HEAT LOSS THROUGH THE BUILDING FABRIC: LOW CARBON CONSTRUCTION PRACTICE

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For domestic buildings to meet current definitions of zero carbon the building fabric and services must achieve 70% reduction in energy use, taking the carbon emissions down to less than 7 Kg CO2/m2. However, there is a significant obstacle to such endeavours. The limited information on the thermal performance of buildings means that the designs are theoretical. Very few models have been tested against the as-built product and where tests have taken place the cyclical process of research and development is taking time to feed back into the design and construction processes. The gaps in our knowledge of building physics are considerable, designs are not robust and buildings are falling short of their expectations. An intensive study of 18 houses was undertaken to examine the design and onsite assembly, comparisons were made between the predicted energy performance and that achieved once the design was built. The heat losses were, on average over 40% worse than predicted. The forensic analysis of the design and construction process revealed that buildings do not perform as designed due to missing or incomplete information, incorrect detailing, ad-hoc adjustments on site, incorrect assembly of materials, poor workmanship and failure to commission buildings and their services properly. From the research, a list of problems has been produced with the aim of avoiding such defects in the future.

Keywords: construction practice, low carbon construction.

CONSTRUCTION, ENERGY USE AND CLIMATE CHANGE

The heating of properties within the UK contributes substantially to the national energy use and, due to our current dependence on fossil fuels, this is increasing quantities of CO2 released into the atmosphere. Increased emissions are closely linked with global climate change and, although this is not the only atmospheric gas contributing to changes (Gorse and Sturges, 2010), steps need to be taken to reduce CO2 (Clarke *et al*., 2009). Furthermore, it is reported that approximately 30% of the UK's total CO2 emissions are attributable to the energy that is used to heat, light and power dwellings (Johnston *et al*., 2004). Given that housing stock generally has a long physical lifetime and slow stock turnover, any decisions made regarding the energy performance of dwellings that result in new or modified buildings today will remain for many generations. To mitigate the effects of climate change and achieve large reductions in the national CO2 emissions, the UK Government is embarking on regulation that aims to make significant reductions in building energy use. However, research has shown that our expectations of low carbon buildings are some way off reality (Bell *et al*., 2010).

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Why can't contractors and designers build buildings that perform?

While the policy should make us more 'sustainable' research shows that buildings fail to perform to the standards specified (Gorse *et al*., 2010; Wingfield, *et al*., 2008; Wingfield, *et al*., 2009) and do not achieve regulatory requirements (Bell *et al*., 2010). In construction, like most other business sectors, we've coined the word sustainability to improve the industry's image and provide an agenda for change. However, research has shown buildings are not meeting the standards that we aspire to, with the heat losses ranging from 9 – 125 % worse than the design values (CeBE, 2011). The building fabric is not performing as expected. The growing body of research has revealed practices that result in buildings that do not perform (Bell *et al*., 2010; Gorse *et al*., 2010). Tests have shown that the same house types, built by the same contractor, to supposedly the same standards, can perform differently. In part, it is suggested that the variations in build performance are a result of professionals and skilled workers failing to understand what constitutes good practice. From a research perspective this is to be expected as the industry is in its infancy with regard to its understanding of building physics. Tests on buildings, in the real world, through an annual heating cycle, take a year. Thus, the speed with which thermal research takes place tends to be slow.

The best time to determine the thermal resistivity of a building is when the internal and external temperatures are greatest, in the UK this is during the winter season. Proper research will take time to understand how building systems behave in different environments. While Salford's Energy House (Energy Home, 2011) will provide information on a single building system within a laboratory setting, it is unlikely to provide data on the many and varying types of properties that are being developed. There are many forms of structure that have emerged over the centuries, each with site built nuances, which will contribute to buildings behaving differently. The weather changes, surrounding landscapes and buildings also affect performance. While there is a need for laboratory tests, there is a greater need to understand the buildings that exist and determine how variations affect their performance.

Across the UK there are very few studies that have actually tested how well buildings work when they are assembled and ready for occupations. Most studies are theoretical, with the performance model of the building system being produced from laboratory metrics that have never been tested or validated in the real world. When the building is assembled, experience shows, that the parts function differently when incorporated in the whole system.

While methods for determining whole building heat loss were being used in the 1970's (Sonderegger, 1978; Sonderegger and Modera,1979; Sonderegger, Condon, and Modera 1980) it is only in the last two years that such tests have been accepted as a standard and are now used by industry. While results are only just emerging, the Technology and Strategy Board's Building Performance and Evaluation programme have adopted a whole house heat loss research methodology (Technology Strategy Board, 2011). As an industry we are now on the verge of understanding how buildings work. Research will tell us much about building performance. The unfortunate consequence of understanding how things work is that it exposes elements of construction that don't work and mistakes previously made. The research also reveals that many of the buildings claiming to be low energy are not performing.

The standards that we aim towards will only be met if we pay attention to detail, and ensure the knowledge emerging from research is embedded in construction operations.

Some of the failures are due to a lack of understanding of how materials perform and components link together, while others are more obvious oversights that should be picked up by the professionals and craft specialist (Gorse *et al.*, 2010).

Buildings have proven difficult to regulate towards improving their energy efficiency, the main reason for this is that energy consumption of buildings results from the interaction of a large number of poorly understood variables (Lowe, 2000), including: the building envelope and its attempts to contain space heating requirements; general construction; operation of the building; building services and energy supply. Thus, the Government target set for all new homes to be zero carbon by, 2016, presents one of the greatest challenges the house building industry has ever had to face (Bell, 2010b).

The emerging evidence of a large gap between the designed performance of dwellings and that achieved when constructed makes the task even more demanding. The discovery of this gap suggests that some information is missing. The design predictions could be wrong, product information may be incorrect, the construction may not be built as expected; there could be faults in the building services and fabric or both.

It makes no sense at all to achieve zero carbon housing in theory only (Bell, 2010b); buildings must actually perform as designed. The designers, developers, construction stakeholders, educators, trainers and the research community must all start to engage in the problem, make sense of it and work towards the low carbon solution. Exemplar buildings do exist which have shown that it is possible to reduce energy used, in some cases by a factor of at least 3 (Lowe, 2000). The problem is understanding how to extend this practice to mainstream construction. The first step is to undertake research and learn what works and what causes problems.

RESEARCH METHOD

Research was undertaken to assess and measure the thermal performance of the fabric of low carbon construction. From early research, it emerged that many of the problems encountered were related to the design and construction processes. Photographic evidence was systematically collected during the construction stage and an intensive examination of the building services and fabric took place once the building was constructed. The buildings were then tested to determine the whole house heat losses using the Leeds coheating method (Wingfield *et al.*, 2010).

In total 18 houses were examined using coheating tests. To help understand the building and its performance, air tightness tests, air leakage detectors, heat flux sensors, kWh monitors, temperature sensors, relative humidity sensors, air quality control monitors and thermal imaging cameras were all used. A forensic examination of the building process and building fabric helped to identify reasons why variations existed in the buildings performance when compared with that predicted.

The research into the building process is explorative, examining the findings of the data collected and gathering together issues that could be considered as areas of further research. The study of only 18 dwellings does not constitute a comprehensive sample of UK housing, but it represents the most extensive study in the UK to date.

The research method adopted to observe the construction could be described as action research. In this case the researchers were testing and monitoring technical aspects throughout the construction period. When technical problems were identified during the design or construction phase this information was fed back to the construction companies and clients involved. Once constructed, the performance of the building fabric was tested and assessed, further problems relating to design and construction were recorded. The work reported here focuses on the technical data that impacts on the building process.

While the sample size is disperse and far from comprehensive, it represents one of the larges samples of research into building performance to date. As the sample is not comprehensive nor sufficiently large to say that the results are representative of house construction, they are indicative. Many of the problems identified during early studies reoccurred on different sites and may well be common across the construction industry. However, at this stage it is important that each issue is considered as an area of exploration.

RESULTS

The following heat loss graph represents a summary of the research led by Wingfield *et al*. (2011) at CeBE Leeds Metropolitan University.

Figure 2 shows the discrepancy in measured versus predicted mean U valued for new UK housing. The mean U value represents the measured U value based on the building envelope area, external walls, floor and roof. The level of variations demonstrates the gap between that expected and that which was achieved. It is clear that some of the dwellings are getting much closer to their expected mean U-value while other dwellings are significantly different.

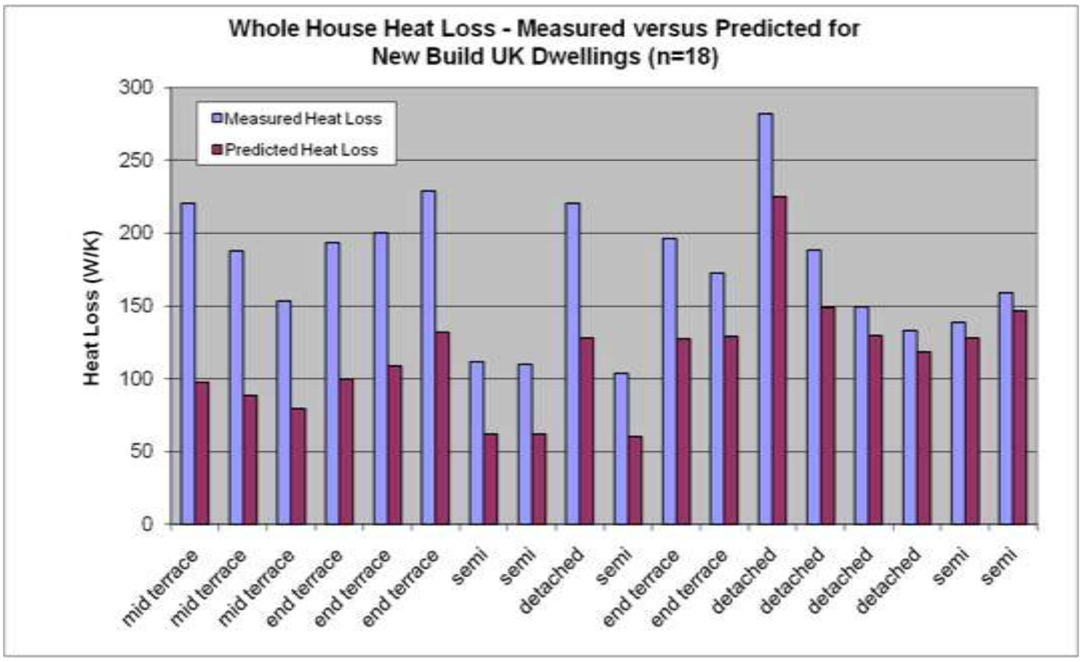

Figure 1. Comparison of measured versus predicted heat loss for new build UK dwellings (Wingfield et al., 2011)

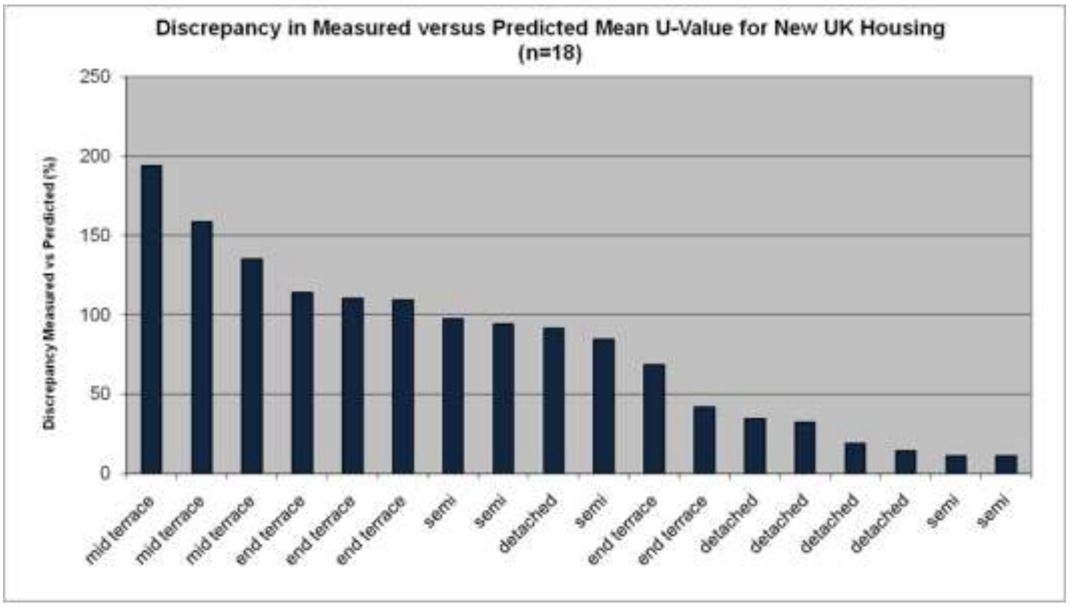

Figure 2. Discrepancy in measured versus predicted mean U-value. (Wingfield et al., 2011)

Figure 3 shows the design and measured values for three of the better performing dwellings. The properties are then compared on the performance they would be required to achieve against Part L, 2010 and Zero Carbon Homes measure. The measured value of the better performing properties are still someway off the Zero Carbon Homes target.

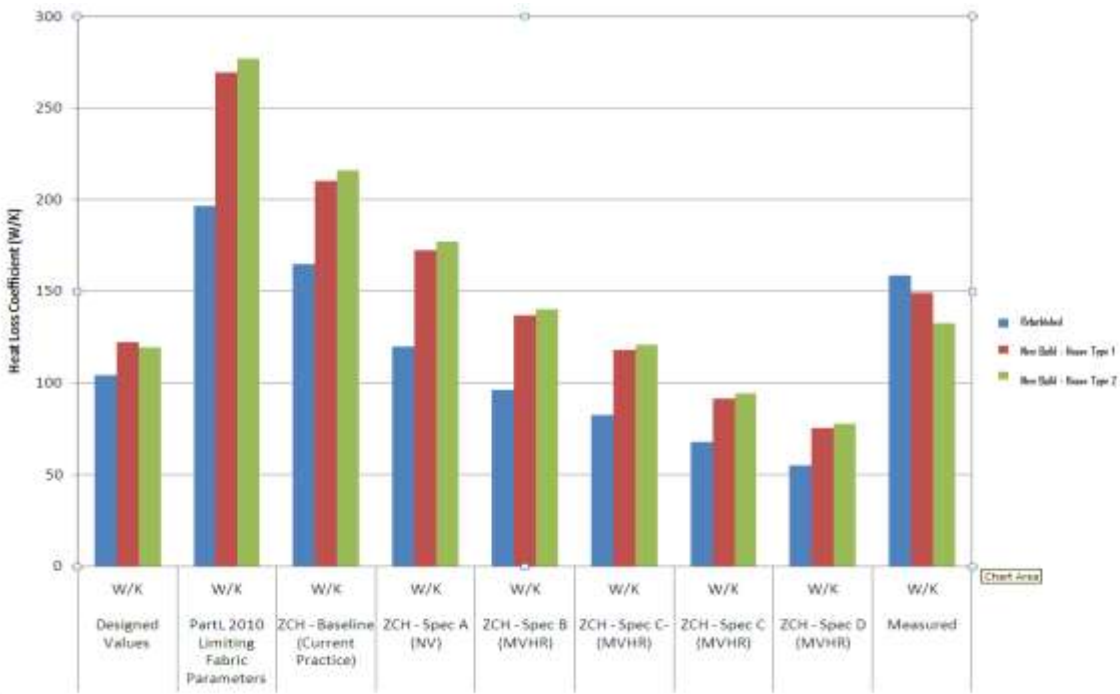

Figure 3. Low carbon dwellings measured value compared against design values for Zero Carbon Homes Targets.

Construction problems identified during the research

Table 1: Problems with design and sequencing of operations

Thermal by-pass
Vents displaced insulation and there were gaps surrounding the vents. Partial fill insulation was pushed off the surface of the wall creating voids on both sides of the insulation.
Entrances and bulk heads produced complicated designs meaning that they were difficult to construct resulting in gaps that led to thermal bypass and cold bridging.
Airtightness
Sequencing of operations meant that air barriers were installed and then punctured to put services through them.
Insulation and air barriers were removed to fit services, once the services were installed the insulation and barriers were not properly replaced.
Cavity barriers were inserted after the brickwork was complete creating difficulties in trimming insulation.
Modification were made to the design, increasing or decreasing sizes of components. The changes resulted in gaps, not considered at the design stage, which needed to be filled by expanding foam on site.
Air barriers and vapour control layers were fixed in the wrong positions. No instructions were provided on how to seal barriers around windows, corners, penetrations and junctions. The folding and layering of building fabrics is problematic if not designed properly.
Incorrect use of tapes and sealants was common. Multi-purpose tapes rarely fix to wood and brick properly. Substrate specific tapes should be used. Dusty, irregular surfaces that are not easily adhered to are notoriously problematic. In such situations, tapes may require compression or mechanical adhesion or, an alternative means of creating a seal may be needed. Alternatively, the substrate material or finish of the substrate may need to be altered to achieve a good bond.
Pressurisation tests and smoke puffers revealed gaps around RSJs and service pipes.
Thin masonry or concrete cracks cause little problems, but wider cracks need to be raked out and filled with sealant. Ceramic materials that shrink need filling.
Loft hatches were used that did not effectively seal.
Sliding doors are a common feature, yet they are a particular area of concern due to the problem of sealing the sliding mechanism.
Services positioned against or close to the wall make it difficult to seal behind the service penetration once the services are installed.
Inability to seal hidden services. Penetrations by some services become inaccessible once the main piece of furniture is installed e.g. behind cylinders and WC.
Services that become hidden by boxes or panels, below shower trays and baths were not sealed.
Structural components such as floor joists that penetrate the walls increased the potential for loss of air tightness, no consideration for alternative means of securing components were suggested.
Air leakage through shrinkage cracks in boxed ducts, changes in materials, window sills, skirting etc. caused problems.

Table 2: Problems associated with the quality and supervision

Products not installed
In some cases insulation was thrown in and not placed properly, in some cases roof insulation was not unrolled.
Cold bridging
Mortar build-up over vents and insulation caused cold bridges across the insulation.
Insulation was obstructed near joists causing cold bridging.
Thermal by-pass
Mortar build-up resulted in discontinuity of insulation. Debris prevented the insulation butting tightly

against the wall and locking together.
Gaps were found between roof insulation, insulation was not fitted under some roof joists.
Gaps were found in party wall cavity socks.
Airtightness
Mortar beds were not filled, thin joint mortar beds were difficult to seal.
Parging applied to walls to ensure an effective air barrier can only be applied to open faces. It's impossible to apply render to walls where fittings obstruct access.
Sealants were applied at surface level rather than properly applied within the gap. The longevity of surface applied sealants is questionable. Sealants with limited flexibility such as builders caulk may not offer a long term effective seal.
Incorrect lifting of prefabricated panels caused damage to the integrity of the panel.
Incorrect expansion strips were used, these were insufficient fill to seal gaps.
Points of air-leakage were commonly found around thresholds, windows and doors, between frame and breather membrane, around and through roof lights, roof panels, at the ridge, eaves and between roof panels.
Air leakage was found around light roses, electrical sockets and other service fittings.
Air leakage also occurred through flooring panels, damaged and poorly sealed panels.
Prefabricated panels with joins in did not offer an effective seal. There was reliance on the integrity of OSB and silicone sealant which failed. Some gaps which were not airtight were too small to inject sealant into.

All of the above items listed have potential to alter the energy performance of the house. The test results revealed that each factor contributed to heat loss.

EVALUATION

The work has revealed problems with the design and construction. The sequencing of construction operations continues to be a problem. With the design process overlapping with construction, careful consideration is needed if components are to be integrated properly.

Many of the problems are occurring in many house types and on different sites. The research suggests that where construction issues become complicated they are not given sufficient attention. In many cases design issues are not resolved allowing the on site staff to make the necessary decision. Ad hoc decisions often result in problems. It is clear that the unstructured assembly of different components and the inclusion of services causes problems. At each material interface the design needs to be examined and the process and sequencing of operations must be considered. Interconnecting voids that lead to thermal bypass should be avoided.

Where services penetrate through the fabric effective seals and methods of applying the seals must be considered. Adhesives and adhesive tapes are now widely used, but in many cases they are unable to perform as they do not stick to the substrate. In some cases this may mean a change to the substrate or changing the finish of the substrate so that it is possible to obtain a chemical fix. Use of adhesive tape on sites should be reduced. Dusty or dirty sites, which are exposed to the weather, can prove to be a challenging environment for such materials.

Products are being selected that are not suitable for low carbon construction and decisions are being made that do not constitute good practice. Emmitt (1999) and Emmitt and Yeomans (2001) suggest that architects generally select products from their favourite set of products, those which are tried, tested and previously used. We are entering a new domain of testing. Currently, construction professionals may be selecting preferred products rather than those that perform. As professionals obtain feedback through effective monitoring, then their ability to select and specify should improve. Currently, some details are not possible to build, it is important that such details are questioned so that solutions are found. Drawings that cannot be built do not manifest into the product that was specified, what is realised is something different.

CONCLUSION

Low carbon buildings do exist and can be built. The challenge of mass produced buildings, is to provide the right detail and processes to ensure buildings are consist with the specified standard and can be reliably reproduced.

In all cases the contractors were attempting to build properly and aware of the monitoring yet still hit problems. While low carbon construction is specified in the form of regulation and client criteria, many buildings are not meeting their targets. The industry is attempting to develop low carbon buildings without a real understanding of the construction process and the performance of components used. Better understanding of components, their assembly, design and the need for improved sequencing of operations is required. Managers and designers are overseeing and supervising tasks that they may not understand. As research identifies the problem areas and solutions the industry can move forward, but the current approach of producing 'grand designs', based on limited knowledge and hoping that they will work is producing substandard buildings.

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