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The Gap between Design & Build: Construction compliance towards 2020 in Scotland

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i. PARTNERS DETAILS

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CONTACT:	**Dr Branka Dimitrijevic** Director CIC Start Online Tel: 0141 273 1408 Email: Branka.Dimitrijevic@gcal.ac.uk www.cicstart.org
ACADEMIC CONTACT:	**SCOTTISH ENERGY CENTRE, EDINBURGH NAPIER UNIVERSITY.** **Julio Bros Williamson** 42 Colinton Rd, Edinburgh, Scotland, EH10 5BT Tel: 0131 455 5139 Email: j.broswilliamson@napier.ac.uk Web: www.napier.ac.uk/sec
PREPARED BY:	**Julio Bros Williamson** – Scottish Energy Centre - Energy & Building Consultant
REVIEWED BY:	**John Currie** – Director of the Scottish Energy Centre, Edinburgh Napier University
SME:	**The Morrison Partnership Ltd - Architects and CDM Co-ordinators**
CONTACT:	**Dr. Cameron Purdie** **Architect** 242 Queensferry Rd Edinburgh Scotland EH4 2BP Tel: 0131 343 3114 Email: cameron.purdie@gmail.com **Mr. George Morrison** **Architect** Senior partner Email: edin@themorrisonpartnership.co.uk

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1. Executive summary

Building regulations are pushing energy and environmental related design and construction standards to higher levels while resources and tools to reach such standards have been stretched in such a way that a performance gap has been created between the expected designed and the actual constructed and occupied.

Buildings of all types have been designed with high energy performance standards which demonstrate that on paper with expected performance results; energy will be used efficiently delivering low carbon emitting buildings. This has not been the case, and performance of many buildings built to specifications and design show that energy consumption figures and bills are higher than the design had predicted initially.
There are many reasons, some are difficult to take into account and others can be minimised by an industry led shift with adequate procurement and communication during construction.

There are discussions over how best to measure the performance of a building and in what ways it should be assessed. There are standards that will address quality related matters in the building design and build; for example Passive House, Code for Sustainable Homes, BREEAM, regional building regulations and others. These standards have a similar goal; to lower the impact of buildings on a site and to lower the demand of energy creating a more environmental design.
The above are design lead standards of which minimal post-construction evaluation is performed. This sort of testing would be useful to a client and user to get a better understanding of whether what was built is really what was designed. Physically and aesthetically the buildings can be as shown in the graphical representations of a design; it is whether the performance and energy efficiency is as predicted that should matter.

It is therefore recommended through the analysis of this paper and the review of other documents and references, that in order to verify if the building is performing and considering all aspects of an energy and ecological standard it should be assessed not only with energy predicted software and calculators but also by conducting post-construction assessments before occupation and during occupation and thereafter graded upon the results. In many ways this could be the basis of payment and funding for future projects.

There are industry led changes which push technology and building envelope innovation to the limits in order to reduce energy and comply with current building standards expectations. The drive is so powerful that many companies are investing in a lot of research and development of materials and products. The best way to assess if these are adequate and meet the design expectations is to implement them and test them as installed to evaluate its real performance. Relying fully on companies expected output and performance will only widen the overall performance gap of the building.

There are advantages and disadvantages of all building methods. The two that have been implemented the most in Scotland are the off-site construction using timber based closed panel modern methods of construction and the on-site more traditional construction using masonry techniques or open panel timber construction.
On site construction demands a large workforce with several trades and subcontractors working at a controlled pace but with many unnecessary overlaps in the process of construction. Waste is also an issue as this form of construction creates a lot of surplus materials and off cuts that end up in a land fill costing and damaging the environment. The advantage is that this method of construction is controlled and traditional and well known in the industry; masonry cavity wall and post & beam. Because its well known trades and subcontractors may bring into force inadequate forms of building that over the years have proven to be inefficient.

Off site construction has been regarded as the more cost effective and time saving method taking away many of the un predicted problems experienced on site, most of the work is done in a factory where computer generated or machine sequential construction methods are applied. In some instances whole wall sections with insulation and all its layers are pre assembled in a factory (with windows, doors and electrical pipe work) ready to be erected on site either manually or with a crane. So far most of these homes are produced individually and there is research being developed into adapting into the mass construction market. This method saves time, decreases faults that may occur on site and creates a level of accuracy that is seldom experienced in on-site construction. Reduction in carbon can also be quantified as trade involvement, transport and waste are all reduced.

The refurbishment market may also present some similar problems. Increased legislation is pushing for the re-use of existing housing and building stock either for improving liveable conditions of buildings or taking advantage of the increasing derelict building stock which can be re-conditioned. Refurbishing these building will need accurate surveying of the current state of the building in order to rescue as much as possible and act technically to enhance and improve the liveable standards.

2. Literature Review

In preparation for this document a list of relevant sources of documents and text were analysed in order to acquire knowledge of other publications which are relevant to this paper.

The basis of this work came from the comments and plan of action mentioned in the Sullivan report by the Scottish Building Standards Agency in 2007[1][1] highlighting the need for revision and analysis of the performance of buildings. Aimed at the reduction of carbon emissions from buildings; it mentions how with higher building standards there is a need in more research to be undertaken and "establish the range of performance that is achieved by the 'best in class' building"[2] [2] and this was commented on to understand if buildings are actually performing as they have been designed. Section 1 points out how the reduction in carbon emissions is a good benchmark to determine performance. In the use of micro-renewables, it indicates the requirement for buildings to be aware of consumption and generation once equipment is installed. It mentions only how high performance buildings should be measured but in fact as building regulations get tougher and more focused on energy efficiency and sustainability, a wide range of housing and building stock will require some kind of evaluation. This section also points out the need for "in use" performance, essential to determine how occupancy plays a big part in building performance.

Section 7 on page 29 of the same document mentions the term 'compliance' which has been highlighted as important for the verification of properties that have been realistically built as they were designed. One observation is that Scottish Building Standards should take a stance of being more methodical in the verification of standards that are applied to buildings before granting permission to build while also verifying during and after the construction that the standards have been followed as designed. This would increase the quality of build making contractors aware that completion certificates will not be awarded if compliance is not followed as it was predicted. One aspect which is mentioned is that "there are no requirements or guidance for inspection or testing" which is correct as there are no obligations to conduct such tests and investigative testing on whether buildings are performing as designed leading to another document which mentions the need for final inspections of buildings, before occupation and during occupation. This is the case of the RIBA outline plan of work (2007) which shows how the design and construction of a building should be organised into different work stages. At the end of the outline the last stage - part L - practical completion and marking final inspections are required and a further post occupancy evaluation should be added. This outline is defined as a suggested plan of work and these are not imposed by building regulations. It also does not specify whether real testing and monitoring should take place. The revised outline which is under consultation (2012/13)[3] [3] does have an enhanced part L work stage where the use of Post-occupancy evaluations are suggested. Once again imposing such work as a means of verifications is not mentioned.
The Sullivan report section 7 page 29 also analyses the need for closing the gap between the 'as designed' and 'as built' and also 'as managed' which is an interesting approach in that many buildings have energy and maintenance building managers that should have an understanding of how buildings are operating and whether it is as predicted. Issues of this performance gap are expanded on in this document.

A document which has been interesting to read and reference has been the NHBC Foundations and the Zero carbon Hub with the title; Low and Zero Carbon homes: understanding the performance challenge[4] [4], it addresses the topic of the performance gap looking at the various areas where this gap can be shortened. It analyses how design expectations can be high and construction practices can have a detrimental effect on the performance of the building once it's been occupied. Although this is a key piece of work, it is limited to addressing concerns over new house building in the UK. The work produced in this document aims to identify the broader need of addressing the performance gap in other building types, i.e. non-domestic, both new build and retrofit. This CIC start piece of work has taken some of the topics mentioned in the Zero Carbon Hub document and has expanded and added more commentary on related topics and case studies.

A document which was taken as guidance is another NHBC publication titled "Carbon Compliance for Tomorrow's New Homes - Topic 4" [5][5]. Once again this document points out the issues around closing the gap in performance in new domestic dwellings focusing on compliance tools that are used to predict energy performance at design stage in comparison with the as built. Similarly to the above NHBC document, the problems identified address only new domestic buildings which are important, but equally important are non-domestic both new and retrofit projects.

[1] Sullivan, L - Scottish Building standards Agency (2007). A low carbon Building standards strategy for Scotland. Arcamedia, Printers Coast

[2] Sullivan, L - Scottish Building standards Agency (2011). Progress Report on the Low Carbon Building Standards Strategy for Scotland. Scottish Government web portal, pdf document not printed.

[3] Royal Institute of British Architects (RIBA) - Practice and Profession Committee, (2012). RIBA Plan of Work 2013: Consultation document. RIBA Press

[4] NHBC Foundation & Zero carbon Hub (2012). Low and zero carbon homes: understanding the performance challenge.IHS BRE Press

[5] Zero Carbon Hub & NHBC (2010). 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. NHBC Foundation, NHBC Printers.

The document by the Joseph Rowntree Foundation on the Elm Tree Mews housing project[6] [5] has been useful to point out many of the gaps experienced in the performance of this project. After detailed post occupancy evaluation (POE) many interesting conclusions were formulated which feed into many of the thoughts this document presents. The POE seeks to learn about issues involved in the delivery of Low and Zero Carbon housing and has concluded in interesting collaboration projects which should help to reduce performance gaps in buildings of this nature. It proposes to have continuous feedback between industry, government and other stakeholders. The building industry should seek to constantly analyse energy and carbon performance data in order to have a repeated improvement feedback.

3. Introduction - Origins and examples of performance gap

Over the years tougher building regulations have added pressure to domestic and non-domestic builders and developers into creating safer and better performing buildings that can make the occupiers satisfied and comfortable. This additional concern and procurement comes at a cost and builders/ developers have recognised this as it directly affects their investment and on the long run on the marketability of the buildings. The construction industry plays an important part in the economic stability of a country and therefore any changes creating onto higher costs will affect the economy.

This can be a debateable topic from all aspects but with the whole cost mechanism aside, the objective is to make buildings better places that can last longer periods and that can be resistant to climatic shifts flexible to resist variations throughout its life span. For this reason standards are becoming the pivotal turning point in the construction industry that brings change raising concerns when upgraded and improved.

Thermal and energy standards have been, for the last decade, part of one of these pivotal changes which create controversy between various sectors in the construction industry and therefore can be controversial. It is not surprising that as a result it's important to specify and design appropriately to comply with energy standards from the start rather than on site and on a later stage.

Creating consensus over implementing energy efficient methods can be transmitted appropriately with time to the construction industry and it's the increased level of accuracy and development which will make it rise its standards. Issues around external and non-controllable aspects of energy can create discrepancies, in many occasions this relates to occupiers and the end users of the properties.

This paper has analysed the gap between the predicted designed stages of a building in conjunction with the constructions stage and compared it to the actual energy use and the forms in which occupiers are adapting and utilising the buildings after completion. In the past this gap was overlooked mainly because standards were not as strict as they are now and also because building users were not concerned about how well they were using their buildings. We now have issues concerned with continuous rise in energy prices affecting all building users, particularly in social housing where fuel poverty is a growing concern. This has created a questionable approach on buildings that claim they are energy efficient by design but have not produced the results expected, displayed as high energy bills. Therefore both government and developers/clients are pushing on decreasing the gap between design and build and using the government energy standards as a benchmark but testing the buildings to prove whether they are functioning as expected.

The use of the Standard Assessment Procedure (SAP) and the non-domestic equivalent (SBEM) has created this benchmark for buildings and as questionable as the tools can be, they give a predicted energy use given all its services and fabric performance.

This study has branched into analysing the reasons for the disparity between the designed predictions and the actual energy use of buildings. It has focused on and highlighted the problems through past analysis of buildings and has highlighted them with actual examples where improvements can be done. Different perspectives will be analysed with the following topics:

- Initial design of building
- Quality of energy predictions
- Issues surrounding construction stage and labour skills
- Occupants behaviour patterns
- Quality and reasoning of building performance evaluations

[6] Bell, M. et al (2010). Low carbon housing: lessons from Elm Tree Mews. Joseph Rowntree Foundation (JRF) & Centre for the Built Environment (CeBE) at Leeds Metropolitan University. Available at: http://www.jrf.org.uk/publications/low-carbon-housing-elm-tree-mews

The cause for the differences in consumption can be due to little consideration in the design and its complexity creating awkwardness during the construction stage together with the occupation patterns that aren't precisely thought of. Communication on site when changes arose and also the skills that tradesmen have in conducting and reasoning energy efficient details has a detrimental effect on the final construction quality and efficiency. Added to that there are complications in the probable change of use of buildings and the level of appliances and other un-controlled energy consuming equipment that uses more energy than predicted. Office equipment and other appliances are an example; at times they are left in operation for longer than predicted periods which in turn lead to excessive abnormal energy wastage.

Much more can be said in terms of a performance gap with a focus on carbon emissions as it can be a quantifiable outcome but in reality not all performance gaps should focus on energy and saving carbon. The built environment covers many other issues that should be addressed that originate from underperforming buildings; these could have an effect on the environment, resources, occupant's satisfaction levels, and health.

4. Methodology

There are many building types that fall under this problem as the building standards are applied across the board. The push towards higher and better energy levels is high in the agenda of architects and construction professionals as well as clients because it provides a certain accreditation and kudos to a company's profile. The main priority is the increase of energy efficiency and as a result the lowering of carbon emissions not to mention the occupier's thermal comfort and general building acceptance.

For the purposes of this document, there were two scenarios in which this gap is most representative together with two building types that were the main culprits in the gap increase as they are the majority among our built environment.

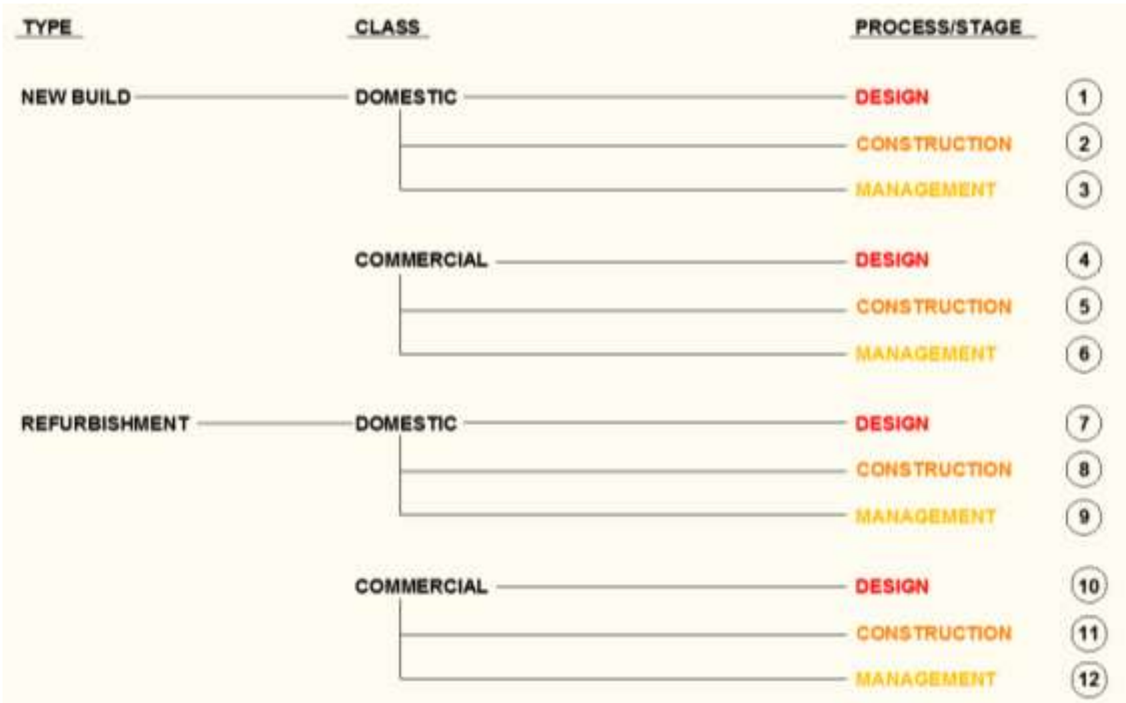
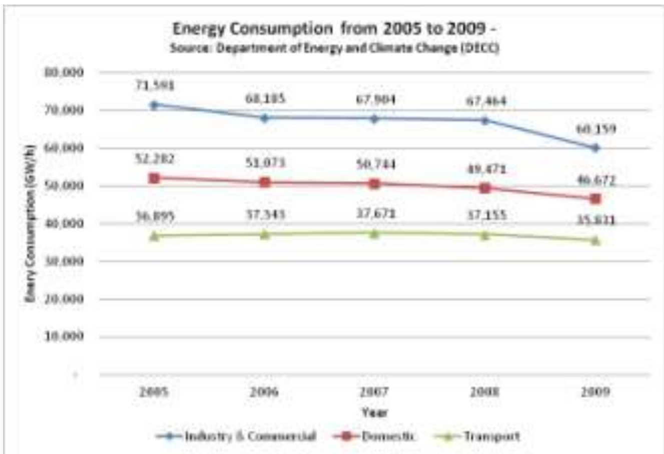


Diagram 01 – Specific areas of further research – colours relate to figure 22 page22

The above diagram lists the areas where further research is needed into the reasons of underperformance and widening of the performance gap. Currently the majority of research is focused on new buildings, particularly new homes in order to fulfil the demand in homes. This demand has not been met, especially in the last 5 years since the economic downturn where proposals of new developments have been cancelled or have been completed at a slower pace. According to Homes for Scotland, the body that supports the Scottish home building industry, particularly housing associations, has claimed that in the last year, only 15,000 new homes have been built in Scotland, compared with 25,000 homes built before the 2008 "credit crunch". Homes for Scotland also have stated that there are 157,000 families on a council waiting list for a home and it is estimated that by 2033 up to 450,000 are needed putting a lot of pressure on the new build market where 21,500 homes have to be built per year. Scotland is playing "catch up" in the amount of homes that are needed. For this reason it is important to look at other options. Refurbishment of homes is one way of tackling this deficit, upgrading current homes and also re-habilitating abandoned homes will contribute to this. It is estimated that by 2050, 85% of homes will still be standing therefore it's important to make them as energy efficient as possible to fulfil the residents comfort and energy requirements.

Research is needed not only in the domestic sector but also in the commercial sector where buildings are consuming vast amount of energy in offices, industry and retail units. Issues on how and how well this can be achieved would be dependent on research around these building types, both in the new build, making sure standards are met, and in the refurbishment of commercial buildings up to a standard where the designed proposed savings in energy are close to the actual. The Carbon Trust is in charge of this sector in the same way Homes for Scotland deals with domestic sector.

In terms of energy consumption in domestic buildings across Britain, reductions have been shown close to 11% while no-domestic buildings by 16%, both compared to figures from 2005 to 2009[7]. In the domestic sector this reduction is due to the improvement in new building standards and also the Scottish House Condition survey which has pushed for housing association to improve their existing stock. Different funding streams have helped to achieve this (CERT, CESP etc). These reductions have been mainly from public sector homes while the private sector only achieves such standards in new buildings leaving older rented or owner occupied homes in many cases are difficult to upgrade and make more energy efficient as there is little control over this.



Graph 01 – Energy consumption in the UK 2005 to 2009

The 12 different scenarios in diagram 01 bring diverse issues that should be explored. Some overlaps could be identified in order to reach post-occupancy energy compliance.

The analysis of the above building types was taken with a critical eye on the procurement of the design and the construction together with the adequate management of the build dealing with construction or design changes, making sure construction skills are up to date with energy issues and also verifying materials have been ordered adequately but most importantly fixed and installed effectively. It is also as important to evaluate the performance in line with current energy standards while also following a set of training sessions with future occupiers to explain the operation of the building.
As observed above management plays a key part in the effective outcome of the building and it can appear at different levels and stages.

Combining practical and on site experience with past building performance was essential in the completion of this document. It was a priority to show the reader examples of typical elements where buildings were not performing or were not built & designed ideally creating increase energy use as a result. The use of infrared thermography and photographic examples will address the issues normally experience in the construction stage.

Focus on the refurbishment of buildings is also crucial. It is known that over the years current building stock has had several modifications and upgrades which have been in many cases conducted by un-trained workmanship with little consideration of the implications the building fabric. In many cases the upgrade of services in properties has left gaps in the fabric causing the rise of air infiltration which has an effect on the thermal performance of the building. The report will look at highlighting these issues by showing photographs of examples and commentary on solutions.

5. Performance gap – causes

The way in which buildings behave depends on many aspects of the design; from the materials specified to M&E services installed. Various standards and quality will portray overall building energy consumption for space and water heating. A more un-regulated account of energy depends on occupiers and how ecologically or technological aware they are in handling a building with a low energy design.

The following sub-topics are directed to various parties that may be involved in the completion of a building or its occupation. The purpose of expanding on these is not to fall under a blame game in the construction industry but simply to widen the concern over practices and roles that can decrease the performance gap of completed buildings.

[7] DECC - Sub-National Energy Consumption Statistics - Total final energy consumption UK statistics. - http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/regional/regional.aspx

As pointed out above there are two typologies of building types which concern the building industry in Scotland; the first relates to the new build industry with on site construction methods and the use of masonry construction and many trades and the offsite construction industry with a better controlled roll out of building components ready to be assembled with small labour needs. The second relates to the refurbishment; this approach is of concern because of the vast amounts of hard to treat domestic and non-domestic buildings Scotland has which require specialist intervention and repair with a focus on older materials and their adequate adaptation.
Both types fall under the sub topics below mentioned and are addressed accordingly.

5.1. Design led tools – assessment and data input for energy predicting calculations & software

The construction and architectural design industry is legislation led and it is for this reason that any shift in the verification and assessment of a system or tendency leads to the need to calculate and make sure what is designed complied with legislative guidelines. This can be experienced both at a small scale with materials and construction processes that require certain standards and testing that can be authenticated, to the compilation of materials and processes in the form of a built construction that as a whole requires verification and a confirmation of performance. The latter one is of such complexity that many elements alter its results.

For this reason a series of tools have been created in the market that can facilitate this job which are use to predict performance outcomes; it's the energy related ones that are of prime importance.

There are two types of calculations, of which some are used more than others depending on its complexity, level of accuracy and dynamism.

- Static calculations – These use standard predicted benchmarks to calculate any energy needs, many times in simple kWh figures for space heating or hot water requirements. They can be used for simple and quick calculations that don't necessarily use all parameters of the building and its surroundings. They rely on basic calculations and can be flexible in dimensions. These calculations are not site specific, although some internal and external temperature figures are required. There is little occupancy patters included but a utilisation factor is assumed instead. Examples if these are simple heat loss and ventilation loss calculations to indicate space heating requirements.

- Dynamic calculations – These are preferred tools used by designers and constructions specialists. They can predict in line with the buildings location and climatic data and estimated account to how the building will react to external fluctuating conditions. Some models use variable base degree day data for example the Building Research Establishments (BRE) Standard Assessment Procedure (SAP) for domestic dwellings and the Simplified Building Energy Model (SBEM) and others are more site specific and obtain data from weather stations located close to that location. They are also tools that can vary to some degree the internal occupancy patterns of the buildings, some better than others, and also can come in the form of a 2D or a 3D prediction display.

The Dynamic tools are used more commonly by the industry; firstly because SAP & SBEM are required by building control, building regulations and many other building standards (Ecohomes, BREEAM and section 7 - Scotland) and secondly because they provide a more realistic prediction of how the building should react and operate. This requires a great deal of effort and design skill whether it's at a preliminary stage in the design or at a more decisive stage. The 2D & 3D software are computer programmes linked to CAD drawings that can be easily modified with parameters assigned appropriately.

The dynamic tools are the preferred in the industry and therefore require a level of training and understanding of the built environment and also of the design itself. The differences in the types are as follows:

- Dynamic variable – These are the SAP & SBEM type that operate with a degree day model, in other words predicted climatic weather in accordance with past weather data indicates in line with an internal set temperature (20-21˚C) the number of days that the dwelling will require heating or cooling to keep this constant internal temperature. The predicted space heating demand can be sensitive to small variations in the input data therefore accuracy of the design is a priority. There are also separate predictions that can be manually added or calculated for example: internal gains, hot water use, lighting and air infiltrations, all linked to occupancy. There are benefits of the use of renewable energy which reduce the carbon footprint of the buildings. The tools calculate the dwelling/ building emission rate (DER) and compare results to a Target emission rate (TER) statistically linked to similar dwellings in homes in Milton Keynes Energy park built in the early 1990's which is constantly updated and recalculated in order to apply new and improved efficiencies as close as the current building industry. These tools are widely criticised because they can be inaccurate which produce assumed occupancy patters that eventually don't indicated reality. Components within the thermal envelope are reliant on their thermal transmission figures.

Other examples of this type are the Passive House Planning package (PHPP) which can be more dynamic that the SAP/SBEM as it incorporates weather files that are site specific that show a more accurate account of fluctuations. PHPP has been validated using dynamic thermal simulations and measured data from a large number of completed Passive house projects. It also makes its calculations using two extreme cold conditions and creates energy requirements using both in the case of extremes. The PHPP has been a preferred tool as it takes into consideration occupancy patterns, shading and over-heating, and extreme fabric efficiency. This tool relies on the "fabric first" approach and is not a carbon emission rate calculator. It purely looks at dwelling efficiency and the reduction in energy demand. Renewables are not considered (only for space and water heating)

- Dynamic effective – These are predicted models that use climatic data from weather station information with an average yearly or monthly data count with averages over longer periods of time from 10 or 20 years back. In terms of materials and fabric performance the software's gives the user the capacity to build up components and assign materials building up high performance. Occupancy is also measurable as well as the type of heating systems and sources of energy. The software works with simple two dimensional plans of the building which aren't modifiable and are reliant on the initial design, any changes would require a new plan to be imported.

  Other type of dynamic thermal simulations are linked into Building Information Models (BIM) which are a more dynamic interface that can be managed to modify a design and output simultaneously with other changes that occur in the design. For instance, if the volume is modified because of structural reasons the thermal and energy requirements will be modified while the changes happen. It's a fully integrated package that can work with other building elements.

Inaccuracies in uploading data on all types of models seem to be the problem in the estimation of the energy consumption. There are many variants within a building that have to be added adequately, and in the location where it requires it in order to get optimum results. Another problem that seems to arise is the verification that the model is accurate. Assumptions and data interpretation can be intuitive and dependant on the installers experience but it is difficult to verify fully the real performance as it's non-comparable unless the building has been repeatedly modelled and verified from previous in-situ data.

Problems arise on expected performance at the time of design and modelling and there is little consideration on accurate accounts on how well and intensively the building will be occupied. This falls under the occupant's use of the building and the electricity or heating use. Times of building use and estimated internal gains can alter and give miss conceptions on the real energy use of the building.

Knowledge on building design and thermal response of materials in conjunction with climatic data and principles of physics are vital in the adequate design and modelling of buildings. If this is performed by inexperienced or untrained staff and conducted using assumptions rather than facts the model and design can be a flaw from the start and predictions will be inaccurate.

5.2. Design aspirations – complexity of building

The complexity of the building appears to be the reason for creating problems during construction and on the overall building performance. When a building is designed with vast amounts of intersections and junctions there is a fear of losing heat through cold bridging, which In order to mitigate would require a detailed design in place.

When a building is complicated in its design it is most likely that its build-ability and complexity on site will create mistakes and problems. The disparity between knowing how to design with construction knowledge can be largely due to the inexperience of some building designers in visualizing a design purely on its aesthetics while leaving the construction methodology for other professionals to overcome. The thought process of designing a building with a sequential construction procedure is vital in the build-ability of a construction. This would lower the risk of placing insulation by adequately wrapping round the element to ensure a limitation on heat transfer that would lower energy wastage.

The inclusion of energy efficiency design consultants within the design team, both to evaluate what has been designed and also advise from the start of the project would minimise any complexity.

5.3. Design specification – Material selection and services for heating or cooling

There are two areas where materials and services may create more than expected energy consumption. The first is the expected manufacturer's thermal quality or efficiency of a material/technology, the second is the adaptability and suitability of a material and technology in the design and operation or occupancy of the building; in other words the correct specification.

It is believed that the manufacturers thermal performance of materials and efficiency of technology (renewable or not) has been tested and certified by third party organisations, (BBA, BRE, UKAS, MCS) verifying that they are expected to perform under certain circumstances within the designed building. What many designers and engineers don't realize is the way these materials/ technology react and perform in situ which can perform differently. This may come down to the way they are operated but also

in the way they are tested as a product. Expectations are made on the results from a test laboratory under testing conditions. Small samples are used and seldom tested in real circumstances in dwellings and with other materials butting in together. Equal to this are the materials/ technology's adaptability into older buildings and materials. A clear example is shown in the retrofit of buildings. New materials are being positioned next to old and in many cases historic breathable materials. The moment a modern material is positioned near it the breathability of the wall/roof component will differ creating long term problems of dampness and moisture accumulation; later on creating health problems to occupiers. Efficiency figures are also at times over estimated. The market forces manufacturers to compete with each other trying their best to shine above each other. This causes uncertainty in the efficiency of their products. Efficiencies are quoted lightly when the real efficiency should be during operation. This would give the real performance of the product.
Technology also suffers a similar path. It is vital to design and specify with occupancy in mind and in cases options of change and growth. This could be experienced in the change of use of building space with internal gains being modified, thus requiring more ventilation or cooling.

Equipment efficiency has to be implemented appropriately for the space and building in question without considering a "one size fits all" approach. An example would be the installation of ventilation systems that depend on pre-designed ducting and fan/ extractor location; if changes occur during construction all of the designs should be amended and rectified, otherwise their performance may differ once the building is occupied. The commissioning of such materials is also vital as this will ensure equipment is installed and operated adequately. Simple flaws like insulation around ducts, the inclusion of attenuators or the sealing of pipe work all are part of a fully functional system.
The design of the controls is also important. In many cases systems are designed in such a way that space heating or water heating is not adequately managed and technology is wrongly being switched on at times when occupants are not using it or simply have un expectedly changed their occupancy patterns. There are also cases in which fluctuations in the UK weather make it impossible for a system to change dramatically from heating or cooling, this is the case of MVHR systems.

5.4. On site workmanship – Construction quality in line with adequate current skill set

The widening of the gap between design and post construction performance is dependent on the quality of the construction work both in understanding the intentions of the design and the quality of workmanship. It is also indispensable for the contractors to understand the sequence of the building construction by introducing different work at different stages. Although this is common practice, in some instances contractors and sub contractors have to enter in repeated occasions, this is the case with new materials or technology that requires pre instalment and then at a later stage the same contractor needs to finish off. Communication among sub contractors is vital and changes have to be communicated down the line as quickly as possible.

What is repeatedly experienced on site with many sub contractors and main contractors is the adaptation and compliance to new and stringent methods of construction. This is the case with new standards both in the current building regulations in the UK and also in emerging standards, for example Passive House and Scotland section 7. These require a more specific and detailed compliance of fabric quality and technology installation in order to lower the demand of energy. Passive house standard is renowned for this as it requires detailing during design that proves near cero psi values in thermal bridging and during construction requires that these are followed strictly. The contractor and sub contractors have to be engaged with the quality of building that is expected of them. It is a new skill that will require extreme air tightness, using new materials and methods of limiting air infiltration.
As Building regulations in the UK get more stringent to the likes of Passive House, the workforce in this country will have to adapt and execute accordingly. In many cases energy efficient buildings are in the hands of contractors who should be updating their skills as standards get more rigorous, sadly some contractors don't do this and bring in traditional not necessarily adequately applied workmanship. The introduction of new skills and methods of adaptation to new standards will have to be embedded into teaching in colleges.

There are two main areas where details are missed and performance may suffer:

- **Installation of insulation- airtightness layers**
  If insulation is not continuous, heat loss is experienced permitting thermal transmission. Cold bridging can also be experienced. Airtightness is compromised by puncturing airtight barriers (VCL, renders, sealed panels) creating air infiltration (heated air escaping) and filtration (cold air entering).
- **Installation of services – Drainage/ water pipe work, Air ducts and electrical pipe work**
  Bad workmanship can leave gaps around pipe work which lowers airtightness. Placement of wiring and pipe work in air tight service zones can be constructed to avoid this.

The following are images and examples of workmanship that can create heat paths that account to energy loss and decrease of building performance.

Fabric performance- Airtightness and thermal loss:

This image shows how different trades collaborate at different stages of the build which if not managed properly faults can occur. Cables that are not fitted in previously installed conduits will uncontrollably penetrate the building envelope creating un-necessary gaps damaging airtightness. This image also shows how the use of sealants or glues can leave gaps and holes.

Figure 01 – Source: SEC J I Currie 2010

Timber elements are fixed on a concrete base that has gaps and holes close to the DPC minimising airtightness. Pieces of wood that are positioned under the timber elements create more gaps in the timber wall. The repetition of these examples around the dwelling would threaten any attempts to make the home airtight.

Figure 02 – Source: SEC J I Currie 2010

In this example a down pipe is penetrating the concrete base leaving gaps around in the concrete slab. The perforation for the down pipe has been done post foundation stage therefore amendments like this one are needed. Leaving these gaps un attended will create further air tightness issues.

Figure 02 – Source: SEC J I Currie 2010

Perforation on the timber construction can also compromise the buildings air tightness and thermal transmission levels. In many occasions services passing by are un-avoidable but it is essential to make trades (plumbers & electricians) aware that holes have to be sealed and adequate tools have to be used in order to make repairs easier and affordable.

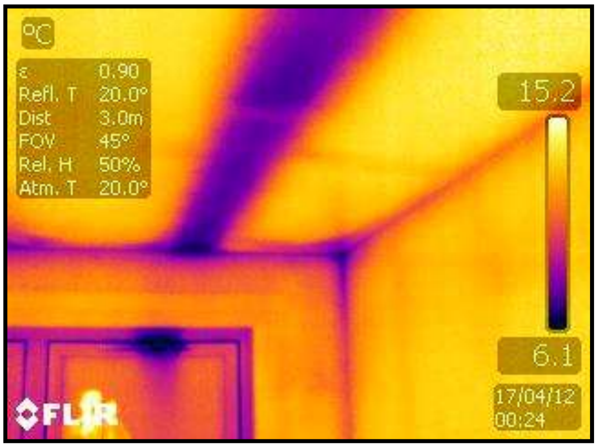
Figure 03 – Source: SEC J I Currie 2010

This infra red thermography image clearly shows a ceiling that hasn't been insulated. The roof void above has been fitted with insulation but at the eaves it has been difficult to place insulation. This could be either caused by missing carelessly the insulation or the complexity of reaching that roof angle has made it impossible to install adequately. Thermal bridging is also cause by a timber joist spanning from front to back.

Figure 04 – Source: SEC J Bros W 2012

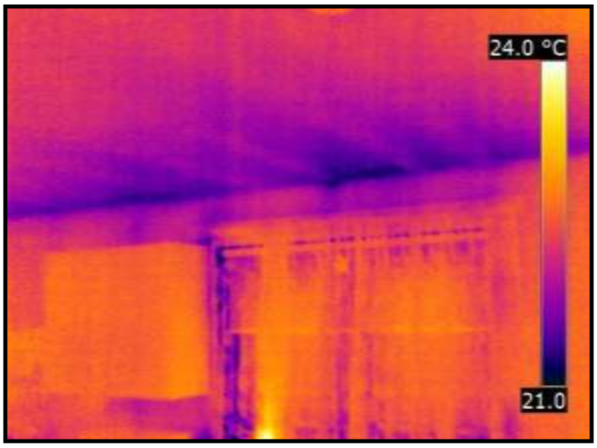
This image indicates a cold spot or thermal bridge/ heat loss at ceiling level where a joist with packed timber elements hasn't been insulated. A cold roof void will transmit cold patches if badly insulated.

Figure 05 – Source: SEC J Bros W 2012



This image shows another example of missing insulation at the ceiling level where it's been installed inadequately. This may be due to ventilation at the cold roof level and where insulation hasn't been laid properly in the ceiling creating bridging effect and cold spots. There is also the possibility of un controlled ventilation in cavities creating heat loss.

Figure 06 – Source: SEC J Bros W 2012



This image shows where insulation has been positioned in between the joists of the roof but the lifting of insulation at lower angles of the joists creates heat loss. The lower temperatures run along the edge of the ceiling/internal wall and will create leakage of heat into the un-heated roof void.

Figure 07 – Source: SEC J Bros W 2012

Services penetrating the air tight layers of buildings are serious air leakage pathways. This flexible pipe work is penetrating the insulation layer creating a gap in between it where air can travel in cavities.

Figure 08 – Source: CJ Walsh – Consultant Architect, Fire Engineer & Technical Controller

Holes and duct work penetrations that haven't been sealed can channel heated air out to cold spaces creating a leakage pathway and also compromising on airtightness of the building. These should be avoided but if un-avoidable adequate sealing and insulation should be included.

Figure 09 – Source: CJ Walsh – Consultant Architect, Fire Engineer & Technical Controller

Older properties that have been designed with ventilated voids behind lining or underneath floors will always have difficulties in creating airtightness. Air gaps around skirting boards are a common air path generating air infiltration. This image shows an extreme situation where a traditional timber floor has been replaced with a composite board to receive tiling or carpet. A different level between the floor and the skirting leaves gaps.

Figure 10 – Source: The Morrison partnership Architects, 2012

Evident air leakage points, for example this image, which shows a raised door that clearly lets heated air out and cold air in to the property making it uncomfortable and energy unconscious. Once again these are issues that should be dealt with when refurbishing a building with draughtproofing.

Figure 11 – Source: The Morrison partnership Architects, 2012

Abandoned electrical and water services can create complexity and confusion when refurbishing a property. The repairs that have been done to properties over the years have created many holes and air pathways escaping out of its envelope. Previous badly performed and planned repairs can also be difficult to fix. Construction skills should be able to assess and repair such examples.

Figure 12 – Source: The Morrison partnership Architects, 2012

Floor boards badly positioned leaving cracks and holes can seriously damage the envelopes energy efficiency by letting air escape easily. Cold air can also filtrate in creating thermal discomfort and energy wastage by heating a space that looses energy continuously.

Figure 13 – Source: The Morrison partnership Architects, 2012

Services and renewable technology

Adequate commissioning and briefing the building users on services operation is vital to achieve energy efficiency in a heating or ventilation system. This example shows how labelling is needed but more importantly access to operational areas of components. If complex systems are made and installed the less occupant awareness and integration.

Figure 14 – Source: Inspectapedia.com

Achieving high standards of installation should be a priority, this image shows a hot water pipe work that has been insulated. Sadly the installers have used standard “duck tape” which can with time and changes in temperature peal and de-laminate itself easily un-covering the insulation and creating heat loss thus lowering the efficiency of the heating system.

Figure 15 – Source: SEC J Bros W 2012

Complexity of pipe work and bad workmanship can create confusion and problems. This image shows cables that are close to pipe work carrying water & connections that have been repaired inadequately. There are also penetrations of drainage pipes through the envelope that are badly sealed. There are many causes here of badly installed devices and many trades working inconsistently.

Figure 16 – Source: The Morrison partnership Architects, 2012

This image shows how a flexible air duct penetrates a structurally insulated panel belonging to a roof. The pipe work hasn't been sealed around the penetration leaving an evident heat loss which will eventually make the heating system underperform as designed.

Figure 17 – Source: SEC J Bros W 2012

A heating and ventilation system has been installed in a cold un-heated room. The ductwork coming in carries heated air into the system and it hasn't been insulated appropriately. Leaving gaps of insulation can create condensation build up on colder surfaces which would lower the lifespan of the ducts and create system in-efficiencies.

Figure 18 - Source: SEC J Bros W 2012

Inadequate sealing methods will create problems of system efficiencies. This boiler duct has been sealed with a plastic bag which may stop air filtration but will not stop heat thermally conducting out of the envelope. Refurbished rooms have to be carefully detailed, especially where services penetrate un-known wall elements.

Figure 19 – Source: The Morrison partnership Architects, 2012

This thermography image shows a typical Victorian tenement with hot air leakage at the chimney flue system. From ground floor all the flues connected at fireplaces that are un-blocked show how heat travels outwards and conducts through the stone wall. This un-controlled heat escaping can be avoided by blocking or reusing existing chimney flues.

Figure 20 – Source: SEC J Bros W 2012

5.5. On site communication – When changes occur are they transmitted adequately?

In traditional circumstances communication in a construction site depends on the main contractor's ability to organise and interpret the design specifications. The initial design has been passed on by the architects and design professionals who have a full understanding of what the client's needs are and what has been accepted as an architectural solution. The contractor can either deliver such work by himself or to sub-contractors who specialise in various construction details. All construction work is initially delivered upon the first set of construction plans and details together with quantifiable amounts in line with design and material specifications.

As the construction progresses it is natural in the building industry to encounter difficulties that may be caused by:

- Client changes
- Architect changes
- Site constrains that were not expected
- Delays that cause the closure of the site (weather, budget, major design changes)
- Material specification difficulties
- Detailing problems

The causes can be many and the repercussions can be detrimental to the success of the project during construction.
It is important to be able to identify these problems as soon as possible and make the adequate changes with the design, specification and be able to transmit them on time to the entire construction team.
It is then equally important to be able to communicate these changes to the adequate subcontractors as soon as possible before the pace of the construction makes it difficult to deliver such changes without any costly modifications with little time repercussions.
Valuable communication skills are needed to transmit this to these team members that will have to quickly change tactic and correct and re-plan the work that has to be carried out that involves the changes. These can come as big design/project turnaround modifications to the original design or can be small sequential ways of delivering a detail but they all should be addressed in a refined way.
Failure to do so can come at various scales but evidently will create bigger problems on the projects evolved lifespan or can make the performance of the building change in such a way that the designed and predicted is no longer.

An example of this can be shown in figure 21. This internal thermography image shows a large heat loss and through the ceiling out into a cold roof void. The blue/black colours represent the colder surface temperatures compared to the rest of the ceiling. After talking to the client/architect, this streak of heat loss matched the dimensions and form of a new service walk way that had been added in the roof void above. The architect/client had changed a specification related to a ventilation system which was now going to be placed in the roof void. This required the construction of a service pathway for maintenance issues. The contractor specifically ordered that insulation should be placed underneath the new plywood walk way, this was evidently not followed therefore the insulation was missing and heat loss was appearing. This was either a communication or a misunderstanding problem that if left un-attended would have meant that energy would be needed to heat that home therefore a greater energy payment and a lower building performance.

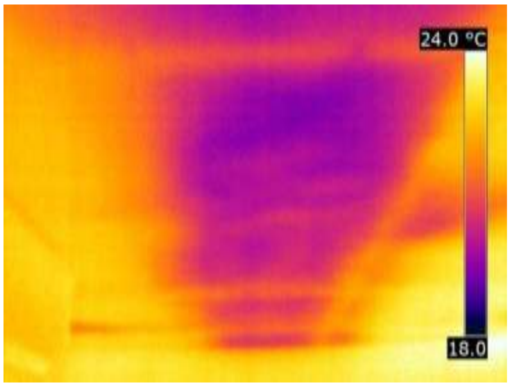


Figure 21 – Roof void walk way – un-insulated.

Examples like the above show how changes and wrong or misinterpreted communication can make buildings very vulnerable to performance gaps.

5.6. Building Performance evaluation – Post construction testing of fabric, services & BMS

One of the tools used for evidently demonstrating how a building is performing is by constantly or at various stages of the building, test and monitor for its performance. This will give an accurate account to how it is functioning pointing out interventions and logging consumption. There are two ways of monitoring such performance:

- As a post occupancy evaluation - a short in situ evaluation of the building that can monitor the performance of the buildings fabric and services. Commonly lasting between 3-6 months. In some occasions it can be performed after completion, during early occupation or at yearly periods.
- Building Management Systems (BMS) – These are installed into the building in order to constantly monitor the buildings performance. In most cases it will control and monitor the services in the building that can be essential to the energy use in the building and the occupants comfort levels. These are useful to calibrate and monitor heating and cooling as well as renewable sources of energy as well as lighting operational models and all in line with the occupant's needs and patterns. They seldom monitor fabric performance but can be adapted to do so with more complexity.

The implementation of the above requires accurate results adequately interpreted so that monitoring can report on the as built and as used performance of the building. The level of expertise required to conduct such tests and monitoring has to be properly executed in order to obtain reliable information to make adequate assumptions and realistic expectations. This level of accuracy has to be reached in order to make significant changes in the building. These could be to rectify the operation of a system or to modify a specification in a design.

In situ analysis of fabric performance is essential at various stages. It is important to do various tests at a very early stage of the building, for example an air tightness test once the airtight layer of a building is ready. It is also good to test the building fully before hand over to the occupiers in order to check if the performance is to the standard designed, for example Passive House requires an air tightness test before handover to verify if it has passed the requirements. It is also recommended to test and check if the services have been commissioned properly prior to occupant's arrival into the property. Equally important is the in-situ tests after occupation between 3-6 months of use. This will indicate how well the property is performing in line with patterns of occupation.
After this period it is essential to do year by year tests to take into account "wear and tear" of the building influencing the energy performance of the building. If faults are identified these can be rectified and lower the exposure to energy wastage.

These in situ tests could be the following:
- Air tightness tests
- In situ U-value and interstitial condensation fabric tests (for refurbishments)
- Internal temperature and humidity monitoring
- Infra red thermography (in and out of the envelope)
- Renewable energy technology re-commissioning checks and performance
- Energy consumption monitoring - metering
- Energy production monitoring
- Smoke tests of leakage pathways

The assessors and people who conduct the tests need to be aware of industry standards that indicate ways of performing such tests in order to be calculating and conducting accurate results and tests.
BMS need to be calibrated, installed and monitored accurately too. It is vital that all services are communicating with each other adequately so that the information captured can be transmitted and an action can be taken either in the form of changes in operation or more intense changes in building use and performance. If these are not programmed properly misinterpretation can arise creating a continuous building under performance which will damage the building and lower occupants comfort levels.

Governmental bodies in the UK have become more aware on the causes and ways of reducing this performance gap by funding building performance studies in short and long term periods to create awareness on how a highly sustainable designed building could be performing and measuring the impact of this in the future. It is assumed that energy efficient buildings are being erected complying with high building standards, and it is essential to quantify this and compare with the as designed expectations. These schemes and funding programmes are part of the Technology Strategy Board, Energy Saving Trust, and others taking interest on new buildings of all sizes and also retrofit programmes on hard to treat buildings. Other projects have taken their own funding to find the real performance, many times linked to the Building Research Establishment (BRE) and others.

5.7. Occupants awareness and behaviour patterns

Some housing providers have been particularly interested in getting an accurate account of minimising complaints and making sure that what has been designed & built meets the needs of the occupants. The aim of good architecture is that it can be a comfortable and functioning space that can fulfil the needs of the users. This isn't always the case; and many times the sections above are the cause for it to the occupant's disappointment.

For this reason it is important to be able to get feedback from the occupier's in order to learn from past mistakes and also make them recognise there are faults in the home or building they are using.

The above can be regarded as a fine science, as dealing with social patterns of living is a complex and time consuming task. All occupants are different and thus have diverse comfort levels which are not predicted easily. The science of thermal comfort levels has devised with different parameters for adequate temperature and humidity levels which human beings are comfortable in. This can be a measure for comfort but in many occasions; age, culture, customs and location may distort any prescribed comfort level.

There are people who are very comfortable at lower temperatures (14-17˚C) while others are happy with high temperatures (25 - 35˚C) occurring for a number of reasons. Some people are comfortable with heating in rooms for long periods of the day regardless of its occupancy while others have heating in living rooms or other public rooms, consciously aware that heating un-used rooms wastes energy. Another example is a cultural and design orientated problem of drying clothes in side homes. For people who don't own an energy thirsty electrical tumble dryer, room clothes drying is common due to space restrictions and the inability to dry clothes outside as a result of poor weather. This in principle is acceptable but for cultural and practicality reasons many home owners go for a quicker but un healthy option of placing damp clothes on top of radiators in the rooms. This can be an un-healthy and energy inefficient way of drying clothes. Firstly un-healthy, because the humidity that is accumulated in the rooms from the clothes can be harmful for respiratory conditions while also creating rooms susceptible to flue infections. This cultural custom also prevents the heating system to operate properly and therefore work inefficiently while also consuming more energy that is needed to heat the room. Examples like these are very common and can influence on the building to perform inefficiently.

It is vital that buildings are monitored to get an indication of what works and what doesn't particularly in social mass built housing. Many housing associations and other housing bodies have taken the option of making simple surveys and occupant perception questionnaires to conclude on how the design is working for the user and how changes can take place latterly or as part of a change process.

The use of energy and technology used in more efficient buildings has created some problems in perceiving why buildings are not performing as they should. In some occasions technology can be faulty but in others it is a question of whether is being operated properly. Many people are not technically orientated and any new; out of the ordinary gadgetry that is introduced to new homes can make them doubt that it works properly losing interest in the technology completely. Other times people are unaware of how and whether it is operating correctly, they may think it is but it is probably working less efficiently. Controlling this can be extremely difficult as everyone can be different and the problems can be very diverse. For that reason monitoring and questioning the user as much as possible can be invaluable to housing and building stakeholders.

A reverse-psychological approach is also needed when dealing with occupants. Creating a conscious approach to building/ technology use will benefit the occupier and life cycle of the building. These benefits can come economically or as a comfort improvement.
Studies on occupational behaviour and the application of reverse psychology in the use of energy indicate that the "guilt" feeling in the wastage of energy with high bills therefore people are keen to lower it. By observing and displaying energy used in homes an awareness of energy use arises and studies have proven that occupants lower their consumption. Showing energy consumption, especially on real time display monitors, has saved up to 20% in gas consumption for heating and 7%[8] [6] in electrical use. Electricity is difficult to lower as homes uncontrolled uses of electricity (appliances and lighting use) are difficult to manage.

[8] Currie, J; Stinson, J; Willis, A; Smith, R.S (2011). Ewgeco – Home Energy Display Trials, Questionnaire, Interview and Energy Use Comparison: Summary Report, Technical Report No. LCBTG/JC/TAYECO/01. Scottish Energy Centre Institute for Sustainable Construction, Edinburgh Napier University. http://www.napier.ac.uk/instituteforsustainableconstruction/lcbtgateway/Pages/NewsandEvents.aspx

The above can be a positive way to lower energy consumption, but it takes away the need for accurately designed and constructed buildings that can initially consume less energy through its enhanced fabric and technology as opposed to other less energy conscious properties.

Housing associations have realised that knowledge of tenants and end users perception on new homes can be the key to improving and designing homes for the future. By producing handbooks, "How to" guides and conducting occupant surveys while also making sure occupants go through an induction and a learning curve to operate their homes will lower the dissatisfaction over the design of new homes and also create adequately operable homes that are saving energy as they were initially designed to do so.

6. Performance gap – an approach to shrinking the gap

Further research into reducing this gap in performance will give an insight into ways of dealing with the above mentioned problems. By identifying them and analysing why they may be happening observing the flaws in the process, a robust procurement method of delivering energy efficient buildings can be created.

The following are areas where more analysis is needed which will help to reduce this gap and therefore be an introduction to further work.

Fabric Performance

In many cases as identified above in sections 5 there seems to be a discrepancy between the design and construction process and the following should be taken into consideration:

- Underestimating the real construction composition within a building element: This could be during a U-value calculation where knowledge in the construction type may include more or less structural timber which will alter heat loss. These examples have to be tackled by training professionals to understand the building design more accurately and also to modify software that can question this.
- Junctions of building elements: U-value calculators only take into account thermal transmission through generalised building components, i.e. the majority of wall type, omitting thermal bridging in junctions. This also ties in with the complexity of the design – geometrically more complex junctions and thermal bridging difficulties.
- Taking into account thermal by-pass in areas where ventilation heat losses can appear: For example party wall cavities, un controlled air circulation, cracks and holes that have appeared in other parts of a building filtrating into other parts of the fabric; this is the case of retrofitted buildings.
- Taking charge of properly communicated changes during design and construction: Supply chain has to be informed in time and making sure it's executed correctly.
- Creating a verified and approved national in situ fabric monitoring set of guidelines that can be applied to all buildings upon completion which can be comparable to similar building types. Testing methodology has to differ between retrofit and new build projects, simply because building envelope aspects are different.

Building services

The design and installation of services has to be well thought of and considered. Many building service engineers set up bigger systems than is actually needed therefore the carbon emissions are higher. This can also be the case for systems designed as being too small for the building making technology work harder therefore working at its maximum capacity most of the time , using more energy.

- It is advisable to be knowledgeable on all aspects of the building in order to size properly. A reduced heat loss through the envelope will require less energy for space heating therefore smaller systems are needed. It is also important to consider efficiency in the heat and electrical management of the system. For example; using solar PV systems to power hybrid renewable technology or using surplus heat generated by a boiler or CHP system for heating greenhouses or other hot water needs (swimming pools)
- During assessment in the SAP calculators a good understanding of the technology and how it fits in to the building simulation is essential.
- During construction it is essential that various performance test are conducted. A commissioning test after completion and also once occupants are operating the buildings is vital.
- In refurbishments designing in line with the current fuel type, space restrictions are critical. There are also restrictions with planning which should be addressed. Current pipe work should be inspected and used if still in good operational condition. Regardless of this, keeping pipe work insulated and properly accessible is important.

- Maintenance regimes are important too. A scheduled maintenance cycle just after occupation is useful so that it can be in line with the commissioning and all issues are corrected. Many times buildings newly built or refurbished suffer from system failure because of dust, rubbish and misuse which can accumulate during construction, blocking pipes, ducts and filters. Conducting a post-construction inspection and maintenance will help the devices operate properly from the start.

Building user

The relationship between the building users and the design of the building can have important implications for energy and carbon performance. This is more relevant when technology has been installed in the buildings which may seem complicated and difficult to operate efficiently.

- Engaging with new technology: Control devices for building users can be a daunting experience which is often avoided or operated as best as it has been understood. This creates confusion and technology operated wrongly altering its performance and using more energy than is needed. This creates discomfort and dissatisfaction.
- By having a wider understanding of the occupants, the designer can simulate and design with those occupancy patterns making it easier to control and to occupy. Many times occupancy is considered as an arbitrary factor when in fact it is vital for the adequate operation of a home.
- Analysing closure times, periods of occupancy, dynamic changes in space use, zoning smaller areas per design feature, orientation or activities should make the design/ simulation closer to the real building use. Changes are evident but the building has to have the ability to dynamically change and adapt.
- Making sure occupants are properly briefed in the operation of technology is essential. Making use of occupants hand books, induction sessions, condensed "how to" guides and having in house energy champions to help occupants when in need is essential.
- Adequate labelling and making sure buttons and switches are evident is essential simplifying the settings and operation.
- Affordability of maintenance and parts replacement: Technology can be very complicated and expensive specially when maintenance is needed and cost of replacing filters and other faulty parts should be affordable. If occupants and users find a system to expensive to maintain, switching to easier high energy consumption devices is preferred.

Building Industry change

Much of the underperformance of building design and construction is embedded in common practice and accredited detailing which may not be suited to all buildings and especially not to highly efficient buildings. The level of detail and performance evaluation that is required for low carbon buildings goes beyond this and a re-structuring of the way we train and teach our professionals has to change.
Additional to this, the construction industry and any given project is full of diverse trades and subcontractors that make the process of a building conception very difficult to control. Communication between all these professionals needs to be concise and detailed to a level that can be understood and effectively executed on site.
Construction presents issues of sequencing which need to be addressed in conjunction with all the building trades and contractors, changes require product and material substitution complex commissioning which impact on performance.

A consideration on expectations of design efficiency and the tools available to execute such standards has to be assessed. A progressive practical shift in mind, similar to Passive House and others has to be quickly channelled into the Scottish construction and design industry. Strict guidelines of design coupled with on site verification of work have to be imposed as the new route to delivering sustainable buildings.

Continuous improvement

Conducting post occupancy evaluations to measure the actual performance of the buildings is an essential tool used to measure the occupier's perception of the project in line with its adaptation and comfort delivery. These studies generate feedback that should be evaluated and disseminated but most importantly acted upon its outcomes. This feedback can be dealt with during at the development and construction stage in a current building (many times less likely) or in future projects learning from mistakes and occupants needs. If there is to be a breakthrough and improvement in the quality of our buildings it is essential that the industry analyses POE studies and implements them in the building process as a deliverable that is included in the work plan of the building design and construction. Making all stakeholders aware that a study will be done of the building and all aspects of the building will be dependent on this outcome should make professionals conscious of the task ahead.

Government also has to be engaged into implementing rigorously a Post Occupancy Evaluation (POE) study of the buildings not just to approve that the building is achieving what was submitted at planning and building control stage but for the long term life time of the buildings.

The shift in change should involve designers and developers in conjunction with the supply chain and its supporting infrastructure of education, professional bodies, skill sets, research community and the government. Figure 22 below shows a progressive industry led diagram which indicates a process in which industry should act on for the reduction of the performance gap in our current and future buildings. It explains how a close link between design, construction and handover is dominated by various deliverables which work among each other depending on what has been designed.
The design stage aims at choosing the type of project that is being built, whether it is a new build or a refurbishment, and where a detailed design specifically focuses on sequential works progressing adequately. At construction stage following proper skills and professional awareness, there are areas that are essential, for example, communication on site, adaptation when change comes into force, linking in with expertise of staff and concluding with high quality control of the building while on site. Finally, the handover procedure, where occupant's feedback is used as a learning curve and POE, commissioning of equipment and a whole building evaluation can be the essential missing piece for a progressive thermally adaptive building.

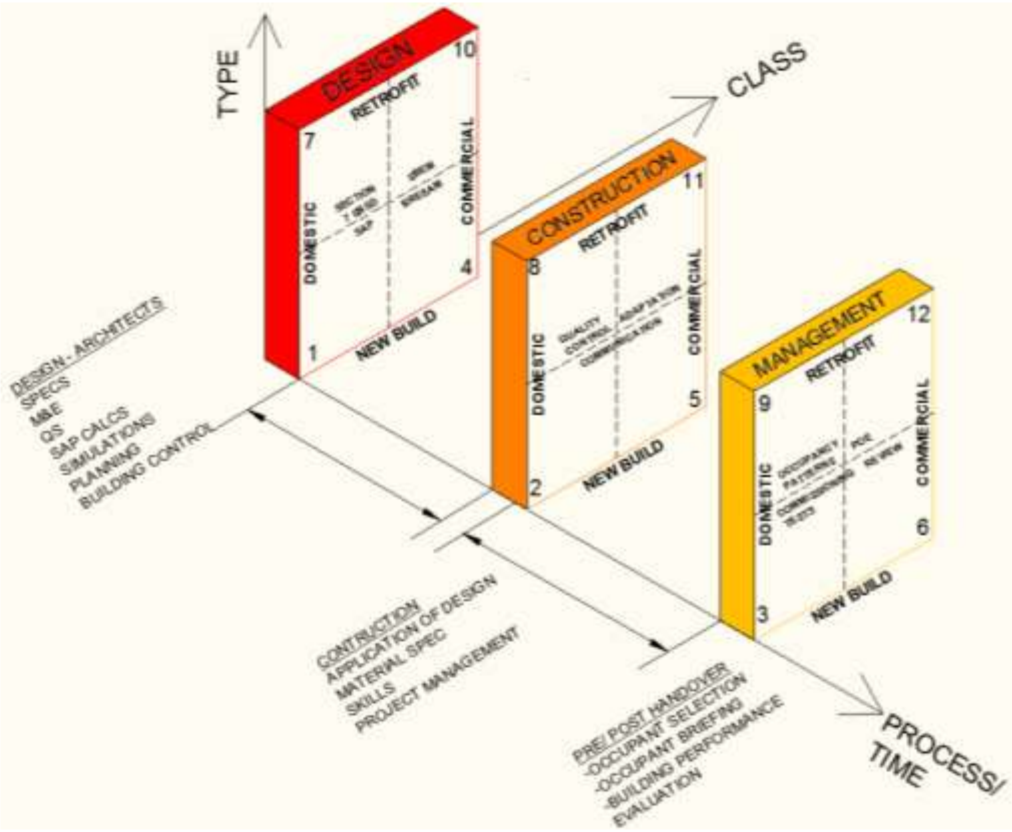


Figure 22 – A progressive building design/ construction model. Source: C, Purdie & J, Bros-Williamson 2012

7. Conclusion

In order to be better equipped for the reduction of the performance gap it is essential to first set a target date where standards will be expected to achieve certain levels of energy reduction such as the 2013 and 2016 low carbon buildings timeline and the zero carbon building compliance. It is difficult to be able to achieve standards with little knowledge of what is needed to be assessed and analysed. The 2013 mile stone is difficult to achieve but procurement and evaluations methods for the 2016 building regulation standards which will be fabric intensive and reliant on on-site renewables would be an initial approach. Creating a manageable set of guidelines that can be embedded into the industry from the start of the building design and prediction stage to the actual evaluation period would be a useful start in the gap reduction in performance. This should be applied to both the new build industry and the ever growing refurbishment industry where regulation and funding streams have dominated the industry.

- New Buildings: A thought process of combining all professionals at design stage making them aware of the expectations and the benchmarks used. Analysis of the advantages and disadvantages of various sequential work between different trades should be a priority.

- Refurbishments: Knowledge of the building is essential; not only of the building dimensions but of the original materials in combination with new materials this would bring knowledge on how to combine them both producing a functional building fabric. With this knowledge in mind it is essential to then have an understanding of the building services available and the space requirements. A methodology of testing refurbished buildings energy efficiency (fabric and services) is needed which differs from a new building in that the historic factor plays a big part.

Once the methodology is set, a shift in the industry mind set will arrive naturally creating a decrease in performance gap narrowing down to better achieving buildings.

This change will come in combination with a process change which can influence good quality buildings and that will be created with the aid of case studies of narrow or wide performance gap buildings in combination with adequate guidance from the government on how to achieve this in all processes in the building (see figure 22) and a final process in which improvement is evident and properly achieved.
It will also be achieved with adequate research and development demonstrating testing methodology, post occupancy performance deliverables and a full understanding of behavioural studies between the buildings and the occupants.

The final stage will be to continue this process with enhanced education and training where apprenticeships and courses all have the same energy efficiency targets and all professionals are aware of the expected deliverables. This will demonstrate that all stakeholders involved are in the same mind thought.

Finally, it is important to point out that continuous monitoring and data collection is needed of these buildings. Buildings change in many ways throughout their life line and this has to be adapted not only aesthetically but also functionally in order to continue its expected performance. Many occupiers change, space is modified and systems upgraded without knowing the initial design outputs and expectations. These changes while in use should be communicated and acted upon.
We know that buildings lose their performance factor as the years go by and maintenance and upgrading is essential which will ensure that our buildings continue being efficient and ecologically worth keeping for many years more.

8. Funding Opportunities

More research is needed into finding out in detail the causes of mistakes and errors that are being made in the whole process of shortening the performance gap of ecological buildings in Scotland. The following are different resources that can help to fund further and more concise studies on this topic to prepare for a 2016 and beyond improvement.

- Scottish Government Housing Research office
- Scottish Building Standards Division
- Follow on vouchers offered by the Scottish Funding Council

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