behaviour. The problem with advice in general however is that it needs to be highly specific to the dwelling and its systems as well as the nature of occupancy and lifestyle (Bell et. al. 1996). This would suggest that there is a role for developers during the handover and initial occupancy phase to ensure that the energy features of the dwelling are understood and that important elements are labelled appropriately. In the case of social landlords (and private sector landlords for that matter) the long term after care processes and provision of advice could be important.

The supply chain and supporting infrastructure

The supply chain and supporting infrastructure consists of both the traditional supply of materials and components but also the supply of skilled labour (at all levels in the process) and areas of the supporting infrastructure such as general construction education, ongoing technical advice systems such as that from the EST, professional bodies and building control.

The material and component supply chain

We have noted on a number of occasions that the materials and component supply chain do not only supply a product but also seek to demonstrate how the product can be incorporated into a particular construction system or design. Indeed some elements of the chain purport to supply, in whole or in part an envelope or services system. Designers and constructors rely, quite reasonably, on the supply chain to provide performance information and calculations that can be included in SAP. However, the evidence on as-constructed performance would suggest that, very often, the claimed design performance cannot be realised on site. The problem is not that the claims are generally wrong but that they are based on nominal estimates or laboratory performance and not as-constructed or as-installed performance.

This is not a surprise. The supply chain are presenting the performance in the manner required, using EU product testing standards and using certified laboratories. The issue is that such a standard performance declaration is not necessarily a good proxy for in situ performance. It would be commercial suicide for a manufacturer or supplier to declare an in situ performance which was worse than that required by agreed standards, in the absence of a regulatory driver. The business would be lost to the supplier that (legitimately) claims the better performance.

In seeking to resolve the issues of underperformance it is vital that designers and constructors work closely with the supply chain on performance issues so that the supply chain understand the tolerances of construction and installation and designers and constructors understand the limitations of the materials and components they are specifying. The objective of such a collaboration is improved products and processes such that declared performance characteristics are based on the performance of materials and components in situ. The responsibility for achieving such an objective lies with the supply chain, designers and constructors but needs to be supported by a robust regulatory framework to standardise performance criteria. Of course, there is much work to be done to ensure that accountability is clear and does not degenerate into legal argument but with the right regulatory and other structures, achieving robust as-constructed performance should not be impossible.

The labour supply chain

The supply of labour with the requisite skills is a very difficult and long term problem. Although a great deal of emphasis is likely to be placed on education and training, which is discussed below in the context of the supporting infrastructure, the structure of the supply chain itself will need to adapt to the demands that will be placed on it by the requirement for zero carbon housing. It is worth reflecting also that many of the labour supply issues that relate to new house building will have a parallel in the housing refurbishment market since many individuals will work in both sectors.

It is not uncommon for difficulties within the construction industry in general and house building in particular to be put down to the growth of subcontracting, usually with reference to obtaining site labour and specialist installers. In principle, there is no reason why subcontracting should not be able to deliver the performance levels sought. However, as with most things in this area the problems lie in ensuring that the whole team from designers (some of whom are subcontractors) to site operatives and sales & marketing staff are clear about their role and responsibilities and that they have the information and skills necessary to perform effectively. This is primarily a matter of improving process for it will be the increasing demands of well defined and improved processes that will drive the demands for a highly skilled and responsive labour supply chain.

Key conclusions and recommendations on the nature of the problem

Our investigation of the underlying nature of the problem has led us to the following key conclusions and recommendations:

- That the underlying physics is robust but that greater understanding is required of as-constructed and as-installed performance. This is particularly so in establishing the impact of air movement around insulation layers, thermal bypassing (all forms) and the 'whole systems' effects of services.
- That many of the uncertainties in the building science can be significantly reduced by the application of sound design and construction principles and well controlled processes supported by evidence from the field.
- That improvements are required in the design process in the following areas:
  - The quality, accuracy and verification of design calculations.
  - The quality, accuracy and verification of inputs into the national calculation model so as to reflect as-constructed or as-installed performance of proposed fabric and services solutions.
  - Increased clarity of responsibilities for detailed design, thermal performance modelling and as-constructed performance predictions as represented in regulatory compliance.
  - Increased clarity of the roles and responsibilities within the supply chain in making and supporting as-constructed performance claims for fabric and services systems.
  - Effective communication of detailed design information to construction teams.
  - Quality of design information, including drawing clarity, specification detail and sequencing requirements for a particular design.
  - Effective use of feedback from construction so as to reflect construction tolerances more robustly (improved buildability and impact on performance).
- That improvements are required in the construction process in the following areas:
  - Performance control and quality assurance systems that ensure adherence to design requirements while maintaining flexibility to respond to design modifications without compromising performance.
  - Construction programming and sequencing at a high level of detail. This should include improvements in the assembly of resources (materials, labour and components) as well as such things as the sequencing of construction operations.
  - Inspection and testing programmes built into the production process designed to demonstrate compliance with the approved design. Such programmes will need to be supported by effective measurement and

inspection tools.

  - Whole house testing, post completion, and practical sampling methods, so as to verify the efficacy of the overall design and production process.
  - Methods and processes for investigating and correcting process anomalies so as to bring performance back into control

- That improvements are required in the provision of performance information provided by the supply chain such that the declared performance of products and systems is standardised and reflects as-constructed and as-installed performance based on agreed measurement methods.
- That a programme of R&D needs to be developed to provide underpinning research in performance measurement, as-constructed prediction and process improvement.

DEVELOPING A SOLUTION

In seeking a solution to the problems of ensuring that, post 2016, the house-building industry is able to demonstrate objectively that its product meets the standards for zero carbon, it is important to distinguish between those things that are under the control of the industry and those that are not. Household energy consumption and associated carbon emissions are the result of a complex interactive system that includes the dwelling fabric, services and the household. However, to a first approximation, the house-building industry only has control over the design and construction of fabric and services but no direct control over the household component. Just as a car manufacturer cannot be held accountable for the way someone drives, a house builder cannot be held responsible for how a dwelling is used. The extent of industry responsibility is illustrated in Figure 6. Being clear about the extent of responsibility is very important, particularly since the target emission rate calculated by SAP and used for regulatory compliance is an estimated rate that includes an allowance for the household component. In developing a solution to the problem of underperformance it will be crucial that the set of use assumptions in SAP are made much more explicit than is currently the case. Some, such as occupancy are reasonably clear but others such as hot water consumption are buried in the modelling formulae.

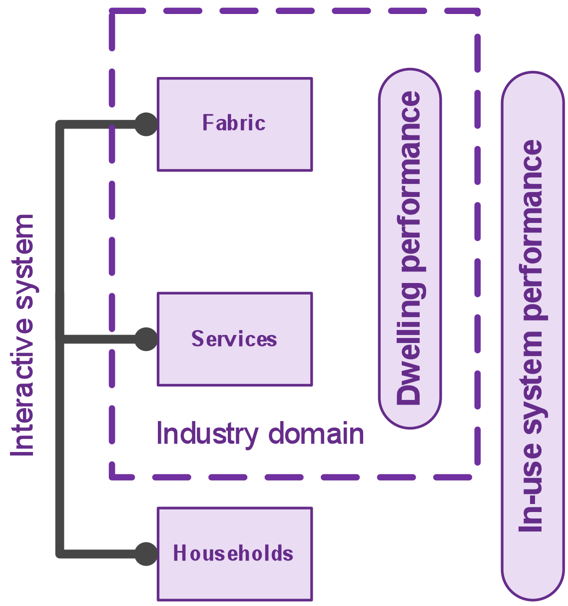

Figure 6 Dwelling and in-use systems performance

Despite the need to focus on the fundamentals of dwelling performance there are important aspects of household interactions that the industry needs to take into account and include in an improved regulatory system for zero carbon homes. Household interactions are often thought of in terms of the user interface and summed up in the need for attention to effective controls that are easy to understand and use. However, this is too narrow a definition and should include also the wider issues involved in providing a home that enables occupants to achieve comfort and lifestyle goals while enabling them to minimise energy consumption and carbon emissions. The problems of improving dwelling design and construction in this domain are complex and there is a serious lack of understanding about the relationships involved. However, there is more understood than is applied, particularly at the level of controls. For example, a great deal of classical ergonomic work has been carried out on displays and controls and design guidance provided for use in other domains such as vehicle design but there is very little clear guidance for controls in dwellings. Regulatory guidance already requires the provision of operation information and this should be improved to include relatively simple things such as control labelling and improved usage advice at hand over. Future regulatory guidance revisions should be considered to improve the interactions between households as detailed design guidance becomes available. The remainder of this section deals primarily with the requirements for improving the as-constructed performance of fabric and services, which is a prime determinant of dwelling performance.

Strategic options for improving dwelling performance

In the consultation document relating to the review of Part L 2010 (CLG 2009) and in an earlier industry advisory group paper (Bell 2008) the following strategic options were identified:

Confidence/tolerance based design[17] – Applying this approach would involve the use of performance confidence factors that result in over-design so as to ensure that the desired level of performance is achieved in almost all cases. The attraction of this approach is its simplicity and directness. However, used on its own, it would result in considerable waste of resources and would not provide an incentive for the industry to tackle the fundamental design and construction problems that have already been described. In addition, the likely variation in performance for many constructions, coupled with a chronic lack of reliable data would make it very difficult to define a fair and reasonable set of tolerance factors in the short term. Before such an approach could be taken, a robust impact assessment on cost would be required to ensure that it was effective

Process control – Adoption of this option would seek to ensure that the house-building industry develop improved control of processes for design and construction that assures or guarantees the required level of as-constructed performance. The attraction of such an approach is that it strikes at the heart of the design and production shortcomings but if applied without reference to tolerance or performance measurement it would always lack the necessary demonstration that improved processes were delivering what they claimed. The complexity of the supply chain, the nature of a house building and the number of small house builders, presents a considerable process improvement challenge and is likely to increase costs at least in the short to medium term. To embark on such an approach without the support of good tolerance based design and performance testing could result in process change but with relatively little performance improvement.

Post completion performance testing – In adopting this option, all or a very large proportion of dwellings would be exhaustively tested in an independent manner so as to drive as-constructed performance. The difficulty with this option, if used in isolation, would be the significant and, potentially unsupportable expense of a very large testing requirement. Similarly, the fact that existing whole house heat loss measurement tools do not allow for measurement outside the heating season (October to April) would risk considerable distortion in the flow of dwelling completions. This, in turn could result in the need to stockpile tested dwellings for sale in the summer months, adding considerable cost. Further costs would be added where dwellings failed, giving rise to extensive rectification works. The net effect of a comprehensive 'testing only' approach would be to the detriment of

[17] In the references quoted this element was referred to as 'conservative design'

SME companies who may find it difficult to manage the costs involved. This would prove to be a barrier for entry for new entities in the market and possibly the exclusion of many already operating.

Although presented as three independent strategic options, to adopt one without reference to the others would seriously undermine the objective of performance improvement and verification. Rather than seeing them as options, all three are necessary components of a well organised efficient and lowest cost design and production process. To achieve low/zero carbon homes the industry needs to ensure that improvements in the design process would take account of performance tolerances (**confidence/tolerance based design**) but would do so in the light of well controlled design and construction process that ensured the accuracy of design calculations, robustness of performance information and good control of construction (**process control**). Further, in order to ensure that processes were working effectively and the correct tolerances were being applied some testing both in production and upon completion would be necessary (**performance testing**). The test results would provide information on the extent to which performance was on track and provide feedback that could be used for continuous improvement of both design tolerance and process control.

An enhanced approach to regulatory compliance

The role of government is to establish a system of regulation that provides a level playing field for industry, ensures that standards are verifiably met and builds an incentive and penalty structure that mobilises the commercial imperatives that drive developers towards robust performance. Put bluntly, the commercial risks of underperformance must be significantly higher than those of over-performance and the rewards of over-performance worth striving for.

Our proposals for an enhanced system are likely to have significant implications for building control. At this stage it is difficult to predict what these may be since much will depend on the detailed design of the regulatory framework. However, the current approach to the control of energy/carbon performance, in which the Building Control Body is seen, de facto, as an extension to the developer's quality control system, needs to change. Whatever system is put in place the guiding principle must be one in which the house builder and supporting cast take absolute responsibility for achieving regulatory standards and provide robust evidence of compliance. This is, of course, no more than a restatement of the formal regulatory position and one which exists in all other regulated industries. In other industries, such as pharmaceuticals or aerospace, failure to meet regulatory standards carries a high commercial risk and this drives internal quality systems. An enhanced regulatory system should seek to achieve the same state of affairs in the house building industry.

In outline, the house building industry would need to demonstrate that;

a) there are robust design and construction processes in place and that they are operating effectively;

b) there is an effective measurement and testing regime in place and

c) objective performance information is provided to demonstrate that control processes are working.

Those developers who were not able to demonstrate such characteristics would have to 'over design' to higher standards and undertake extensive 3rd party testing to demonstrate that they were achieving the required levels of performance.

Outline of the proposed approach

Page 31 sets out the three pillars on which the proposed new approach is based and the following sub-paragraphs show how they could be combined to provide a robust national performance assurance system.

a) **Key performance parameters** – The national calculation methodology will define a number of key performance parameters, such as whole dwelling heat loss (both fabric and air leakage), services efficiencies, and renewable generation capacity, against which the performance of the dwelling will be assessed.

b) **Design confidence factor** – Each key performance parameter will be calculated according to standard theory but have a confidence factor applied that acts as an incentive for designers to improve the control of design. Those who demonstrate a high level of control, which is verified through an appropriate accreditation system (see below), will have a very small or no factor applied and those that cannot will have a larger factor applied. The size and application of factors would depend on further work on the details of such an approach. The adjusted parameters will be used in the calculation of the as built Dwelling Emission Rate (DER).

c) **Construction confidence factor** – A factor would be applied as an incentive for constructors to improve their control over construction. This would work in the same way as the design factor.

d) **Accredited design and construction** – Demonstration of good control over design and construction will be dependent on the establishment of an accreditation system that will give separate accreditation for design processes and construction processes.

e) **Accredited fabric and services systems** – The accreditation process would allow for system specific accreditation for off site and other systems (both fabric and services) that are provided as a complete package and include design and construction. See below.

f) **Post completion performance testing** – In order to demonstrate that the system is working it will be necessary to undertake third party post completion testing on a sample of dwellings (for example 1 in 50). Where testing indicates that performance is within expectations, a report will be provided on the level achieved and, if appropriate, any observations on areas that could be improved. Initially the provision of information itself would be sufficient to drive improvement (see chapter 6 Transition Planning). Later, where test results indicate that the tested dwellings do not meet the required standard, further testing and investigation will be required within a specified period to establish the reasons for underperformance.

Box 1 presents an illustration of the way the proposed new system could work in practice for a timber frame scheme with a well controlled design and construction process. In the scenario presented in box 1, the adoption of good control and the use of accredited processes, including those of the manufacturer, enables the design to be optimised. However, where such control is not in place a developer would need to apply design and construction confidence factors that would increase the DER above the optimum. This would mean that lower theoretical U and Ψ values would be required in order to accommodate the confidence factor. Similarly, the confidence factor would reduce the system efficiency values applied. The net effect is likely to be the need for an increased specification of insulation and services and an increase in the amount of renewable technologies. In addition to an increased specification requirement, the developer would be subject to an increased post completion testing regime.

Box 1 Example of a new compliance system

Note: this example is for illustration only and should not be interpreted as a definitive or preferred detailed solution.

Development: Traditional timber frame walls with a combination of insulation between the studs and externally, pitched roof insulated at ceiling level and an internal membrane to ensure an air leakage of less that 3 $m^3/(m^2.h)$@50Pa. constructed to achieve 70% carbon compliance with a fabric performance designed to meet the minimum energy efficiency standard.

Developer: Large developer with technical department but outsourced detailed design and SAP assessment.

Design

The developer has reviewed their processes in the light of the development of zero carbon regulations and the introduction of a new process orientated system for Part L. As a result of the review, they now partner with a detailed design firm who are commissioned to provide an accredited design service, which includes SAP modelling. All input calculations (U values, Ψ values etc.) are undertaken by staff with recognised qualifications. The use of an accredited SAP tool and inputs go through a rigorous internal quality control check to ensure that inputs are accurate and that the SAP tool is used appropriately. Also their deign accreditation requires that, for every scheme, a full set of detailed drawings and sequencing instructions is provided for use on site.

The design involves a timber frame system that has been developed by a particular manufacturer and for each house type the heat loss from each panel has been calculated taking into account all timber elements and thermal bridging at openings and other junctions. The manufacturer provides an average U value for the walls and thermal bridging values for all junctions. The manufacturer also guarantees the performance of the system according to strict rules as to quality of the concrete base and the installation of the frame and associated cladding (which is to be done on site and which the manufacturer will oversee). The manufacturer has undertaken extensive lab and field testing of the proposed system and has obtained accreditation for its use in dwellings. All services runs are planned and the accredited design firm have verified manufacturers claims taking into account pipe runs and other factors that may reduce system performance.

Construction

The developer operates an accredited construction system including the management of subcontractors.

The developer uses partnering subcontractors who are familiar with the construction systems used and have been trained in their application. The site is supplied with a full set of detailed drawings, specifications and sequencing instructions and the construction programme is established in detail. Airtightness is checked on every dwelling by the site manager upon completion of the timber frame and sealing of the air barrier. Any rectification work required is completed prior to installation of finishes. The accreditation of the developer's site processes required a rigorous inspection routine to assess continuity of envelope insulation and insulation of services pipe work. Services commissioning tests include an appropriate level of performance testing to check likely in-use performance. These are undertaken by an accredited services subcontractor.

Any modifications to the design or material/product substitutions are made with reference to the accredited design partner who checks the performance specification and assesses any implications for the SAP calculation and notes the change. Details of on site problems such as buildability are fed back to the design company on a regular basis.

As a matter of policy the developer undertakes a review of all routine test and inspection data on fabric and services on a regular basis and undertakes whole house heat loss measurement (co-heating and pressurisation testing) on a small sample of each house type and reports the data to the accredited body.

Confidence factors applied

The national calculation methodology recognises the accredited status of both design and construction systems used. A factor of 1 (no increase) is applied to the fabric heat loss calculations and no reduction is made in the declared system efficiencies or in the renewable generation capacity.

Post completion performance testing

In order to demonstrate that their processes are delivering the required performance, the company commission a small number of third party post completion tests annually. This not only enables the company to continue to apply a confidence factor of 1 (no increase) but secures their market position as a high quality house builder.

Accreditation of design

The detail of the accreditation process needs to be worked out by the industry including the supply chain and building control, working in partnership with government. The following illustrates some of the elements that may need to be considered.

In order to be able to claim very low or zero confidence factors for design and/or construction, designers and constructors would need to demonstrate to a third party that the processes they used resulted in outputs necessary for the delivery of low energy homes. In doing so they would become registered as accredited organisations for design or construction or both. If appropriate there could be more than one level of accreditation with different confidence factors.

example aspects include:

a) **Design management** – This would require designers to demonstrate that the way they managed their design, including staff competency and checking arrangements resulted in error free calculations, detail design drawings and specifications that were clear, buildable and accompanied by adequate information of sequencing of operations. Similarly, that design modification during construction did not compromise energy/carbon performance.

b) **Modelling and calculation** – The use of quality controlled modelling software and general competency requirements with processes for verification of input data and checking of calculations. External accreditations are likely to feature. However, the use of such external accreditations must fit into internal process management structures that include checking and verification processes.

c) **Detailed design, sequencing and commissioning** – Designers should demonstrate that large scale detailing is carried out, full specifications are provided and the requirements effectively communicated to construction teams. The use of accredited details and how they are adapted are likely to be part of this process. In addition to traditional detail design information, specification should be included of the sequencing of operations, critical check/inspection points and, in the case of services, specification of commissioning and testing plans so as to ensure that provision for such testing is made from the outset.

d) **The use of fabric and services systems** – Where whole systems such as prefabricated envelopes or services packages are used, they should have their own accreditation that assures as-constructed performance. In applying such systems the 'host' organisation overseeing the whole design would need to show that they had the necessary arrangements in place to be able to integrate the system into the rest of the design.

e) **The supply chain** – The involvement of the supply chain in design should be clear and their responsibilities, particularly for as-constructed performance claims, clearly defined.

Accreditation of construction

As with accreditation of design the detail of the accreditation process needs to be worked out by the industry and government.

example aspects include:

a) **Construction process management** – As in design, a clear set of processes would need to be demonstrated.

b) **Detailed operation planning and sequencing** – The equivalent of detailed design, this area would include ensuring that design information was available and used by operatives and that arrangements for effective planning and sequencing of operations were in place. Such processes will need to be linked to other higher level processes that deal with the marshalling of resources.

c) **In-production testing and inspection** – In-production testing is likely to become increasingly important, particularly if there is to be some sample post construction testing. Processes would need to be very clear about the nature of the testing and inspection to be carried out, its frequency and timing. Indeed, changes may be required to an existing construction process so as to facilitate this. Air pressurisation testing, for example, could be undertaken by site staff at air barrier completion so as to verify performance before it is covered by finishes. The extent of testing would be demonstrated by test results that could be audited and reviewed when post completion testing was carried out.

d) **Services testing and commissioning** – As with fabric, a full testing regime for services would need to be specified either as part of the commissioning process or during installation. For example, problems with kinked pipework causing flow restrictions could be identified before systems are connected up by conducting routine flow measurement procedures.

e) **The use of fabric and services systems** – Where such systems are specified, effective control of installation and fitting would need to be demonstrated. This may be addressed by the use of specialist installation teams as is often done currently. However, the principle of effective control would need to be extended to the supplier and the specialist team.

Accredited fabric and services systems

The role of the supply chain is very important to the accreditation system since manufacturers of fabric and services materials and components are in a unique position to provide a strong lead in the development of standard systems that can be incorporated into house type design. Such systems could include a whole structural system such as the timber frame example in box 1 or, at a different level, the design by an insulation manufacturer of an insulation product that is designed to interface with masonry to form a walling system. The manufacturer would have undertaken appropriate testing and have a standard process for ensuring effective as-constructed performance on site.

Services systems could be accredited in a similar way as fabric. The manufacturers of boilers and heat pumps, mechanical ventilation with heat recovery or renewable energy systems could have their systems accredited. For fabric and services to be accredited they would need to demonstrate that they have robust procedures in place to verify their performance claims based on as-installed performance not bench or lab performance. This would encourage a systems approach which took into account the interactions between the different components in the system and the realities of a construction site. Those systems with accredited in use performance data would benefit from lower confidence factors. Such an approach would build on the 'in use' factors which are currently applied to some ventilation services under Part F of the Building Regulations.

As with design and construction accreditation, manufactures and 3rd party bodies would be central to the development of such a system. System confidence factors would need to have due regard to current and impending EU regulations.

A practical accreditation system

In designing a workable accreditation system it will be important not to reduce the whole endeavour to a box ticking exercise. This means that auditing and checking of process should be output based. Thus, one would not seek to check in detail if papers have been signed off and boxes ticked but to look at outputs such as actual working drawings, design calculations, the availability of drawings on site and, most important of all, the results of in-production and post construction testing. The proof of process will lie in such outputs not in the ticking of input boxes.

Post construction testing to verify process

The final proof of performance of any product lies in the testing of the whole product. In the case of dwelling performance, testing of fabric and services post construction and prior to occupation would be necessary. However, it is important to understand that the role of the final performance test is not to seek to reject or rectify those that fail (although this may be necessary in rare occasions) but to verify the integrity of the processes used to produce the house.

The proposed system would seek to ensure that house builders commissioned their own independent post construction tests and were subject to some audit evaluation of test data and a small number of external audit tests. During a transition phase the output could be largely informative to the house builder providing feedback on their processes. However, this would be done in the knowledge that at the end of the transition phase the consequences of failure could result in a number of actions depending on the extent of failure and the proposals that are instigated to improve performance. The regulatory position is likely to be a complex one and much more work will be required before the regulatory structure could be designed in detail.

Developing the detail

The enhanced approach outlined in this section is not meant as a detailed blueprint but as an indication of the type of arrangements that should be considered and the sort of issues that would have to be addressed if low energy homes are to perform consistently in practice. At first glance the proposals may look like a reengineering of the construction processes. However, in many cases the approach recommended will be an extension of some of the elements that already exist. Much could be done through standardisation of design details (an improved version of accredited details) and of processes based around the range of dwelling types used.

At this stage it is very difficult to predict the precise shape of such processes and there is an urgent requirement for detailed work on the design of an effective compliance system and on the support the industry will require to make it work. Clearly there is a need to work through the proposals in some detail and to explore the impacts on developers across the range of development volume. However, the advent of national schemes such as Part E robust details and the redesign of the accredited details system for Part L, which was proposed in the recent consultation (CLG 2010), would provide some support that all developers could use, depending on their assessment of the costs and risks involved.

The time scale for implementing these recommendations needs to be realistic. There is a great deal of work to be done not only in shaping the compliance system but also in providing time for new processes to be developed and for the considerable amount of research, development and training required. Some of the issues involved in both refining proposals and preparing the industry for what is likely to be a significant paradigm shift are discussed in the transition planning section below.

Government policy issues

In seeking to pursue the sort of improved system set out above it is necessary to understand the context set by a whole host of government initiatives. Contradictions between building regulations and planning guidance create conflict that the industry in general and developers in particular, have difficulty resolving, leading to confusion rather than mutual support. Other initiatives delivered through social housing policies, pilot schemes for zero carbon housing and other government inspired and funded initiatives appear to be fragmented and present a confusing picture. The issues are to do with coordination and ensuring that the initiatives are mutually supporting and the lessons learned are fed back into the industry and future regulation so that the support they provide for zero carbon housing is effective.

One of the most important roles of government in the next 6 to 10 years will be to support the R&D effort that will be required. However, there is a need for a considerable rethink of how funding is coordinated, channelled and used to lever commercial resources. Also, through the Homes and Communities Agency, the Government control considerable land and other resources that are currently being used to develop pilot projects. This represents an opportunity to develop the R&D base. However anecdotal evidence to date would suggest that monitoring and research programmes are fragmented and are often more concerned to showcase or promote rather than strengthen understanding. The current picture is not dissimilar to the state of urban renewal funding some 15 years ago with a patchwork of different funding streams from different departments and government agencies that became uncoordinated and impossible to navigate.

All improvement processes need feedback. One of the most important roles for Government policy lies in building the feedback loops and infrastructure that will help to generate the solutions that will improve performance. However, building effective feedback loops into the processes that will deliver zero carbon housing is likely to be very difficult. The problem of feedback needs to be tackled at two levels. Level one (micro) should focus on the needs of developers and development teams so that the myriad of detailed learning items are understood and built into revised processes as part of a continuous improvement cycle. Level two (macro) needs to look at the larger picture and is largely a matter for the government and the industry working in partnership. This level is concerned with gaining feedback on the performance of the strategy overall and the extent to which changes at the micro level are having an impact on the overall improvements at a national scale.

In order to ensure that feedback is provided on the achievement and maintenance of the objective (the macro level), processes should be put in place that track performance based on post construction audit testing and other data submitted as part of the assessment. Such data would constitute an invaluable database that provided a constant stream of evaluative evidence. Such evidence could be used to shape future policy, regulation and industry practice.

Central to the provision of feedback and continuous improvement is the ability to measure and evaluate performance. One of the reasons why evaluation studies following a change in regulation tend to be based on the opinions of building control officers (public and private sector) and others, supplemented since 2002 & 2006 with air leakage test evidence, is that whole dwelling performance measurement (fabric & services) is both time consuming and expensive. However, it is true also that there has been very little methodological development work to improve the position. The net result of the lack of research into practical measurement methods is that comprehensive measurement remains expensive and difficult. It is important that we seek to break out of what is fast becoming a vicious circle. Different methods will be required depending on whether one is seeking to provide feedback at the micro or macro level and work will be required to ensure that both systems can operate effectively and in a resource efficient manner.

The move from predicted performance to actual performance represents a significant change. The notional 70% carbon compliance reduction in emissions that has been assumed in policy modelling could result in a larger actual shift as the performance gap is closed. This should be taken into account when reviewing the 70% Carbon Compliance level and the impact of changes as a result of an enhanced compliance approach.

Key Conclusions and recommendations on developing a solution

The group have formed the view that closing the performance gap and keeping it closed will require a solution that accounts for construction tolerances, improves design and construction processes and measures performance. We conclude that:

- The proposed approach (starting on page 32) shows promise and should be adopted as a starting point for further work. However, its effectiveness will depend on detail design and pilot testing.
- A detailed approach be developed and worked up that can be piloted on specific sites. The pilot studies should include all actors who have a role to play including building control the supply chain and certification bodies as well as designers and developers.
- That change in the building control system is likely to be required to enable the effective output audit of schemes and developer processes, including an appropriate level of post construction measurement.
- The introduction of confidence factors and sample post construction testing should be taken into account when reviewing the proposed carbon compliance level of a 70% reduction
- A performance database be established as part of the enhanced compliance process so as to provide data to inform future regulation and policy
- It is unrealistic to expect the industry to make the transition to a radically new compliance system by 2016. The development of detailed proposals should seek to set out a transition timetable that is achievable. In our view it is unlikely that the transition will be complete before 2020.

IMPLICATIONS FOR THE MODELLING TOOL AND ASSUMPTIONS

Closing the performance gap is much less concerned with the nature of the modelling tool than other working groups. In essence, the performance issues are much more concerned with the processes and cultures within the industry than with the model that is used to predict carbon emissions.

However, the performance assumptions and the quality of the inputs to the modelling tool are fundamental to ensuring a realistic prediction of performance. The proposed application of confidence factors within the model will act as powerful incentives for improvements in the way industry operates and assures performance.

The conclusions of the group on how to tackle the performance gap have the following implications for the modelling tool and compliance system:

a) The compliance process should ensure that the inputs to the model are a true reflection of as-constructed performance. This will require improved guidance on design and modelling as well as improvements in modelling and design procedures that trap and eliminate input errors.

b) The model should be able to take account of adjustments that need to be made to reflect the different levels of confidence in performance expectations based on the level of process control exercised in design and construction.

c) The model should be able to accommodate the system specific confidence factors.

d) If developers and their teams are to be judged on the performance of their dwellings, as verified by a measurement programme, it will be important that the model provides the appropriate output against which performance is measured. Such output will provide explicit performance parameters for fabric and services on which the in-use carbon emission rate is based and should be amenable to measurement and testing.

e) In order to avoid difficulties and confusions over the physical performance of the fabric and services and performance in-use, the model should make explicit the occupancy and usage assumptions on which targets and actual emission rates are based.

f) The success of any compliance system designed to improve performance and close the gap between what is modelled and what is achieved on the ground will depend on the provision of performance data collated cohort by cohort. Although not a particular issue for the modelling tool, the compliance policy should include for the routine collection and collation of such data. Of course the nature of the data and the methods for collection would need to be worked out in detail but without it there would be no macro feedback loop to inform future policy and regulation.

Key conclusions & recommendations on the modelling tool

Our key conclusions and recommendations on modelling implications are that:

- The compliance process should ensure that all inputs to the model are a true reflection of as-constructed performance.
- The model should be able to take account of adjustments that need to be made to reflect the application of confidence factors for design, construction and specific fabric and services systems.
- The model output should provide a clear statement of the fabric and services performance used to calculate the as-constructed Dwelling Emission Rate. Such parameters should be amenable to measurement and testing as part of the compliance process.
- The occupancy and usage parameters used in the calculation of the Target Emission Rate and Dwelling Emission Rate are reviewed and made explicit.
- The compliance process be developed to include means by which performance data is collated nationally for use in the development of policy and in making further improvements to the compliance system.

TRANSITION PLANNING

Perhaps the most important starting point is for industry to acknowledge the need for performance to be demonstrated through improved processes supported by measurement evidence. To this end the there is an urgent requirement for government to provide a clear signal of intent to the industry and to provide a time table for change. Such a signal is crucial so that those developers who choose to invest in improving processes will know that they will be rewarded for doing so and those that do not will run the risk of placing themselves at a significant long term disadvantage.

Given the likely existence of a performance gap and no prospect of it closing on its own, there is an urgent need to engage with the industry at every level to explore, in some detail, how a process improvement approach, backed up by confidence factors and measurement, can be implemented and built into the regulatory structure. To this end we propose that a joint industry and government group be established to undertake and oversee the detailed design task. It should take the proposals in this report as its starting point and be informed by the experience of, amongst others the National Home Builders Council, Robust Details Ltd, air pressure testing organisations and the research community.

Currently there is no incentive for the different actors in the industry to incur the development and R&D cost that will be necessary to make improvements. If ways of improving the position are to be developed at all levels from regulation to construction sequencing there will need to be transitional policies in place that demonstrate how the gap can be closed. An R&D programme is one element but there needs also to be some benefit to the developer to take part in an improvement programme.

Policies aimed at trialling a different approach to building control would have to have concessions for the developer built in. For example a self certification element for participating developers in pilot projects which would exempt them from the normal building control process and therefore enable them to switch resources to develop their performance control processes. Other incentives could include tax breaks and/or direct cash contributions such as through Technology Strategy Board (TSB) programmes. The Knowledge Transfer Partnership programme administered by TSB provides a very useful model and potential source of funding for such pilot work. However, the pilots would have to be undertaken as part of a coordinated programme that spanned some 5 or 6 years of continual process improvement and evaluation.

The transition to verifiable zero carbon standards should begin immediately (Figure 7) with a development programme that will address the following issues:

a) The provision of guidance and blueprints for design, construction and the supply chain on process development and control. This is likely to require a series of pilot schemes in which existing processes are unpicked, the issues of detail identified and improved processes attempted and evaluated. Given that such work is likely to take a number of years per scheme it will be important to build in dissemination routes that operate from the beginning so that early results can be fed into the industry and into other pilot schemes without waiting for final reports.

b) The compliance system itself will need to be included in pilot schemes so that input is gained from the building control community and an evaluation carried out of the extent to which the existing system can absorb the changes envisaged.

c) The transition programme should be capable of teasing out the sensitivities in the approaches tested so that those areas that are likely to yield the greatest return are identified and developed much more rapidly than those that have less impact on performance.

d) Investigations and pilot schemes will need to consider the impact on development organisations at both ends of the volume spectrum in particular the likely impacts on SMEs and their ability to deal with the demands placed upon them by zero carbon requirements.

e) The implications for the materials and component supply chain and the development of processes that ensure the declaration of as-constructed or as-installed performance as part of the regulatory structure. This will have implications beyond the UK since many manufacturers and suppliers operate internationally. The implications for European Standards will be of particular importance.

f) The transition period should be used to address the requirement for increased skills at all levels within the industry. This will involve marshalling a broad range of resources from the Higher Education Funding Councils and Skills Councils to individual training and professional development run within the industry and its professional bodies and trade associations.

g) In addition to the need for pilot schemes a significant research and development effort will be required to enable as-constructed performance to be reliably predicted and the development of robust field methods that can be used in a production context.

Given the extent of change there may be a need for a light touch transitional phase built into regulation. The consequences for post-construction test failure referred to in item f) on page 33 will present a particularly difficult area. Although the regulatory requirement for testing may be introduced in 2016, it is likely that for between 3 to 5 years the consequences of failure may need to be limited to the provision and publishing (via the on-construction Energy Performance Certificate – EPC) of information only. Indeed it may be that this is sufficient to ensure improvement. At the end of the transition period further actions may be appropriate such as requiring increased site based generation or additional funding for allowable solutions. As the details are worked out it may be that other areas may need transition arrangements following initial regulation in 2016.

Transition plan

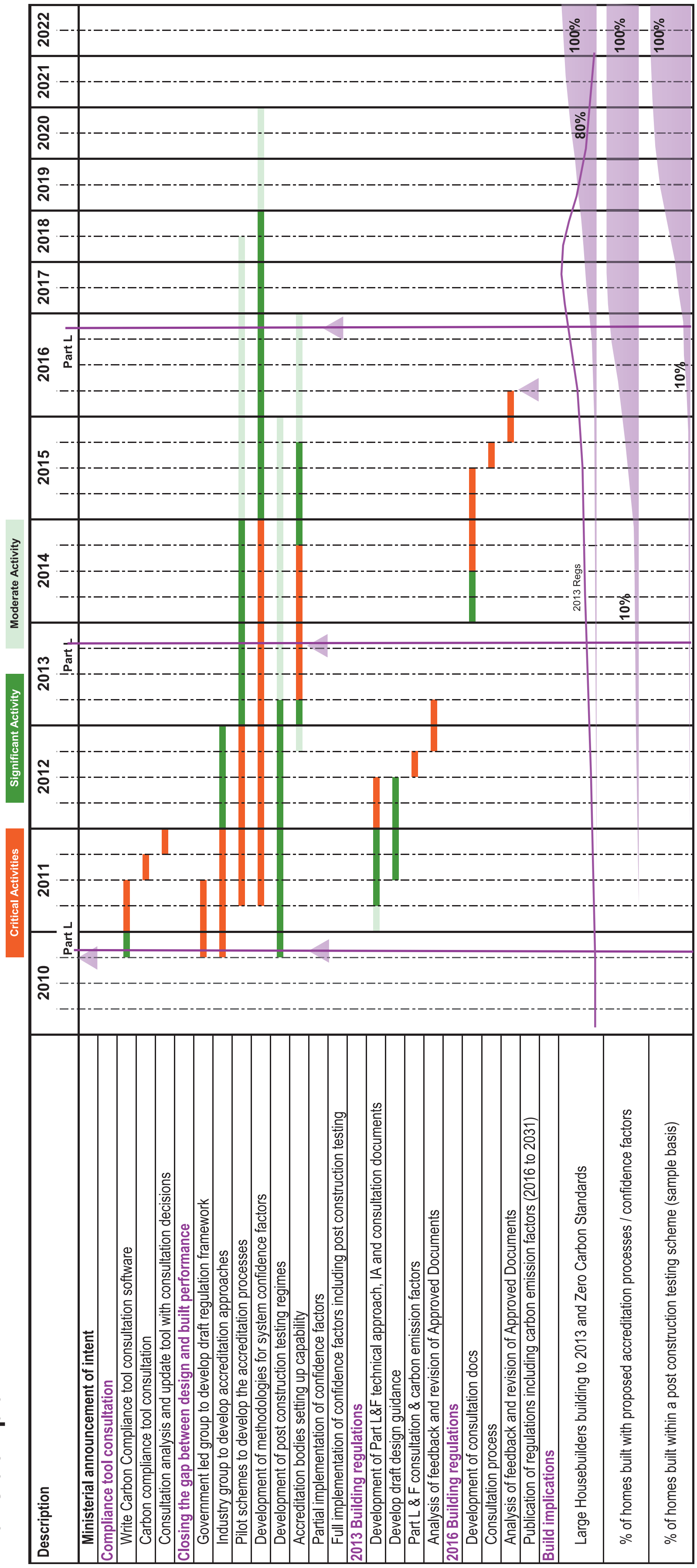

Figure 7 Key actions and deliverables to address the gap between designed and built performance

Key conclusions and recommendations on transition planning

- That the Government make a strong declaration of intent in the next 6 to 12 months setting out the shape of the proposals and intended transitional periods to allow the industry time to absorb the implications of the change.
- That work begins immediately on the detailed development of a workable compliance system based on the discussion in this report.
- That the detailed design work be undertaken by a joint industry and government group reporting to the Department for Communities and Local Government.
- That impact and sensitivity analysis is undertaken, as the details are developed, of the various options. This should include costs, commercial imperatives and sensitivities to a number of key risks
- That the implications for the role of building control and the likely scope for different arrangements for verification of process control and the audit of testing arrangements be investigated.
- That a series of pilot schemes are instigated designed to develop process blueprints for the sort of control systems that will be required (Industry led).
- That guidance and model processes are developed, based on the findings from the blueprint pilot studies.
- That the particular issues that arise for different types of developer, from SME to large PLC developers, their consultants and supply chains, be investigated as part of the pilot studies.
- That the implications for the materials, systems and component supply chain be investigated in detail and needs established. The EU implications of the impacts of suppliers will need to be included.
- That transition planning for education & training is undertaken and the resources of public and private sector bodies be harnessed. The training should be at all levels from operative to senior management and should be closely associated with a parallel R&D programme.
- That a co-ordinated R&D programme be established to maximise the value of the work, focussing on development of:
    - testing and inspection tools.
    - scientific understanding of the systems effects in use and the characterisation of such effects.
    - methods of predicting as-constructed performance in fabric and services systems.
    - blueprints for process control.
    - audit methods for use in the compliance system.

CONCLUSIONS AND RECOMMENDATIONS

Principal conclusions

Detailed conclusions and recommendations have been provided at the end of each section of the report. In these final paragraphs we highlight some of the more general conclusions and recommendations from the work as a whole.

In broad terms the group concluded that concerns about the energy and carbon performance of new housing are well founded. This posses a risk which could undermine the Government's policy on zero carbon housing and represents considerable commercial risk for industry as a whole. There is less certainty as to the full extent of the problem because the primary evidence is based on a relatively small number of studies and performance measurements. However, it is noted that a larger body of evidence exists with respect to performance and construction defects in general, which when combined with the primary evidence, leads us to conclude that the problem of energy and carbon underperformance in mainstream housing may be widespread.

The current compliance regime encourages the wider housebuilding industry and supply chain to deliver a theoretical rather than actual performance. We are of the view that there is a need for government and industry to investigate ways of ensuring that, post 2016, the house building industry and its supply chain are able to demonstrate, objectively, that zero carbon housing standards are achieved in practice and not just in theory.

Our investigations have led us to the view that addressing the problem will require a concerted and coordinated effort by the Government, industry, its supply chain and its supporting infrastructure, which is made up of industry groups, building control organisations, professional institutions, trade associations, skills councils, educators and the research community.

The key areas of work revolve around the development of a regulatory system that encourages well controlled design and construction processes backed up by a sound understanding of construction tolerances and an effective system of performance measurement. However, meeting what is likely to be one of the most significant challenges the house building industry have ever had to face will require considerable research and development and a major education and training effort designed to equip industry personnel with the skills they need.

The extent of the change required is considerable and will take time. Although 2016 will be an important staging post for putting an effective compliance system in place, it is likely that transition arrangements designed to close the performance gap will need to run until at least 2020. If the goal of full compliance in practice is to be achieved by 2020 it is important that work begin immediately on the tasks that will be required, many of which have been set out in this report.

Government should provide a clear statement that it will provide the appropriate regulatory framework using the findings of this report as its starting point. Such a strong signal is crucial since it will provide the confidence for the industry to invest in the improvements needed and drive the R&D and training effort.

Principal recommendations

We recommend that work begin almost immediately on the detailed design of a new framework based on the findings of this report. Also, that the work be undertaken by a joint Industry and government group with priorities set using risk assessment processes and informed by the experience of developer organisations, their supply chain and building control. In addition contributions should be sought from, among others, the National Home Builders Council, Robust Details Ltd, air pressure testing organisations and the research community.

Detailed design work should make extensive use of pilot studies to investigate the key issues and test detailed proposals as they emerge. They should take as their starting point the following principles discussed in this report.

- **Clear performance parameters** – The key physical performance parameters that are the basis of the Dwelling Emission Rate (DER) calculation should be made more explicit and used to evaluate as-constructed performance.
- **Confidence factors** – As a means of providing an incentive for designers and developers to improve the control they exert over design and construction, a series of factors should be applied to the relevant physical performance parameters in the DER calculation. The factors should reflect the level of control in design and construction.
- **Accreditation of design and construction** – In order to facilitate the application of low or zero confidence factors an accreditation scheme should be developed, which would enable developers and designers to demonstrate that their control processes are robust and deliver robust performance.
- **Accreditation of fabric and services systems** – One route to robust performance could be to make use of particular construction or services systems that have been type tested in the field and are supplied and incorporated into the dwelling under certain supervision arrangements.
- **Post completion testing** – Post completion testing should be undertaken on a sample basis and the results fed back to the developer and their designers so as to improve processes. Where failures occur these should be subject to further investigations and corrective actions which would could include increased testing and/or the application of confidence factors until improvements are demonstrated.
- **Audit arrangements** – Auditing and testing of accredited design and construction organisations should avoid overly bureaucratic processes. To this end a system of audit should be developed that is output based, focusing on what is produced and the performance of the completed dwelling rather than on the process inputs.

The introduction of confidence factors and sample post construction testing should be taken into account when reviewing the proposed carbon compliance level of a 70% reduction

That existing programmes should be harnessed to both define the detailed nature of the requirements and deliver the education, training and research that is required.

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