



Delivering a low-energy building

Making quality commonplace

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Studies repeatedly show that buildings do not achieve their design criteria, in energy efficiency terms, when tested post-completion.

Low Carbon Construction, Innovation & Growth Team Final Report, HM Government, Autumn 2010.

"A quality culture where tradesmen take ownership of their work in a 'no blame' culture is alien to the construction industry. In the adversarial culture that is widespread, costs are cut to the bone and contractors are looking to charge sub-contractors for any alterations or delay and to charge the client for chargeable works not in the tender. In such an environment, the tradesman on site has no awareness of the impact of his work on the eventual performance of the building, and the various trades are interested only in meeting time and cost targets, not in working together to create a quality outcome."

A contractor talking to Build with CaRe, (2012)

Build with CaRe is an international project with the ambition to help mainstream low-energy construction in the North Sea region and across the EU. Build with CaRe (BwC) is partly funded by the Interreg IVB North Sea Region Programme, European Regional Development Fund. Please visit www.buildwithcare.eu.



If the energy consumption of an occupied home is greater than its designer predicted, then its carbon dioxide emissions will also be higher than predicted – this is the 'CO₂ performance gap'. There appears to be a growing body of research evidence that new housing is failing to deliver the anticipated levels of CO₂ emissions, although there is relatively little understanding within the wider industry of what might be causing this.

Low and zero carbon homes: understanding the performance challenge (NF41), NHBC Foundation and Zero Carbon Hub, February 2012

New non-domestic buildings: What have we tended to find, for many years now?

- *They often perform much worse than anticipated, especially for energy and carbon, often for occupants, and with high running costs, and sometimes technical risks.*

What works, what doesn't work, and how we can fix it: using Building Performance Evaluation (BPE) for rapid improvement, Bill Bordass, 27 September 2011

The Task Group considers that examples of failures in typical design, installation and commissioning practice are all too common and these will have the effect of reducing the performance of systems. Badly performing systems may not deliver the anticipated carbon savings and may result in degraded IAQ with related consequences for health.

Mechanical Ventilation with heat recovery in new homes; Interim Report; Ventilation and Indoor Air Quality Task Group, Zero Carbon Hub, January 2012

"We need to have a Rolls-Royce or BMW approach to quality. I'm asking why only a few builders have achieved this."

Andrew Stunell OBE MP, Parliamentary Under Secretary of State, Department for Communities and Local Government, at the EcoBuild Conference, London, March 2012

EFry is one of the rare buildings where users give it unprompted praise – “I love it. It combines a sense of tranquillity with aesthetic delight”. By any standards the occupant survey results are excellent, one of the best seen by BUS in over ten years of similar studies. EFry is thus likely to become a role model for future building design and management.

The Best Building Ever? PROBE Team's verdict on the Elizabeth Fry Building, Building Services Journal, April 1998

How was this achieved? at no extra cost

- *integrated total design team commitment*
- *passivhaus expertise*
- *passivhaus integrated into design from day one*
- *constant focus on simplicity of design and detailing*
- *relentless focus on value engineering to achieve cost*
- *a committed contractor dedicated to delivering passivhaus*
- *ongoing teamwork throughout construction stage*
- *focussed workshops with all key sub-contractors*
- *rigorous and regular site inspection*

Designing & delivering the Wolverhampton passivhaus schools at no extra cost, Jonathan Hines, Architype; Nick Grant, Elemental Solutions and Matt Wisdom, Thomas Vale Construction, UK Passivhaus Trust Conference, October 2011

“You just don't have the bills you would have in a normal house”

“The houses are so light and spacious”

“I'm happy putting my children's bunk beds by the window as there's no draughts, and the glass is not cold”

“I'm less stressed. Having a lovely house we are proud of and look forward to coming home to is benefitting all of us”

Comments by residents of passivhaus homes at Wimbish Essex by Hastoe Housing Association, Martin Ingham, *Wimbish Passivhaus: Building Performance Evaluation, Interim Report* – March 2012.

In office buildings, the salaries of workers exceed the building energy and maintenance costs by approximately a factor of 100 and salaries exceed annualized construction or rental costs by almost as much. Thus, even a 1% increase in productivity should be sufficient to justify an expenditure equivalent to a doubling of energy or maintenance costs, or large increases in construction costs or rents.

Estimates of Potential Nationwide Productivity and Health Benefits from Better Indoor Environments: An Update, William J Fisk, Chapter 4 in *Indoor Air Quality Handbook*, eds: J. D. Spengler, J.M. Samet, and J.F McCarthy, McGraw Hill, 1999, LBNL42123

In Brief...

- Buildings are responsible for 40 per cent of carbon emissions across the EU. Only by greatly reducing the energy use by existing buildings can the EU hope to meet its targets for greenhouse gas reduction and for enabling a successful low-carbon economy.
- Evidence from new buildings in the UK, both domestic and non-domestic, shows that there is a big gap between predicted and actual energy use. In almost all cases studied, buildings perform worse, sometimes far worse, than design predictions would indicate.
- Refurbishment of existing buildings is a more complex process than designing and building new ones. The documented problems with new buildings make it certain that similar or worse 'energy gap' problems will be found in refurbishment of the existing building stock.
- The energy 'performance gap' was observed in the UK in studies of non-domestic buildings in the 1990s and remains in more recent studies of both homes and non-domestic buildings. The gap is not closing.
- The buildings in which the energy 'performance gap' was discovered were thought to be 'leading-edge' and energy efficient (but were not built to passivhaus quality standards). Hence it must be assumed that most buildings will perform even worse. Unless there is major change in construction practice, actual energy use by new buildings will be far higher than anticipated.
- This 'energy performance gap' means that current and future building codes and standards cannot ensure delivery of buildings that comply with these codes. Requirements such as the UK so-called "zero-carbon homes" or the European Performance of Buildings Directive are ineffectual without confidence that buildings, either new or refurbished, will perform as designed and as Energy Performance Certificates (EPCs) claim.
- The principal cause of the energy performance gap is the 'traditional construction model' where there is poor teamwork across the design and construction process, leading to hidden defects that compromise energy performance as well as, in many cases, to overly-complex buildings that are difficult to manage and often create uncomfortable and unproductive internal environments.
- The energy performance gap is mirrored by serious problems with MVHR (mechanical ventilation and heat recovery) installations in the UK. Both issues arise from the quality problems caused by the 'traditional construction model'. Poorly-installed or poorly-functioning MVHR potentially creates serious air quality and health problems for occupants of buildings.
- If construction practice does not change, not only will greenhouse gas emissions from, and energy bills for, buildings be far higher than anticipated,

but occupant health is likely also to suffer from poor air quality and from over-heating in summer.

- It is very likely that the problems present in the UK are also present, to a greater or lesser degree, in most or all other EU Member States.
- Detailed evaluation of buildings, post-construction, for energy use, internal air quality, and occupant satisfaction, happens only rarely. The defects that give rise to the energy performance gap are hidden from view and will not be picked up by normal fault finding practice. Post-construction evaluation must become much more mainstream.
- Low-energy buildings in the UK have been successfully commissioned, designed, and constructed, at no extra cost, using quality principles of teamwork and partnering. These examples demonstrate that high quality construction is perfectly possible with existing workforces. All that is required is for management to want to deliver a high quality product.
- There is now good evidence from several European countries that the passivhaus standard ensures the necessary high quality of construction leading to good internal air quality and high levels of occupant satisfaction, as well as to very low energy use for heating and cooling.
- A new build regulatory mandate at or near to the passivhaus standard is essential for the successful delivery of new low-energy buildings across the EU. Only with a new build standard of this nature can supply chains be developed and high quality practices become standard.
- A similar quality transformation must also occur within the refurbishment sector; only with the same quality approach as for passivhaus new build can successful low-energy refurbishment of the existing building stock be achieved, and can the EU meet its climate change targets.
- Further beneficial consequences of the necessary quality transformation in construction will be a high performance and competitive construction industry and supply chains, and the elimination of fuel poverty and of the serious health problems that result from poorly performing buildings (and of the great costs to society that such problems create).
- In the commercial sector, low-energy buildings, successfully delivered, will lead to a more productive workforce, reduced maintenance costs and better rental incomes. The potential financial benefits of low-energy buildings far outweigh any extra initial costs of construction.
- As is the case in other industries, the adoption of demanding quality standards for construction, and the teamwork and partnering that are essential to achieve these standards, will almost certainly result in no higher initial costs than would arise anyway, and far lower lifetime costs.

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Passivhaus and low energy buildings

In this report, we make considerable reference to “passivhaus fabric energy standards” and “passivhaus standards of quality in design and construction” of homes and other buildings. There are demanding standards for maximum design energy use for heating and for total primary energy use if a building is to be certified as complying with the Passivhaus Standard (links and references are provided in the Chapters that follow). To meet these demanding standards requires that the building be considered as a total system in the design process and that quality standards in construction are high. Without such quality and attention to detail, defects will inevitably be created that will mean that the passivhaus energy standard cannot be met.

If carbon emissions are to be reduced and climate change targets met, all new buildings, domestic and non-domestic, must be built such that they minimise energy demand for heating and cooling, predominantly through fabric measures. Over time the existing building stock must be refurbished to achieve similar standards of very low energy use.

Codes and standards that require buildings, either new or refurbished, to be low energy in performance will not, by themselves, however, guarantee low energy performance. There is a growing body of evidence showing that conventional construction practice will not deliver the required low-energy performance no matter what building codes or energy performance certificates might say.

To guarantee that low-energy targets can be achieved in practice requires a proven approach that demonstrates that standards can be met. The best current exemplar of such an approach is the Passivhaus standard. The Passivhaus standard delivers because of the quality and attention to detail in both design and construction that are necessary to ensure certification. The required quality standards are not unique to Passivhaus, but without the demands on the design and construction processes that must be met to achieve the Passivhaus standard, the quality and attention to detail, essential if low-energy buildings are to be reliably delivered, seem rarely to be achieved in practice. The traditional construction industry model cannot reliably deliver low-energy buildings.

The critical change that must happen if low-energy buildings are to be successfully delivered in practice is a transformation in the quality and attention to detail achieved in construction from commissioning through to handover. There is clear evidence now that the Passivhaus standard can be met, cost-effectively, for new build homes and many other buildings. Hence, adopting the Passivhaus standard, or codes that provide for a comparable outcome, is the only practical and reliable mechanism to ensure the successful delivery of new low-energy buildings.

For refurbishment of existing buildings to low-energy standards, it will often also be the case that the Passivhaus standard for refurbishment can be met. In some situations, it may not be cost effective to aim for quite such a demanding energy transformation and installation of mechanical ventilation with heat recovery, for example, may not always be a practical option. Whatever the actual energy target, however, a transformation in quality across the design and construction process is just as essential for successful refurbishment of existing buildings to achieve necessary low-energy targets as it is for new build. The building must be considered as a total system and quality standards and attention to detail must be extremely high.

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1. The problem and how to tackle it

1.1. Overview – the problem

This report is concerned, in the main with UK buildings and the evidence about energy performance that has been gathered over the last two decades. It is unlikely, however, that the picture described here is unique to the UK¹. The report deals, in particular, with the energy ‘performance gap’ that is observed for both domestic and non-domestic new buildings and how to eliminate this. The energy ‘performance gap’ means that buildings perform more poorly, sometimes far more poorly, in use than their design performance predictions would indicate.

What this means is that, unless design and construction practices change, estimates of potential energy and greenhouse gas savings achievable by constructing new buildings, and by refurbishing existing buildings to be much more energy efficient, may be greatly over-estimated. Whatever building codes or directives, or energy performance certificates for buildings, might say, the energy savings predicted in design will be illusory or at least far smaller in practice than anticipated.

More energy efficient buildings could be one of the biggest sources of energy and carbon savings across the EU, and are a fundamental plank of strategies to tackle climate change². These strategies will be undermined unless ways are found to bring the energy performance of buildings in practice in line with design predictions. This report describes how this can be achieved.

Small defects in buildings that create gaps in insulation, that make possible air flows where these should not exist, or that prevent total sealing in joints, may not impact on the appearance, structural integrity, or general utility of buildings. Until recently, such defects have been unseen and ignored. They lie hidden alongside other defects that are more visible (called ‘snags’ in the trade), that are taken for granted as part of the construction process outcome and, depending on circumstances, may or may not be found and fixed before or after occupation.

¹ For example, Hans Eek of the Swedish Passive House Centre (www.passivhuscentrum.se) has written about the situation in Sweden: *“It is frequently asserted that the costs of passive houses are higher than for outmoded conventional buildings. This myth may be due to the fact that in recent years the building industry has not built to the quality stipulated in the regulations. Buildings are handed over to the property managers who, after the guarantee period of perhaps two to five years, must bear the cost consequences of lazy building. This is not enough time for problems to emerge.”*, Passivhuscentrum Newsletter No 6, February 2010, English language version.

² *Energy Roadmap 2050*, European Commission, Brussels, COM(2011) 885/2, 15 December 2011, http://ec.europa.eu/energy/energy2020/roadmap/doc/com_2011_8852_en.pdf; *The Recast Energy Performance of Buildings Directive*, http://www.cibse.org/content/documents/Knowledge_Bank/EPBDBriefingFINAL2011.pdf.

The unseen defects, however, can dramatically degrade the energy performance of a building. This may not have mattered when energy was cheap and energy performance of buildings was anyway poor. But now it is urgent to improve the energy performance of both new and existing buildings in order to reduce carbon emissions, to decrease fuel bills and reduce fuel poverty, and to improve the internal environmental quality of many buildings.

The situation today is that irrespective of what building codes might say, the actual energy performance of buildings is likely to be far worse than the design specification because of the unseen defects (and also, as many studies show, because other things often don't work as they should; we provide some background in this report). What all this means is that we cannot rely on building codes or EU Directives to guarantee delivery of low-energy buildings, either as newly built or as refurbished.

The problem is one of quality. The focus in construction has been on reduction of capital cost while the quality in design and construction that would eliminate the unseen defects is frequently overlooked. This situation is no longer tolerable. This paper demonstrates that it need not be tolerated. Improving the quality of construction is essential if low-energy buildings are to be delivered. At the same time, there is clear evidence that internal environments and occupant comfort and satisfaction will also be improved. As we note in this report, these gains will not only create healthy environments and well-being in homes, but can create improved working conditions and enhanced productivity in commercial buildings with financial benefits far outweighing any occasional increase in capital cost.

This transformation in quality has already happened in many other industries with benefits in costs as well as in performance. As Deming pointed out many years ago, defects are not free. Somebody makes them and gets paid to make them – and someone else often then also gets paid to fix them. Examples exist in construction that demonstrate that high quality – and the low-energy and well-liked buildings that result – need cost no more than building in the conventional way. We highlight particular examples in this report.

There have been calls for a transformation in quality in construction in the UK over many years, in the first instance because of the cost reductions that could ensue. While processes to cut costs have moved forward, these changes have not yet delivered the quality essential to deliver low-energy buildings. A quality transformation is now essential in order that the reduction in carbon emissions from the building stock, essential if climate change targets are to be met, can actually be achieved.

This paper highlights examples that demonstrate how quality can be achieved through a simple adjustment in working methods that creates teamworking and partnership from concept and design through to construction and handover. For new build homes and other buildings, the passivhaus standard now provides a template for quality that is proven and can reliably deliver low-energy buildings.

1.2. The situation today

There is rarely any detailed evaluation of buildings' performance post-handover, after construction. The energy 'performance gap' has only become evident as a result of specific detailed studies that we mention. Buildings may well perform adequately in other respects and may even win awards. However, there does seem to be a correlation between good energy performance of a building and good perceptions by occupants. Buildings designed to be low-energy and delivered in a quality way such that they actually perform as low-energy buildings, are often perceived to be good places to live or to work in. As we show, such high-quality buildings need not cost any more than buildings delivered in a more conventional way.

The energy 'performance gap' is a consequence of the way that most buildings are commissioned, designed and constructed. Unlike in some other industries, there are no generally-followed quality processes that can guarantee energy performance and nor, often, does there seem to be the teamwork that can create the quality in detailing during construction that is necessary to eliminate the unseen defects that compromise energy performance. This problem of quality is not a new problem; it has been highlighted in more than one report, but in respect of energy performance the issues seem to persist.

This generic problem of quality in construction means that no building can legitimately be called a low-energy building unless it can be demonstrated to perform as one, or, unless a quality process involving teamwork at all stages has been involved in commissioning, design, construction and evaluation. There are documented examples of such quality in place and we highlight two examples: the Elizabeth Fry Building at the University of East Anglia in Norwich, commissioned in 1992 and opened in 1995, and new passivhaus schools at Wolverhampton, opened in 2011.

These buildings cost no more than building in a conventional manner but the quality and teamwork that went into their delivery demonstrated the process that is essential to guarantee delivery of a low-carbon building. Sadly, although the building of the Elizabeth Fry Building was well documented in the 1990s, the lessons it taught were not learned within the industry. Now, however, there is sufficient experience and knowledge of construction to passivhaus principles that the quality processes essential to deliver passivhaus energy standards can become the standard that guarantees delivery of low-energy buildings of whatever kind.

1.3. The energy performance gap

Studies in the 1990s of non-domestic buildings considered to be leading-edge and better-managed than the average (the PROBE studies) revealed many situations of alarming divergence between actual and design energy use. Energy performance was often much worse than anticipated, and occupants were also often critical of the buildings.

More recently, the UK Low Carbon Buildings Programme revealed very similar results, again with what were supposedly leading-edge, non-domestic buildings.

There has been less detailed study of domestic buildings (homes) but quite recent work comes to very similar conclusions. Actual energy performance is often very considerably worse than design performance and certainly never better.

The only conclusion that can be drawn is that the great majority of buildings being built today, and that have been built in the two decades or so since energy efficiency became a priority issue, do not perform to the standard anticipated from their design specification. There is little sign of any significant change or improvement in the near future.

The result is that no building, unless its performance is monitored to confirm compliance, can be considered to be a low-energy building, no matter what its design performance or what its Energy Performance Certificate (EPC) might say. We cannot rely on Directives, building codes or other certifications alone to deliver the improvements in energy efficiency of buildings that are widely seen to be necessary if greenhouse gas reduction targets are to be achieved. Only a demonstrated commitment to, and achievement of, quality and teamwork from commissioning through design and construction can deliver the low-energy buildings we need.

1.4. Low-energy buildings in practice

We are fortunate that there do exist outstanding low-energy buildings that match their design intent. Two examples we highlight cost no more than buildings obtained in a conventional way. They were built several years apart and have very different philosophies of thermal control – one has high thermal mass, the other is of lightweight construction. However, they share many features in terms of the quality, teamwork and attention to detail that characterised their design and construction. These similarities allow us to define the process that must be followed if a building is not only to be designed as a low-energy building but is also to perform as one.

The Elizabeth Fry Building at the University of East Anglia in Norwich was the only one of the twenty buildings looked at in the PROBE studies that met all three criteria of low-energy performance, high occupant satisfaction and comfort, and also value for money. The Elizabeth Fry Building, commissioned in 1992 and opened in January 1995, was probably the most air-tight building in the UK at the time and one of the most energy efficient. Its performance is still outstanding.

Other buildings that consistently meet design expectations are buildings that are designed and built to the passivhaus standard. The Elizabeth Fry Building was modelled in detail to ensure that it could meet demanding conditions in summer in particular. Likewise, passivhaus buildings are modelled in detail to ensure they can meet the passivhaus energy standard. The construction process for passivhaus demands high quality standards to ensure that detailing is undertaken correctly. The unseen defects that will otherwise compromise energy performance must be

avoided to ensure that the building will satisfy stringent air tightness tests. As with the Elizabeth Fry Building, teamwork and quality mark out the design and construction of a passivhaus building.

The Elizabeth Fry Building was designed and built before there was widespread awareness of passivhaus principles. We now know that passivhaus new build is deliverable in the UK, just as in Germany and other continental European countries, at little or no extra cost if the appropriate teamwork and quality standards are in place. We highlight a recent example of two new passivhaus schools in Wolverhampton that demonstrate passivhaus construction at no extra cost to conventional build. These schools are of lightweight construction, and contrast to the Elizabeth Fry Building that uses thermal mass to assist temperature control³.

Not only can passivhaus buildings be built cost effectively across Europe, but experience reveals that the internal air quality and the living experience of passivhaus homes and schools are outstanding. Just as with the Elizabeth Fry Building, there is a synergy between low-energy performance and occupant satisfaction and comfort.

1.5. What happens in new build shapes refurbishment too

Although we focus in this report on new buildings, the arguments will apply with equal, if not more, force to the refurbishment of existing buildings. Refurbishing an existing building to a low-energy standard is more complex than building new because the existing building will not have been designed for low-energy performance. In addition, unanticipated problems will almost certainly arise during the work and demand solution as work proceeds. Hence any energy performance gap is likely to be worse, on average, for refurbished buildings than for new buildings.

As we have highlighted in *Refurbishing Europe*⁴, across the EU, the refurbishment of existing buildings provides the major challenge to creating an energy-efficient building stock. The great majority of buildings that will be standing in 2050 have already been built. If we cannot build new low-energy buildings with any confidence that design energy targets will be met, then the chance of delivering a low-energy building stock via refurbishment is essentially zero, in which case EU energy and climate change targets absolutely cannot be met.

³ Lightweight construction is a design choice; another passivhaus school has recently been completed in the UK, Montgomery Primary School at Exeter, and this has high thermal mass – see http://www.concretecentre.com/online_services/case_studies/montgomery_primary_school.aspx, and <http://www.jp.a.uk.com/projects.php?cat=Education>.

⁴ *Refurbishing Europe: An EU Strategy for Energy Efficiency and Climate Action Led by Building Refurbishment*, Bruce Tofield and Martin Ingham, Build with CaRe, February 2012, <http://www.buildwithcare.eu/news/231-refurbishing-europe>.

The quality practices necessary for successful refurbishment will first be learned and adopted in new build construction, however. Hence, getting it right, and learning to deliver low-energy new buildings in a quality fashion is far more important than might be thought just by comparing the number of new build starts to the volume of refurbishment necessary over the coming decades. Getting it right in new build is the key to getting it right in refurbishment and to meeting climate change ambitions.

This spill-over from new build quality to exceptional quality in refurbishment has already been demonstrated in Sweden where expertise in passivhaus new build construction has been applied to the refurbishment⁵ of early 1970s apartments at Brogården in Alingsås⁶ in the south of Sweden. Not all building refurbishment projects will aim for the very demanding passivhaus standard⁷ but the quality process discussed in Chapter 3 can be followed whatever the actual energy efficiency saving targeted.

1.6. Definition of a low-energy new building

In Chapter 2 we define a low-energy new building as follows:

A low-energy new building is a building that is designed to achieve or to come close to the passivhaus standard and one where passivhaus or similar quality processes are followed to ensure that design energy use is realised in practice without compromising occupant comfort and satisfaction.

This definition is chosen because passivhaus has now been shown to be a practical new build option for the construction industry. It is also necessary because the implementation of an advanced energy efficiency standard such as passivhaus is the only approach that can deliver the energy and greenhouse gas savings that are necessary to achieve climate change targets. In addition, the implementation of such a standard via a properly documented quality process creates an internal environment that provides for excellent occupant comfort and satisfaction.

⁵ Presentation by Hans Eek, Swedish Passive House Centre, Build with CaRe conference, Norwich, October 2010, <http://www.buildwithcare.eu/downloads/Public/Annual-Conference-2010/Presentations-Thursday-21-Oct/Hans-Eek-Passivhus-Centrum-Sweden-21-Oct-2010.pdf>, and *Skanska Case Study 64, Brogården, Sweden*, http://skanska-sustainability-case-studies.com/pdfs/64/64_Brogarden_v001.pdf.

⁶ A description of the apartments and their refurbishment together with other aspects of the work and the engagement of the occupants is given (in Swedish) on the website of the housing association, Alingsåshem, http://www.alingsashem.se/index.php?page=brogardens_ombyggnad.

⁷ EnerPHit – the Passive House Certificate for old buildings, http://passipedia.passiv.de/passipedia_en/certification/enerphit.

1.7. ‘Low-energy’, ‘low-carbon’ and “zero-carbon”

Also in Chapter 2 we differentiate between the terms ‘low-energy’ and ‘low-carbon’ and explain why we focus in this report on low-energy buildings⁸. We point out why renewable energy installed in or on a building is not a substitute for fabric energy efficiency (fabric efficiency is the focus of the passivhaus standard) but note the interesting options for use of renewable energy and energy storage that become possible when a very high fabric energy efficiency is achieved in a low-energy building.

We review the findings of the UK PROBE and Low Carbon Buildings Programmes to highlight why a low-energy building can only be so called when it demonstrates high energy efficiency in operation. The design energy performance (or the Energy Performance Certificate, the EPC) is, for most buildings, meaningless without evidence from operation. Finally, we outline why the UK definition of so-called “zero-carbon homes” is inadequate and unlikely to deliver low-energy homes, but describe new projects that show that the passivhaus standard is indeed a practical new build option in the UK.

1.8. Quality processes and delivery of a low-energy building

In Chapter 3, we focus on the process of design and construction that can ensure delivery of a low-energy building with particular reference to the Elizabeth Fry Building and the new passivhaus schools in Wolverhampton. We highlight and describe the importance of the brief, and of innovation and what this means in building design. The need for teamwork and partnership working throughout the design and construction process is emphasised, also for design completion before construction commences, and for attention to detail in construction to ensure total quality.

Effective post-construction evaluation and monitoring happens only rarely. It should become routine and its importance is stressed.

We summarise key issues under the following headings:

- **The brief must be clear and appropriate**
- **Innovation may be necessary but building operation must be simple**
- **Modelling of building performance is essential**
- **Teamwork throughout is essential**

⁸ As we note in Section 2.1, it is important not to ignore the energy embedded in materials of construction and the construction process and to minimise these wherever possible. This report, however, focuses on the operational energy of buildings, in particular on the energy for heating or cooling. This is by far the largest contributor to building energy use at present in the UK and most of Europe and is directly addressed by improving the quality and effectiveness of the building fabric. Hence our definition of a low-energy building.

- **Design must be finalised before construction begins**
- **Attention to construction detailing is essential**
- **Post-construction evaluation is essential**

In the final section we note new software developed at UEA within Build with CaRe that is able to capture building management system (BMS) data and translate this into easily viewable information to help building occupants and others understand building energy use and how this has varied over time, and hence to assist continuing improvement in energy use and efficiency.

We note that awards for so-called ‘green buildings’ may reflect neither actual energy use nor occupant comfort and satisfaction. Buildings that may give a good image to occasional visitors such as judges of architectural merit may be neither energy efficient nor pleasant to work in. The only reliable assessments are monitoring of actual energy use and independently conducted occupant surveys.

1.9. Underlying causes for performance gaps

Chapter 4 summarises the evidence for the energy performance gap both for non-domestic and domestic buildings (homes). Evidence of problems and concerns with non-domestic buildings that were thought to be ‘leading edge’ and energy efficient were found in the PROBE studies in the 1990s. These problems were again revealed in the more recent Low Carbon Buildings Programme.

Similar problems are found with modern homes. Neither building assessment processes nor energy performance certificates (EPCs) provide a realistic assessment of actual energy use which is almost always greater, sometimes several times greater, than design estimates or predictions.

The problems found are compounded by lack of a culture of continuous improvement in construction. Issues and concerns seem frequently to be ignored so that improvement does not happen. We discuss the case of West Suffolk House, a BREEAM Excellent building, that was studied in the Low Carbon Buildings Programme. This has been promoted as a sustainable building that has created a better work environment but, in fact, independent study of the building and of occupant satisfaction revealed energy use much higher than the design estimate, and also marked and widespread occupant dissatisfaction.

We outline the problems observed in the different studies and the reasons for these which, for non-domestic buildings, very often include “feature packed but not functional buildings, unmanageable complex controls and building management systems”. The underlying causes, common to both non-domestic buildings and to homes, seem to be lack of quality in construction compounded by a lack of evaluation, monitoring and feedback.

The present situation is very serious because it means that demand reduction and climate change targets cannot be met. The energy performance gap will, in many cases, be compounded by problems with internal air quality and occupant well-being. The problems observed in new build construction will be even more prominent in homes and buildings refurbished to become supposedly more energy efficient.

The Zero Carbon Hub has pointed out that the problems observed reflect quality issues that are endemic across the design, construction and handover process. The only dependable way to transform construction quality so that design energy use targets are achieved is to move to or close to passivhaus or similar standards with quality processes as were followed in the building of the Elizabeth Fry Building in the 1990s and the Wolverhampton passivhaus schools more recently.

The endemic quality problems are reflected, in miniature, in problems observed in the installation and operation of MVHR (mechanical ventilation and heat recovery) systems. MVHR will be essential in most new and very many refurbished buildings that aim to achieve low-energy operation, but failures in design, installation and commissioning are widespread. The underlying cause of the problems, as with the energy performance gap, seems to be “traditional construction model” where different skills or trades work in isolation and where quality is inevitably compromised.

1.10. Quality in construction

The endemic quality problems that are now alarmingly revealed in the inability of the construction industry to deliver low-energy buildings have been highlighted many times in the past. In Chapter 5 we summarise key points made in the Egan Report over a decade ago that are still to be addressed.

We highlight that achieving the passivhaus standard requires exactly the quality standards that Egan was calling for. These standards have been successfully achieved not just in other industries but also in construction wherever management has taken pride in delivering quality and has enabled the teamwork and partnering that are essential to deliver it. The construction of the Elizabeth Fry Building in the 1990s and the Wolverhampton passivhaus schools more recently demonstrate that the quality necessary to deliver low-energy buildings can indeed be delivered by today's workforce.

Without such quality, the consequences will be extra and unnecessary fuel bills for building occupants, the likelihood of uncomfortable or unhealthy internal environments, greenhouse gas targets not achieved, and unnecessary energy supply and security problems. By adopting passivhaus or similar quality standards, the construction industry can innovate and flourish while helping Member States and the population of the EU avoid these serious and costly dangers.

The Zero Carbon Hub has acknowledged these exact issues: *“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.”

Such integration cannot happen without a radical change in attitudes to quality and will not happen without a radical change in quality standards demanded by regulation. It can take effect most easily and effectively by the adoption of passivhaus or similar quality standards.

1.11. How good buildings enhance well-being and productivity

In Chapter 6 we summarise evidence collected from many countries that links good environmental quality in office and similar buildings with greater productivity. A building built to high quality standards, such as the Elizabeth Fry Building, is not only very energy efficient but will also create a perception of comfort and of increased productivity by the occupants.

Over the lifetime of a commercial office building, construction cost is several times less than maintenance costs and up to two hundred times less than building operating costs, which are principally the cost of staff. Therefore, aspects of a building that impact positively on productivity can yield a very significant financial benefit.

Work by Building Use Studies Ltd, based on evidence from over 150 buildings internationally, shows a strong correlation between overall comfort and perceived productivity. A strong component of overall comfort is personal control – the ability of the person being questioned to exercise personal control over their workplace environment. Correlated with a sense of personal control is a greater tolerance of any source of discomfort.

What is common to low-energy buildings such as the Elizabeth Fry Building and passivhaus homes and schools is the provision of a comfortable environment where occupants can get on with their life or their work without being distracted by environmental concerns or discomfort. People are productive at work and will experience a sense of well-being if at home.

While low-energy buildings do not, of themselves, create more productive environments, the quality processes necessary for their successful delivery also lead to the creation of internal environments that enhance well-being without the discomforts or lack of control that are evident in so many other buildings, even ones that may be claimed in design to be ‘green’ or ‘sustainable’.

The financial benefits of low-energy buildings seem very likely to extend far beyond low fuel bills to lower maintenance costs, healthier occupants and less cost to society of ill-health, better rents and occupancy levels in commercial and office buildings, and more productive work environments. Such benefits are also likely to outweigh any costs of making the transition to quality many times over, while the costs to society at large of not creating quality and foregoing the ability to deliver low-energy buildings will be huge.

2. What is a low-energy building?

“The performance gap – On the non-domestic side, reports on the measured performance of projects funded under the Low Carbon Buildings Programme show that energy use and carbon emissions can be up to three times higher than expected from the design intent, suggesting that, for typical new builds and refurbishments, there has been little improvement in the in-use energy performance compared to design expectation since the PROBE studies of the 1990s. Further research conducted for the Carbon Trust puts the relative gap between design and in-use performance as high as 500%. ... The Zero Carbon Hub report on closing the gap between designed and built performance summarises much of the existing evidence base for thermal underperformance in housing...”

Building Britain: The path of sustainable growth for the built environment, Aldersgate Group, February 2012, <http://www.aldersgategroup.org.uk/reports>.

This report focuses on information from the UK. From discussions with partners in several European countries, however, it seems unlikely that the issues noted here are unique to the UK¹.

As we note in the Overview (Section 1.1), apart from energy performance, structurally and in terms of their general utility, most buildings perform adequately. There is rarely, however, any detailed evaluation of the energy performance of buildings after construction but before occupation. The energy ‘performance gap’ has only become evident as a result of particular detailed studies that we mention. The ‘performance gap’ means that buildings perform more poorly, sometimes far more poorly, in respect of energy use than their design performance would indicate.

The ‘performance gap’ seems to be a consequence of the way that buildings are, for the most part, commissioned, designed and constructed. A generic problem of quality in construction means that almost no building can be called a low-energy building unless it can be demonstrated to perform as one. Eventually, if quality practice is followed as outlined in Chapter 3, we anticipate that evidence will accumulate to demonstrate that a process involving teamwork at all stages from commissioning to handover and beyond can guarantee energy performance.

We define a low-energy new building as follows, and outline in this Chapter the reasons why we adopt this definition.

A low-energy new building is a building that is designed to achieve or to come close to the passivhaus standard and one where passivhaus or similar quality processes are followed to ensure that design energy use is realised in practice without compromising occupant comfort and satisfaction.

The passivhaus energy standard for refurbishment⁷ will be an appropriate target for many, hopefully most, building refurbishment projects, particularly for homes where the benefits of improved well-being and very low heating bills will have especial impact. But no matter what the actual energy target for refurbishment, the same quality processes that are followed in construction to passivhaus standards must be adopted if low-energy performance is to be guaranteed.

2.1. Low energy means low operational energy

The present report is concerned with buildings that are efficient in terms of the energy used in operation⁹ which is why we use the term low-energy building rather than low-carbon building¹⁰. What we mean in practice by a low-energy building is a building that requires only modest amounts of energy to heat (and occasionally to cool¹¹) it. Hence this report is concerned, in particular, with how to deliver a building

⁹ We note in *Building Performance Evaluation: Why and How*, Martin Ingham and Bruce Tofield, Build with CaRe, March 2012, http://www.buildwithcare.eu/images/pdfs/bpe_why_and_how_march_2012.pdf, that the energy used in operation of a building, in particular energy used for heating, is, in the great majority of cases, the dominant source of energy use (see Footnote 21) and of greenhouse gas (in most countries carbon) emissions over the lifetime of the building. As buildings become, we hope, much more energy efficient, then other uses of energy become proportionally more significant. A focus on operational energy and hence on building fabric and energy for heating, in particular, is necessary, in the first instance, to drive down the energy used by today's buildings as well as by new buildings. As low-energy buildings become more common-place, however, it will be important also to focus on and to minimise other areas of energy consumption including hot water provision, lighting, and the use of appliances of all kinds, as well as on the energy embedded in the materials of construction. This report focuses primarily on operational energy as this is still the dominant area of energy use by buildings and is the essential primary focus whatever else might also be considered.

¹⁰ In *Building Performance Evaluation: Why and How*⁹, we describe in Section 2 what is meant by Low-Carbon Construction. Because energy use in operation of a building, in particular energy used for heating, is, in the great majority of cases, the dominant source of energy use and of greenhouse gas emissions, a building that is very economical in the use of energy for heating will be, relative to most other buildings, a low-carbon building. However, as we note in *Building Performance Evaluation: Why and How*, description of the operational energy tells us nothing about the greenhouse gas emissions embedded in the construction materials used for a building. These may be energy intensive materials such as concrete, or carbon sequestering materials such as wood. Hence we prefer to call a building that is very economical in the use of energy for heating a low-energy building rather than a low-carbon building. We would give the latter name to a building that is not only energy efficient in operation but is also constructed principally from low-embedded-energy (hence low-carbon) materials such as wood or hemp and lime. As we note elsewhere in this section, the term 'low carbon building' has, in the UK, become rather meaningless because issues of fabric efficiency are conflated with issues to do with renewable energy installations.

¹¹ In Build with CaRe we are concerned with buildings in the partner countries in particular: south Sweden, north Germany, Belgium and The Netherlands, as well as the UK. Hence heating during winter, is, in the great majority of buildings and for housing in particular, the biggest user of energy during operations (there will be exceptions such as the use of energy for refrigeration in many supermarkets, for example). While cooling in summer can be a serious problem in poorly designed buildings, for example those that have large amounts of glass in facades, with the need for air conditioning and cooling, summer heat is not so challenging to building designers and operators as in much hotter countries in the south of Europe. That

that has a building fabric capable of maintaining, with minimal heating (or cooling) requirement, a comfortable internal environment during winter in particular, but also during the other seasons including summer.

2.2. “Low-carbon” or “zero-carbon” may or may not be ‘low energy’

We note in the following paragraphs reference to so-called “low-carbon” or “zero-carbon” buildings. It is, in principle, possible to offset the greenhouse gas (often summarised as carbon⁹) emissions in operation by renewable energy systems installed at or on the building, so making the terminology “low-carbon” or “zero-carbon” accurate in some respect. However, as we discuss, if the operational energy is not reduced to the minimum achievable level through efficient building fabric design, then the overall building system is certainly not efficient and nor is it low energy.

For the purposes of this report, a building that may be called by others “low-carbon” or “zero-carbon” is not a low-energy building if the operational energy is not at a suitably low level. This distinction becomes important when considering so-called “zero-carbon homes” proposed for the UK from 2016 (see also Section 2.7).

The original UK definition of zero-carbon homes, in the release¹² of the Code for Sustainable Homes in 2006, made clear (p7) that achieving Code 6 (the highest level with the most demanding environmental standards) would imply: *“A completely zero carbon home (i.e. zero net emissions of carbon dioxide (CO₂) from all energy use in the home).”*

Achieving such a zero-carbon home would necessarily imply excellent fabric efficiency as well as installed renewable energy systems. However, as has been discussed in a recent paper¹³, the standard for UK “zero-carbon homes” has been progressively watered down since this 2006 definition until half the emissions can

said, for low-energy buildings as discussed in this paper, either new or refurbished, the high levels of insulation and air tightness can lead to over-heating during summer unless this aspect is properly considered and dealt with at the design and construction stages. We describe how this was done for the Elizabeth Fry Building at the University of East Anglia and is done for passivhaus homes in the UK and elsewhere. It is important to note that a well-designed low-energy building should, if operated well, be able to resist overheating. The problems experienced with hot buildings in the 2003 European heat wave (http://en.wikipedia.org/wiki/2003_European_heat_wave) were not caused by low-energy buildings but by overheating in the conventional building stock which is a much more widespread problem. Some more background to preventing overheating is provided in Footnote 184.

¹² *Code for Sustainable Homes: A step change in Sustainable Home Building practice*, Department for Communities and Local Government, December 2006, http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf.

¹³ *An investigation into recent proposals for a revised definition of zero carbon homes in the UK*, Robert S. McLeod, Christina J. Hopfe and Yacine Rezgui, Energy Policy, 46, 25-35 (July 2012), <http://dx.doi.org/10.1016/j.enpol.2012.02.066>.

potentially be offset through market-based mechanisms, so-called ‘allowable solutions’. This is a far cry from the zero-carbon definition of 2006.

McLeod et al note¹³ the potential concerns of such a diluted definition: *“Although these ‘allowable solutions’ are not yet clearly defined the transition away from meeting the balance of the annual energy requirement through high levels of energy efficiency and from directly connected renewable energy infrastructure will have significant implications, both for GHG emissions as well as for a number of wider social and sustainability indicators.”*

We have highlighted this drift from a meaningful zero-carbon definition of new homes in Chapter 6 of *Refurbishing Europe*⁴: “Zero-carbon homes no longer zero carbon”. The authors of *An investigation into recent proposals for a revised definition of zero carbon homes in the UK*¹³ point out that most forms of carbon offsetting are inherently complex to implement and monitor and that the ‘allowable solutions’ so far proposed for so-called “zero-carbon homes” in the UK are unlikely to be an exception to this.

A UK-defined “zero-carbon home” seems unlikely to fall into any acceptable category of low-energy building. This is not only because of the drift in definition but also because of the concerns about the ‘performance gap’ (see the Box at the head of this Chapter and Chapter 4). If there is no guarantee that a building will perform energy-wise as planned, indeed a likelihood that it won’t, then the building cannot be called low-energy whatever the claims of designers, whatever an Energy Performance Certificate (EPC) might say, and irrespective of whether it is called a “zero carbon building”. We discuss the performance gap in Chapter 4. See also Sections 2.5 and 2.7 below.

The fundamental problem with attempts to find a suitable definition for “zero-carbon homes” lies in the original, political, decision in 2006 to mandate construction of “zero-carbon homes” in ten years’ time, in 2016 (and “zero-carbon buildings” of all kinds by 2019). Instead of focusing on low-energy homes and fabric efficiency as the essential pathway, attention has been diverted to discussion of how renewable energy can be installed on-site or elsewhere in order to offset some variable amount of energy used in the home. This diversion has wasted much time and effort and led to sub-optimal decision making (see Section 2.7, *“Zero-carbon homes” will not satisfy greenhouse gas targets*). We hope it is not too late to realise the problem and to revert to a more sensible course such as a requirement for compliance with passivhaus standards that we propose in this report.

2.3. Renewable energy is not a substitute for fabric efficiency

Installation of renewable energy technologies should not be seen as an alternative to improving the fabric efficiency of buildings, but this is what seems to have happened in the search for a definition of a “zero carbon home” in the UK. By all means install renewable energy technologies where appropriate as this will reduce

overall demand for conventional fossil-fuel derived energy. Thus, installing PV panels on suitably oriented roofs or elsewhere will displace conventional electricity¹⁴, whatever the nature of the building fabric, with any excess being exported to the grid. But installing renewable energy technologies within a building where the fabric is poor in order to compensate or to offset operational energy may just perpetuate unnecessary waste.

For example, installing a larger-than-necessary heat pump¹⁵ in a building with only moderate to poor fabric energy efficiency, is wasteful. Such action diverts funds from more effective action on the fabric to improve building energy performance and so reduce greenhouse gas emissions. The heat pump will be larger than necessary and will require extra electricity supply for its operation that cannot then be used elsewhere. If such practice is followed on a wide scale a bigger and more expensive renewable electricity supply network will be needed¹⁶.

Similar considerations apply to the operation of MVHR (mechanical ventilation with heat recovery). If air tightness is not enhanced to or near to the passivhaus standard, then an MVHR system will have to work much harder than necessary and will thus use extra energy in operation. It might not even recover as much value in heat as it costs to run.

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- ¹⁴ The EEX Transparency Platform shows on a daily basis the load-levelling impact of solar PV and wind energy installed in Germany, <http://www.transparency.eex.com/en/>. Earlier in 2012, the electricity generated by the nearly 28GWp installed PV capacity in Germany enabled the electricity grid to continue operation despite the closure of nuclear power plants following the Fukushima incident (*Germany 'saved by the sun' from post-nuclear blackouts*, EurActiv, 16 July 2012, <http://www.euractiv.com/energy/germany-saved-sun-post-nuclear-b-news-513905>).
- ¹⁵ Considered as a renewable energy device in the UK: see *Renewable Heat Incentive*, Department of Energy and Climate Change (DECC), March 2011, <http://www.decc.gov.uk/assets/decc/What%20we%20do/UK%20energy%20supply/Energy%20mix/Renewable%20energy/policy/renewableheat/1387-renewable-heat-incentive.pdf>.
- ¹⁶ In *Refurbishing Europe*⁴, we noted in Chapter 7 the potential impact of the weakening of the definition of a "zero-carbon home" in the UK. It was decided in 2011 by the UK Government that only regulated emissions (heating, lighting, hot water) would need to be offset by renewable energy for a home to be called "zero carbon". Unregulated emissions – that is emissions associated with use of all appliances in the home – could be ignored! Such a decision makes a mockery of the term "zero carbon" of course but the watering down of standards also has a direct impact on the investment needed for energy supply. As the UK Committee on Climate Change noted in its 3rd Progress Report in June 2011: *"This change in definition has some potential implications for carbon budgets. In our fourth budget report, we had assumed no emissions or additional electricity capacity requirement from new homes. We now estimate that by 2030, new homes could require up to an additional 6TWh of electricity which would have to be met by low carbon electricity generation capacity."* (*Meeting Carbon Budgets - 3rd Progress Report to Parliament*, Committee on Climate Change, June 2011, <http://www.theccc.org.uk/reports/3rd-progress-report>).

2.4. But with a highly efficient fabric renewable energy and energy storage become very interesting

In contrast to the potential problems with so-called “zero carbon homes” in the UK, in situations where fabric thermal efficiency is built to (or improved during building refurbishment to) very high levels, efficient local energy supply – in many cases by renewables – and possibly also storage, become both possible and economic.

For example, in *Refurbishing Europe*, Section 10.8⁴, we gave the example of a 1950s apartment block being refurbished to passivhaus standard in Hamburg, Germany. The heating and hot water were provided by a small gas engine¹⁷ that was also generating electricity supplied to the grid. Heat storage, for all the heating and hot water needs for twenty-seven apartments, was provided in the form of large cylinders of hot water (total 4000 litres), enabling the engine to run only for a few hours a day when the price of electricity is highest, or when the thermal stores are depleted.

As operational energy is reduced to low levels, as in this example of passivhaus apartments, then total energy requirement for building operation can be very significantly reduced. Options such as the Lichtblick mini-CHP system in the Hamburg apartments become interesting, not just enabling local energy generation and storage, but also distributed “swarm electricity”¹⁸.

The total energy use for the Elizabeth Fry Building at the University of East Anglia, reviewed below, was only half that considered good practice at the time, while annual heating energy required for passivhaus homes is, on average, only around ten per cent of that required for the general housing stock (per unit floor area) as shown for German homes in Figure 1¹⁹. A similar result is found for new passivhaus

¹⁷ Running on natural gas at present but with the possibility of running on biomethane in the future; as energy use for heating is cut by ninety per cent when homes and buildings are converted to passivhaus standards, natural gas for heating can potentially be substituted by biomethane distributed either via the existing gas grid or via more local systems. We note the potential for generation of renewable methane and renewable liquid fuels using renewable energy in Chapter 2 of *Refurbishing Europe*⁴; see *Hybrid PV-Wind Renewable Methane Power Plants - a Potential Cornerstone of Global Energy Supply*, Ch. Breyer, S. Rieke, M. Sterner, and J. Schmid, Preprint to be published in the proceedings of the 26th European Photovoltaic Solar Energy Conference, 5–9 September 2011, Hamburg, Germany; http://www.q-cells.com/uploads/tx_abdownloads/files/16_6CV.1.31_Breyer2011_HybPV-Wind-RPM-Plants_paper_PVSEC_preprint.pdf, and *Energy storage via carbon-neutral fuels made from CO₂, water, and renewable energy*, R. J. Pearson et al, Proc. IEEE (Special Issue: Addressing the intermittency challenge: Massive energy storage in a sustainable future), 100(2), 440-460 (2012).

¹⁸ See http://www.lichtblick.de/h/english_information_395.php.

¹⁹ A similar figure is shown in http://passipedia.passiv.de/passipedia_de/grundlagen/was_ist_ein_passivhaus where the stock buildings are from Kassel with an average heating energy per year of 158kWh/m². At http://passipedia.passiv.de/passipedia_de/betrieb/nutzung_erfahrungen/messergebnisse/messergebnisse_zum_energieverbrauch it is stated that the average heating energy consumption in the existing housing stock in Germany is about 160 kWh/m² a year, and we estimate the figure for Great Britain to be similar, also about 160 kWh/m² per year. Hence the average heating energy requirement per year for the passivhaus

homes in Wimbish, Essex, UK, that have been monitored by Build with CaRe²⁰ and that also appear to comply in use with the passivhaus limit of 15kWh/m²/yr energy for heating (as also achieved by the German passivhaus homes shown in Figure 1).

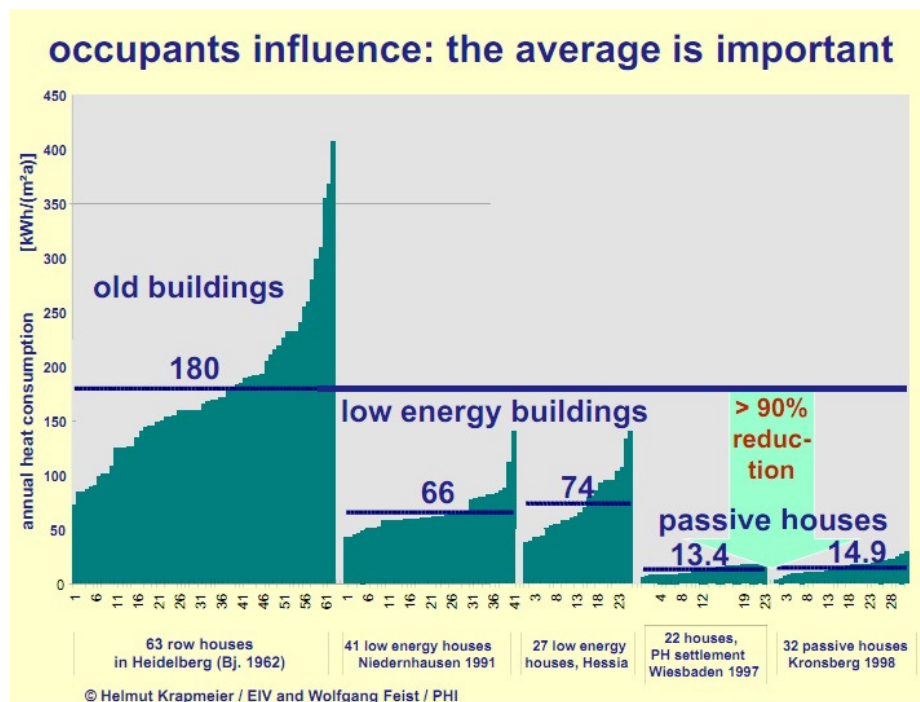


Figure 1. A comparison of the annual energy use for heating (per m² of floor area) for German passivhaus homes in Wiesbaden and Kronsberg with low-energy homes in two towns and with older buildings in Heidelberg. The low-energy homes were built in 1991 but to energy standards as good as those applying today¹⁹.

Because energy for heating is such a large component²¹ of total energy use in buildings, such a large reduction in energy for heating translates into a very big

homes is only ten per cent or less than for the building stock as a whole (based on unit floor area) in both Britain and Germany.

²⁰ See <http://www.buildwithcare.eu/news/238-energy-data-in-a-non-technical-manner> that has a link to *Wimbish Passivhaus: Building Performance Evaluation, Interim Report – March 2012* by Martin Ingham, Build with CaRe, March 2012, http://www.buildwithcare.eu/images/pdfs/wimbish_passivhaus_interim_report_march_%202012.pdf.

²¹ Figures 2.6 and 2.7 in *Low Carbon Construction, Innovation & Growth Team Final Report*, HM Government, Autumn 2010, <http://www.bis.gov.uk/policies/business-sectors/construction/low-carbon-construction-igt> show heating as being responsible for 53 per cent of carbon emissions in housing in the UK, and 46 per cent in non-domestic buildings.

saving in total energy use. Thus, even though the appliances used by occupants in the Wimbish passivhaus homes are those they have purchased as normal or brought with them, total annual energy use at the Wimbish passivhaus homes is, on average, less than one-third of that for the UK housing stock as a whole (per unit floor area). If appliances were all highly energy efficient this figure would be as low as one-quarter or less without doubt.

A study²² of the first Swedish passivhaus homes, 20 terrace style apartments at Lindås in southern Sweden, occupied in 2001, has shown they also comply in use with the passivhaus limit of 15kWh/m²/yr for heating. As is normal (see Figure 1), the total energy use across the different apartments varies by a factor of more than two, but the average heating energy for a year per m² is 14.3kWh, less than a quarter of that for homes built to the Swedish building regulations. In terms of total energy use, the saving relative to conventional Swedish homes of the same size was between 50 and 75 per cent.

Similar dramatic savings in energy use are observed for homes refurbished to passivhaus standard. The refurbishment of the 1970s apartments at Brogården in Sweden to passivhaus standards brought about a reduction in annual heating energy of 83 per cent (115kWh/m² to 19kWh/m²) and in total energy use of 60 per cent (216kWh/m² to 86kWh/m²)⁵.

Reductions of operational energy of this magnitude do then, indeed, make it possible - and often sensible - to generate all the remaining energy used – or even more - by on-site renewables (the original intention of the UK for “zero-carbon homes”¹²). This is the philosophy of the zero-energy house or the plus energy house²³.

Once building fabric becomes so efficient that such an approach becomes possible then the wider energy supply system can be transformed with cities and communities becoming more nearly self-sufficient²⁴. But the first key step is the

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- ²² *Houses without heating systems, Lindås, Benchmark Study*, European Sustainable Urban Development Projects, http://www.secureproject.org/download/18.360a0d56117c51a2d30800078413/Lind%C3%A5s_Sweden.pdf; note that the Figure in this report showing as a comparison the energy consumption for homes built to comply with Swedish building regulations has some errors; the total energy consumption per year for conventional homes of this size should be 15,000kWh not 1,500kWh, and the energy used for heating should be 7500kWh not 7000kWh (the correct figures have been provided separately in presentations to Build with CaRe).
- ²³ See, for example, <http://www.plusenergiehaus.de/> and <http://www.nollhus.se/>, and a summary in http://en.wikipedia.org/wiki/Zero_energy_building. *Small is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size*, Amory B. Lovins et al (Earthscan Ltd, 2003 and <http://smallisprofitable.org/>) reviews the many benefits of small-scale and local energy supply.
- ²⁴ We discuss these issues in more detail in Sections 10.8 and 10.9 of *Refurbishing Europe*⁴. A comprehensive review of the benefits of a more rational energy supply system is given by Walt Patterson in *Keeping the Lights on: Towards Sustainable Electricity* (Earthscan, 2007). Patterson highlights the fact that electricity is a process, not a commodity. Sadly, UK energy policy, dominated by the interests of the big

transformation of the building stock fabric to a very high standard of energy efficiency. This can only happen if effective quality processes are followed as this paper discusses.

2.5. Low-energy performance in use is what matters, not design predictions or EPCs

As the quotes in grey^{25, 26, 27} at the front of this report make plain, there is clear evidence that many, probably most, buildings now being built, both domestic and non-domestic, are not achieving their design criteria in energy efficiency terms. The recent quote from the Aldersgate Group²⁸ in the box at the head of this Chapter summarises these concerns about supposedly “low-carbon” buildings in particular.

There is, it is clear from these quotes, widespread awareness in the UK that design predictions on energy use are unlikely to be realised in actual building operation. But a building designed to be low energy can only be called a low-energy building if it actually performs as one. Delivery of a low-energy building must include demonstration or confidence that the building does indeed perform as planned.

energy supply companies (as we discuss in Section 10.1 of *Refurbishing Europe*⁴), gets into serious difficulties by trying to treat electricity as a commodity. Pricing becomes ever more arcane and the systems within which electricity is used are largely ignored. The consequence is that increasing the efficiency of energy use, generally the most cost effective option, seems less prominent in UK government policy than development of energy supply. We highlight these important issues at some length in *Refurbishing Europe*.

²⁵ “Studies repeatedly show that buildings do not achieve their design criteria, in energy efficiency terms, when tested post-completion.” Low Carbon Construction, Innovation & Growth Team Final Report, HM Government, Autumn 2010, <http://www.bis.gov.uk/assets/biscore/business-sectors/docs/10-1266-low-carbon-construction-igt-final-report.pdf>, Section 3.6.1, p70.

²⁶ “If the energy consumption of an occupied home is greater than its designer predicted, then its carbon dioxide emissions will also be higher than predicted – this is the ‘CO₂ performance gap’. There appears to be a growing body of research evidence that new housing is failing to deliver the anticipated levels of CO₂ emissions, although there is relatively little understanding within the wider industry of what might be causing this.” Low and zero carbon homes: understanding the performance challenge (NF41), NHBC Foundation and Zero Carbon Hub, February 2012, <http://www.nhbcfoundation.org/LinkClick.aspx?fileticket=yZNmr%2fhHew8%3d&tabid=500&mid=1183>, Executive Summary.

²⁷ “New non-domestic buildings: What have we tended to find, for many years now?”

- They often perform much worse than anticipated, especially for energy and carbon, often for occupants, and with high running costs, and sometimes technical risks.”

What works, what doesn’t work, and how we can fix it: using Building Performance Evaluation (BPE) for rapid improvement, Bill Bordass, 27 September 2011, presentation downloadable from the Usable Buildings Trust website, <http://www.usablebuildings.co.uk>.

²⁸ “An alliance of leaders from business, politics and society that drives action for a sustainable economy”, <http://www.aldersgategroup.org.uk/about/our-aims>.

Claims that buildings may be admirable in respect of some design code or other (for example BREEAM²⁹) are mere speculation until it is demonstrated that the buildings perform as designed. We note below (Section 4.1) the example of West Suffolk House, a BREEAM Excellent building and a demonstration building in the UK's Low Carbon Buildings Programme (LCBP)³⁰, but which performed poorly in terms of energy use and also in respect of occupant satisfaction.

Successful delivery of a low-energy building will involve the processes not just of construction but every link of the chain from specification and design through to handover and operation (Chapter 3). A building can only be a low-energy building if it is created via a high-quality design and construction process that eliminates unseen defects and other problems that otherwise make low-energy operation difficult.

As already noted, the focus of a low-energy building must be on the building fabric with on-site renewable energy technologies only becoming useful and important, as discussed above, once fabric excellence is achieved. The UK's Low Carbon Buildings Programme (LCBP) was ill-named for it conflated study of renewable energy technologies with seemingly rather limited study of more effective approaches to building fabric. As just noted, one building from the Programme, the £21.5m BREEAM Excellent West Suffolk House, which was observed in operation, demonstrated very effectively exactly how not to deliver a successful low-carbon (or low-energy) building (Section 4.1).

The LCBP Final Report³⁰ indeed points out: *"A key outcome of the research shows that despite genuine intentions to develop a low carbon building, expectations often fail to translate into reality. Evidence gathered during the programme suggested this is caused by issues related to both the management of projects and issues that arose during the design, installation and operation of the technologies involved. Such issues can occur at all stages of a project, from inception to completion. ... Clearly, there were large discrepancies between modelled and actual energy consumption – actual energy use was typically up to 5x greater than predicted"* (as the quote by the Aldersgate Group in the Box at the head of this Section also notes).

A Figure from the LCBP Final Report shows (Figure 2) predicted versus actual energy consumption for five (unidentified) buildings that were studied. For three of these, the actual energy use is several times that predicted.

²⁹ "The world's leading design and assessment method for sustainable buildings", <http://www.breeam.org/>.

³⁰ *Low Carbon Building Programme 2006-2011, Final Report*, Mike Gardiner, Helen White, Monika Munzinger and Will Ray, Department of Energy & Climate Change (DECC), August 2011, <http://www.decc.gov.uk/assets/decc/11/funding-support/fund-opportunities/2578-lcb-programme-2006-11-final-report.pdf>.

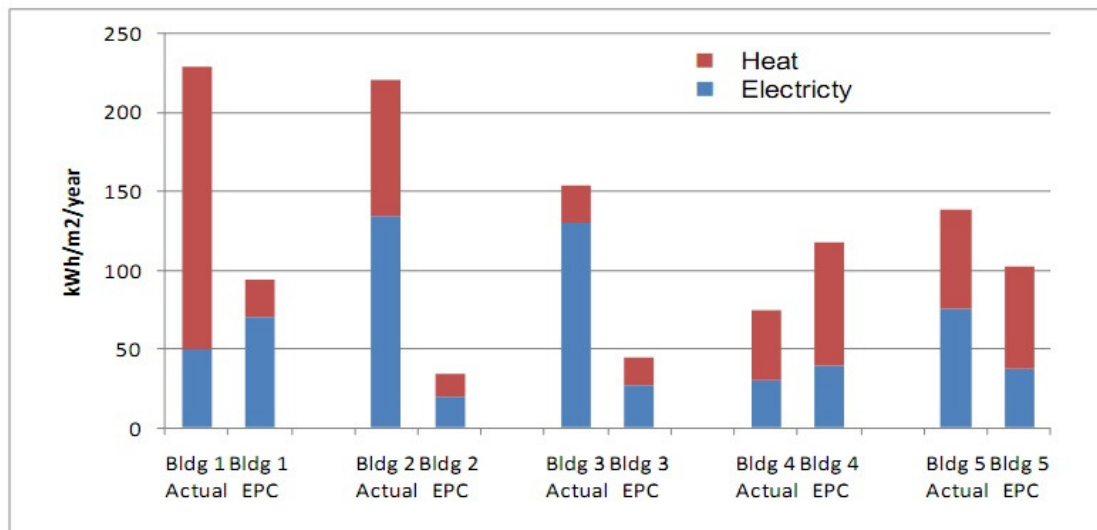


Figure 32 - Comparison of actual building performance vs. EPC rating.

Figure 2. A figure from the Low Carbon Buildings Programme Final Report³⁰ showing comparison of actual building performance versus predicted performance (EPC ratings). For Buildings 1, 2 and 3, the actual energy use is several times higher than predicted.

Sadly, this experience in recent years mirrors experience of the 1990s where several buildings were evaluated during the PROBE studies³¹. A pervasive problem was unnecessarily high – often much higher than specified in design – energy consumption.

As the PROBE buildings, and also those in the LCBP, were considered to be leading-edge and better managed buildings than the average, it can only be concluded that “unnecessarily high energy consumption” of new buildings is a continuing problem that is endemic throughout construction. The PROBE buildings were all non-domestic but this conclusion is reinforced by more recent studies²⁶ of domestic new-build homes that reveal poorer-than-specified fabric energy efficiency.

This poor performance may not have mattered when energy was cheap and energy performance of buildings was anyway poor. The defects that give rise to it would largely have been unseen and unknown. But now it is urgent to improve the energy performance of both new and existing buildings in order to reduce carbon emissions,

³¹ From 1995 to 1998, the PROBE project (**P**ost-occupancy **R**eview **O**f Buildings and their **E**ngineering) undertook and individually published surveys of sixteen recently-completed buildings (seven office buildings, five educational buildings, and four other buildings), together with a range of introductory and overview reports (with four more buildings also studied a little later). A link to all PROBE reports and publications can be found on the Usable Buildings Trust website, <http://www.usablebuildings.co.uk/> (click on Probe). The Usable Buildings Trust was developed in large part as a consequence of the PROBE studies, see <http://www.usablebuildings.co.uk/Pages/Unprotected/UBTWhatDoWeDo.pdf>.

to decrease fuel bills and reduce fuel poverty, and to improve the internal environmentally quality of many buildings.

As we describe in *Refurbishing Europe*⁴ (and above, Section 1.5), any problems in new build will be amplified in refurbishment of the existing stock. Hence it will be impossible to create a low-energy and low-carbon building stock if current practices are followed. Whatever design estimates might predict, experience shows that actual performance will be worse, often several times worse, than predicted (see Figure 2).

This problem of the “performance gap” is discussed in Chapter 4. It is related to and caused by endemic quality issues within the construction industry that have been identified in one report after another commissioned by the UK Government but that apparently remain little changed (Chapter 5). As we show for the Elizabeth Fry Building at UEA below, however, it has been perfectly possible to deliver a low-energy building for no added cost since the early 1990s provided that a quality process is followed.

Sadly, it is no surprise that the Elizabeth Fry Building was the only building in all the PROBE studies that delivered both excellent energy performance and excellent occupant satisfaction at acceptable cost³². Even more sadly, in spite of the wide circulation and promotion of the PROBE findings, little seems to have changed for the better in respect of mainstream construction processes as regards energy-efficient buildings.

Happily, there now exist processes and practices that mirror what was achieved at the University of East Anglia in the early 1990s and that can indeed make successful delivery of low-energy buildings possible at little or no extra capital cost. In particular, the passivhaus standard^{19, 33} defines the energy performance standards that a new low-energy building should aspire to.

Adopting passivhaus principles brings further benefits as well as a low-energy building with an excellent internal environment. Because achieving the passivhaus standard demands a high quality process from start to finish, adopting passivhaus principles can help transform construction processes to become high-quality, just as is now routine in many other industries. The example of the Wolverhampton passivhaus schools we discuss in this report show how this can be achieved in practice.

³² “For example, in the Probe series of post-occupancy studies, only one out of 20 buildings looked at – the Elizabeth Fry Building, University of East Anglia, Norwich, UK – could reasonably be argued to meet all three criteria” [occupant satisfaction and good environmental and energy performance at acceptable cost], *Building evaluation: practice and principles*, Adrian Leaman, Fionn Stevenson and Bill Bordass, Building Research & Information, 38(5), 564-577 (2010).

³³ In English: http://passipedia.passiv.de/passipedia/en/basics/what_is_a_passive_house.

2.6. A low-energy building

A low-energy building is one where fabric energy efficiency is as effective as possible in minimising the energy needed for space heating (and cooling¹¹). Other energy uses are also kept to a minimum⁹. A low-energy building is also one where the design energy use is realised in practice.

As just noted, such design ambition cannot be guaranteed with today's practices in building design and construction. We describe in Chapter 3, with reference to particular projects, how quality can be built into the design and construction processes to guarantee that design energy performance is actually achieved. Such a quality approach is essential if low-energy buildings are to be successfully delivered and greenhouse gas and climate change ambitions are to be met³⁴.

The passivhaus standard³⁵ has, over twenty years, achieved a demanding but level of fabric energy efficiency for new build homes and other buildings whilst also keeping other energy uses to a minimum. Build with CaRe³⁶ has studied passivhaus projects in partner countries, both for new build and refurbishment, and this standard and the quality required to realise it are now widely achievable.

Hence we define a low-energy new building as:

a building that is designed to achieve or to come close to the passivhaus standard and one where passivhaus or similar quality processes are followed³⁷ to ensure that design energy use is realised in practice without compromising occupant comfort and satisfaction.

Not only is the passivhaus standard achievable but achieving it could be a mark of quality that the industry could exhibit with pride³⁸. As Nick Grant, UK Passivhaus

³⁴ All these aspects are reviewed in detail in *Refurbishing Europe*⁴.

³⁵ An introduction to passivhaus and a description of the design, construction and performance of recent new passivhaus homes in the UK is given in *Wimbish Passivhaus: Building Performance Evaluation, Interim Report – March 2012* by Martin Ingham²⁰.

³⁶ See <http://www.buildwithcare.eu/> and links therein. Many examples of passivhaus construction are given on the Build with CaRe web pages.

³⁷ Building to the passivhaus standard defines a high quality process that creates a high probability that performance in practice will be as designed. However, a high quality process does not demand that passivhaus energy targets are always mandatory. The Elizabeth Fry Building at the University of East Anglia in Norwich (opened January 1995 and designed before there was wide awareness of passivhaus technology in the UK), that we discuss below, was designed and built to a quality process that guaranteed a low-energy building. The approach to quality cannot be short-circuited but does not demand any specific definition of energy performance. However, passivhaus is now so well established that it creates a template that is tried and tested in many countries, is straightforward to follow, and can guarantee low-energy performance.

³⁸ The reason why the construction industry in most countries does not promote passivhaus quality more widely can only be surmised but may lie in reluctance to change, ignorance of the benefits of passivhaus, and concern over costs (see Section 2.7). The reluctance of many Governments to specify or enforce more

Trust³⁹ Technical Director and consultant for the Wolverhampton passivhaus schools has said⁴⁰: *“It is great when airtightness is seen as a badge of honour, something to take pride in rather than a compliance hassle.”*

2.7. Why the UK definition of “zero carbon homes” won’t do.

Misplaced concerns and watered-down definition

In the 2009 report by the UK’s Zero Carbon Hub⁴¹ on proposed building fabric energy efficiency standards for new homes (FEES)⁴², Figure 32 illustrated responses to a questionnaire about concerns of negative consequences that might follow from different levels of ambition in terms of fabric energy efficiency (Figure 3 below).

Spec A in the Figure is a modest improvement on the then current practice with increasing level of ambition to Spec D which is equivalent to passivhaus standard. Because of these concerns expressed by the industry and summarised in this Figure, the proposed fabric energy efficiency standard was set by the Zero Carbon Hub at a less demanding level than passivhaus and without a requirement for the quality processes that building to the passivhaus standard demands and that would ensure that energy performance in practice was as predicted in design.

In other words, the fabric energy efficiency standard for new so-called “zero-carbon homes” in 2016 was set according to the concerns of the industry at large in 2009, not according to what might be possible or desirable in 2016. Worse still, a ‘performance gap’ was effectively guaranteed so that the energy performance of “zero-carbon homes” in practice is very likely to be significantly worse even than the relatively undemanding definition proposed⁴² and accepted by Government.

demanding building codes in respect of energy use also means that there is no regulatory driver in many countries forcing change of the magnitude required if building energy use is to be significantly reduced.

³⁹ <http://www.passivhaustrust.org.uk/>.

⁴⁰ Trust’s Technical Director Nick Grant on Passivhaus uptake in the UK, 23 January 2012, <http://www.passivhaustrust.org.uk/news/detail/?nId=64>.

⁴¹ The body set up in the UK to define how “zero-carbon homes” (see Section 2.2) could be defined and developed, see <http://www.zerocarbonhub.org/>.

⁴² *Defining a fabric energy efficiency standard for zero carbon homes, Task Group Recommendations*, Zero Carbon Hub, November 2009, <http://www.zerocarbonhub.org/resourcefiles/ZCH-Defining-A-Fabric-Energy-Efficiency-Standard-Task-Group-Recommendations.pdf>.



Figure 32: Task group Assessment Matrix completed

Figure 3. A schematic illustration of increasing concern about negative consequences by members of the Zero Carbon Hub Task Group as building fabric energy efficiency increases from Spec A (modest improvement on the then current practice) to Spec D (equivalent to passivhaus standard). [Figure 32 in *Defining a fabric energy efficiency standard for zero carbon homes, Task Group Recommendations, Zero Carbon Hub, November 2009*⁴²]

To compound this dilution of fabric energy efficiency, as noted above (Section 2.2), the definition of a UK “zero-carbon home” has been progressively watered down until half the carbon emissions can potentially be offset through market-based mechanisms which means, in practice, that they are unlikely to be offset in real terms at all. In other words, what are now euphemistically called “zero carbon homes” in the UK should really be called now “just about half-way to zero carbon homes”.

Air quality in homes and schools – the benefits of passivhaus

As we note below (Section 2.8) in respect of passivhaus projects now underway in Norwich and Norfolk, the industry is actually able to respond far more rapidly than the Zero Carbon Hub conclusions might indicate. Were the concerns of 2009 (Figure 3), therefore, even justified? We believe not.

It is understandable that there was increased concern for all the aspects highlighted in Figure 3 as the suggested standards for new homes diverged increasingly from those current at the time. However, there was only high concern about “Complexity

of ensuring householder health and wellbeing” and about “Upfront build cost”. These concerns related, in particular, to the use of mechanical ventilation and heat recovery (MVHR) in homes – necessary in very-well-insulated passivhaus homes (*householder health and wellbeing*) – and to build costs for passivhaus homes (*Upfront build cost*).

We now know that these concerns reflected lack of knowledge in 2009 more than reality today in 2012 and are probably quite irrelevant in respect of regulations for 2016 and beyond. We outline the reasons why in turn.

While it is certainly the case that the quality of MVHR installations in the UK gives serious cause for concern – as we discuss below (Section 4.3) – we also know that, where quality practices are followed, as in passivhaus construction, MVHR provides an excellent and high quality internal environment that is appreciated by occupants.

The paper *An investigation into recent proposals for a revised definition of zero carbon homes in the UK*⁴³ notes (Section 6.2) that: *“The vast majority of post occupancy studies concerning Passivhaus dwellings show that consistently high levels of occupant satisfaction and very good IAQ levels are typically reported in dwellings served by whole house MVHR systems. Similar findings have also been confirmed in MVHR ventilated Passivhaus schools, a context characterised by high occupant densities typically necessitating higher rates of ventilation air changes as a result.”*

The benefits of passivhaus schools, including those of air quality, have been described by Bretzke in a paper⁴³ about passivhaus schools in Frankfurt, Germany. Bretzke notes that the improved air quality provided by the MVHR over conventional ventilation means more alert and attentive students and staff alike. A similar result in terms of excellent air quality and internal environment is found in the recently-built passivhaus homes at Wimbish in Essex²⁰. The reasons have been summarised⁴⁴ by Hans Eek of the Swedish Passive House Centre¹. Presentations to Build with CaRe about passivhaus homes in Hamburg, in Schleswig Holstein, and in Sweden all also demonstrate very considerable levels of occupant satisfaction.

Concern over air quality in schools is widespread across many countries and the impact on pupils’ attention and performance has been summarised recently by

⁴³ *Frankfurt: the results from Passivhaus schools*, Prof Axel Bretzke, AECB Conference: *Passivhaus Schools: The Route to Low Energy Schools in the UK?*, 11 December 2009, RIBA, London, http://aecb.net/PDFs/PHS_Conference_09/PHS_AxelBretzke.pdf (link from the conference page at <http://aecb.net/phschools2009.php>).

⁴⁴ *“High build quality and healthy living are assured because quality control in the passive house is so comprehensive throughout the design and building process, with education in basic building physics for the client, consultants and skilled construction workers, and because of the mandatory moisture and air tightness checks during construction. This should be mandatory for all building construction.”*, Hans Eek, Passivhuscentrum Newsletter No 6, February 2010, English language version.

Bakó-Biró et al⁴⁵. Evidence of poor indoor air quality in UK schools has been provided more than once⁴⁶ but there seems little action being taken to address these issues⁴⁷. The recent James Review⁴⁸ about construction and maintenance costs of schools in the UK was perhaps not appraised⁴⁹ of the impairment of pupil attainment in the typical school environment where high CO₂ levels indicate poor indoor air quality with a negative impact on attention and concentration comparable to that of missing breakfast⁵⁰.

We doubt if any review commissioned by Government would recommend that pupils come to school without having eaten breakfast. Yet ignoring the benefits of passivhaus construction for schools would appear to be leading to a policy with

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- ⁴⁵ *Ventilation rates in schools and pupils' performance*, Zs. Bakó-Biró, D.J. Clements-Croome, N. Kochhar, H.B. Awbi and M.J. Williams, *Building and Environment* 48 (2012) 215-223, doi:10.1016/j.buildenv.2011.08.018; the authors conclude that: "The present study strengthens the evidence [previously] reported ... but for a larger sample of schools and for over 200 children, that poor ventilation rates in classrooms significantly impair children's attention and vigilance."
- ⁴⁶ For example, in *Ventilation and Indoor Air Quality in Schools – Guidance Report 202825*, Building Research Technical Report 20/2005, Paul Ajiboye, Martin White, Hilary Graves and David Ross, Building Research Establishment for Office of the Deputy Prime Minister: London, March 2006, (<http://www.communities.gov.uk/documents/planningandbuilding/pdf/144155.pdf>) and *Carbon Dioxide Levels and Ventilation rates in Schools*, Coley, D.A. and Beisteiner, A., *International Journal of Ventilation*, 1(1) 45-52 (2002). Most recently, problems and concerns about naturally ventilated schools have been summarised in *Airing the task ahead*, Ewen Rose, *CIBSE Journal*, January 2012, 25-27.
- ⁴⁷ *A Children's Environment and Health Strategy for the United Kingdom*, Health Protection Agency, March 2009 (http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1237889522947) merely states, Para 4.2.1: "Currently there is a lack of coordinated action to improve indoor air quality". The *National Healthy Schools programme in England* has been disbanded under the guise of "Localism". The *Complete Healthy Schools Toolkit* (<http://www.education.gov.uk/schools/pupilsupport/pastoralcare/a0075278/healthy-schools>) is silent on ventilation and classroom air quality. Classroom ventilation now falls under the aegis of Building Regulations but these can no more guarantee acceptable air quality in use than they can energy performance.
- ⁴⁸ *Review of Education Capital*, Sebastian James, April 2011, <http://media.education.gov.uk/assets/files/pdf/c/review%20of%20education%20capital.pdf>.
- ⁴⁹ All the Review has to say on the environment within schools is (Para 2.7): "there is very little evidence that a school building that goes beyond being fit-for-purpose has the potential to drive educational transformation. The generally held view was that the quality of teachers and leaders has a much greater impact on attainment than the environment."
- ⁵⁰ "Thus, in a classroom where CO₂ levels are high, students are likely to be less attentive and to concentrate less well on what the teacher is saying, which over time may possibly lead to detrimental effects on learning and educational attainment. The size of this decrement is of a similar magnitude to that observed over the course of a morning when students skip breakfast.", The effect of low ventilation rates on the cognitive function of a primary school class, Coley, D.A., Greeves, R and Saxby, B.K., *International Journal of Ventilation*, 6(2), 2007, 107-112.

similar negative outcomes. The current poor state of very many UK schools⁵¹ ought to stimulate a desire to create an environment conducive to learning and alertness. We highlight new passivhaus schools at Wolverhampton in the next Chapter.

Air quality in homes – potential problems with ‘zero-carbon homes’

More generally, experience shows quite clearly that rather than creating problems as in the response “*Complexity of ensuring householder health and wellbeing*” (Figure 3), building new to the passivhaus standard creates improved health and wellbeing whether in homes or in schools. The transformation in quality of design and construction necessary to ensure passivhaus energy standards are met is also necessary to ensure well-installed and operating MVHR (Section 4.3).

The concern about MVHR in 2009 (*Complexity of ensuring householder health and wellbeing*: Figure 3) deflected attention from the real problem which is air quality. The concern seems to have reflected, in reality, awareness about poor quality processes in UK construction and a view that attempting to build to the passivhaus standard - with the consequent need for MVHR - would inevitably create problems because of poor quality MVHR installation and operation. Hence it would be better in the minds of those responding, it would seem, to relax air tightness standards so that MVHR would not be essential. Stick with natural ventilation, avoid the demanding passivhaus standards, and so avoid addressing the quality issues.

Unfortunately, avoiding addressing the quality issues means, as we discuss in this Section, that low-energy homes cannot be reliably delivered. A high quality process would, of course, deliver a properly functioning ventilation and heat recovery system⁵² as is already the case in German passivhaus homes and schools⁴³.

What the Zero Carbon Hub should have been asking was: “*what will happen in practice in “zero carbon homes” after 2016 that will be better insulated and more air-tight than today’s homes but possibly without MVHR*”. Some of the problems that are likely without MVHR, including overheating and poor internal air quality, were summarised in a recent presentation⁵³. In other words, avoiding the construction quality issue does not avoid the potential problem of poor internal air quality. This is almost certain to arise anyway – along with the energy performance gap – without a commitment to transform the quality of construction.

⁵¹ Schools aren't fit for pupils to learn in, warn four in 10 headteachers; Observer poll finds schools are crumbling despite promise by coalition of £2bn for repairs, Jessica Shepherd, The Observer, Sunday 20 May 2012, <http://www.guardian.co.uk/education/2012/may/20/schools-unfit-to-learn-in>.

⁵² See also *Passivhaus ventilation: It's not a lot of hot air*, Mark Siddall for the AECB, 11 April 2012, http://aecb.net/news/wp-content/uploads/2012/04/Indoor-Air-Quality-and-Ventilation-10-04-12_MJS-KdS-51.pdf.

⁵³ *Health & Well Being : Ventilation, Condensation and Internal Air Quality*, Angela Godrich, Notting Hill Housing, presentation at Good Homes Alliance event, *Health and Well-being for Occupants: Ventilation, condensation and Internal Air Quality*, 10 November 2010, <http://www.goodhomes.org.uk/downloads/members/angela-godrich-notting-hill-housing.pdf>.

As in passivhaus schools⁴³, MVHR is essential to provide a high quality environment in well-sealed, well-insulated homes. The problem to be solved is not mechanical ventilation but how to build to high quality. So-called “zero carbon homes” without MVHR will potentially present very major problems with ventilation and internal air quality. The only way to tackle the energy performance gap and also to ensure “householder health and wellbeing” is to tackle the construction quality issues.

The cost of building passivhaus

The supposed increased cost of new passivhaus homes (*Upfront build cost*, Figure 3) likewise reflects the cost premium for uncertainty, or for anything new in the construction industry, rather than any likely reality in 2016. But as building codes in all EU partner countries seem likely to become more demanding, any cost premium for passivhaus will become small or even zero. As we note below, a quality process will avoid the costs of creating and then fixing poor quality which may be several per cent of the cost of many buildings constructed today. It will also deliver a building that works as planned and is liked by its occupants. As supply chains develop, extra costs of items such as passivhaus windows and doors will also drop⁵⁴ and the long-term cost benefits of passivhaus quality will become glaringly evident.

As was noted by the architects of the Wolverhampton passivhaus schools discussed below⁶⁸, “*If you think it costs more it will*”. These schools were delivered to passivhaus standard at no extra cost relative to a ‘typical sustainable school’ and the team had to ensure that unjustified extra costs (the very costs that were reflected in the response shown in Figure 3) were eliminated⁵⁵. Likewise – with effort, thought and teamwork between the architect, the building services engineers, and the consultant, on fabric quality – a design for the Elizabeth Fry Building was created (Sections 3.3 and 3.7) that could be delivered at no extra cost relative to a building that would have been designed and built in a conventional way.

The quality process that delivers a low-energy building also delivers the acceptable cost, whether to the passivhaus standard today, or for the Elizabeth Fry Building fifteen years before. Of course, if passivhaus construction is attempted in a low-quality way, or indeed, if there is an attempt to convert a non-passivhaus design to achieve passivhaus, then it will indeed be expensive because of the unnecessary costs added on (see Section 3.6) and the many mistakes to fix or changes to make

⁵⁴ Slide 13 in Footnote 43 shows even in 2008 an advertisement for a German store offering triple-glazed windows for the price of double-glazed

⁵⁵ Sometimes, a cost comparison for passivhaus relative to a less demanding code is derived by taking a standard design and costing the two options. It is almost inevitable that the passivhaus option will then appear to be more expensive. Without doubt this would have been the case for the Wolverhampton schools had such an approach been taken. What the Wolverhampton example shows is that a passivhaus building must be designed as a passivhaus building so that the benefits of passivhaus can be realised with an appropriate design. As the Wolverhampton team made clear⁶⁸, this means short-term work and effort at the design stage, but the benefits will be long-term over the life of the building.

to achieve the standard⁵⁵. Only poor quality processes or not starting with an appropriate design brief mean high cost.

“Zero-carbon homes” will not satisfy greenhouse gas targets

As noted above (Section 2.2) the original political concept of “zero carbon homes” has led to sub-optimal choices. There is no good reason why homes should be loaded with renewable energy systems in an attempt to create a so-called “zero carbon home” when the fabric efficiency is less than optimal. The concept of the plus-energy house²³ is much more sensible, where, once fabric energy efficiency is optimised, renewable energy options can then be considered (see Section 2.4).

In particular, the concept of the “zero carbon home” has now led to a perverse situation where what is proposed in the UK will, in fact, make it very difficult to achieve greenhouse gas reduction targets. The most compelling reason why a transformation within the construction industry to high quality processes is essential is that the less demanding standards of fabric efficiency such as proposed⁴² by the UK Zero Carbon Hub, and the UK Government, for so-called “zero-carbon homes” cannot deliver the energy saving and greenhouse gas emissions reductions that are essential⁵⁶.

As the paper, *An investigation into recent proposals for a revised definition of zero carbon homes in the UK* notes¹³:

“Achieving CO₂ emission cuts of 80–90% from the total stock by 2050 represents an enormous technological and logistical challenge. ... It is evident therefore that any new buildings will need to go well beyond operational zero carbon in order make a positive contribution to reducing net GHG emissions over the 1990s baseline. ... Viewed on a meta scale, recent modelling by the Department of Energy and Climate Change (DECC) illustrates that the implementation of an advanced energy efficiency standard (such as the Passivhaus standard – Level 4) is the only approach that leads to a long term reduction in the total domestic heating demand.” The authors are saying that only passivhaus standards can enable the energy demand reductions that are needed.

Without adoption of passivhaus standards, the situation in practice will, in fact, be even worse than this analysis suggests because it does not take into account the energy ‘performance gap’ (Chapter 4). Because of the performance gap that will inevitably arise for both new build and refurbished stock unless quality processes are put in place, the actual gap between what would be achieved and what is necessary will be considerably greater even than these authors suggest. Hence moving to the passivhaus standard for new build, and adopting the construction quality standards that underpin this, is even more urgent than they describe.

⁵⁶ The issues concerning global greenhouse gas emissions and the urgency of action to reduce them are discussed in detail in *Refurbishing Europe*⁴.

The authors note¹³ that: *“Over the past two decades more than 30,000 Passivhaus buildings have been successfully constructed across continental Europe, demonstrating that such a standard could be practically implemented as a template for a more robust UK zero carbon policy.”* The examples in this paper confirm this statement. The passivhaus standard and passivhaus quality are eminently achievable as new examples in Norwich show.

2.8. Passivhaus in practice

Is the passivhaus standard as practical to implement as these authors suggest¹³? One recent example – apart from that of the Wolverhampton passivhaus schools discussed in Section 3 – suggests that it should be and that concern over costs is misplaced.

In November 2009 – just as the Zero Carbon Hub’s recommendations on fabric energy efficiency standards for “zero-carbon homes” (Footnote 42) were published – an executive of Broadland Housing Group in Norwich attended a Build with CaRe conference in Oldenburg, Germany⁵⁷, and heard about and saw passivhaus quality for the first time. Broadland Housing Group realised that passivhaus was the way forward for energy efficient homes that could provide high-quality, cost-effective environments for tenants. Broadland Housing has, in the succeeding two years, created a quality process for delivering passivhaus new homes.

The UK’s largest passivhaus project, over two hundred new apartments at Carrow Road, Norwich, has now received provisional planning permission and should begin construction early in 2013. A description of this and other on-going Broadland Housing passivhaus projects was given⁵⁸ by Andrew Savage, Executive Director, Business Growth, for Broadland Housing Group, at the Build with CaRe seminar in Brussels, 7 March, 2012.

Not only does Broadland Housing now have several passivhaus projects in the pipeline but funding for the Carrow Road project is planned to come from private institutional investors⁵⁹, demonstrating the long-term financial value implicit in passivhaus construction⁶⁰ in addition to the energy and environmental benefits.

⁵⁷ The conference is reviewed at <http://www.buildwithcare.eu/articles/66-conferences/142-annual-conference-2009>.

⁵⁸ See <http://www.buildwithcare.eu/news/235-seminar-in-brussels> for links to all the presentations. Download the Broadland Housing presentation, *Transnational learning – the confidence to make a change* from http://www.buildwithcare.eu/images/pdfs/bwc_andrew_savage_120307.pdf.

⁵⁹ *Bid to build UK’s largest Passivhaus scheme*, Tom Lloyd, Inside Housing, 9 March 2012, <http://www.insidehousing.co.uk/ihstory.aspx?storycode=6520823>.

⁶⁰ For example, no central heating system to install or maintain, and very low heating costs hence more reliable rent income.

The Wimbish passivhaus scheme in Essex by Hastoe Housing Association²⁰ demonstrates that passivhaus homes can be built in the UK, that they work, and that they provide outstanding quality for occupants. The Broadland Housing experience demonstrates that any organisation with the desire to provide a quality home can proceed with passivhaus in very little time to create long-term financial benefit and incurring only modest, if any, additional up-front cost.

As awareness of passivhaus becomes more widespread, adoption of the passivhaus standard can become the default standard for new homes across the EU if Member State Governments require it. As just discussed, this has indeed to happen if energy and climate change targets are to be met. It will, in addition, create major health and well-being benefits.

Refurbishment too

As already noted (Section 1.5), quality issues and the 'performance gap' will be at least as serious, if not more so, for building refurbishment as for new build. Similar quality standards based on passivhaus principles will also be essential for building refurbishment aimed at improving energy performance if the necessary energy and carbon savings in refurbishment are actually to be achieved. Not all building refurbishment projects will aim for the very demanding passivhaus standard⁷ but the quality process discussed in Chapter 3 can be followed whatever the actual energy efficiency saving targeted. The platform for quality that is essential if the massive programme of building refurbishment to low-energy standards across the EU⁶¹ is to be satisfactorily undertaken must be the development of skills and supply chains in a rapidly expanding passivhaus new build programme.

The transformation that can be achieved in existing poor-quality housing is shown in the thermal image (Figure 4) taken on a cold January day in 2012 of a London home, refurbished using passivhaus principles, showing minimal heat loss compared to its untreated neighbours.

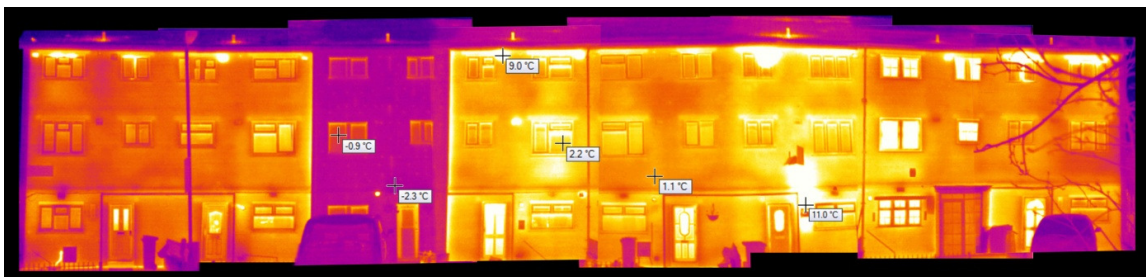


Figure 4. Thermal image of a 1950s or 60s terrace house in London refurbished using passivhaus components showing minimal heat loss on a cold day in January 2012 compared to the neighbouring homes on either side; copyright here:architects.

⁶¹ Discussed in detail in *Refurbishing Europe*⁴.

3. Delivering a low-energy building in practice

“Overall FRY [the Elizabeth Fry Building] presents the best example yet of virtuous processes with careful briefing, team selection, design, construction, commissioning, monitoring and operation leading to unusually high levels of satisfaction, together with low energy consumption.”

*“It is often claimed that new buildings are but a drop in the ocean, with annual output representing no more than 1% of the total stock. However, it is clear that in the next century major improvements in energy performance will be essential; and if our new buildings are part of the problem and not the solution, this will be a massive lost opportunity. **Many issues exposed in Probe are also equally applicable to the alteration, refurbishment and management of existing buildings; and to the equipment used in them.** It is also timely to link such issues to the Egan focus on improving the building industry’s performance and cost-effectiveness.”*

PROBE Strategic Review 1999, Final Report 2: Technical Review, Bill Bordass, Robert Cohen and Mark Standeven, <http://www.usablebuildings.co.uk/Probe/ProbePDFs/SR2.pdf>.

The PROBE studies³¹ in the 1990s clearly identified the key processes that need to be followed in order to deliver a low-energy building. The PROBE study authors, as the quote in the box above makes clear, also realised the importance of creating the right quality structure within construction to enable not just the successful delivery of new low-energy buildings but also effective low-energy refurbishment of existing buildings. Their reference to Egan is a link to the necessary quality processes.

The Egan report, *Rethinking Construction*¹⁵⁹, published in 1998, was highly critical of quality processes within the construction industry. As we have noted in Chapter 2, these concerns, expressed fourteen years ago, have not gone away. Now, however, a transformation to a high quality construction regime is essential if successful delivery of low-energy buildings, either new or refurbished, is to be achieved.

In following Chapters we provide more detail on the energy performance gap including reference to the PROBE findings on non-domestic buildings (Section 4.1) and about how the concerns identified in PROBE still remain (with reference to West Suffolk House from the UK LCBP (Low Carbon Building Programme³⁰)).

We outline (Chapter 5) the quality concerns identified in *Rethinking Construction*¹⁵⁹ (the Egan Report) that underlie the problems observed in PROBE and that remain to this day. In particular, the problems identified by Egan underlie worries about the performance gap of new homes, currently gaining the attention of the Zero Carbon Hub (Section 4.2), and about the installation and performance of MVHR (mechanical ventilation with heat recovery) systems (Section 4.3).

In this Chapter we outline key process steps necessary to deliver a low-energy building with particular reference to two well-documented examples, the Elizabeth Fry Building at the University of East Anglia¹⁰³, opened in 1995, and passivhaus schools recently constructed at Wolverhampton in the UK⁶⁸. These examples demonstrate that the teamwork and radical transformation of quality, called for by Egan and achieved by the auto industry in the 1980s⁶², are indeed possible and have been achieved in practice in construction. Now they must become the common-place if the targets⁶³ for low-energy construction and greenhouse gas reduction are to be achieved.

As we have noted already in Chapter 2, adoption of passivhaus standards for new build is essential if the reductions in greenhouse gas emissions from the building stock, needed to achieve climate change targets, are to be achieved. Passivhaus quality standards are also essential if design energy performance is to be achieved in refurbishment. Hence passivhaus quality and standards provide the benchmark for guaranteed and successful delivery of low-energy buildings.

3.1. Getting it right

Getting it right: Robust buildings

- *Get the brief right, based on practical insight.*
- *Get the standards right: avoid mission creep.*
- *Get the fabric right: passive measures.*
- *Get the services right: gentle engineering.*
- *Get the other things right: ICT, catering etc..*
- *Get the controls right; and their user interfaces.*
- *Get it built right; with a suitable procurement path.*
- *Get it finished right: commissioning, operator and user engagement, handover, aftercare.*
- *Get it operated and used right, information, training, monitoring and review, troubleshooting and fine tuning.*
- *Keep it up to the mark, monitoring, feedback and continuous improvement.*
- *Don't make it too difficult and expensive to look after.*

Building services: avoiding unnecessary energy demand and use through careful design and operation, Bill Bordass, Passivhaus schools conference, RIBA, 11 December 2009, http://www.aecb.net/PDFs/PHS_Conference_09/PHS_BillBordass.pdf.

Figure 5. Getting it right – creating robust buildings – evidence from the PROBE studies.

⁶² Discussed in more detail in Section 8 of *Refurbishing Europe*⁴.

⁶³ See Sections 3 and 8 in *Refurbishing Europe*⁴

The PROBE studies³¹ of the 1990s provided the evidence base. This has been summarised by Bill Bordass of the PROBE team as shown in Figure 5 above.

What does all this mean in practice? Experience from the Elizabeth Fry Building and from the Wolverhampton passivhaus schools highlights seven key aspects to ensuring a high-quality, low-energy building.

- **The brief must be clear and appropriate**
- **Innovation may be necessary but building operation must be simple**
- **Modelling of building performance is essential**
- **Teamwork throughout is essential**
- **Design must be finalised before construction begins**
- **Attention to construction detailing is essential**
- **Post-construction evaluation is essential**

We discuss these aspects in turn with particular reference to the Elizabeth Fry Building⁶⁴ and to the Wolverhampton passivhaus schools.

3.2. The brief must be clear and appropriate

For a domestic property, the brief might be quite simple as for the passivhaus homes at Wimbish²⁰: “achieve passivhaus”⁶⁵. For a larger and more complex building such as the Elizabeth Fry Building at UEA, with three lecture theatres and many offices and seminar rooms, the brief must be more detailed.

The client for the Elizabeth Fry Building at UEA, Peter Yorke of the UEA Estates Office, and the architect, Richard Brearley⁹⁹, wrote⁶⁶: *“The brief for the Elizabeth Fry Building was written in 1992. It required the new building to be extremely good value for money both in capital and running costs. Although the building was to demonstrate low-energy design principles, it was not to cost more than more orthodox approaches. ... When we analyzed the brief it became evident that the building could house at any one time a population of around 800 people in an internal floor area of about 3000m². With these numbers heat gains and adequate*

⁶⁴ We emphasise again that it was the high quality approach from initial design through construction to post-construction evaluation that was the platform for the success of the Elizabeth Fry Building. This was not designed quite to meet passivhaus energy and air-tightness standards, but, in the two decades since the Elizabeth Fry Building was conceived, passivhaus standards have now been shown to be eminently achievable for new build homes and other buildings. Hence we refer quite generally to passivhaus quality.

⁶⁵ From discussion with the architects, Parsons and Whittle, <http://www.parsonswhittle.co.uk/>. Of course, the design brief would have been more detailed in terms of living space, outward appearance, and so forth.

⁶⁶ *Elizabeth Fry Building, University of East Anglia, Norwich*, Peter Yorke and Richard Brearley, Chapter 13 (pp112-119) in *Green Buildings Pay*, Editor Brian Edwards, E & FN Spon, London (1998).

*ventilation in the summer were identified as critical items which had to be addressed.*⁶⁷

There must likewise be close engagement between client and the design and build teams for a new school. This was described⁶⁸ at the UK Passivhaus Trust Conference, 24 October 2011, for the two new passivhaus primary schools in Wolverhampton for the City Council, by Jonathan Hines of the architects Architype⁶⁹, by Nick Grant of the passivhaus consultant Elemental Solutions⁷⁰, and by Matt Wisdom of the contractors Thomas Vale Construction⁷¹. The team had already built a low-energy school in Wolverhampton (not quite to passivhaus standard) that had been monitored for two years, had performed well, and had been an attractive focus in its neighbourhood. It was noted in the presentation that the quality of space, and the environment created through the use of natural materials, in the earlier school provided a calm, uplifting atmosphere.

During the project, as at UEA for the Elizabeth Fry Building, there was close cooperation with the client and also (at Wolverhampton) the involvement of pupils. The one absolute condition imposed on the team was that the schools designed to the passivhaus standard should cost no more than schools designed and built in a conventional way. This condition was met, so showing that the supposed increased costs of passivhaus construction that concern much of the industry (Figure 3 and Section 2.7) need not be a problem after all – as long as the work is done to create an appropriate design^{55, 72} and construction is undertaken to high quality as discussed below.

⁶⁷ Separately, Peter Yorke has written: “Getting the first 1% of any project right – which means writing at least an outline brief, commissioning the design team and thinking about feasibility and success – is a demanding task but crucial to success. ... A good brief, written by an informed client, is a major determinant of the success of the project, for it ensures that both client and architect know what they are together setting out to achieve. ... If your architects do not get a strong statement of your objectives, they do not really know what it is that you want.” in *A View from the Estates Office*, pp34-38 in *Design Quality in Higher Education Buildings: Royal Fine Art Commission Seminar*, 21 November 1995, Thomas Telford (1996).

⁶⁸ *Designing and delivering the Wolverhampton passivhaus schools at no extra cost*, video of presentation at <http://www.youtube.com/watch?v=MffKNX5qLLw&feature=plcp&context=C23be7UDOEgsToPDskIbKR26JoGTqORZd-9ICJA> (link from http://www.passivhaustrust.org.uk/videos_and_downloads.php) and slides at <http://ukpassivhausconference.org.uk/sites/default/files/WolverhamptonSchoolsPresentation%20231011.ppt%20%5BCompatibility%20Mode%5D.pdf>.

⁶⁹ <http://www.architype.co.uk/>.

⁷⁰ <http://www.elementalsolutions.co.uk/>.

⁷¹ <http://www.thomasvale.com/>.

⁷² The key point made by the Wolverhampton Schools team is that good design keeps things simple and hence keeps costs down. A very similar attitude was evident in the design of the Elizabeth Fry Building. In both cases the design teams worked very hard to find design solutions that would fit the clients’ needs while keeping costs under control. Simplicity is a key aspect of low-energy buildings and is emphasised throughout this paper; see, in particular Section 3.3, sub-heading *Keep it simple and do it well*.

The additional benefits of good low-energy design

Indeed, there is now a joint venture between Architype and Thomas Vale Construction to deliver passivhaus projects, in particular new schools⁷³. The press release notes that: *“...the partnership has just completed the UK’s first ever Passivhaus standard accredited primary schools for Wolverhampton City Council, at zero additional capital cost to that of traditional construction techniques and the so-called ‘standardised schools’ concepts.”* The press release goes on to highlight the rewarding educational opportunities of passivhaus design compared to so-called ‘standardised schools’. These benefits are in addition to radically low energy consumption and optimised comfort and air quality for the occupants (Section 2.7), both teachers and pupils⁴³.

These additional benefits of low-energy buildings do not just apply to schools.

As we note below for the Elizabeth Fry Building, good design created not only a building with outstanding energy efficiency but also one that scored highest of all buildings for occupant comfort. The quote at the front of this report summarises this perception: *“EFry is one of the rare buildings where users give it unprompted praise – ‘I love it. It combines a sense of tranquillity with aesthetic delight’”*.

The comments by occupants of the new passivhaus homes at Wimbish in Essex, also at the front of this report, convey a similar delight: *“The houses are so light and spacious”* and *“I’m less stressed. Having a lovely house we are proud of, and look forward to coming home to, is benefitting all of us”*.

The quality of design needed to achieve a low-energy building will indeed also create a building that is enjoyable to live and to work in. This combination of benefits should be compelling both for homeowners and tenants, and, in a non-domestic setting, for businesses. The gains in perceived productivity in low-energy buildings (and negative perceptions in many buildings that did not perform to their design specification) appear to provide very significant financial benefits (or losses) - see Chapter 6 below.

3.3. Innovation may be necessary but building operation must be simple

The issues of summer heat gain and ventilation raised in the brief for the Elizabeth Fry Building were serious. The University, aware of potential cost and of concerns about ‘sick building syndrome’, was adamant that air conditioning was not to be employed. Thermal mass was chosen as the preferred means of satisfying the demand from the University that the building should demonstrate low-energy design principles, but modelling showed that thermal mass alone would be unable to cool

⁷³ Thomas Vale/Architype JV first to deliver Passivhaus Partnership, 5 January 2012, <http://www.thomasvale.com/news-media/press-releases/january-2012/09012012-thomas-valearchitype-jv-first-to-deliver-passivhaus-partnership.html>.

the building in summer. This dilemma led to an innovative solution, proposed by the building services engineers, Fulcrum⁷⁴, the use of the Swedish Termodeck⁷⁵ system⁷⁶.

The Elizabeth Fry Building was only the second Termodeck building to be built in the UK so, in one sense, there was considerable risk. But UEA staff were taken to Sweden to hear from occupants of Termodeck buildings before the final decision was made and the behaviour of the building was modelled with help from Sweden to ensure that thermal performance would be adequate.

Good teamwork between all parties, including the contractor, Willmott Dixon⁷⁷, ensured that the use of Termodeck to assist ventilation and temperature control was successfully achieved. While more expensive than conventional construction, the lack of any need for a conventional radiator-based heating system reduced costs (just as it does for passivhaus) enabling total costs to be kept down to no more than for a conventional construction approach.

Innovation in design is not just the use of new technology as with Termodeck at UEA. The presentation on the Wolverhampton schools noted the constant focus on simplicity of design and detailing and a relentless focus on optimising and improving design to achieve cost targets. While not necessarily innovation in the sense of introducing quite new technologies or materials, this attention to detail at every point of the design to ensure compliance both with passivhaus standards and also with the cost limits is innovative in comparison to conventional approaches to design and construction. This focus on appropriate design⁵⁵ mirrored what was done in the design of the Elizabeth Fry Building and is key to creating a building that is simple to operate and well-liked by occupants as well as being low-energy in operation.

Bill Bordass of the Usable Buildings Trust³¹ has described⁷⁸ how, through good design, the impact of the multiplier effect can enable very large reductions in energy

⁷⁴ Led by Andy Ford, now Technical Director for buildings and infrastructure, Mott MacDonald Fulcrum, <http://www.buildings.mottmac.com/aboutus/>.

⁷⁵ <http://www.strangbetong.se/koncept-komponenter/koncept/termodeck/> and http://www.tarmacbuildingproducts.co.uk/products_and_services/termodeck.aspx.

⁷⁶ Termodeck, and its use in the Elizabeth Fry Building and subsequently in several further buildings at the University of East Anglia, has been described in the Build with CaRe report *Low Energy Buildings, UEA*, by Martin Ingham, October 2010, http://www.buildwithcare.eu/images/pdfs/first_page_downloads/uea_low_energy_buildings-bwc-oct2010.pdf. More detail is given in the Build with CaRe report on UEA's most recent Termodeck building: *Thomas Paine Study Centre: How it works*, by Martin Ingham, March 2012, http://www.buildwithcare.eu/images/pdfs/tpsc_how_it_works_march_2012.pdf, link from <http://www.buildwithcare.eu/articles/78-partners/236-how-to-capture-energy-use-data-for-large-buildings>.

⁷⁷ <http://www.willmottdixongroup.co.uk/>.

⁷⁸ *Building services: avoiding unnecessary energy demand and use through careful design and operation*, Bill Bordass, Passivhaus schools conference, RIBA, 11 December 2009, http://www.aecb.net/PDFs/PHS_Conference_09/PHS_BillBordass.pdf.

use – six-fold or more - for example for lighting and for MVHR. This is the kind of innovation through attention to detail that is necessary to meet the passivhaus standard⁷⁹. It also creates a very high quality building that is simple to operate and well-liked by those living or working in it.

Thus the Elizabeth Fry Building scored highest of all buildings on the Building Use Studies Comfort Index database⁸⁰ during the PROBE investigations³¹ (Figure 6) while having the minimum specific annual gas use of all the PROBE buildings (Figure 7). Indeed, the score for overall comfort in summer was higher than in winter showing the success of the team's efforts to deal with the challenge of potential summer overheating.

Figure 6.1 Comfort index showing Probe buildings and BUS dataset

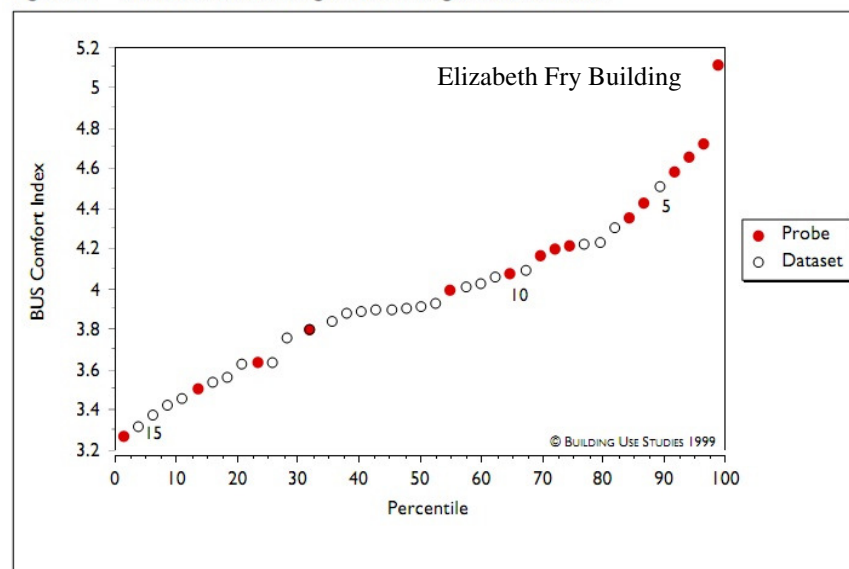


Figure 6. The BUS Comfort Index database in 1999 showing the PROBE buildings in red; the Elizabeth Fry Building scores by far the highest of all buildings then on the database (the comfort index combines scores for summer and winter temperatures, air quality, lighting, noise and overall comfort). Source: *PROBE Strategic Review 1999, Final Report 4: Strategic Conclusions*, Bill Bordass, Adrian Leaman and Paul Ruysevelt, <http://www.usablebuildings.co.uk/Probe/ProbePDFs/SR4.pdf>.

⁷⁹ Such attention to reducing unnecessary energy use – in effect to reducing waste – is standard practice in other industries but not yet widely so in construction. A quotation from Shigeo Shingo in describing the approach of Toyota and other firms in the automotive sector was our heading of Section 8, *Energy as Waste*, in *Refurbishing Europe*⁴: “Many people settle for eliminating the waste that everyone recognises as waste. But much remains that simply has not yet been recognized as waste or that people are willing to tolerate.”, Shigeo Shingo in *Study of the Toyota Production System from an Industrial Engineering Standpoint*, translated by Andrew P Dillon (Productivity Press, 1989; originally published by Nikkan Kogyo Shimbum Ltd, Tokyo 1980). In construction, waste of energy is tolerated in many areas as described by Bordass⁷⁸.

⁸⁰ See <http://www.usablebuildings.co.uk/WebGuidePDFs/BUSFlyers.pdf>.

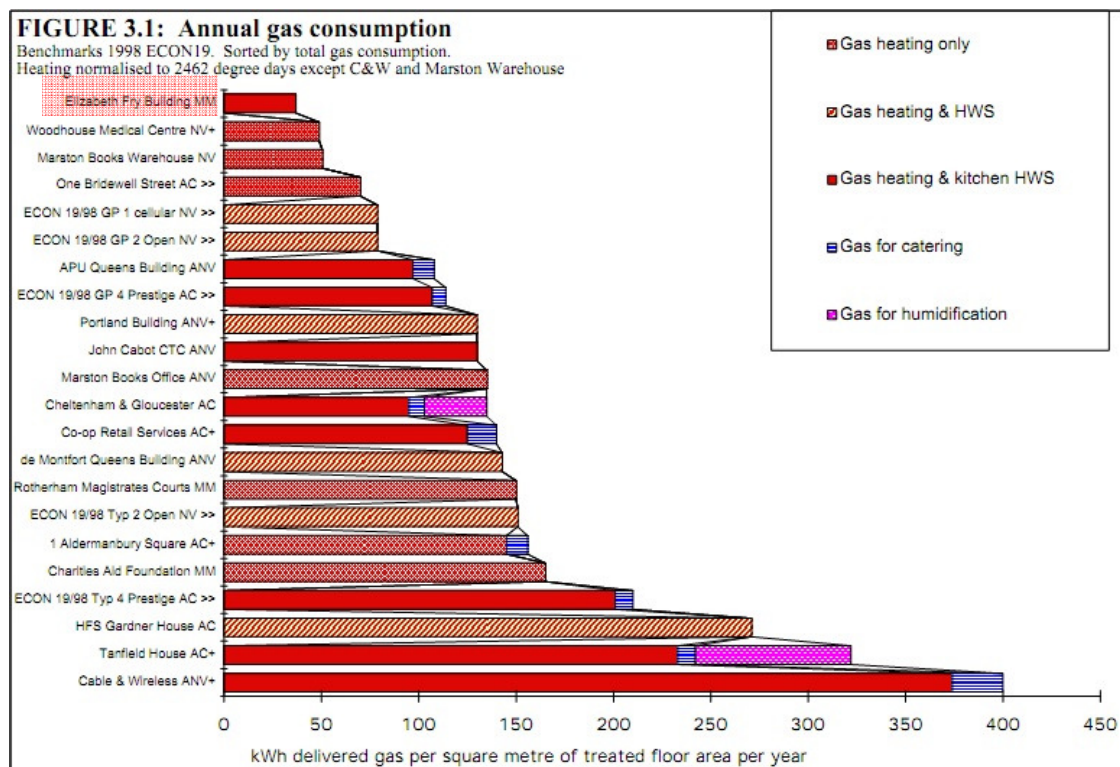


Figure 7. Annual gas consumption per m² for the PROBE buildings. All the buildings use gas for heating. The Elizabeth Fry Building has the lowest gas use of all the buildings although it used gas for hot water and in the kitchen as well as for heating. Source: *PROBE Strategic Review 1999, Final Report 2: Technical Review*, Bill Bordass, Robert Cohen and Mark Standeven, <http://www.usablebuildings.co.uk/Probe/ProbePDFs/SR2.pdf>.

Innovation requires teamwork

The Box at the head of this Section notes the conclusion of the PROBE team⁸¹ that: *“Overall FRY [the Elizabeth Fry Building] presents the best example yet of virtuous processes with careful briefing, team selection, design, construction, commissioning, monitoring and operation leading to unusually high levels of satisfaction, together with low energy consumption.”*

But the innovation that enabled the successful design and construction of both the Elizabeth Fry Building and the Wolverhampton passivhaus schools required teamwork of a nature not normal within the industry. As the PROBE Technical

⁸¹ *PROBE Strategic Review 1999, Final Report 2: Technical Review*, Bill Bordass, Robert Cohen and Mark Standeven, <http://www.usablebuildings.co.uk/Probe/ProbePDFs/SR2.pdf>.

Review noted⁸¹: *“Outsourced contractors (and presumably the contracts they were working to) also seemed to be more likely to maintain the status quo than to question and improve it”*. In other words, the industry preference for sub-contracting – that is still pervasive (see Chapter 5) – was likely to inhibit the kind of innovation necessary to achieve a low-energy building and was a probable contributory cause to the persistent problems identified with many buildings within the PROBE studies.

In contrast, the PROBE Strategic Review noted⁸¹ that the excellent outcomes for the Elizabeth Fry Building occurred where: *“a committed client and a design team which had worked with them before were able to make thoughtful and responsible innovations, to take advice where necessary, and to deliver - via a committed contractor - an attractive, comfortable and energy-efficient building at normal cost levels.”*

Note the emphasis on *“thoughtful and responsible innovations”*. Elsewhere in this PROBE Strategic Review⁸¹ the authors highlighted some persistent problems including: *“Often too much complication, leading to technical problems, unintended consequences, and difficulties for management. “Keep it simple and do it well” is a strong message.”*

Keep it simple and do it well

“Keep it simple and do it well” is a strong message. The point is that innovation and technology must make a building easy to operate and to manage if it is to be useful and successful. Or as one of the authors of the PROBE Strategic Review has recently noted⁸²: *“Unmanageable complication is the enemy of good performance. So why are we making buildings technically and bureaucratically complicated in the name of sustainability, when we can’t get the simple things right?”*

The *“thoughtful and responsible”* use of Termodeck in the Elizabeth Fry Building enabled the design and construction of a building that could be managed by the University’s facilities management team to give excellent performance (once an effective building management system was in place – see Section 3.8 below). This success contrasts with the *“technical and bureaucratic complication”* that the PROBE study authors noted so often and which is still making so many buildings difficult if not impossible to manage well⁸³.

⁸² What works, what doesn’t work, and how we can fix it: Using Building Performance Evaluation (BPE) for rapid improvement, Bill Bordass, Presentation to Institute for Sustainability and FLASH+, Building confidence in low-carbon solutions, 27 September 2011, <http://www.usablebuildings.co.uk/Pages/UBEvents/UBEventsIfS27Sep11.html>.

⁸³ Several examples of current problems in building management and operation from UK schools are provided in *Work in Progress*, Judit Kimpian and Esfandiar Burman, CIBSE Journal, March 2012, pp39-44. For example: *“In the case of automated high-level openings, cheaper actuators are frequently chosen – and these can jam. In other cases the infrared security sensors were found to be triggered by insects or even air movement. After a few incidents like this the automated night-time ventilation gets turned off.”* And: *“When it comes to control of heating, cooling and ventilation, the biggest culprits are building management systems*

Construction to passivhaus quality emphasises this focus on simplicity because the excellence of the fabric minimises the need for ancillary technology. As Nick Grant, passivhaus consultant on the Wolverhampton schools⁶⁸ has said⁴⁰: *“Keep it simple has always been my mantra and this is crucial if you want to build a genuinely low energy building such as a Passivhaus.”*

A cartoon shown in the presentation⁶⁸ about the schools illustrates this focus on simplicity (Figure 8). A passivhaus building is smart, not because of all the technology that can go wrong or can be ignored, misused or abused, but because the need for such technology has been designed out. Only an MVHR system is required to provide the outstanding internal air quality. The innovation comes in the thought required to establish a design that will both comply with the passivhaus standards and also minimise cost.

It is easy to imagine that so-called ‘smart buildings’ that incorporate a great deal of technology will make successful low-energy building management straightforward. The evidence to date indicates exactly the opposite. Buildings that are designed to be simple to operate with the minimum of technology seem to be those that perform most reliably and effectively.

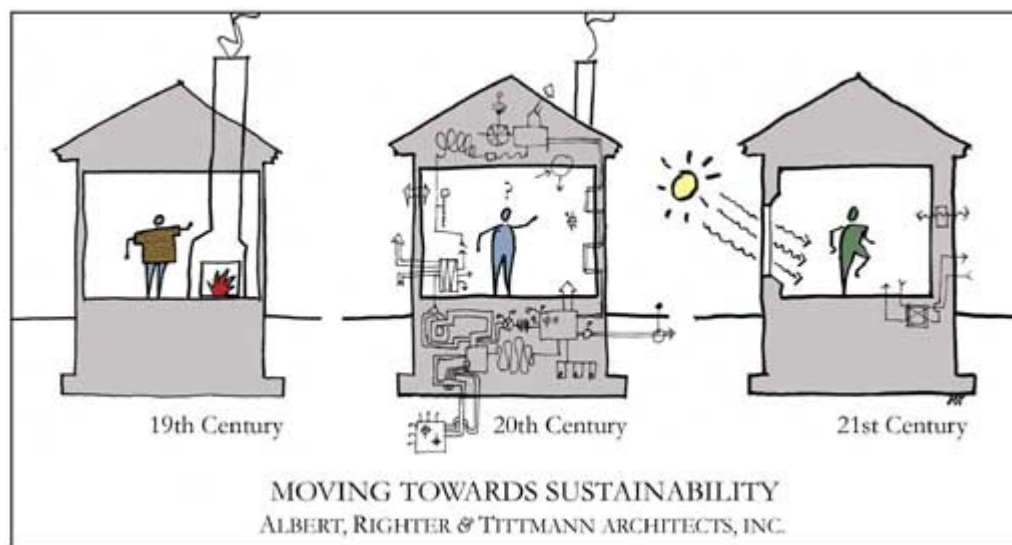


Figure 8. A schematic illustration – shown in the presentation about the Wolverhampton passivhaus schools⁶⁸ - of how passivhaus construction enables movement towards sustainability with increasing simplicity. The original is at <http://www.alriti.com/sustainability/index.php>.

(BMS) and commissioning. The frustration with BMS in schools is so great that Roundtable participants wanted to design them out altogether. Finding a building with a well-run system, where main and sub-meters are measuring what they were intended to and are hooked up to the BMS is a rarity.”

3.4. Modelling of building performance is essential

The thermal performance of the Elizabeth Fry Building was modelled – by the inventor of Termodeck, Loa Andersson – before construction in order to ensure that internal temperatures could be maintained at acceptable levels even on hot summer days. The occupant survey results (Figure 6) are testament to the success of this strategy.

A key aspect of passivhaus quality is the energy modelling to ensure that the passivhaus limits of energy use can be achieved. The thermal modelling software package, PHPP, PassivHaus Planning Package⁸⁴ is used for this purpose. Not only must design attention be paid to heating in winter but also, as for the Elizabeth Fry Building, to ensuring that over-heating does not occur in summer.

Attention to detail in the design of the Wolverhampton passivhaus schools has been described in the presentation⁶⁸ where the attention paid, for example, to the kitchen, to the reduction of heat losses in pipe runs, to the impact of energy use for computers and other technology, and to ensuring the availability of easy-to-use secure night ventilation are noted. Also noted was the need for detailed drawings for areas where defects could pose particular problems, for example corners. An outline description of the design and modelling process for Hastoe Housing Association's new passivhaus homes at Wimbish in Essex is given in the Interim Report²⁰.

Modelling to this level of detail was not deemed necessary for buildings that were not designed to be energy efficient. Many overheat anyway. Without it, however, energy-efficient buildings cannot be effectively designed. Whatever the aspiration, without detailed modelling, there will almost certainly be either excess energy used for heating in winter or over-heating in summer, and, most likely, both outcomes.

3.5. Teamwork throughout is essential

The Egan Report¹⁵⁹, noted at the start of this Section, identified the lack of teamwork in construction in the UK as a major brake on innovation and quality: *"The experience of Task Force members is unequivocally that quality will not improve and costs will not reduce until the industry educates its workforce not only in the skills required but in the culture of teamwork."*

As noted in Section 2, the problems highlighted by PROBE, in particular the unnecessarily high energy consumption of many buildings, exacerbated by the high levels of air infiltration often measured, still remain problems today, both for domestic and non-domestic buildings. One principal cause of these problems already noted (Section 3.3, Heading: *Innovation requires teamwork*) identified by PROBE⁸¹, seems to be the sub-contracting culture and the lack of teamworking this

⁸⁴ http://passipedia.passiv.de/passipedia_en/planning/calculating_energy_efficiency/phpp_-_the_passive_house_planning_package.

can cause, resulting in a lack of attention to detail. The inevitable consequence is problems, whether in technology that does not work well, in poor living or working environments, or in inadequate finishing and consequent air leakage that lead to high energy use for heating.

As we note below in Chapter 5, all the issues raised by the Zero Carbon Hub as potentially causing the worrying energy ‘performance gap’ could be solved if the culture of teamwork, essential in building to the passivhaus standard as at the Wolverhampton schools, or as practised in the design and construction of the Elizabeth Fry Building, were to be adopted. As these two examples highlighted, doing things differently but better yields higher quality and user satisfaction with no added cost.

The fact that, in spite of the extensive documentation about Elizabeth Fry in several PROBE reports, such teamworking seems as atypical today as it was in the 1990s, seems to indicate the presence of deep-seated issues within the construction industry that militate against the successful delivery of low-energy buildings.

From conversations we have had with individuals within the industry as part of Build with CaRe (see Chapter 5), it would seem that it is normal practice to push risk down the chain to sub-contractors. Within the adversarial culture generally current in the industry, it is then impossible to create the teamwork that is essential to ensure the high quality that will guarantee delivery of a low-energy building. Such issues have been explicitly raised in discussion about the many problems presently observed with MVHR installations (Section 4.3).

In such settings that currently prevail, there is likely to be extensive substitution of materials or components in pursuit of cost cutting⁸⁵, and sequencing will be done for convenience rather than to ensure quality. There will be little teamwork between the architect and M&E contractors, leading inevitably to the kinds of problems presently apparent in MVHR installations (Section 4.3). RIBA Work Stages⁸⁶ may appear to provide a coherent platform for achieving ultimate quality but the evidence from the studies quoted in this report seems to be that the outcomes do not match the intent.

Design and Build contracts are common-place and are presumed to help reduce costs of construction. However, the architect is frequently then novated to the contractor rather than working directly for the client. The principle may be good but the practice may limit the teamwork necessary to develop a high quality design.

One advantage of design and build is claimed to be that work on site can begin even before the final design is complete⁸⁸ because of the level of control vested in the

⁸⁵ For example⁸³: “In the case of automated high-level openings, cheaper actuators are frequently chosen – and these can jam.” In the development of the design of the Wolverhampton passivhaus schools, there was a focus on bringing down cost but, unlike the example of cheaper actuators, this was not at the expense of endangering performance. In contrast to value engineering that creates problems, the value engineering in passivhaus design simplifies design and makes performance more robust.

⁸⁶ [http://www.architecture.com/Files/RIBAProfessionalServices/Practice/OutlinePlanofWork\(revised\).pdf](http://www.architecture.com/Files/RIBAProfessionalServices/Practice/OutlinePlanofWork(revised).pdf).

contractor. Such a practice may appear to reduce costs but risks compromising quality. As we note next, if passivhaus quality is to be guaranteed, the design in all its detail must be finalised before construction begins. If not, then decisions are likely to be made that will compromise the achievement of passivhaus limits for energy use and a low-energy building is unlikely to be delivered.

The examples of both Elizabeth Fry and the Wolverhampton passivhaus schools demonstrated how a quality approach emphasising teamwork can not only deliver new buildings to time and to cost but can also deliver high-quality, low-energy buildings that are enjoyable and productive to work in. The Wolverhampton passivhaus schools presentation highlighted the fact that, because of the teamwork, there were no contractual claims in either direction. The low energy performance and high comfort score of the Elizabeth Fry Building are shown in Figure 7 and Figure 6 above.

Similar benefits in respect of teamworking to enable high quality refurbishment of apartments at Brogården in Sweden were described by Hans Eek of the Swedish Passivhus Centrum at the Build with CaRe conference in Norwich, October 2010⁵.

An adversarial approach, with a focus on contracts and claims rather than on teamwork, may give the impression of minimising up-front costs but the long-term costs of energy inefficient buildings and of buildings that provide poor working environments will far outweigh (see Chapter 6) any apparent short-term gains in up-front construction costs (and, as the examples in this Chapter show, teamwork is the most effective route to cost reduction as well as to quality). In fact, it is just as likely that there will be no short-term gains with an adversarial approach, the only winners being lawyers.

A current example of the problems that can arise when the approach between parties seems to be adversarial rather than one of teamwork involves the guided busway in Cambridge for which the developer is the County Council. This was originally expected to open in early 2009 and to cost £116.2m. It was eventually commissioned in August 2011 – over two years late - and the Council had spent £149.9m by July 2011. There is now a claim for £55m by the Council against the contractor and a counterclaim of £43m by the contractor against the Council⁸⁷.

As the Wolverhampton schools presentation made clear, the problem with quality in construction is not with the supply chain or with sub-contracting as such, it is with the culture and attitudes that normally apply. As Matt Wisdom of Thomas Vale said⁶⁸: *“For us passivhaus is the future of construction - if we take the partnership and collaborative approach it's achievable - if we take the contractual approach it'll never work.”*

As just noted, there were no claims in either direction on this project. Of course there will be contracts but the approach will be one that aims for a quality outcome

⁸⁷ *Atkins drawn into dispute over Cambridgeshire busway*, Alexandra Wynne, New Civil Engineer, 3 May 2012, p5.

not an adversarial one. Both this example and that of the Elizabeth Fry Building showed that all that need change is management attitudes. A management focus on teamwork and on quality (Section 2.6 and Footnote 40) can transform outcomes and ensure delivery on time and to cost of a building that has outstanding performance.

3.6. Design must be finalised before construction begins

The importance of detailed modelling to ensure that a building can perform according to specification has been noted. A consequence of this is that changes to design or materials cannot be permitted unless it is categorically clear that performance will not be compromised.

As already noted, a supposed advantage of design and build is that work on site can begin even before design has been finalised, so reducing costs⁸⁸. However, such a practice must almost inevitably compromise successful delivery of a low-energy building. Not until the design is complete can compliance with passivhaus or other criteria be assured via PHPP or other appropriate modelling package.

'Value engineering' will also happen extensively where cheaper, perhaps inferior, products are substituted for those initially specified and with predictable problems⁸⁵. The design and build contractor may assure the client that everything is in order but there is no way of checking this for energy performance without detailed thermal testing which, in practice, almost never happens. The building is not considered as a system – which it has to be when modelled in detail - but as a collection of individual components.

The typical outcome, still current today, was described by Amory Lovins of the Rocky Mountain Institute⁸⁹ in a talk⁹⁰ to the RSA⁹¹ some years ago where he explained how (not) to achieve an energy-efficient building: *"It requires that you optimise the whole system. What normally happens is that some value engineer comes along and says, 'You don't need these windows. They're too dear. Let me save you \$8 a square metre. I'll put in this other stuff.' Well, the window looks like it costs less, but then of course you need more cooling and more fan capacity. It's like squeezing a balloon; it pops out somewhere else. By optimising each component separately it's quite easy to pessimise the system."*

Most cars and appliances are not designed this way but buildings, it seems, often are. They are not considered as a system either in design or construction. The benefit of passivhaus quality is that it demands system thinking. Of course, design

⁸⁸ See, for example, *Design and Build - A review of some of the principles*, <http://www.thkp.co.uk/media/bulletins-new/Design%20and%20Build%20HK.pdf>.

⁸⁹ <http://www.rmi.org/>.

⁹⁰ *Greening the building and the bottom line*, Amory Lovins, Lecture to the RSA, 3 March 1997.

⁹¹ <http://www.thersa.org/>.

and build can lead to an exemplary result if the brief is good and if the contractor adopts a quality approach but, given much current practice, the odds against this seem long.

3.7. Attention to construction detailing is essential

On passivhaus construction sites in Germany, it is standard practice for architects or their representatives to visit a construction site, if not daily, then several times each week. They will want to inspect critical detail⁹² while this is still visible. If such detail has been covered up before inspection, then it will be required to be uncovered.

We have been shown (in English) the detailed quality management documents⁹³ used by Hamburg Build with CaRe partner ZEBAU (Zentrum für Energie, Bauen Architektur und Umwelt), while architect Christine Reumschüssel of DR-Architekten, Hamburg⁹⁴, reviewed quality passivhaus procedures in talks during her visit⁹⁵ to UEA in February 2012 when she spoke about the construction of the first passivhaus in China, the Hamburg House⁹⁶, at the 2010 Shanghai Expo, and the construction of a passivhaus apartment for the disabled in Hamburg⁹⁷.

During visits to passivhaus construction projects in Hamburg and elsewhere, we have seen, for example, the care with which insulation material is cut and joined to avoid air paths that could create heat loss, the careful design of balcony elements to create structural integrity but avoiding thermal bridging, and the careful attention to the taping of joints and to minimising air leakage.

Such attention to detail, and such care in handling materials, are almost unheard of on a UK construction site⁹⁸ but was achieved both during the construction of the Elizabeth Fry Building and of the Wolverhampton passivhaus schools. Normally, however, in conventional construction practice, little will be checked before it is covered and faults and defects will remain hidden, only to be revealed after construction is completed in poor air tightness (if tested) and, eventually, high energy use. Sadly, by then, as the PROBE studies³¹ demonstrated, it is too late to identify most of the problems and the building owners and occupants have to suffer the consequences (see more on the performance gap in Chapter 4).

⁹² For example sealing of windows.

⁹³ See <http://zebau.de/gutachten-und-zertifizierung/>.

⁹⁴ <http://www.dr-architekten.de/>.

⁹⁵ <http://www.buildwithcare.eu/component/content/article/232-german-passivhaus-architect-visits-uea>.

⁹⁶ <http://www.dr-architekten.de/node/363>.

⁹⁷ <http://www.dr-architekten.de/node/532>.

⁹⁸ Note the comment by Matt Wisdom of Thomas Vale Construction below in this Section.

The design team for the Elizabeth Fry Building, architect Richard Brearley⁹⁹ of John Miller and Partners¹⁰⁰ and Andy Ford of building services engineers Fulcrum⁷⁴ realised that, for their design to succeed, in addition to the design elements that reduced thermal gain and maximised passive cooling, exceptional thermal insulation was necessary and thermal bridging, normally common-place, must be avoided. In addition, in order to minimise energy use for heating in winter, the air tightness of the structure would also have to be exceptional.

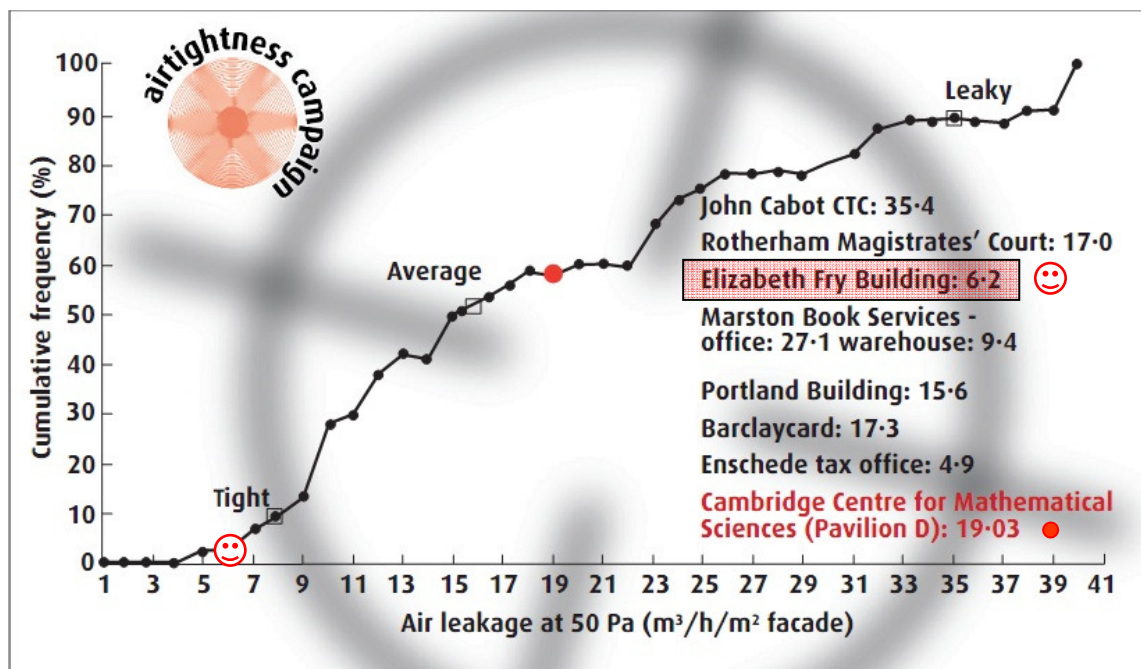


Figure 9. The air-tightness of several buildings on the BRE/BSRIA database (Figure 4 in PROBE 23, the final PROBE study, *The Centre for Mathematical Sciences, Cambridge*, The PROBE Team, Building Services Journal, July 2002, pp57-62). The cumulative distribution represents a sample of three building types: those designed to be airtight (Tight), buildings designed without airtightness as a design criteria (Average), and some older buildings (Leaky). The red dot shows the result for the Cambridge building completed in 2001 and the smiley face the result for the Elizabeth Fry Building completed in 1995.

David Olivier of Energy Advisory Associates¹⁰¹ was brought in to help specify how these objectives could be achieved and the outcome was reflected in the achievement of a heavily-used 3250m² building heated only by two domestic 24kW

⁹⁹ <http://www.sidellgibson.co.uk/about-sidell-gibson/our-people/richard-brearley.php>.

¹⁰⁰ <http://www.sidellgibson.co.uk/about-sidell-gibson/associated-practices/john-miller-and-partners.php>.

¹⁰¹ <http://www.energyadvisoryassociates.co.uk/>.

gas boilers (with a third installed as spare) that was probably the most air-tight building in the UK at the time¹⁰² (Figure 9).

Figure 9 shows the air leakage for a new building at Cambridge University on a greenfield site, delivered in 2001, several years after the Elizabeth Fry Building was opened. Although the new Centre for Mathematical Sciences at Cambridge was designed with a low-energy agenda, the air tightness for the section studied, Pavilion D, was below average ($19.03\text{m}^3/\text{h}/\text{m}^2$ at 50Pa – shown as the red dot).

In comparison, the air tightness of the Elizabeth Fry Building, measured in 1998, was $6.2\text{m}^3/\text{h}/\text{m}^2$ at 50Pa (shown as the smiley face), one of the most air tight buildings in the database. These results demonstrate the importance of the attention to detailing that is essential if low-energy performance is to be achieved in practice.

Quality detailing demands quality teamwork

What was – and remains – unusual about the construction of the Elizabeth Fry Building was the teamwork that transferred the knowledge of David Olivier - that was built into the design - into good practice on site during construction. As the PROBE study¹⁰³ describing the building noted about the sealing of the triple-glazed windows to minimise cold bridging and air leakage: *“These unusual features required clear explanation to the site workers and special checking of critical details before being concealed by internal finishes.”* In other words, these critical details were checked before being concealed, just as happens for passivhaus construction in Germany (and elsewhere) today.

UEA's Clerk of Works, Tony Evans, was on site every day during construction¹⁰⁴ to ensure that this detailing was undertaken correctly and with care, and gained good cooperation from the contractor Willmott Dixon⁷⁷.

A quality building stands the test of time

Interestingly, when retested in 2011, the air-tightness of the Elizabeth Fry Building was even better than in 1998, being measured¹⁰⁵ at $5.3\text{m}^3/\text{h}/\text{m}^2$ at 50Pa. It is

¹⁰² *Teaching low energy*, Roderic Bunn, Building Services, April 1995, pp19-23 (this article provides details of the companies involved in the design and construction of the Elizabeth Fry Building, the main suppliers and key information on building parameters).

¹⁰³ *PROBE 14: Elizabeth Fry Building*, The PROBE Team (Mark Standeven, Robert Cohen, Bill Bordass and Adrian Leaman), Building Services Journal, April 1998, ppE20-E25.

¹⁰⁴ Tony Evans, personal communication.

¹⁰⁵ *Test of Time*, Bill Bordass and Adrian Leaman, CIBSE Journal, March 2012, pp30-36, and *Elizabeth Fry – ageing gracefully?*, Roderic Bunn, Delta T Magazine, February 2012, pp8-10 (subscription required – also at *Does a building lose its airtightness over time?*, Roderic Bunn, BSRIA News, April 2011, <http://www.bsria.co.uk/news/elizabeth-fry/>). See also the Build with CaRe website, *Revisit to the Elizabeth Fry Building*, 3 March 2012, <http://www.buildwithcare.eu/component/content/article/233-revisit-to-the-elizabeth-fry-building>.

thought that the ventilation plants may have been sealed more thoroughly in 2011 than in 1998 but this result, after nearly seventeen years of intensive use, is proof of the quality of work in the construction. This air-tightness translates into a rate of 1.24 air-changes per hour (ACH). This, for a building opened in 1995, is far better than will be required for so-called zero-carbon homes in the UK from 2016¹⁰⁶, over twenty years later, and demonstrates the lack of ambition in the proposed zero-carbon definition (Section 2.7).

This result for Elizabeth Fry is not quite as good as the air-tightness limit for a passivhaus building of 0.6ACH but there was no awareness of this requirement at the time of the design and construction of Elizabeth Fry. There is little doubt that further improvements in air tightness could have been achieved¹⁰⁷ at the Elizabeth Fry Building had this been specified.

In his article about the revisit of the PROBE team to the Elizabeth Fry Building in 2011¹⁰⁵, Roderic Bunn wrote: *"In many ways Elizabeth Fry was the construction industry's Higgs Boson – rare proof that it was possible to build both an energy efficient and highly comfortable and usable building"*.

This analogy certainly highlights the vanishingly small number of buildings that actually achieve these desirable outcomes but is inaccurate in one vital respect. To discover proof of the existence of the Higgs Boson required massive expenditure on a huge underground accelerator, the Large Hadron Collider. Achieving the success of the Elizabeth Fry Building required no extra expense at all. It merely required the design and construction teams to undertake a construction project to a high standard of care and quality – something that, sadly, today still seems almost as elusive as the Higgs Boson.

The problem is not with skills but with management

If management is committed to a quality approach, the quality demonstrated in the design and construction of the Elizabeth Fry Building could become standard and common-place. Buildings with the performance of Elizabeth Fry and of passivhaus homes and buildings could become similarly common-place.

There is much discussion about the supposed skills challenge ahead¹⁰⁸ but what is often obscured is where the solutions lie. As Matt Wisdom of Thomas Vale Construction made clear in his presentation⁶⁸ on the building of the Wolverhampton passivhaus primary schools, existing teams today can deliver total quality without any need for major new initiatives. All that is required is for management to want to

¹⁰⁶ For homes, 2019 for non-domestic buildings.

¹⁰⁷ David Olivier, personal communication.

¹⁰⁸ See for example, *Home Building Skills 2020: Report and recommendations, Preparing to deliver tomorrow's new homes*, NHBC, Zero Carbon Hub and Construction Skills, October 2010, <http://www.homebuilding-skills.com/uploadFiles/mciFiles/HomeBuildingSkills-Report-Oct2010.pdf>.

do it this way and to insist that it is done this way – on site – just as happened during the building of the Elizabeth Fry Building many years before.

What was demonstrated in the building of the Wolverhampton schools was a single-minded determination to avoid defects and to fix them immediately if found - using thermal imaging and smoke testing to reveal them as work progressed. As Matt said, leaks could not have been fixed at the end of the work – it would have been too time-consuming and too expensive. But he noted, sadly, that such attention to detail was *“unheard of on a construction site”* (he was forgetting the Elizabeth Fry Building!).

Just as for Elizabeth Fry, it was the demanding requirements for air tightness and the need to demonstrate avoidance of thermal bridging that made such attention to detail essential. Without such attention to detail the passivhaus air tightness standard could not have been met. It was the determination by Thomas Vale to meet the air tightness standard that made necessary the teamworking environment on site that made it possible to meet the standard. That the standard was met shows that the major problem within the industry is not workforce skills but lack of management leadership and lack of a pride in quality.

Lack of management concern for quality is why such attention to detail is, as Matt Wisdom said: *“unheard of on a construction site”*. As we noted above (Section 2.6), Nick Grant⁴⁰, consultant for the Wolverhampton passivhaus schools said: *“It is great when airtightness is seen as a badge of honour, something to take pride in rather than a compliance hassle.”* The performance gap (Chapter 4) and problems with quality (Chapter 5) would cease to be problems if management took such pride. Successful delivery of low-energy buildings would become common-place and standard practice.

Quality and teamworking are even more important for refurbishment

As noted above (Section 1.5) such attention to detail is at least as important in low-energy refurbishment of existing buildings as for new build - if not more so – because in refurbishment complete modelling is not possible before work starts. Issues and problems that could not have been predicted will arise once work is underway and they must be understood and dealt with in a quality manner so that unseen defects are eliminated.

Sadly, at present, such attention to detail is just as *“unheard of”* in refurbishment as in new build (see Chapter 5). If attitudes to quality in refurbishment do not change then energy savings that are predicted following refurbishment work, that Governments will proclaim, and that owners think they are paying for, will not be achieved.

The refurbishment of early 1970s apartments at Brogården in Alingsås in the south of Sweden mentioned above (Sections 1.5, 2.4 and 3.5) demonstrates⁵ how quality can be achieved in refurbishment in exactly the same manner as for new build – via teamworking and attention to detail at every stage. Sadly, such teamworking in refurbishment is still almost *“unheard of”* in most countries. The recipe for change is

exactly the same as for new build – leadership by management. Without change, successful low-energy refurbishment will be rarer than low-energy new build is today. Demand reduction and climate change targets cannot be met.

3.8. Post-construction evaluation is essential

We have emphasised the importance of teamwork and attention to detail in commissioning, design and construction of a new building. Such a quality approach does not stop at handover. As we have emphasised, a building can only be called a low-energy building if it can be demonstrated in practice to behave as one. Monitoring and evaluation are important, but not just to demonstrate good performance – or, indeed to reveal poor performance. The delivery process must continue after construction to ensure in particular that the building occupants can understand and manage the building effectively.

To ensure that a building does indeed perform to its specification, attention to detail must continue beyond handover. If this does not happen – and frequently it does not – then the occupants - or those responsible for managing the building - may be unable to manage it effectively. Building performance may be far poorer and energy consumption far higher than could be achieved, while occupant satisfaction may be far below what was anticipated. Also, of course, without monitoring and demonstration, the potential for improvement disappears.

Building performance evaluation (BPE)⁹ is vital for several reasons:

- **To identify problems (as in the PROBE and LCBP studies)**
- **To identify successes (as in the UEA buildings and the Wimbish homes)**
- **To enable improvement in design and construction practice**
- **To help occupants understand building operation**
- **To help occupants learn how to optimise performance and minimise energy use.**

Past and current programmes

The PROBE studies³¹ and the Low Carbon Building Programme³⁰ revealed the gap between design and performance for what were assumed to be leading-edge and better managed buildings than the average (Section 2.5 and Figure 2). These worrying outcomes – and similar concerns over the performance of homes²⁶ – have led the UK Government's Technology Strategy Board (TSB), the national innovation agency¹⁰⁹, to fund an £8m, four-year programme to conduct case studies of building performance to understand how the buildings perform, and why¹¹⁰.

¹⁰⁹ <http://www.innovateuk.org/>.

¹¹⁰ See <http://www.innovateuk.org/content/competition/building-performance-evaluation-.ashx>.

We have described the TSB programme in Sections 4 and 5 of *Building Performance Evaluation: Why and How*⁹. As part of the TSB programme we are monitoring buildings very similar to those featured in this Chapter: the University of East Anglia's latest Termodeck building, The Thomas Paine Study Centre⁷⁶, and passivhaus homes at Wimbish in Essex, completed in 2011 by Hastoe Housing Association²⁰.

These new passivhaus homes do indeed show the expected ninety per cent reduction in energy for heating relative to the average for British homes (Section 2.4) and the excellent air quality and internal environment (Section 2.7) that results from passivhaus quality in design and construction.

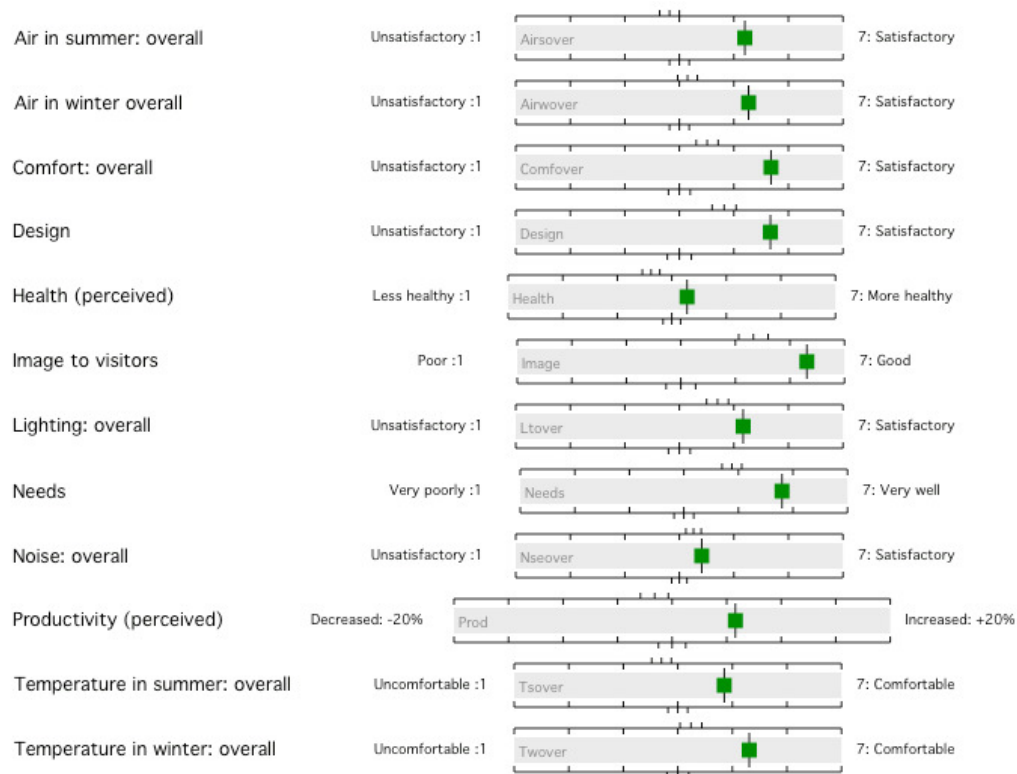


Figure 10. Building Use Studies (BUS) occupant survey results⁸⁰ for the Thomas Paine Study Centre at the University of East Anglia (for more detail see the report referenced in Footnote 76). The diagram shows average responses by staff to twelve key questions. The satisfaction score runs from 1 (poor, on the left) to 7 (good) on the right, apart from the question on perceived productivity that goes from 20 per cent decrease to 20 per cent increase. Green squares show that, for all questions, the average scores are significantly better than benchmark levels at the 95 per cent confidence level.

The Thomas Paine Study Centre (TPSC), like the Elizabeth Fry Building before it, seems to combine excellent energy efficiency with an exceptional level of occupant satisfaction. On every single one of twelve key questions, TPSC scores above average relative the overall buildings database⁸⁰ (Figure 10 above). As a result, this building sits easily within the top ten per cent of the hundreds of buildings surveyed in respect of the perceptions of those working in them.

The database for homes is far smaller than that for non-domestic buildings against which the Thomas Paine Study Centre is compared, but the occupants' perceptions of living in the Wimbish passivhaus homes are easily the most positive in all the studies so far undertaken (Figure 11 below). This excellent result is emphasised by comments from residents shown in the box on the front pages of this report.

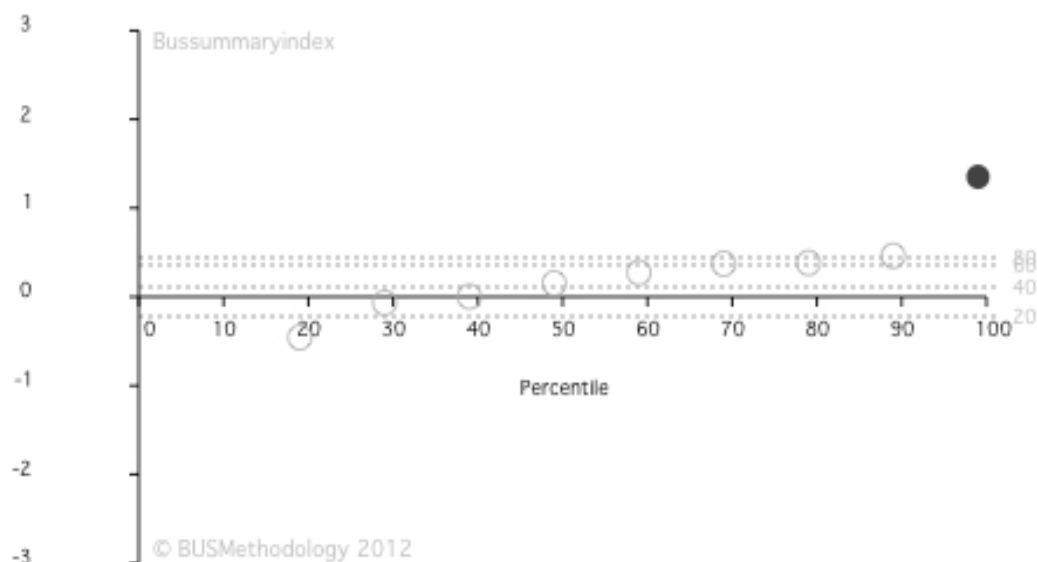


Figure 11. Building Use Studies (BUS) occupant survey result⁸⁰ Summary index for the passivhaus homes at Wimbish in Essex (for more detail see the report referenced in Footnote 20). The Summary index is an average of the composite Comfort and Satisfaction indices that each average several variables in the occupant survey. This figure shows the data for domestic properties currently available. The vertical axis ranges from very negative perceptions (-3) to very positive perceptions (+3). The Wimbish result is the filled circle and is by far the most positive response to date.

Buildings are more like ships than cars

Post-construction evaluation involves a process extending from handover to use over one, two or more years. As the PROBE team noted¹¹¹, buildings are more like ships than cars: *“Few buildings roll off the production line having been designed, prototyped, tested and refined over a substantial period. Most are built individually to a site, context, design and specification which may be similar to previous buildings, but is seldom identical.”*

This does not mean that a pursuit for quality similar to that pioneered by Toyota^{62, 79} and other car companies should not be followed. We have emphasised the importance of quality throughout the design and construction process in this Section. But buildings, even if pre-fabricated in factories, are erected on site, often in inclement conditions, and in very modest numbers compared to most makes of vehicle. There is not the testing and evaluation on testbeds and “on the road” that any new model of car will have been subject to and the controls are more subject to user whim, misuse or, sometimes, abuse¹¹² because safety is less of an issue for a stationary building than for a vehicle travelling at speed on a busy road.

It does mean both that post-construction evaluation and monitoring are essential and also that a focus on simplicity in operation (Section 3.3, Heading *Keep it simple and do it well*) creates the best platform for good building management. This is why passivhaus buildings perform so well. The simpler the control system, the easier a building is to control and to make both comfortable for occupants and as efficient as possible in its use of energy.

The PROBE study investigators have noted that making buildings more complicated leads to problems and difficulties and not to ease of control⁸²: *“Unmanageable complication is the enemy of good performance. So why are we making buildings technically and bureaucratically complicated in the name of sustainability, when we can’t get the simple things right?”* We have already noted⁸³ examples of how building management suffers when controls become too complex.

¹¹¹ PROBE Strategic Review 1999, Final Report 4: Strategic Conclusions, Bill Bordass, Adrian Leaman and Paul Ruysssevelt, <http://www.usablebuildings.co.uk/Probe/ProbePDFs/SR4.pdf>.

¹¹² A vehicle’s electronic control unit (ECU) is programmed to optimise performance and is unseen by and inaccessible to drivers. Buildings, domestic or non-domestic, cannot be ‘driven’ in an analogous manner and are much bigger in size than most cars or even the biggest vehicles. There is usually more than one occupant, even in domestic buildings, and sometimes many hundreds in non-domestic buildings. Building control, whether via a simple domestic heating system, or via a building management system involving hundreds of sensors as in a building such as the Thomas Paine Study Centre (see Section 4.7 of *Thomas Paine Study Centre: How it Works*, Footnote 76) is not analogous to the ‘black box’ control of a vehicle via an ECU that interprets the instructions from the driver’s use of the brake or throttle.

The importance of information at handover and beyond

Even in the simplest building, occupants need easy-to-understand explanations of what to do. The handover process to occupants at the Wimbish passivhaus homes was described in Section 5 of *Wimbish Passivhaus: Building Performance Evaluation Interim Report – March 2012* (Footnote 20). Admittedly, living in a passive house was a new experience for all the new occupants, but the process revealed the need for close and continuing engagement if optimal performance was to be obtained.

There seems little doubt that the conclusions from this work²⁰ at the Wimbish passivhaus homes are relevant in a much wider context, whether in passivhaus homes or more conventional homes and buildings. Building owners or occupants need help and clear and simple advice on how to best manage the building they live or work in. They rarely get it. We have discussed some of the potential problems with so-called smart meters, which will supposedly overcome barriers to more efficient use of energy, in Section 10.5 of *Refurbishing Europe*⁴.

The data in Figure 1 show the several-fold variation in heating energy use for “old buildings”. Similar results are found in studies elsewhere. This variation reflects the different activities of the occupants but it is the average over the whole building stock that we compare with the average for passivhaus homes such as at Wimbish (see Footnote 19 for more details).

This wide variation of energy use for heating in today’s building stock almost certainly hides wide variation in efficiency of energy use by occupants as well as differing family size, habits and appliance use. Only with advice and information on energy use, metering and controls can most occupants be expected to engage in any productive fashion with energy efficiency.

Living in a passivhaus home must aid this engagement. Occupants become aware, often for the first time, of how energy efficient and pleasant living in a home can actually be – witness the quotes on the front pages of this report. We hope that such experience can be a powerful stimulus to occupants to think about how to reduce their energy use, not just for heating, but for hot water and for appliances as well. But help and advice will still be needed – as will also a cost-effective supply of highly energy efficient appliances.

The data for passivhaus homes in Figure 1 show a comparable variation for heating energy to conventional homes but, because passivhaus homes are so efficient, the absolute variation is tiny compared to that for the “old buildings”. Such data show the huge benefit demonstrated by low-energy buildings such as passivhaus homes.

The data in Figure 1 do not include energy for hot water and appliances. It is to be hoped that these figures will also be low but, at Wimbish for example, electricity use, largely due to appliances, was little different from the UK average. It was the ninety per cent reduction in energy use for heating that brought total energy use down by over three times compared to the average. Even in many passivhaus homes, there

remains great scope for reducing total energy use while maintaining or even improving the quality of life.

Efficient management of bigger buildings

As buildings get bigger, the potential for energy savings becomes larger, even for energy efficient buildings, as does the potential for inefficiencies that may be unrecognised. The post-handover study of the Elizabeth Fry Building described in the PROBE study¹⁰³ and summarised in *Test of Time*¹⁰⁵ demonstrated how, even for a building that had been designed and built in a quality manner – as outlined above – only a detailed study of performance post-handover could bring the energy use in practice down to the predicted value.

One piece of “value engineering” for the original building that did not provide value was the provision of a very basic control system that did not permit the University’s Estates’ staff to understand the building’s behaviour. In 1995, the first year of use, gas use for heating was 65kWh/m² – still exceptional for the UK¹¹³ but not as good as was being achieved in several Termodeck buildings in Sweden.

It was fortunate that the Government of the time was funding an Energy Efficiency Best Practice Programme and the partners involved in Elizabeth Fry were successful in bringing the building into this programme. The study¹¹⁴ revealed some of the reasons why energy use for heating was higher than anticipated and pointed to the need for a new strategy where data from building sensors could be fed back to a more responsive building management system (BMS) and monitored by the University’s Estates’ staff.

As a consequence of the Best Practice study, the building was linked to the University’s new BMS from Trend Control Systems Ltd¹¹⁵ and the data and flexibility this provided enabled much more effective – and simpler - control. In 1997, the year analysed in the PROBE study, gas use for heating had been cut by half (to 31kWh/m² for heating and 4.2kWh/m² for hot water). This was a saving of around 100,000kWh of gas per year, every year, of interest to any organisation one would hope. Such a saving must be achievable¹¹⁶ in very many buildings and should justify much more detailed attention than is normally given.

Detailed post-handover study of this kind was then, and remains today, unusual – hence the need for the TSB programme presently underway¹¹⁰. In the normal course of events, the gas use initially observed for Elizabeth Fry would probably have been tolerated. Indeed, the Elizabeth Fry Building would have been

¹¹³ See the spread of data for the PROBE buildings in Figure 7.

¹¹⁴ *The Elizabeth Fry Building, University of East Anglia – feedback for designers and clients*, Energy Efficiency Best Practice Programme, New Practice Final Report 106, March 1998, accessible at <http://www.uea.ac.uk/estates/environmentalpolicy/New+Practice+final+report>.

¹¹⁵ Still in use and described in *Thomas Paine Study Centre: How it works*, Footnote 76.

¹¹⁶ We note below¹⁷⁶ that considerable energy savings are likely to be possible in many existing buildings.

considered a 'good building' energy-wise, but would have been only half as efficient in energy use for heating as it was ultimately shown to be capable of being. The benefit from the care and effort put into the design and construction would not have been fully exploited.

A similar gap between observed and predicted energy use for heating was also found during initial operation of the University's next Termodeck building, the ZICER (Zuckerman Institute for Connective Environmental Research) Building, opened in 2003. Again, careful monitoring identified an improved control strategy, and heating energy was reduced to the predicted value¹¹⁷.

Soft Landings

A positive outcome of this work^{103, 114} on the Elizabeth Fry Building – and of the PROBE studies as a whole – has been the development of the Soft Landings concept¹¹⁸. The Usable Buildings Trust, developed, in part, as a consequence of the PROBE studies³¹, and BSRIA¹¹⁹, responsible for the air tightness testing of the Elizabeth Fry Building¹²⁰, work together to support the construction industry and its clients to apply Soft Landings¹²¹.

A Soft Landings process has already been applied to several new schools¹²² and this process is being followed for the new Wolverhampton passivhaus schools⁶⁸ with very positive engagement of teachers and pupils. Even the most expertly designed and constructed low-energy buildings need a handover and commissioning process to gain the full benefit of this investment as examples from the Elizabeth Fry Building to new passivhaus homes and schools show. Soft Landings is a process that can facilitate the teamwork necessary to enable optimal outcomes both from building management and energy efficiency perspectives and also from the perspective of the occupants.

¹¹⁷ Turner, C.H., Tovey, N.K. and Fulk, K. (2006) *Case study on the energy performance of the Zuckerman Institute for Connective Environmental Research (ZICER) Building*, ASHRAE Transactions 112 PART 2: pp 320-329. See also Section 3.3 on the ZICER Building in *Thomas Paine Study Centre: How it Works*, Footnote 76.

¹¹⁸ Soft Landings means designers and constructors staying involved with buildings beyond practical completion, to assist the client during the first months of operation and beyond, to help fine-tune and de-bug the systems, and ensure the occupiers understand how to control and best use their buildings

¹¹⁹ <http://www.bsria.co.uk/>.

¹²⁰ <http://www.bsria.co.uk/news/elizabeth-fry/> and Footnote 105.

¹²¹ <http://www.bsria.co.uk/services/design/soft-landings/>; *Soft Landings Core Principles*, March 2012, is available from <http://www.bsria.co.uk/news/sl-coreprinciples/>.

¹²² *Soft Landings for Schools: Case Studies*, Edited by Mike Buckley, Bill Bordass and Roderic Bunn, BSRIA BG 9/2010, <http://www.bsria.co.uk/services/design/soft-landings/guidance/>.

On-going monitoring and improvement

The Soft Landings process may extend up to three years after handover but almost all buildings will be used and occupied for far longer than this. As a result of staff turnover, building modifications, and other changes, it can be very easy for energy efficiency standards to slip, even for the most energy efficient buildings. While the on-going performance of the Elizabeth Fry Building remains good, with performance better than many brand new buildings, there is always room for improvement¹²³.

Possibly, the University of East Anglia has been fortunate in having a tradition of excellence in its Estates Office that extends back to the construction of the first university buildings in the 1960s. Earlier commissions^{124, 125} in the 1980s, before the Elizabeth Fry Building, had highlighted the possibilities and potential benefits of energy efficient buildings. The University was experienced in commissioning new and innovative buildings, in maintaining its buildings, and in seeking out ways of saving energy.

Other organisations owning, commissioning or maintaining larger buildings may not possess such experience and expertise. A building management system (BMS) by itself will not seek out energy inefficiencies or encourage energy efficiency; the objective is to maintain comfort levels.

There is also considerable evidence that BMS systems in practice are complex and not easy to operate to maximum effectiveness. In 2005, BSRIA¹¹⁹ conducted a survey¹²⁶ of facilities managers, asking about their experience with building management systems they were operating. Fifty-seven per cent of respondents reported that heating and cooling plant ran simultaneously. A general complaint was that controls were very often over-specified, only used to a fraction of their capability, and were too complex for the building user to understand.

As already noted (Section 3.3, *Keep it simple and do it well*), exactly these kinds of problems were highlighted in the PROBE studies: *"Unmanageable complication is the enemy of good performance. So why are we making buildings technically and bureaucratically complicated in the name of sustainability, when we can't get the simple things right?"*¹²².

It seems that little has changed since: *"The frustration with BMS in schools is so great that Roundtable participants wanted to design them out altogether. Finding a*

¹²³ Some aspects are discussed in the Conclusions of *Test of Time*, Footnote 105.

¹²⁴ http://www.rickmather.com/project/category/climatic_research_unit#/project/category/climatic_research_unit.

¹²⁵ *New low energy multi-residential accommodation, Constable Terrace, University of East Anglia*, Energy Efficiency Best Practice Programme, New Practice Final Report 80, 1995, available from <http://products.ihs.com/cis/Doc.aspx?AuthCode=&DocNum=86583>.

¹²⁶ Reported in *"The trouble with design..."*, Building.co.uk, 3 May 2006, <http://www.building.co.uk/the-trouble-with-design%e2%80%a6/3066727.article>.

*building with a well-run system, where main and sub-meters are measuring what they were intended to and are hooked up to the BMS is a rarity.*¹²⁷

One way to help both facilities managers and building occupants understand and improve the efficiency of energy use is to have a simple-to-understand display of energy use that can show current and historic energy use data. Then, if there is upward drift in some aspect of energy use, this can be seen and examined, or the impact of actions and changes can be looked at.

Most building management systems (BMS) are not designed to make this easy to do. As the name implies, they are designed to facilitate day to day management of a building and not to collect and collate historical data or to interpret metered data. In most cases, the BMS data will be inaccessible to anyone not involved in building management and, in any case, will not be easy to interpret.

As part of the Build with CaRe project, we have supported development of software that captures BMS data to provide current and historic energy use data in an easy-to-visualise form that can be studied not just by the Estates' maintenance team but by anyone working in a building or engaged in the promotion of energy efficiency. Indeed, the new software also makes it easy to compare one building with another.

*An Energy Display System for UEA Buildings*¹²⁷ describes the software written to interface with the University's Trend BMS¹¹⁵ and with the existing CRed System tool¹²⁸ at the University of East Anglia. The software should be readily compatible with any similar BMS and should be of great assistance to organisations that wish to promote energy saving in buildings over the long term.

3.9. Summary of success factors

We reproduce here (Figure 12, Figure 13 below), summaries by the PROBE team about the Elizabeth Fry Building, and by the Wolverhampton passivhaus schools team, about the reasons for success of these projects.

¹²⁷ *An Energy Display System for UEA Buildings*, Andrew Courtenay, March 2011, http://www.buildwithcare.eu/images/pdfs/tpsc_energy_display_project.pdf, link from <http://www.buildwithcare.eu/articles/78-partners/236-how-to-capture-energy-use-data-for-large-buildings>.

¹²⁸ <http://www.lcic.com/about-cred-system>.

Together, these success factors are summarised by the principles discussed in this Chapter:

- **The brief must be clear and appropriate**
- **Innovation may be necessary but building operation must be simple**
- **Modelling of building performance is essential**
- **Teamwork throughout is essential**
- **Design must be finalised before construction begins**
- **Attention to construction detailing is essential**
- **Post-construction evaluation is essential**

The Elizabeth Fry Building

- A good client
- A good brief
- A good team
- Specialist support
- A good, robust design
- Enough time and money (but to a normal budget)
- An appropriate specification (and not too clever)
- A good, interested contractor (and a traditional contract)
- Well-built (attention to detail)
- Well controlled (after monitoring)
- Post-handover support
- Management vigilance

Figure 12. Success factors for the Elizabeth Fry Building¹²⁹

¹²⁹ From Figure 6 in: *Assessing building performance in use 5: conclusions and implications*, Bill Bordass, Adrian Leaman and Paul Ruysssevelt Building Research and Information 29 (2), 2001, 144-157, <http://dx.doi.org/10.1080/09613210010008054>.

The Wolverhampton Passivhaus Schools

- Integrated total design team commitment
- Passivhaus expertise
- Passivhaus integrated into design from day one
- Constant focus on simplicity of design and detailing
- Relentless focus on value engineering to achieve cost
- Committed contractor dedicated to delivering passivhaus
- Ongoing teamwork throughout the entire construction stage
- Focussed workshops with all key sub-contractors
- Rigorous and regular site inspection

Figure 13. Success factors for the Wolverhampton passivhaus schools¹³⁰

3.10. What to avoid

As we have noted in this report, the hidden defects that prejudice energy efficiency may not be apparent, even to those charged with managing a building. They will certainly not be apparent to visitors who will focus on superficial appearance. Such visitors may include judges examining a building for some competition or other. Hence there can be no guarantee that just because a building wins a “green building award” or similar accolade, or is “well thought of by visitors”, that it is either energy efficient or liked by those who have to work in it.

We describe below the problems with West Suffolk House (Section 4.1) but note here two examples recently shown⁸². One (Figure 14 below) shows energy use data for a “green building of the year”. Both gas and electricity use after two years of operation are double the design prediction and greater than the “good practice benchmark”. It would seem that appearance rather than outcome was judged. As we have stressed, a building can only be called a low-energy building if it actually performs as one.

¹³⁰ From Slide 119 of *Designing and delivering the Wolverhampton passivhaus schools at no extra cost*, Footnote 68.

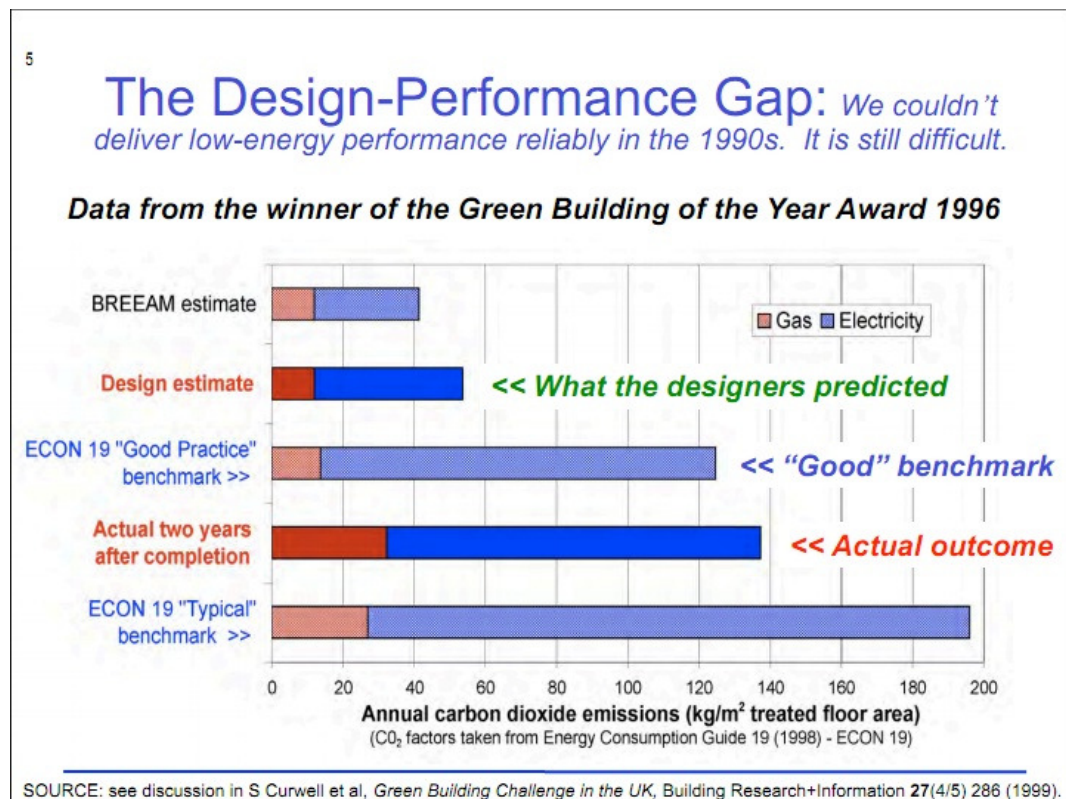


Figure 14. Energy use data for a “green building of the year”. Both gas and electricity use after two years of operation are double the design prediction and greater than the good practice benchmark. Slide 5 in *What works, what doesn't work, and how we can fix it: Using Building Performance Evaluation (BPE) for rapid improvement*, Bill Bordass, Presentation to Institute for Sustainability and FLASH+, Building confidence in low-carbon solutions, 27 September 2011, <http://www.usablebuildings.co.uk/Pages/UBEvents/UBEventsIfS27Sep11.html>.

The second example⁸² shown (Figure 15 below) is of an unpublished occupant survey of an award winning school from 2009. In Figure 10, above, for the Thomas Paine Study Centre at the University of East Anglia, every response shown was above average relative to the benchmark. For the award-winning school, the only above-average score was “image to visitors”. Perceived productivity was over ten per cent negative and, for eight of the twelve factors reported, including noise, needs, temperature in winter and summer, overall comfort and perceived health, average responses were worse than the benchmark. Those working in this school were aware that it looked good to occasional visitors such as award judges, but it seems to have been a pretty awful place to work in¹³¹.

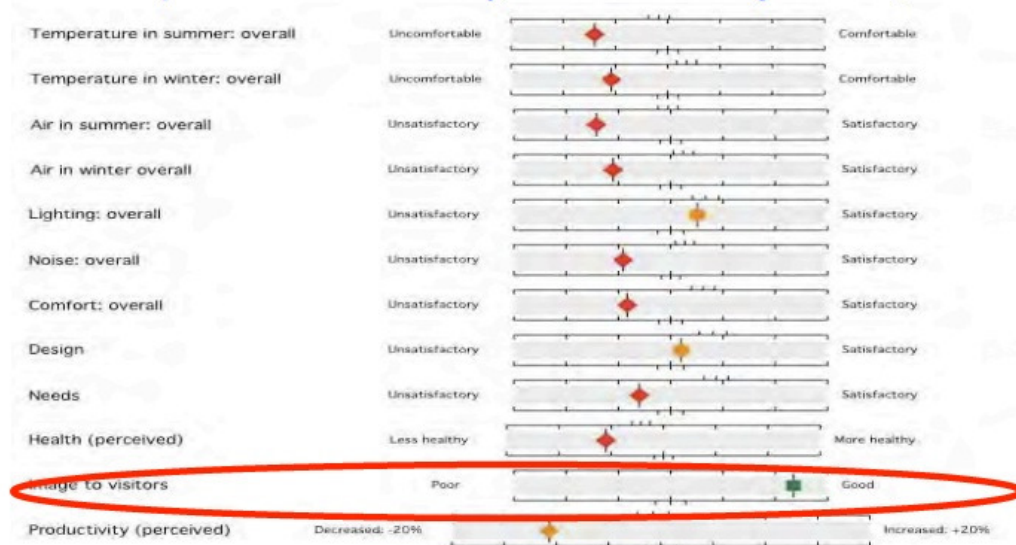
¹³¹ Similarly, for West Suffolk House (Figure 18), the only better-than-benchmark response in the occupant survey was for “image to visitors”.

Such problems with buildings that win architectural awards are nothing new. A report from 2006 noted¹³² that: “Winners of the prestigious Stirling prize for architecture, which will be announced tonight, have been lauded by architects but are often beset by faults and loathed by the people who use them, according to one of the government’s design advisors.” Just such a response was found in the occupant survey of West Suffolk House (Section 4.1).

11

Credibility gaps: Occupant satisfaction

Staff questionnaire survey, award-winning school, UK



The judges may not experience what the occupants do!

SOURCE: Unpublished occupant survey of an award-winning school 2009. Courtesy of Building Use Studies Ltd.

Figure 15. Building Use Studies (BUS) occupant survey results⁸⁰ for an award-winning school in 2009. The diagram shows average responses by staff to twelve key questions. The satisfaction score runs from 1 (poor, on the left) to 7 (good) on the right, apart from the question on perceived productivity that goes from 20 per cent decrease to 20 per cent increase. Red diamonds show where average scores are significantly worse than benchmark levels at the 95 per cent confidence level, orange indicates averages that are similar, and green squares show where average scores are significantly better. The only above average response is ‘image to visitors’ while eight out of twelve responses are significantly worse than the benchmark. Compare these responses with those for the Thomas Paine Study Centre at UEA (Figure 10) where all twelve responses are above average. Slide 11 in *What works, what doesn’t work, and how we can fix it: Using Building Performance Evaluation (BPE) for rapid improvement*, Bill Bordass, Presentation to Institute for Sustainability and FLASH+, Building confidence in low-carbon solutions, 27 September 2011, <http://www.usablebuildings.co.uk/Pages/UBEvents/UBEventsIfS27Sep11.html>

¹³² *The truth about those iconic buildings: the roofs leak, they’re dingy and too hot*, Matt Weaver, The Guardian, 14 October 2006, <http://www.guardian.co.uk/uk/2006/oct/14/communities.arts>.

4. The Energy Performance Gap

“Studies repeatedly show that buildings do not achieve their design criteria, in energy efficiency terms, when tested post-completion.”

Low Carbon Construction, Innovation & Growth Team Final Report, HM Government, Autumn 2010, <http://www.bis.gov.uk/assets/biscore/business-sectors/docs/l/10-1266-low-carbon-construction-igt-final-report.pdf>, Section 3.6.1, p70.

We outline the evidence for this damning statement by the UK Innovation and Growth Team, firstly for non-domestic buildings (Section 4.1), and then for domestic buildings (homes), Section 4.2. Problems widely encountered with mechanical ventilation and heat recovery (MVHR) installations reflect the on-going quality issues that are the root cause of the energy performance gap and are summarised in the final section (4.3) of this Chapter.

It is disappointing that so little urgency is attached to tackling this fundamental problem of quality in construction. In Chapter 5 we describe the on-going quality concerns that have been articulated in a series of reports over the years. The examples described in Chapter 3, the Elizabeth Fry Building and the Wolverhampton passivhaus schools, demonstrate that exceptional quality can be achieved at no extra cost if the working methods are changed to emphasise partnership, teamworking and adherence to the highest quality standards.

It is quite clear that without a transformation in quality of construction across the whole process from design to evaluation, the energy performance gap and related problems in new buildings such as are observed with MVHR systems cannot be tackled. The energy performance gap and other problems for occupants will remain.

The energy performance gap is largely a problem identified in new buildings but is almost certain to be even more of an issue for refurbishment (Section 1.5). A quality approach is even more important in tackling low-energy refurbishment of existing buildings, which, in Europe, is by far the biggest challenge in moving to a low-energy building stock⁴.

Without a transformation in quality led by practice in new build construction, it is inevitable that even bigger problems will be encountered in refurbishment. Energy saving and climate change targets will not be met and a great many buildings, whether new or refurbished, will remain uncomfortable and potentially unhealthy.

We have already noted the link between quality of construction and occupant satisfaction (see Sections 2.7, 3.3 and Figure 10 for example). For homes, high quality, low-energy buildings will mean healthy internal environments and better

occupant well-being, as exemplified by the comments from occupants of new passivhaus homes on the front pages of this report.

For non-domestic buildings, quality of construction can create significant improvement in perceived productivity (see Figure 10 for example). The potential economic benefits from such 'soft' benefits can significantly outweigh those from energy savings and can make investment in quality and energy efficiency very attractive. We outline some of the information on productivity in buildings in Chapter 6.

It is clear from examples across Europe that passivhaus ambition can make possible the transformation in quality that is essential if new build low-energy buildings are to become the norm. As we note in this report, adopting passivhaus quality demands nothing more than management determination to deliver a high quality building. The examples already discussed show that for homes, schools and almost certainly for many other building types, passivhaus quality need cost no more than a conventional approach to construction.

Adopting passivhaus quality for new build is the essential step now both to eliminate the performance gap and deliver high-quality construction, and also to create a platform for high-quality refurbishment of existing buildings to low-energy, often passivhaus, standard.

4.1. The Performance Gap - Non-Domestic Buildings

Figure 5 above (Section 3.1) summarises the success factors for getting a low-energy building right, based on the evidence from the PROBE studies³¹. We have outlined these success factors in more detail in the previous chapter. Sadly, as noted in Section 2.5, these success factors seem rarely to be followed in practice. One of the PROBE study team has recently summarised (Slide 16 of Footnote 27) what is so often found (Figure 16 below): *"worse energy performance than anticipated, unmanageable complication, controls a mess....."*

As we have already emphasised (Sections 2.5, 3.10), neither an accreditation such as BREEAM Excellent, nor receipt of architectural awards, necessarily makes a building green in the sense of being a successfully performing low-energy building. As noted in Section 3.10 above, this same presentation²⁷ (Footnote 27, Slide 5) also highlighted the design-performance gap for a building given a "Green Building of the Year" award. CO₂ emissions from both gas and electricity use were over twice the design predictions (Figure 14 above).

The present paper is principally concerned with buildings and their energy use but, as noted in the previous Chapter, a well-designed and constructed low-energy building, such as the Elizabeth Fry Building at UEA, will also achieve outstanding levels of occupant satisfaction. By contrast, a building where the processes outlined in Chapter 3 have not been followed may not just be a poor performer in energy terms but is also likely to create problems and difficulties for those who occupy it or work in it. The performance gap seems to extend from energy use to occupant

(dis)satisfaction as we note for West Suffolk House below and as shown for the “award winning school” in Figure 15.

Such occupant survey results are a warning that a building that seems attractive to occasional visitors, such as judges of building awards, may actually perform in practice very poorly indeed¹³³. As Figure 15 above indicates, judges may not experience a building in the way that occupants do. The contrast in the occupant responses shown in Figure 15 with those for the Elizabeth Fry Building and the most recent Termodeck building at UEA, the Thomas Paine Study Centre (Figure 10), is striking. Such results emphasise the vital importance of post-construction evaluation (Section 3.8).

New non-domestic buildings: What have we tended to find, for many years now?

- They often perform much worse than anticipated, especially for energy and carbon, often for occupants, and with high running costs, and sometimes technical risks.
- Design intent is seldom communicated well to users and managers. Designers and builders go away at handover.
- Unmanageable complication is the enemy of good performance. So why are we making buildings technically and bureaucratically complicated in the name of sustainability, when we can't get the simple things right?
- Buildings are seldom tuned-up properly. Controls are a mess. If we have more to do, what chance do we have?
- Modern procurement systems make it difficult to pay attention to critical detail. A bad idea when promoting innovation.

What works, what doesn't work, and how we can fix it: using Building Performance Evaluation (BPE) for rapid improvement, Bill Bordass, 27 September 2011, presentation downloadable from the Usable Buildings Trust website, <http://www.usablebuildings.co.uk>.

Figure 16. A summary of findings for non-domestic buildings in the UK; they often perform much worse than anticipated²⁷.

In terms of energy performance, the Strategic Conclusions chapter of the PROBE Strategic Review¹¹¹ noted that: “*Nearly all Probe buildings claimed to be energy efficient, but the range of annual consumption and emissions was massive, with a factor of six between the highest and the lowest, and even greater variations in some individual end uses.*”

What caused these problems and inefficiencies? The PROBE Technical Review Chapter⁸¹ highlighted the pervasiveness of persistent problems.

¹³³ We suggest that any buildings nominated for architectural or other awards should have independent energy audits and independent occupant surveys carried out beforehand.

- *Unnecessarily high energy consumption, particularly in the air conditioned buildings and areas; exacerbated by excessive levels of ventilation, humidification and plant operation.*
- *High levels of air infiltration. Pressure tests showed that only two of the eight buildings in Probe 2 met reasonable standards (and motorised openings for automated natural ventilation could themselves be very leaky). A lack of controlled airtightness not only wastes energy directly but causes poor comfort and additional plant running hours. It also undermines the benefits of good insulation and requires plant to be routinely oversized.*
- *Little energy management activity, even in otherwise well-managed buildings and in those for which energy efficiency had figured prominently in the brief.*
- *Often too much complication, leading to technical problems, unintended consequences, and difficulties for management. "Keep it simple and do it well" is a strong message.*
- *Poor functionality, usability and manageability of controls, both manual (e.g. windows) and automatic (which also reduced comfort)*
- *Little or no provision for monitoring and fine-tuning systems after occupancy.*

The previous Chapter has outlined how all these concerns can be overcome with a quality approach to design and construction. Where this is attempted, the results are outstanding. As the PROBE Technical Review noted⁸¹:

"The best example of combining comfort and energy efficiency was the Elizabeth Fry Building, where a committed client and a design team which had worked with them before were able to make thoughtful and responsible innovations, to take advice where necessary, and to deliver - via a committed contractor - an attractive, comfortable and energy-efficient building at normal cost levels. ... Overall FRY presents the best example yet of virtuous processes with careful briefing, team selection, design, construction, commissioning, monitoring and operation leading to unusually high levels of satisfaction, together with low energy consumption."

Have things improved since the 1990s? It would seem not.

As another of the PROBE study team, Roderic Bunn of BSRIA¹¹⁹, has recently noted¹³⁴, with the exception of the findings for the Elizabeth Fry Building, the PROBE studies between 1996 and 2001 frequently found energy consumption to be a factor of three higher than 1990 benchmarks, buildings to be feature-packed but not functional, and controls to be unmanageably complex.

¹³⁴ *School Design: a Soft Landings syllabus*, Roderic Bunn, Paper at The Natural Ventilation of UK School Classrooms Conference, Chartered Institute of Building Services Engineers Schools Design Group and Natural Ventilation Group, London, 4 October 2011.

Sadly, Bunn noted that things were little better between 2006 and 2010 in the Low Carbon Buildings Programme³⁰ where twenty-three buildings were studied. Once again, Bunn noted the prevalence of feature packed but not functional buildings, unmanageable complex controls and building management systems, and energy consumption over three times the figures calculated.

The problem seems to be one of lack of quality in design and in construction compounded by lack of evaluation, monitoring and feedback. Rather than taking a quality approach to design and construction, those responsible seem to add complexity in a vain attempt to achieve the desired outcomes. Failure to achieve these outcomes is almost inevitable but the owners and occupants have little recourse to any effective action. A new building cannot be traded in like a new car and problems appear only over time.

The complexity of controls and of building management systems, and the frequent inadequacy of metering, mean that actual performance data is probably non-existent in very many cases. The supposedly better-than-average buildings in the PROBE and Low Carbon Buildings Programmes are exceptional only in being closely studied. The results for most buildings are unknown but must be assumed to be similar or worse to those studied in PROBE and LCBP. As Roderic Bunn said¹³⁴: *“Unmanageable complexity is the enemy of good performance ... energy use is climbing not falling”*.

The solution, as already noted, is to adopt a quality approach, exemplified by the attention to detail necessary to achieve the passivhaus standard, and focusing on simplicity and ease of operation. Other building assessment processes either reward complexity or do not demand quality in both design and construction. They assess a building before it is even built and require no evaluation of actual performance.

What is particularly unhelpful, however, is the provision of misleading information about poorly performing buildings implying that they are actually as good as the designers and assessments such as BREEAM may claim. Such misinformation makes learning and improvement difficult if not impossible.

West Suffolk House

West Suffolk House in Bury St Edmunds, Suffolk, is just such an example. This £20m, 6439m² building, occupied in March 2009, is discussed here because it demonstrates the problems – and the performance gaps – that present-day building procurement processes so often create and also highlights the reluctance of the industry to acknowledge the problems. The reluctance to reveal and discuss the realities of building performance make it almost impossible to learn from experience and to improve.

The intentions of the clients for West Suffolk House, St Edmundsbury Borough Council and Suffolk County Council, were surely admirable, but the manner of the design, construction and handover processes, as reported, seemed exemplars of how not to deliver a low-energy building (the opposite, almost entirely, it would

appear, of the principles outlined in Chapter 3). Sadly, there seems little evidence that West Suffolk House is unusual in either procurement, design or construction practice. Soft landings (see Section 3.8) will, if widely introduced, certainly help, but if low-energy performance in practice is actually to be achieved, radical change also in design and construction is essential, with passivhaus or similar quality principles becoming the norm. Only a certain amount can be achieved post-construction.

Rather than use West Suffolk House as an exemplar and learning experience of how improve, it has been promoted¹³⁵ (p55) as an excellent example of sustainable asset management: *“The example of a building with long-term benefits is the joint property solution by St Edmundsbury Borough Council and Suffolk County Council. They have created a sustainable building, West Suffolk House, of BREEAM Excellent grade with incorporated passive design and energy efficiency features using renewable energy sources.”*

The case study for West Suffolk House described on the following pages of *Leaner and Greener*¹³⁵ notes that revenue savings of £924,000 per year have been achieved using modern ways of working. The report goes on to say that: *“West Suffolk House has created a better work environment and achieved increased staff productivity”*.

The actual outcome could not be more different to that implied by this optimistic statement. West Suffolk House was evaluated as part of the UK’s Low Carbon Buildings Programme³⁰ and the findings were reported¹³⁶ in 2011. In summary:

“the building emits 88.4kgCO₂/m², which is nearly three times the design estimate, meaning it could not fairly be described as a low-carbon building. To add insult to injury the building is slated by its occupiers¹³⁷ who complain the building is either too hot or too cold, makes them ill and is noisy.”

Energy use is shown in Figure 17 and the occupant satisfaction (or rather dissatisfaction) survey in Figure 18.

These are outcomes for a building given a BREEAM ‘Excellent’ rating and an EPC ‘A’ rating. In fact¹³⁶: *“The building received an EPC rating of A but this high energy*

¹³⁵ *Leaner and Greener: Delivering Effective Estate Management*, Westminster Sustainable Business Forum, London, February 2011, <http://www.policyconnect.org.uk/sites/default/files/Final%20version%20-%20blacktype%20-%20Leaner%20and%20Greener.pdf>.

¹³⁶ *Post occupancy: Is your building really so green?* by Thomas Lane, Building.co.uk, 1 July 2011, <http://www.building.co.uk/buildings/special-projects/post-occupancy-is-your-building-really-so-green/5020231.article>. This article was composed from more detailed reports written by Roderic Bunn^{138 139}.

¹³⁷ Roderic Bunn wrote¹³⁹: *“The building is perceived to be an unhealthy work environment by 66 per cent of the occupants. Many complain of fatigue, sleepiness, headaches, and greater incidence of colds and flu viruses. A majority of occupants complain of poor ventilation, workplaces that are either too stuffy or too draughty, and noise breakout from the ground floor atrium and cafe. “Too hot, stuffy and noisy” was a common refrain. These comfort problems are perceived to reduce productivity.”*

use means the display energy certificate is an E.” Hopefully things have improved in the three years since occupation but this comparison between design and actual performance is stark.

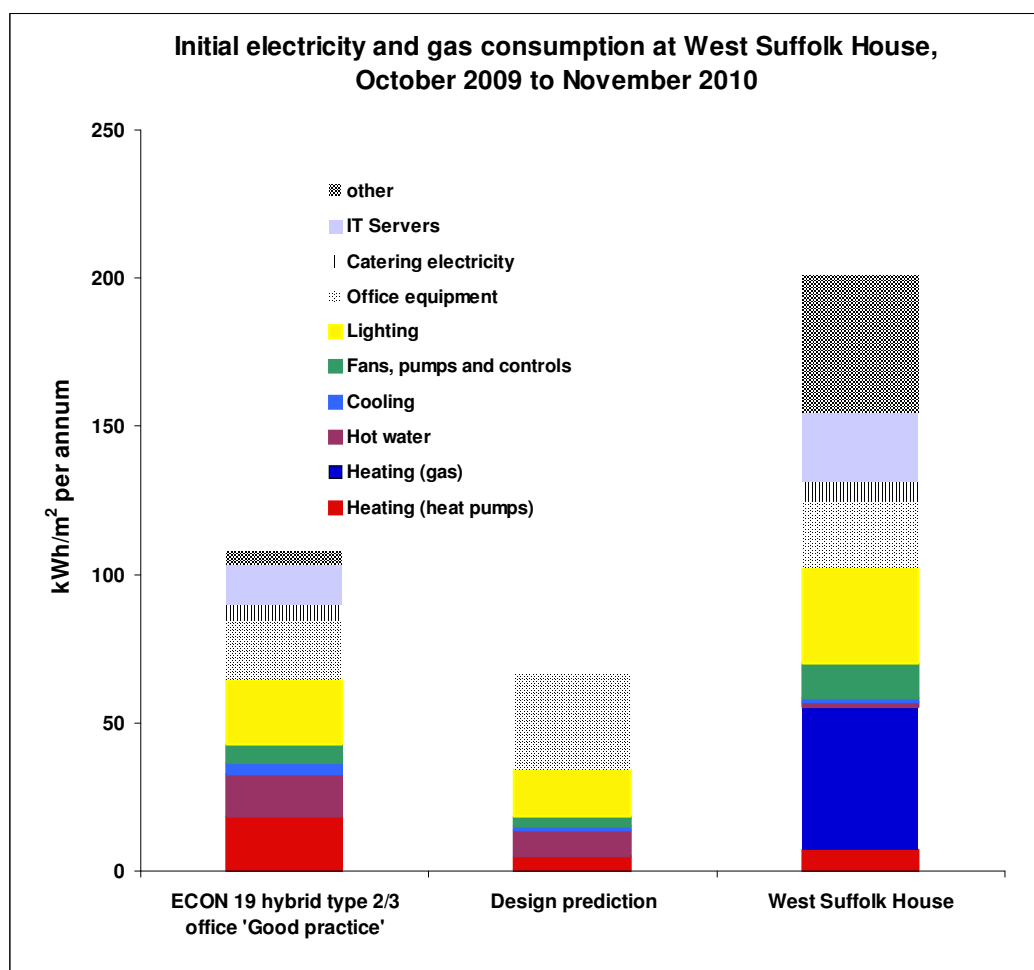


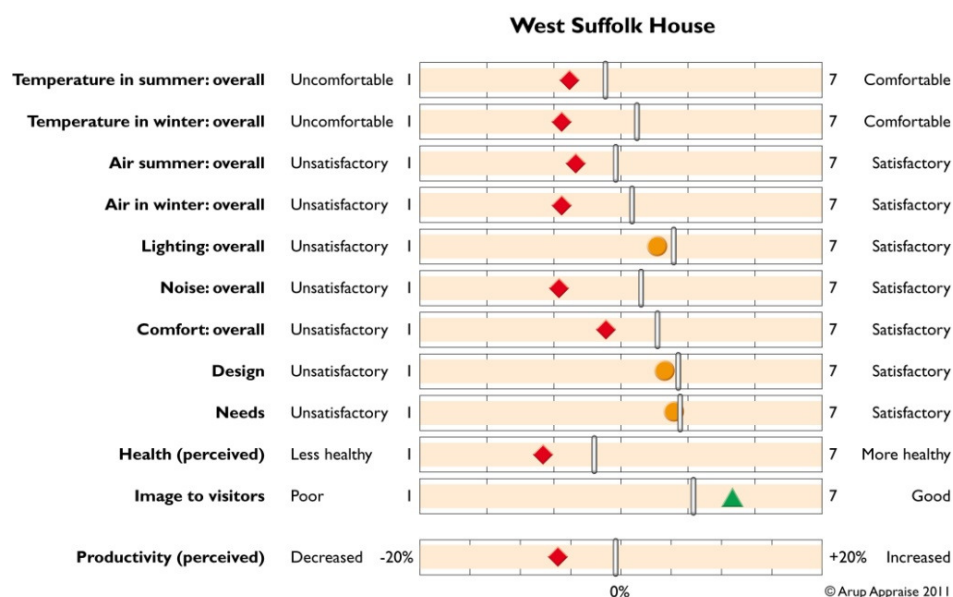
Figure 17. Energy performance of West Suffolk House¹³⁶ compared with design modelling and the relevant benchmark from Energy Consumption Guide 19 (ECON 19).

Roderic Bunn of BSRIA¹³⁸ provided the detailed information¹³⁹ on which the summary report¹³⁶ was based. He wrote¹³⁹: “One of the glaring findings from the

¹³⁸ Principal Consultant in building performance analysis at BSRIA Ltd who worked for the Carbon Trust on the Low Carbon Buildings Performance programme and is a lead Building Performance Evaluator for the Technology Strategy Board.

¹³⁹ *West Suffolk House*, Roderic Bunn, June 2011.

analysis is the huge disparity between actual emissions and the emissions predicted by the simulation model. The difference between prediction and reality is so great, that one might conclude that simulation models are wholly inadequate for setting realistic ambitions for energy use and carbon dioxide emissions. The EPC thus generated creates an illusion for both client and design team that is shattered by actual performance data.” The comparison between this conclusion and the detailed energy modelling for passivhaus **Error! Bookmark not defined.**, is striking.



Green triangles represent mean values significantly better or higher than both the benchmark and scale midpoint. Amber circles are mean values no different from benchmark. Red diamonds are mean values worse or lower than benchmark and scale midpoint. The UK benchmarks are represented by the white line through each variable.

Be careful to read the directions of the scales and the scale labels.

Figure 18. The results¹³⁶ of the occupant satisfaction survey for West Suffolk House carried out in February 2011 (two years after occupation). The building has 541 workstations and 241 survey forms were returned. Note that the majority of indicators are worse or lower than the benchmark and scale midpoint. Only the score for image to visitors is significantly better (as also noted in Figure 15)! In contrast to the claim in *Leaner and Greener*¹³⁵, perceived productivity is significantly poorer than the benchmark. Compare this result with the survey for UEA’s Thomas Paine Study Centre (Figure 10), carried out a few months later in July 2011, where every indicator is green.

What went wrong? The summary report¹³⁶ notes a rushed design and build phase that was cost-driven with design changes and cost-savings being made during the

construction process, lack of a proper commissioning plan, inadequate metering, and a design with deep floorplates that made successful natural ventilation very difficult to achieve.

Low-energy buildings cannot be delivered by adding increasing levels of complexity to a design and construction process driven primarily by considerations of cost as seems to happen so often today. Roderic Bunn, also involved in the PROBE studies of the 1990s is quoted in the summary¹³⁶: *“What we knew 10 years ago from the PROBE projects is that unmanageable complexity is the enemy of good performance. What we are doing is introducing complexity into buildings without thinking about procurement, commissioning and training people how to use these systems.”*

*Leaner and Greener*¹³⁵ notes elsewhere (p29) the very significant benefits that can be achieved in existing buildings by attention to energy use and meter readings and by action, often low cost action, that can lead to reduced energy use and hence to significant financial savings. *Leaner and Greener*¹³⁵ also points out (pp28, 29; see also Chapter 6 below) that non-energy savings, a consequence of improved productivity and reduced sickness, can represent an even greater benefit of a green building than cost savings from reduced energy use. This is because, as we discuss in Chapter 6, the cost of people in buildings is usually many times the cost of energy – or, indeed, of construction. If people are more productive and take less sick leave as a consequence of their workplace environment, then the so-called ‘soft’ benefits can be impressive indeed.

However, as the above Figures in this Chapter warn, the adjectives ‘green’ or ‘sustainable’ are meaningless unless backed up with actual data both for energy use and for occupant satisfaction. The implied conclusion that simply calling a building ‘green’ or ‘sustainable’ (as was done in *Leaner and Greener* for West Suffolk House), or having an excellent BREEAM or EPC rating (as did West Suffolk House), thereby automatically produces improved productivity, reduces sick leave, and creates impressive financial savings is plainly wrong. Perceived productivity in West Suffolk House is significantly below the UK benchmark and occupants claim the building makes them ill.

In contrast, genuinely low-energy buildings, such as the Elizabeth Fry Building and passivhaus buildings across Europe, really do create a sense of well-being¹⁴⁰. Where surveys have been done, as at the Elizabeth Fry Building and the Thomas Paine Study Centre (Figure 10), perceived productivity, comfort, and well-being, are indeed above benchmarks, indicating that buildings that really are low energy in performance as well as in name can yield significant benefits beyond their energy economy (we provide more background in Chapter 6).

¹⁴⁰ See the quotes at the front of this report and the findings noted in Footnote 43. Findings by Build with CaRe partners for passivhaus homes in Germany, Sweden and Holland bear out these conclusions.

4.2. The Performance Gap - Domestic Buildings

While most homes are far smaller and, in principle, simpler to design and to construct and to operate than the, mostly, much larger, non-domestic buildings discussed above, the problem of the performance gap remains. This fact indicates that the origins of the energy performance gap problem lie within the design and construction process itself. The problem is common to all building types.

As is the case for non-domestic buildings, very few homes are evaluated via reliable building performance evaluation (BPE)¹⁴¹ but the evidence from what studies there are is alarming. As Bill Bordass has recently summarised⁸², BPEs in recent domestic buildings reveal massive potential for improvement (Figure 19)

BPEs in recent domestic buildings reveal massive potential for improvement

- Frequent shortcomings in thermal integrity.
- Design for natural ventilation and cooling is often compromised.
- Controls were often far from intuitive, poorly located, and giving little or no feedback on performance and unintended operation.
- As programmers become more powerful, fewer people can programme them, and so cease to make adjustments to suit need.
- How systems are supposed to work was usually poorly recorded.
- Developer or landlord representatives who explained the technology to occupiers usually didn't understand it themselves!
- MVHR systems were often poorly understood, installed and maintained. Maintenance access could be poor too.
- Many solar hot water systems weren't working properly; or their potential was being usurped by boiler controls, unintended use of immersion heaters, or over-zealous anti-legionella measures.

What works, what doesn't work, and how we can fix it: using Building Performance Evaluation (BPE) for rapid improvement, Bill Bordass, 27 September 2011, presentation downloadable from the Usable Buildings Trust website, <http://www.usablebuildings.co.uk>.

Figure 19. Problems in homes revealed by Building Performance Evaluation, BPE.

¹⁴¹ "Not since the early 1990s has any large-scale post-occupancy monitoring of the fuel consumption of homes been undertaken in the UK", Footnote 144, p16.

The Zero Carbon Hub⁴¹ is well aware of this problem and the performance gap has been detailed and discussed in several reports^{142, 143, 144}. The magnitude of the issues were summarised in the Executive Summary of *A Review of the Modelling Tool and Assumptions, Topic 4*¹⁴²:

“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.”

It's even worse than this. If the industry cannot build new low-energy homes that really are low-energy in performance then demand reduction and climate change targets cannot be met (see Section 2.7). If there are major issues with new-build then, as we have already noted (Section 1.5), such issues will be even more prominent in homes that are refurbished supposedly to become low-energy homes.

Building occupants are unlikely to become aware of the specific defects that cause an energy consumption performance gap because the faults that create thermal bridges and air leakage will all be hidden from view. Because of the wide variation in individual energy use in homes (see, for example, Figure 1) occupants may well not even be aware that their homes are performing poorly.

As discussed above in Section 2.7, paragraphs on *Air quality in homes – potential problems with “zero carbon homes”*, however, what occupants almost certainly will notice in new homes without mechanical ventilation (or where mechanical ventilation is inadequately installed – see Section 4.3 below), that are better insulated and more air-tight than today's, is over-heating¹⁴⁵ and poor air quality. Indeed, there is concern today that undiagnosed ventilation and indoor air quality problems may be widespread¹⁴⁶.

¹⁴² 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*, Zero Carbon Hub, August 2010, http://www.zerocarbonhub.org/resourcefiles/TOPI4_PINK_5August.pdf.

¹⁴³ Carbon Compliance for Tomorrow's New Homes, *A Review of the Modelling Tool and Assumptions, Overview of Findings and Recommendations*, Zero Carbon Hub, July 2010, http://www.zerocarbonhub.org/resourcefiles/CARBON_COMPLIANCE_GREEN_OVERVIEW_18Aug.pdf.

¹⁴⁴ *Low and zero carbon homes: understanding the performance challenge (NF41)*, NHBC Foundation and Zero Carbon Hub, February 2012, available at <http://www.nhbcfoundation.org/Researchpublications/NF41/tabid/500/Default.asp>; see also Footnote 26.

¹⁴⁵ “Overheating risk is a significant concern, with implications for carbon emissions, health and consumer choice. There is some anxiety that homes we are building today may be at risk of overheating even in the current climate. Given the prospect of significant warming, well within the expected lifetime of homes, this risk will increase with potentially serious consequences.”, Footnote 143, Executive Summary, p7.

¹⁴⁶ “...many new low-energy homes that are not monitored, may have undiagnosed ventilation and indoor air quality problems.”; reference *Ventilation and good indoor air quality in low energy homes*, Melissa Taylor

Demands for compensation and expensive rectification work as mentioned will most likely arise not so much from the study of energy bills but from problems from overheating and poor air quality. The only reliable way to transform construction quality and so avoid such problems – that will represent a massive misuse of investment if they are not tackled – is to move to passivhaus or similar standards for new build with processes as summarised in Chapter 3. As we note below, however, this is not the route the industry is proposing.

Whole house heat loss results

The concerns about an energy performance gap for homes are demonstrated in a figure showing measured versus predicted whole house heat loss for new build dwellings (Figure 20). These show data collected at as-built homes before any influence of occupant behaviour. They show, in other words, the performance of the fabric alone, and for houses that, for the most part, were built to demonstrate energy efficiency. Hence it would be expected that this sample would be at the excellent end of overall performance.

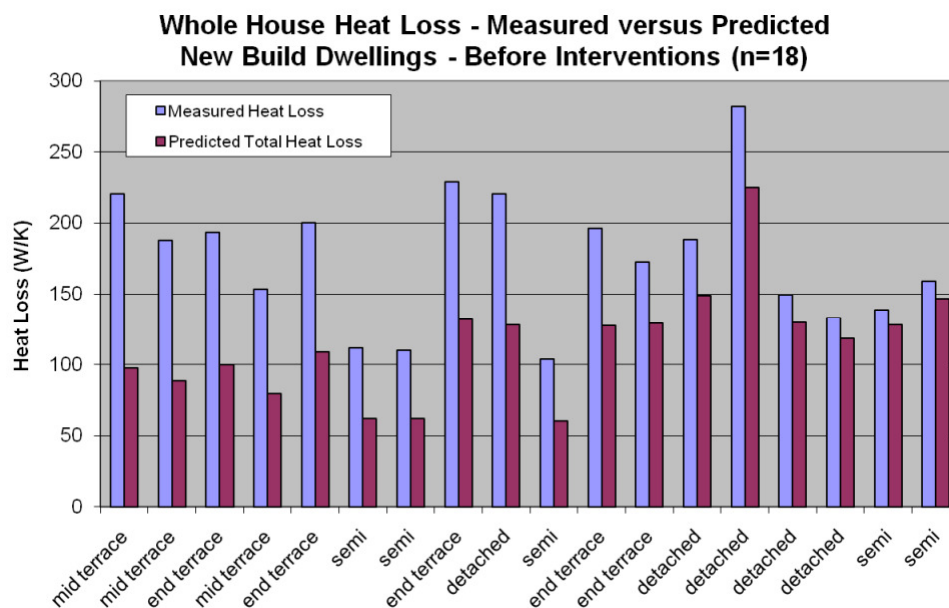


Figure 20. Measured versus predicted whole house heat loss for new build homes. Source: Centre for the Built Environment, Leeds Metropolitan University; Jez Wingfield Presentation at the Good Homes Alliance, Low Carbon 4 Real event April 2011, see http://www.goodhomes.org.uk/library_files/105. The same Figure is also shown in the reports referenced in Footnotes 142 and 143.

and Laura Morgan, Good Homes Alliance, November 2011,
<http://www.goodhomes.org.uk/downloads/news/VIAQ%20final%20120220%20-%20PUBLICATION.pdf>, p73.

Admittedly, the sample size is small but as Reference 142 (p12) notes:

“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. ... 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.”

Tackling the problem – or not? The *“traditional construction model”*

Figure 19 above outlined the range of problems observed in new homes after construction and that reveal massive potential for improvement. These problems reflect endemic quality issues and the *Carbon Compliance Overview*¹⁴³ correctly pointed out (p41) that these same quality issues that also give rise to the performance gap are endemic across the design, construction and handover process (Figure 21).

Problems that have been found include:

- Incorrect specification of building materials in design; incorrect data used in design.
- Design weaknesses not recognised by compliance model.
- Construction details inadequately specified in design, or not well enough communicated to site.
- Building materials not conforming to specification or not performing in situ as expected.
- Inappropriate substitution of one material (or supplier) for another as a result of decisions made on site.
- Compliance compromised by poor sequencing of stages of construction.
- On-site construction not conforming to design; ‘buildability’ not considered in design.
- Calculation or input errors in design or compliance testing.

Carbon Compliance for Tomorrow’s New Homes, A Review of the Modelling Tool and Assumptions, Overview of Findings and Recommendations, Zero Carbon Hub, July 2010, http://www.zerocarbonhub.org/resourcefiles/CARBON_COMPLIANCE_GREEN_OVERVIEW_18Aug.pdf.

Figure 21. Problems that can lead to poor quality in new homes and to an energy performance gap in particular as detailed in the report referenced in Footnote 143, p41. This reference notes that: “difficulties do not simply arise on site, but may be traced all the way back to design and products/systems specification.”

Essentially all these problems could be solved by following the principles detailed in Chapter 3 and that were followed, for example, in the construction of the Elizabeth Fry Building and the Wolverhampton passivhaus schools. Both these projects

demonstrated that low-energy buildings could indeed be delivered at no extra cost, and by a workforce that had no special training apart from instruction on quality in detailing.

However, this is not what is proposed. Instead an accreditation scheme is suggested¹⁴², but even the Zero Carbon Hub which suggested this has doubts about its effectiveness. As the most recent Zero Carbon Hub document¹⁴⁴ on the performance gap notes: *“The Zero Carbon Hub has made a case for a government accreditation scheme for builders of low energy homes¹⁴², although it is unclear how this would work with large-scale subcontracting of labour.”*

It is indeed unclear how an accreditation scheme would work apart from creating a massive box-ticking exercise. *Low and zero carbon homes: understanding the performance challenge¹⁴⁴* therefore recommends: *“In the mass market, and in keeping with the philosophy of keeping things simple, increased use should be made of what is already available. There are numerous industry publications, training schemes, good practice guides, etc, the potential of which for closing the performance gap is far from exhausted.”*

Modest improvement may be possible but change hasn’t happened to date and there is no sense that the necessary change is on the horizon. Hence it seems highly unlikely that such use of existing methods can come anywhere near to enabling that transformation in quality that is essential if high-quality low-energy buildings are to be reliably delivered. The quality problem is endemic¹⁴⁷ and will not be solved without a transformation in management attitudes. Good practice guides, however well-intentioned, don’t seem quite sufficient.

The detailed Zero Carbon Hub study of the performance gap¹⁴² noted in a section on *“A Review of the Evidence”* (p11) the succession of reports on the construction industry that had commented on endemic quality problems. These reports, although widely quoted, have not yet led to action on quality that will eliminate the performance gaps.

As we note next in discussing problems with MVHR (mechanical ventilation and heat recovery) installations, it is the *“traditional construction model”* that gives rise to the problems. The *“traditional construction model”* is still in place and seems very deep-rooted. Neither an accreditation scheme, nor use of existing good practice publications, training schemes and the like, seem likely to stimulate the necessary change in an industry that has resisted change in spite of one report after another.

The problems, identified in many studies, were discussed above (Section 3.5 and Section 3.7, paragraphs on *The problem is not with skills but with management*) and are detailed in Chapter 5 below. An adversarial culture fed by extensive subcontracting makes it impossible to develop the teamwork and partnering that are essential to sustain high quality processes.

¹⁴⁷ As noted by the Zero Carbon Hub in its own study (Footnote 142, pp20, 21) of the performance gap – see Chapter 5 for more detail.

The need for passivhaus quality

The adoption of passivhaus quality, as has been now demonstrated in the UK as well as in countries on the continent of Europe, can, however, drive the necessary change with benefits not only to building owners and occupants but to the whole construction industry as well. The principal change that is necessary is not massive new expenditure on design or on building materials nor massive expenditure on skills and training. Rather, as Thomas Vale Construction demonstrated at Wolverhampton (Section 3.7), and UEA and its partners did with the Elizabeth Fry Building some years earlier, what is needed is a management focus on quality and on the teamwork necessary and essential to deliver a low-energy building.

Why the lack of enthusiasm by the Zero Carbon Hub for the kind of major change that is really needed? It would appear that the Zero Carbon Hub is unconvinced that volume housebuilders would accept the quality measures implicit in passivhaus new build construction. As the most recent report on the performance gap¹⁴⁴ says (of passivhaus quality): *“Such an approach clearly has merit in reducing the performance gap, but it is arguably unrealistic to expect volume housebuilders to change their practices so radically.”*

Really? Any of the world’s car makers that had taken such an approach to quality in recent decades would now be out of business. Why should the construction industry be any different? As Thomas Vale Construction has shown with the Wolverhampton passivhaus schools, it is perfectly possible to adopt passivhaus quality with the existing workforce and at no extra cost. The examples are now in place for the whole industry to learn from. All that is required is the desire to create a quality product.

Should we not expect volume housebuilders in particular to see achievement of passivhaus quality as a badge of honour¹⁴⁸ and a demonstration of the quality commitment to those who buy their new homes? The quality transition will become even easier as more stringent low-carbon standards come into place in the coming years.

If the systems were put in place to make passivhaus or comparable quality mandatory for new build then everyone would benefit. The energy performance and quality of homes and other buildings would be transformed as would occupants’ health, well-being and – in non-domestic buildings – productivity (see Chapter 6). There would then be no doubt that energy saving, demand reduction and climate change targets for buildings could indeed be met. Fuel poverty could be eliminated. The competitiveness of the construction industry and its supply chains would be transformed.

¹⁴⁸ In Section 2.6 we quote Nick Grant, Passivhaus Trust³⁹ Technical Director and consultant for the Wolverhampton passivhaus schools, who has said⁴⁰: *“It is great when airtightness is seen as a badge of honour, something to take pride in rather than a compliance hassle.”*

While this report focuses on the UK there is little doubt that all the issues apply, to a greater or lesser degree, to other countries across the EU.

In the next Chapter we review in more detail the quality concerns regarding the construction industry and the importance of teamwork through the whole process. Addressing these concerns is the fundamental and essential step to guaranteeing the successful delivery of low-energy homes. Firstly, we summarise recent findings on installations of mechanical ventilation with heat recovery (MVHR) systems. These findings highlight exactly the problems that have been brought to the fore in consideration of the energy performance gap and how they are caused by the “*traditional construction model*”.

4.3. The performance gap – MVHR

The endemic quality problems in construction are displayed, in miniature, in the installation and performance of mechanical ventilation with heat recovery (MVHR) systems. As the industry in the UK moves towards the so-called zero carbon homes target (see Section 2.7), it is highly likely that MVHR will become the dominant means of ventilation in the majority of new homes. As already noted in Section 2.7, in passivhaus homes and schools in mainland Europe today, MVHR systems consistently supply excellent indoor air quality with high levels of occupant satisfaction^{43, 44}.

A recent Zero Carbon Hub report on MVHR¹⁴⁹ has pointed out (p22) that a good quality indoor environment is particularly important because most people spend more than 90% of their time indoors, and more than half of this time at home. The report gives background information to studies on air quality in homes and the problems caused by dampness¹⁵⁰ and by house dust mites¹⁵¹, for example.

Without adequate ventilation, other pollutants such as nitrogen dioxide from gas cooking stoves, and volatile organic compounds from paints and furnishings can also accumulate. The Zero Carbon Hub report¹⁴⁹ highlights potential concern with modern homes that may be quite tightly sealed but poorly ventilated:

¹⁴⁹ *Mechanical Ventilation with Heat Recovery in New Homes*, Interim Report, Ventilation and Indoor Air Quality Task Group, Zero Carbon Hub, January 2012, http://www.zerocarbonhub.org/resourcefiles/ViaqReport_web.pdf.

¹⁵⁰ “The presence of many biological agents in the indoor environment is due to dampness and inadequate ventilation. Excess moisture on almost all indoor materials leads to growth of microbes, such as mould, fungi and bacteria, which subsequently emit spores, cells, fragments and volatile organic compounds into indoor air. Moreover, dampness initiates chemical or biological degradation of materials, which also pollutes indoor air. Dampness has therefore been suggested to be a strong, consistent indicator of risk of asthma and respiratory symptoms (e.g. cough and wheeze).”, Footnote 149, p21

¹⁵¹ “Howieson et al refer to changes in the design and use of the domestic environment over the latter part of the 20th century that are likely to have led to a significant increase in house dust mite concentrations and that this may be the prime cause of the rising incidence of asthmatic symptoms in children, the UK having the world’s highest prevalence of asthma symptoms in 13–14-year-olds.”, Footnote 149, p35

“Only a few homes built to contemporary standards of airtightness have been studied in the UK but, worryingly, these studies identified high levels of relative humidity and nitrogen dioxide in a significant minority of the homes surveyed and high total volatile organic compound levels in over half of the homes. Evidence from other countries was also reviewed and the Task Group concluded that many pollutants are present within the internal environment of homes and that these tend to be at their highest in new homes or homes that have been recently refurbished.”¹⁵²

Hence new energy efficient homes, or many homes refurbished to a high standard of energy efficiency, will almost certainly suffer air quality problems with potential impact on occupant health if MVHR is not present or is present but is not operating efficiently. When MVHR is working well, ventilation will supply adequate quantities of fresh and filtered air, and remove stale air and the pollutants in it, as long as filters are changed, cleaned or washed regularly. The impurities collected by the filters would, without the presence of MVHR, be inhaled by the occupants of these homes¹⁵³.

Because the fabric of a passivhaus building is so effective in retaining heat, recovering the heat from the outgoing air via mechanical ventilation with heat recovery (MVHR) is often the only auxiliary form of heat needed in a passivhaus home or building (in addition to the heat from the sun and from people and appliances in the building).

Where passivhaus quality is not present, however, problems are likely to appear in MVHR installation and operation just as they appear elsewhere (Figure 19 and Figure 21) and in an energy performance gap. Rather than providing excellent indoor air quality, poorly designed or installed MVHR systems can create noisy and potentially unhealthy environments.

The Zero Carbon Hub report¹⁴⁹ notes (p6) that: *“The Task Group considers that examples of failures in typical design, installation and commissioning practice are all too common and these will have the effect of reducing the performance of systems. Badly performing systems may not deliver the anticipated carbon savings and may result in degraded IAQ [indoor air quality] with related consequences for health.”*

Just as it is important to get construction detailing designed and installed correctly in order to deliver a low-energy building, so it is equally important to design and install

¹⁵² Footnote 149, p6

¹⁵³ An image (from bere.architects.co.uk) of an MVHR filter removed after 6 months in central London is shown on slide 14 of a presentation about passivhaus given to local people, district councillors, and others interested in the passivhaus project at Tye Green, Wimbish in Essex (see Footnote 20): *Towards Zero Carbon: A Short Introduction to Passivhaus at Tye Green*, Paul Smyth, Inbuilt Ltd, [http://www.wimbishpassivhaus.com/Introduction to Passivhaus Paul Smyth Uttlesford DC.pdf](http://www.wimbishpassivhaus.com/Introduction%20to%20Passivhaus%20Paul%20Smyth%20Uttlesford%20DC.pdf). See also <http://www.bere.co.uk/tags/mvhr> for a picture of filters removed from a London property after only four months because they had trapped so much pollution from the air. Without MVHR this pollution would be in the air that people breathe in their homes.

ventilation systems correctly in order to deliver a healthy internal environment in a low-energy building. The aspects of fabric performance (energy use) and MVHR (ventilation and air quality) are complementary parts of the overall process. Problems with either energy performance or air quality are, at root, quality problems reflecting poor teamwork. Both can be solved by a quality approach to construction based on teamwork and partnership working.

The issues and concerns that are presently apparent in MVHR installations¹⁴⁹ have been comprehensively detailed in presentations given at a recent conference¹⁵⁴. A presentation¹⁵⁵ by Andrew Farr of the Green Building Store¹⁵⁶ noted (slides 5 and 6) that passivhaus quality does indeed encourage good MVHR design and that well-installed MVHR will provide:

- *High air quality*
- *Effectively imperceptible ventilation to the inhabitants*
- *High thermal efficiency/low heat losses*
- *Low electricity consumption, and will also be*
- *Easy to service.*

However, he emphasised that, in order to achieve good MVHR design and installation, good communication is essential between the passivhaus designer, the energy consultant, the architect, the M&E (mechanical and electrical) consultant or designer, and the main contractor. In other words, a partnership model of working – or, more simply, teamwork – is necessary, just as it is to design and build a low-energy building (Chapter 3). He contrasted this approach with the sequentially phased “*traditional construction model*”¹⁵⁷.

As just noted (Section 4.2), it is this “*traditional construction model*” that is responsible for the defects in design and construction that lead to the energy

¹⁵⁴ *Healthy homes: ventilating right for good indoor air quality*, Good Homes Alliance, UK Indoor Environments Group conference, 22 February 2012, presentations available at <http://www.goodhomes.org.uk/events/101>.

¹⁵⁵ *Ensuring optimal performance of Mechanical Ventilation Heat Recovery (MVHR) systems*, Andrew Farr, presentation at Good Homes Alliance, UK Indoor Environments Group conference, 22 February 2012, *Healthy homes: ventilating right for good indoor air quality*, <http://www.goodhomes.org.uk/downloads/events/Andrew%20Farr%20-%20Green%20Building%20Store.pdf>.

¹⁵⁶ <http://www.greenbuildingstore.co.uk/>.

¹⁵⁷ As did other speakers at the conference also, for example Ian Mawditt of Four Wall Consultants Ltd., *Ventilation installations: some common problems*, presentation at Good Homes Alliance, UK Indoor Environments Group conference, 22 February 2012, *Healthy homes: ventilating right for good indoor air quality*, <http://www.goodhomes.org.uk/downloads/events/ian%20Mawditt%20-%20Four%20Walls%20Consulting.pdf>. Mawditt emphasised the need for a collaborative chain of command: one system, one team, that avoids the silos present in what Farr (Footnote 155) called the “*traditional construction model*”.

performance gap. It is evident that the “*traditional construction model*” also leads to profound problems in installation and operation of MVHR systems as was made clear by several presentations at the conference¹⁵⁴.

Thus, Alan Gilbert of BSRIA¹¹⁹ noted¹⁵⁸ that 95 per cent of dwellings tested in 2011 and 2012 failed to meet the ventilation requirements contained in the UK Building Regulations, with many installations having multiple types of failure. Of 40 buildings tested in respect of mechanical ventilation, 33 (over 80 per cent) had ductwork incorrectly fitted. Poorly installed ductwork was said without question to be the largest cause of systems not performing properly.

We have noted in several places the concern that if new build constructions do not perform satisfactorily, then it is likely that matters will be even worse for refurbishment projects. This, sadly but predictably, was the BSRIA conclusion as regards mechanical ventilation. Things were bad for new build but even worse for refurbishment projects. Defects noted in refurbishments included supplies in wet rooms, extracts in living areas, no ducting fitted, two terminals in a bathroom – supply and extract, direct line of sight between a bedroom and a bathroom (supply) wall grille. As Gilbert noted¹⁵⁸: “*The list goes on and on.*”

These presentations all agreed that a different mode of working involving partnership and teamwork is essential if MVHR quality is to be assured.

¹⁵⁸ *Practical experience of common ventilation problems*, Alan Gilbert, presentation at Good Homes Alliance, UK Indoor Environments Group conference, 22 February 2012, *Healthy homes: ventilating right for good indoor air quality*, <http://www.goodhomes.org.uk/downloads/events/Alan%20Gilbert%20-%20BSRIA.pdf>.

5. Quality in construction

“The experience of Task Force members is unequivocally that quality will not improve and costs will not reduce until the industry educates its workforce not only in the skills required but in the culture of teamwork.”

Rethinking Construction, 1998, The report of the Construction Task Force to the Deputy Prime Minister on the scope for improving the quality and efficiency of UK construction (The Egan Report), http://www.constructingexcellence.org.uk/download.jsp?url=/pdf/rethinkingconstruction/rethinking_construction_report.pdf, Chapter 4, para 56.

Over ten years ago, the Egan Report¹⁵⁹, named after its chairman, Sir John Egan, identified the lack of teamwork in construction in the UK as a major brake on innovation and quality as the quotation in the box above makes clear.

A few years later, the Barker Report in 2004 highlighted¹⁶⁰ concerns about UK housebuilding, exacerbated by the prevalence of sub-contracting that still persists. While there has hopefully been some improvement since that review, the prevalence of sub-contracting remains and is still of concern (Sections 3.3 and 3.5).

The UK Office of Fair Trading, in a follow-up study to the Barker Report, quoted¹⁶¹ the numbers of snags (faults) that inspectors would expect to find in newly-completed homes (after the builder had completed work): *“Estimates from two snagging companies indicate that they would expect to find around 40 snags for one bedroom houses and flats and around 70-75 snags for an average three bedroom family home”*.

¹⁵⁹ *Rethinking Construction, 1998*, The report of the Construction Task Force to the Deputy Prime Minister on the scope for improving the quality and efficiency of UK construction (The Egan Report), http://www.constructingexcellence.org.uk/download.jsp?url=/pdf/rethinkingconstruction/rethinking_construction_report.pdf.

¹⁶⁰ For example in Chapter 6: “...housebuilders do not have to deliver a good product, or high levels of customer service, to win market share. ... The industry must improve the quality of customer service. ... The need to improve standards applies right across the industry... Of particular concern is the low level of training undertaken by the industry. Levels of training are low compared to other industries and by international standards. ... International comparisons of apprenticeships within the key crafts of bricklaying and carpentry show that Germany trains nearly three times as many apprentices per hundred workers than the UK... These general problems with training provision are exacerbated in the housebuilding industry by the prevalence of sub-contracting...”, ‘Delivering stability: securing our future housing needs’, The Barker Review (2004) at <http://www.barkerreview.org.uk/>.

¹⁶¹ *Homebuilding in the UK: A market study*, Office of Fair Trading, September 2008, OFT 1020, para 4.149, http://www.offt.gov.uk/shared_offt/reports/comp_policy/oft1020.pdf.

These numbers do not inspire confidence that the quality of detailing necessary to ensure delivery of a low-energy building will be achieved and the evidence reviewed in Chapter 4 confirms this concern. Whether snags found by inspectors – that relate in the main to clearly observable problems – or the energy performance gap – that relates in large part to unseen defects that are covered from view – the evidence still reveals that quality is not of a standard to guarantee successful delivery of low-energy buildings.

It was the continuing existence of these concerns over quality that gave rise to recent remarks by the UK Government Minister, Andrew Stunell¹⁶². The Minister was also reported as saying: *“Twenty years ago the British car industry was a joke because cars were broken when they left the factory. British houses are still a joke because they leave the factory broken.”*

This analogy may not be popular within the industry but it reflects exactly what Egan was reporting over a decade ago and seems, sadly, an all-too-accurate summary of the way things remain¹⁶³. As we highlight on the front page of this report, one contractor, who is concerned about quality, recently told Build with CaRe:

“A quality culture where tradesmen take ownership of their work in a ‘no blame’ culture is alien to the construction industry. In the adversarial culture that is widespread, costs are cut to the bone and contractors are looking to charge sub-contractors for any alterations or delay and to charge the client for chargeable works not in the tender. In such an environment, the tradesman on site has no awareness of the impact of his work on the eventual performance of the building, and the various trades are interested only in meeting time and cost targets, not in working together to create a quality outcome.”

What is to be done? Egan also described how the highest quality standards could, with the right management attitudes, be achieved in the UK and other countries:

“World-wide benchmarking studies of car and component manufacturing in the early 1990s revealed a two to one gap in performance and a 100 to one gap in quality between Japanese and Western car manufacturers. The opening of the Nissan, Toyota and Honda plants in the UK showed that this level of performance could also be achieved in plants outside Japan.”

Buildings are not cars but the successful delivery of low-energy buildings demands a similar approach to quality – designing and delivering every detail correctly - that the

¹⁶² “We need to have a Rolls-Royce or BMW approach to quality. I’m asking why only a few builders have achieved this”, Andrew Stunell OBE MP, Parliamentary Under Secretary of State, Department for Communities and Local Government, at the EcoBuild Conference, London, March 2012, reported in *Stunell: Performance of UK homes is a ‘joke’*, Joey Gardiner, Building.co.uk, 22 March 2012, <http://www.building.co.uk/technical/sustainability/ecobuild/stunell-performance-of-uk-homes-is-a-%e2%80%98joke%e2%80%99/5033859.article>.

¹⁶³ As noted above in Sections 3.3, 3.5 and 3.7, paragraphs under heading *The problem is not with skills but with management*.

automobile industry has followed¹⁶⁴. Passivhaus standards require just such a quality approach and the examples we have highlighted, the Wolverhampton passivhaus schools and, earlier, the Elizabeth Fry Building, do indeed demonstrate that quality in construction, as called-for by Egan, can be achieved in the UK, as in other countries, and at no extra cost. The keys are attention to detail at every stage and teamwork across the whole process but it is management providing leadership that must turn these keys (Section 3.5).

Self-evidently, a car production factory is a far cry from a 'muddy field' where a new building might be erected, but what underpinned the quality transformation by the car industry was neither the factory nor the car but the attitude to quality. At every stage from design through to manufacture there is emphasis on teamwork, on the necessary skills, and on quality, with every person in the chain encouraged to take part in a culture of continuous improvement. What is absolutely essential to enable this to happen is management commitment to quality and a partnership approach that enables the teamwork that is essential if quality is to be achieved.

Of course, buildings are not produced and completed on a production line for delivery to a customer. Even with modular pre-fabricated production¹⁶⁵, buildings must be finished on site. No matter what the nature of the building, its actual performance can only be understood through a process of post-construction evaluation (Section 3.8). But these factors just make the teamwork and partnering approach even more essential if quality and performance are to be guaranteed.

As we have emphasised in this report and also in *Refurbishing Europe*⁴, quality construction and the successful delivery of low-energy buildings bring multiple benefits. Without such quality, the consequences will be extra and unnecessary fuel bills for building occupants, the likelihood of uncomfortable or unhealthy internal environments, greenhouse gas targets not achieved, unnecessary energy supply and security problems, and an industry that resists innovation and quality.

Getting quality right first time brings cost as well as quality benefits. Building in faults or snags in construction is a waste. As Deming observed¹⁶⁶ when the United

¹⁶⁴ We have described the background to what is now called 'lean thinking', the influence of Toyota and other Japanese companies, and the links to passivhaus quality in *Refurbishing Europe*⁴, Section 8, *Energy as Waste*.

¹⁶⁵ For example the low-energy, all-electric homes built in 2009 by Saffron Housing Association at Diss, Norfolk, and monitored by Build with CaRe; description at <http://www.buildwithcare.eu/articles/78-partners/134-low-energy-homes-in-diss>; report *Overcoming the Barriers to Low Carbon Construction*, Bruce Tofield, November 2009, at http://www.buildwithcare.eu/images/pdfs/overcoming_the_barriers-low_energy_homes_at_diss_norfolk_jul10.pdf; evaluation report *Skelton Road Building Performance Evaluation – Interim Report*, Martin Ingham, April 2011, at http://www.buildwithcare.eu/images/pdfs/interim_report_v04d.pdf. Although not designed or constructed quite to passivhaus standard, the total primary energy demand for one 98m² family house for one year has been monitored to be less than the passivhaus standard of 120kWh/m².

¹⁶⁶ *Out of the Crisis*, W Edwards Deming, (MIT Centre for Advanced Engineering Study, Cambridge, Mass) 1982.

States was trying to come to terms with the superior quality of Japanese goods in the 1980s: *“Defects are not free. Somebody makes them, and gets paid to make them.”* Occupants of buildings that do not perform according to their energy efficiency specification are paying twice over for poor quality. Firstly for the defects that have been created and secondly for the extra fuel bills that result. They will have to pay a third time if they wish to put right the faults.

Interestingly, the detailed Zero Carbon Hub study about the performance gap¹⁴² identified exactly the nature of the problem that has to be solved (in the section *The Nature of the Problem*, pp20, 21):

“Ultimately, the required diffusion of understanding can only take place if coupled with improvements in the design and construction process and informed by feedback. ... 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.” “Lack of focus on integration of processes” means, in translation, “lack of teamwork and partnership”.

The Zero Carbon Hub then quotes¹⁴² from the Egan Report¹⁵⁹:

“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.”

This is exactly what was done in the design and construction of the Elizabeth Fry Building and the Wolverhampton passivhaus schools. It is exactly what working to passivhaus quality demands.

As the Zero Carbon Hub report¹⁴² goes on to say quite unequivocally: *“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.”*

This sentence summarises the essence of the present report. But as we have argued (Section 4.2), such integration cannot happen without a radical change in attitudes to quality within and across the industry¹⁴⁸. The endemic and persistent nature of the problems that create poor quality and lead to the energy performance gap mean that the radical change needed will not happen without a radical change in quality standards demanded by regulation. Change will take effect most easily and effectively by adopting passivhaus quality standards for new build homes and other buildings. Without such a change, as the Zero Carbon Hub report itself makes clear, the transition to low-energy housing (and to low-energy buildings of all kinds) will be almost impossible.

6. How good buildings enhance well-being and productivity

"In office buildings, the salaries of workers exceed the building energy and maintenance costs by approximately a factor of 100 and salaries exceed annualized construction or rental costs by almost as much. Thus, even a 1% increase in productivity should be sufficient to justify an expenditure equivalent to a doubling of energy or maintenance costs, or large increases in construction costs or rents."

Estimates of Potential Nationwide Productivity and Health Benefits from Better Indoor Environments: An Update, William J Fisk, Chapter 4 in *Indoor Air Quality Handbook*, eds: J. D. Spengler, J.M. Samet, and J.F McCarthy, McGraw Hill, 1999, LBNL42123.

In a dwelling such as a passivhaus home with excellent energy efficiency and excellent air quality, the benefits to the occupants will be direct in terms both of low energy bills and also better health and well-being. There will certainly be great indirect benefit to society also. In *Refurbishing Europe*, Section 9, *Creating a new reality*, we noted the recent report of the UK Pro-Housing Alliance¹⁶⁷ that estimated that poor quality housing is a public health problem resulting in £7bn annual costs in the UK alone to the NHS, social services and education bodies. Across the EU, such costs will be multiplied many-fold.

In a non-domestic building where people are working, there can likewise be indirect but very significant financial benefits from improving the indoor environmental quality. There is evidence that a building built to high quality standards, such as the Elizabeth Fry Building, is not only very energy efficient but also creates a perception of comfort and of increased productivity by the occupants.

It is very difficult to measure directly the productivity impacts of different environmental conditions but perceived productivity as self-reported is probably the best proxy. As the box at the head of this Chapter summarises, Fisk has noted¹⁶⁸:

"In office buildings, the salaries of workers exceed the building energy and maintenance costs by approximately a factor of 100 and salaries exceed annualized construction or rental costs by almost as much. Thus, even a 1% increase in productivity should be sufficient to justify an expenditure equivalent to a doubling of

¹⁶⁷ *Recommendations for the Reform of UK Housing Policy*, August 2011, The Pro-Housing Alliance, <http://www.cieh.org/WorkArea/showcontent.aspx?id=38462>.

¹⁶⁸ *Estimates of Potential Nationwide Productivity and Health Benefits from Better Indoor Environments: An Update*, William J Fisk, Chapter 4 in *Indoor Air Quality Handbook*, eds: J. D. Spengler, J.M. Samet, and J.F McCarthy, McGraw Hill, 1999, LBNL42123.

energy or maintenance costs, or large increases in construction costs or rents. At present, we can develop only crude estimates of the magnitude of productivity gains that may be obtained by providing better indoor environments; however, the projected gains are very large. ... In two example calculations, the potential financial benefits of improving indoor environments exceed costs by factors of 9 and 14."

Even if the correlation between actual and perceived productivity is only modest, such potentially very large financial benefits of better indoor environments might be expected to encourage building developers and owners to consider this aspect far more than they actually appear to do. In this Chapter we present evidence that the high-quality environment in many low-energy buildings does indeed enhance productivity. Rental income may also be greater and more reliable. The financial benefits of low-energy buildings can extend far beyond the savings in energy costs.

The perceived productivity of the Elizabeth Fry Building in 1998, two or so years after occupation, was +5% (see Footnote 105) and very significantly better than the benchmark value. It is still positive today and still significantly better than the benchmark, while that of the much newer Thomas Paine Study Centre at UEA (Figure 10) is +6% and in the top ten per cent of all responses. In contrast, the perceived productivity at West Suffolk House (Figure 18), two years after occupation, was more than -5% negative and significantly worse than the benchmark.

The difference in perceived productivity between the energy efficient UEA buildings and West Suffolk House, is over 10 per cent. As the extract from the reference in Footnote 168 makes clear, even a 1% productivity increase *"should be sufficient to justify an expenditure equivalent to a doubling of energy or maintenance costs, or large increases in construction costs or rents."*

Comparisons such as these indicate that building owners and developers that ignore how a building can impact on occupant satisfaction might be paying a significant but unrecognised financial penalty. Such hidden costs are rarely taken into consideration when building costs are calculated but developers, building owners or occupiers that understand these potentially very large soft benefits might make significant gains by aiming to achieve positive occupant satisfaction through attention to building function and operation.

A very useful report¹⁶⁹ on the productivity benefits of energy-efficient buildings was produced by the Rocky Mountain Institute in the 1990s, and a more recent and comprehensive review of studies in this field is given in *Creating the Productive Workplace*¹⁷⁰ in which it is noted¹⁷¹ that¹⁷²: *"Fisk goes on to consider the direct*

¹⁶⁹ *Greening the Building and the Bottom Line: Increasing Productivity Through Energy-Efficient Design*, Joseph J Romm and William D Browning, Rocky Mountain Institute, 1994, revised 1998; http://www.rmi.org/Knowledge-Center/Library/D94-27_GreeningBuildingBottomLine.

¹⁷⁰ *Creating the Productive Workplace*, 2nd Ed, Edited by Derek Clements-Croome, Taylor and Francis, 2006.

¹⁷¹ *Indoor environment and productivity*, Derek Clements-Croome, Chapter 3 in *Creating the Productive Workplace*, Footnote 170.

linkage between human performance and environmental conditions and writes that for US office workers, there is a potential annual productivity gain of \$20-200billion.”

Wheeler and Almeida arrive¹⁷³ at similar potential figures for the UK:

“Our new research shows that poorly designed offices cost UK business up to £135billion a year. UK managers and senior managers estimate that an improved workplace would increase employee productivity by 19 per cent and their own productivity by 17 per cent. This evidence suggests that the potential that might be unlocked by improving British offices is equivalent to a productivity leap on a grand scale.”

Even if this estimate is several-fold over-optimistic, it still justifies the authors’ assertion that: *“Business leaders need to look at properties not as a fixed cost or overhead but as an asset that could make the real value in the business – its people – work smarter.”*

One interesting study¹⁷⁴ concerned the financial impact of a more productive internal environment in the new SMUD¹⁷⁵ call centre:

“While the potential influences of physical conditions may be subtle, even small improvements in worker productivity are of great practical importance. For the call center we were able to attach a monetary value to increased speed in answering calls, since the SMUD call center functions as a self-contained budgetary department within the larger organization. Based on yearly operating costs provided by SMUD management, a 7 per cent improvement in performance, such as that associated with a better break view, was worth \$1,270/m² (\$118/sf) per year in 2003. This is an astonishing number, given that the entire cost of construction of a low-rise office building for a comparable period in Sacramento was \$910-\$1,300/m² (\$85-120/sf) during the same period.”

In other words, the increased productivity measured as a consequence of providing a better external view during break periods – along with other benefits of working in a new purpose-built building – was comparable, per m², in just one year, to the entire cost of construction of a low-rise office building in the Sacramento area. Once again, even if there are other factors in play, the financial impact of a more productive environment is big.

More modest but still very interesting figures were given in *Leaner and Greener*¹³⁵. While, as noted above (Section 4.1) this report promoted a fictitious perception of

¹⁷² In referring to Fisk, Footnote 168.

¹⁷³ *These four walls: The real British Office*, Gary Wheeler and Alessandra Almeida, Chapter 22 in *Creating the Productive Workplace*, Footnote 170.

¹⁷⁴ *Windows and office worker performance: The SMUD Call Center and Desktop Studies*, Lisa Heschong, Chapter 17 in *Creating the Productive Workplace*, Footnote 170.

¹⁷⁵ SMUD is the publicly owned Sacramento Municipal Utility District in California, supplying electricity to the Sacramento region, <https://www.smud.org/en/index.htm>.

West Suffolk House, it has other, sensible, suggestions for promoting energy efficiency in buildings. On p29, under the heading *Value of Sustainability*, a figure of over £160/m²/year is estimated for the financial benefit of productivity improvement enabled by an improved working environment for an office in the UK public sector.

This figure is several times the annual saving estimated¹⁷⁶ to be achievable by easily achievable energy efficiency measures (£24/m²/year) but, of course, it is the well-planned environmental improvements including energy efficiency measures that make possible the productivity improvements. While not equal to actual building costs in a single year, as the SMUD findings indicated, a figure approaching £200/m²/year from energy and productivity benefits is still very interesting.

The financial benefits from reduced sickness (£36.33/m²/year) and from productivity improvement (£126.72/m²/year) were calculated¹⁷⁶ by assuming all staff earned an average public sector salary¹⁷⁷, and a 5 per cent productivity improvement and a 40 per cent reduction in sickness absence resulting from an improved working environment. These impacts of an improved working environment were chosen with reference to detailed study of the effects of refurbishment to certain floors of an office block in Melbourne, Australia, 500 Collins Street, that was begun in 2002¹⁷⁸.

The Australian study was conducted with two existing tenants who moved from un-refurbished floors to newly refurbished space in the same building. The results showed a 39 per cent reduction in average sick days per employee per month after the move, 9 per cent improvement in average typing speeds of secretarial staff, and a significant improvement in overall accuracy. There was also a 7 per cent increase in billings ratio for professional staff, despite a decline in average monthly hours worked, indicating higher office productivity.

Added to these benefits, however explained, are also improved letting and rental capability as well as lower maintenance costs for the improved floors of 500 Collins Street¹⁷⁸. In total, examples of this nature demonstrate that a building providing good environmental quality and working environments may yield a financial benefit relative to a building that does not have these attributes of at least ten to twenty per cent of actual building costs each year.

Looked at in this light, it seems perverse to focus on construction cost as the main arbiter in determining the attributes of a commercial building such as an office block.

¹⁷⁶ Leaner and Greener¹³⁵, p29

¹⁷⁷ The benefit from improved productivity and reduced sickness would be even larger for a building containing more highly-paid staff.

¹⁷⁸ *500 Collins Street Melbourne Building Refurbishment Project*, 1200 Buildings, http://www.melbourne.vic.gov.au/1200buildings/Documents/1200_Buildings_MCC_500_Collins_St_Case_Study.pdf, and *Employee Productivity in a Sustainable Building: Pre- and Post-Occupancy Studies in 500 Collins Street*, A Study commissioned by Sustainability Victoria and the Kador Group, http://www.resourcesmart.vic.gov.au/documents/500_Collins_Productivity_Study.pdf.

As was noted by Fisk¹⁶⁸ for the USA, and some years ago also by Evans et al¹⁷⁹ for the UK, over the lifetime of a commercial office building, construction cost is five times less than maintenance and related costs and two hundred times less than business operating costs, principally the cost of staff. Staff costs dominate over lifetime construction and maintenance costs. Therefore, aspects of the building that impact positively on staff productivity, or reduce sick leave, can, as already noted, yield very significant benefit.

Of course, attributing cause and effect to examples of increased productivity is a hazardous exercise¹⁸⁰. However, the Building Use Studies database⁸⁰ now contains information from a large number of occupant studies across many countries. This database permits more reliable trends to be established than might be attributed to single building studies such as those of the SMUD call centre or the 500 Collins Street office building.

In *Productivity in Buildings: the 'killer' variables*¹⁸¹, Leaman and Bordass emphasise that perceived and actual productivity are very likely strongly associated and note that: *"From our own work, and from the literature, we can guesstimate that productivity gains (or losses) of up to about 20 per cent may be attributable to the effects of buildings on their occupants."*

From the PROBE studies³¹ they deduce: *"perceived differences of up to 25 per cent between comfortable and uncomfortable staff, with uncomfortable staff showing consistently lower productivity."*

Revealingly, the majority of results from buildings are not nearly so positive on perceived productivity as those reported from the Elizabeth Fry and Thomas Paine buildings at UEA or from 500 Collins Street in Melbourne, Australia. Leaman and Bordass note¹⁸¹ that only in thirty per cent or so of buildings in the dataset do occupants, on average, report perceived productivity scores above zero and, for all UK buildings in the 2004 dataset, *"the mean perceived productivity score for all UK*

¹⁷⁹ *The Long Term Costs of Owning and Using Buildings*, Raymond Evans et al, Royal Academy of Engineering, 1998, http://www.raeng.org.uk/news/publications/list/reports/The_Long-Term_Costs_of_Buildings.pdf.

¹⁸⁰ The best-known example is perhaps the so-called Hawthorne effect, cited as the positive impact on productivity of management attention and engagement in experiments at the Hawthorne works of the Western Electric Company in Chicago, in the late 1920s. The standard interpretation, as given for example in *Management and the Worker; An Account of a Research Program Conducted by the Western Electric Company, Hawthorne Works, Chicago*, Fritz J Roethlisberger and William J Dickson (Harvard University Press, 1939), has been rather discredited by later study of what actually went on. See for example, *The Hawthorne defect: Persistence of a flawed theory*, Berkeley Rice, <http://www.cs.unc.edu/~stotts/204/nohawth.html>. Also, the chapter entitled *The Ideological Origins of the Humanist Revolution*, pp97-121 in *The Management Myth*, Matthew Stewart (W. W. Norton & Company, New York and London, 2009) is a very readable account of the myth of the Hawthorne effect and the people who created it.

¹⁸¹ *Productivity in Buildings: the 'killer' variables*, Adrian Leaman and Bill Bordass, Chapter 10 in *Creating the Productive Workplace*, Footnote 170.

buildings is minus 2.1 per cent.” Hence building occupants do not score positive productivity lightly!

Of the ‘killer’ variables of buildings that appear to have most impact on productivity¹⁸¹, the link with comfort is particularly striking (Figure 22).

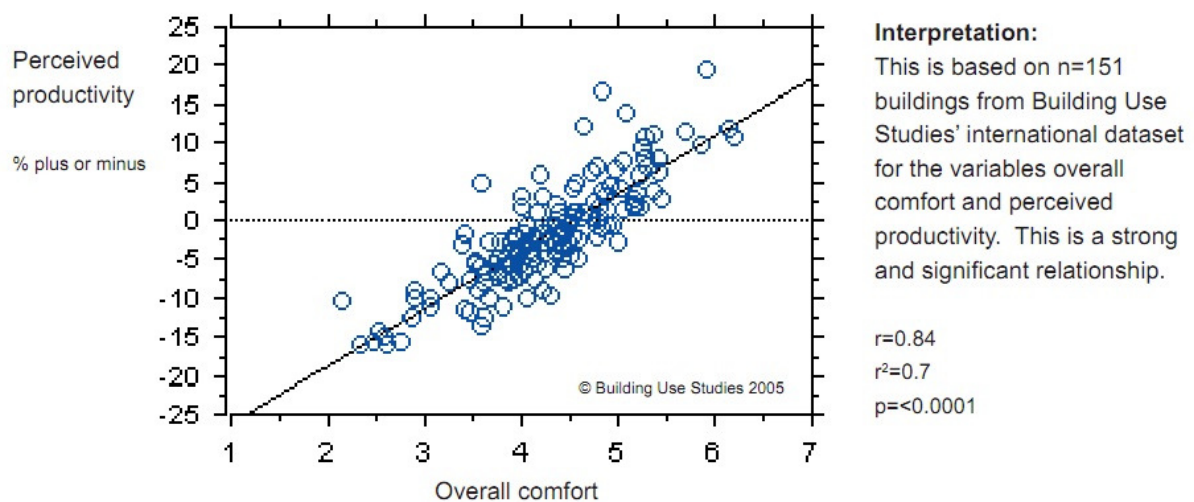


Figure 22. The positive relationship between perceived productivity and perceived comfort drawn from data on 151 buildings in the Building Use Studies' international dataset. Overall comfort is an umbrella variable which covers people's perceptions of heating, cooling, ventilation, lighting and noise taken together in an overall assessment (Figure 10.3 in *Productivity in Buildings: the 'killer' variables*, Adrian Leaman and Bill Bordass, Chapter 10 in *Creating the Productive Workplace*, Footnote 170)

What is revealing about this “*strong and significant relationship*” in Figure 22 is that overall comfort includes personal control, the ability of the person being questioned to exercise some personal control over their workplace environment. As Leaman and Bordass write¹⁸¹: “*In study after study, people say that lack of environmental control is their single most important concern, followed by lack of control over noise.*”

The authors note that people are more forgiving of discomfort if they have some effective means of control over alleviating it – but that many modern buildings seem to have just the opposite effect.

Just as the construction industry seems unwilling to act on quality so it seems also unwilling to act on the evidence about the benefits of personal control and perceived comfort. As Leaman and Bordass write¹⁸¹: “*In spite of the wealth of research and occupier evidence that high perceptions of personal control bring benefits like better productivity and improved health, designers, developers, and sometimes even clients seem remarkably reluctant to act on it.*”

Leaman and Bordass provide several reasons why this might be, of which one is the split in building design between architectural and building services tasks. Exactly the split indeed that seems to provide an explanation for the generally poor installation and performance of MVHR systems in the UK (Section 4.3), and one aspect of the *“traditional construction model”* (Sections 4.2, 4.3, Chapter 5). The teamwork and partnership working that are essential to deliver a low-energy building are, therefore, also necessary to deliver a building where occupants can feel comfortable and productive.

The key question then is, do low-energy buildings¹⁸², in particular, provide an environment where occupants feel comfortable and in control and hence highly productive? The answer from the Elizabeth Fry Building and Thomas Paine Buildings at UEA is clearly ‘yes’.

A low-energy building does not, by itself, cause improved productivity but the teamwork, care and thought that ensure that the building functions as it should will also ensure a largely comfortable environment with few of the sources of dissatisfaction that so irritate people. As Leaman and Bordass have observed in a study of occupant perceptions in so-called ‘green’ buildings¹⁸³: *“Users tend to not worry about comfort as such, but discomfort. They react when a ‘crisis of discomfort’ has been reached”*.

As well as the building itself behaving well, the care and teamwork that are characteristic of the design and construction of a low-energy building will also have provided more information to occupants than is the norm. Once again¹⁸³:

“If people understand how things are supposed to work and what they are for – window controls, perhaps, or thermostats – they tend to be more tolerant if things do not turn out quite as well as they should. The clearer design intent is to the user, the more likely users are to make sacrifices or compromises. Users are much less satisfied when they cannot see how things are supposed to work, or are subject to arbitrary interventions by technologies over which they have little or no control, or just plain angry with buildings that seem to ride roughshod over basic users’ needs.”

The responses of occupants living in the new passivhaus homes quoted on the front pages of this report demonstrate a similar positive response¹⁸⁴ to the UEA buildings,

¹⁸² Not ‘green’ or ‘sustainable’ buildings because, as has been noted already, such terms have no meaning in practice and relate more to design perceptions or to outward appearance than to actual building performance. As Leaman and Bordass point out¹⁸¹: *“And do not mix up energy-efficient buildings with ‘green’ buildings. Just because a building is called ‘green’ does not necessarily mean that it will be energy-efficient in actual use.”* The example of West Suffolk House, a supposedly low-energy, ‘green’ building, with a BREEAM Excellent rating, but with over -5% perceived productivity and very negative occupant perceptions, has been detailed in Section 4.1.

¹⁸³ *Are users more tolerant of ‘green’ buildings?*, Adrian Leaman and Bill Bordass, Building Research & Information, 35, 662-673 (2007).

¹⁸⁴ It is important for any low-energy building that it is designed carefully and that occupants are able to understand how to use the controls in an appropriate way. Passivhaus homes - like any conventional

and these short-term responses are supported by evidence from long-term surveys after several years of occupation by residents of the first passivhaus homes in Sweden at Lindås in southern Sweden¹⁸⁵ and in Schleswig-Holstein in northern Germany¹⁸⁶.

Passivhaus homes and buildings, as well as other low-energy buildings such as the Elizabeth Fry and Thomas Paine Buildings, provide a comfortable environment where occupants can get on with their life or their work without being distracted by environmental concerns. People are productive if at work and will experience a sense of well-being if at home. Such achievement is largely a consequence of the teamwork that produces a well-designed, well-constructed and well-functioning building. The resulting simplicity of operation that is a characteristic of low-energy buildings avoids the problems and the discomforts that were so apparent (Section 4.1) in West Suffolk House for example.

The key factors of teamwork and simplicity that lead to excellent building fabric and low-energy operation lead also to creation of an excellent internal environment. Together, these factors can generate a sense of comfort and well-being that seem, fairly conclusively, to lead to enhanced productivity.

The financial benefits of low-energy buildings seem very likely to extend far beyond low fuel bills to lower maintenance costs, healthier occupants, less cost to society of ill-health, better rents and occupancy levels in commercial and office buildings, and more productive work environments. Such benefits are likely to outweigh the costs of making the transition to quality many times over, while the costs to society at large of not creating quality and foregoing the ability to deliver low-energy buildings will be huge.

homes - can overheat in summer if design is not properly thought through, and new occupants of passivhaus homes and buildings need to have the differences to conventional living simply explained. As we have noted in this report, great care was taken in the design of the Elizabeth Fry Building to understand the potential for overheating in summer and to take steps to deal with this, and great care was taken to minimise internal heat gains in order to avoid overheating in the Wolverhampton passivhaus schools⁶⁸. A useful summary of issues to consider is given in *Understanding overheating – where to start: An introduction for house builders and designers (NF44)*, NHBC Foundation, July 2012, <http://www.nhbcfoundation.org/Researchpublications/NF44/tabid/515/Default.aspx>. The teamwork that is a theme of this report must extend from developer through designer and builder to the occupants and managers of buildings if overheating and air quality problems are to be avoided in buildings that are far better insulated and far more air-tight than are most buildings today (see also Section 2.7).

¹⁸⁵ *Erfarenhetsåterföring från de första passivhusen - inomhusmiljö, beständighet och brukarvänlighet (Experience and evaluation of the first passive houses - the indoor environment, durability and user convenience)*, Eva Sikander, Svein Ruud, Kristina Fyhr and Owe Svensson, SP Sveriges Tekniska Forskningsinstitut, 2011, http://nyheter.vgregion.se/upload/Milj%c3%b6sekretariatet/Milj%c3%b6%20%c3%b6vrigt%20i%20till%20pre ssmeddelanden/SP%20Rapport%202011_26%202011-06-09.pdf (Build with CaRe paper, in Swedish); see also Footnote 22 (in English) about energy use at the Lindås homes.

¹⁸⁶ *Long-term Evaluation of Passive Houses in Schleswig-Holstein*, Winfried Dittmann and Klaus Wortmann, April 2010 (presentation to Build with CaRe).

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The Build with CaRe project provided a remarkable opportunity to learn across the North Sea Region about innovation in construction and the benefits of low-energy buildings. We have been very fortunate also to engage with industry partners in the UK who have used the networks provided by Build with CaRe to develop exciting and innovative projects in Norfolk and elsewhere and have also provided important opportunities for monitoring and learning about building performance in practice. I would like to thank all Build with CaRe partners for their learning and friendship and many colleagues in the UK who have given time and resource to support the promotion and understanding of low-energy buildings. Particular thanks go to Bill Bordass, Roderic Bunn, David Daniels, Winfried Dittmann, Hans Eek, Tony Evans, Andy Ford, Erik Franke, Jan Gerbitz, Martin Ingham, Adrian Leaman, John Lefever, Ulrike Maccariello, David Olivier, Martyn Newton, Christine Reumschüssel, Andrew Savage, Britta Stein and Peter Yorke. I hope this report can aid the speedy introduction of low-energy homes and buildings, both new and refurbished, in the UK and elsewhere. Any errors or misperceptions are mine alone.