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The Sustainability Challenge: Measurement to reduce Global Emissions

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Abstract Purpose – Modern Man’s impact on the Ecosystem, sustainability and the built environment’s contribution to global emissions are highlighted. The review provides a specific focus on the thermal performance of buildings and work undertaken to recognise and reduce wasted heat energy. Drawing on current research, data on buildings achieving enhanced levels of energy efficiency are presented and underperformance is discussed. While it is clear that domestic properties can perform, the pressure from legislation has been limited and significant gaps in thermal building performance continue. The paper proposes a model for building performance, based on control of fabric and services and the influence of occupant behaviour. The work also demonstrates where significant change has been achieved through processes of testing, measurement and monitoring.

Design/methodology/approach – Drawing on a number of current research projects, this paper identifies the emergent methods for testing buildings and assessing fabric energy efficiency.

Findings – The research identifies methods suitable for understanding and assessing building fabric performance. Using established methods, the performance metrics identify a significant difference between those achieving the energy efficiency standards and those failing to meet their designed performance.

Originality/value – Highlighting the issue of sustainability is common place, but few have identified practical process measures that differentiate innovation that can lead to significant improvements in the building stock and identify those failing to achieve target performance.

Keywords Integration - Building Performance, Energy Monitoring, Sustainability, Thermal Performance Testing

Paper type - Viewpoint

Sustainability: The Eco System in Context –where we live

The grass is not always greener on the other side, and as a matter of the best astronomical science, our neighbouring planets have little to offer even if we wanted to relocate (Boss, 2009). Exploration for signs of life focus on exoplanets beyond our solar system, well outside Man’s ability to travel (Boss, 2009; Mazza, 2015). The Earth’s atmosphere, biodiversity and ecosystem are unique, requiring protection before the window of opportunity to stop irreversible climate change closes (Ceballos, *et al.*, 2015). Sustainability, in a significant way, can begin at home and to be specific, benefits can be achieved if improvements are made to the way we live, design, build and operate homes. The value of such change is already recognised; the housing stock can make a meaningful contribution and is legislated to become more energy efficient and less carbon intensive (Vadera *et al.*, 2008; CLG, 2009; EPBD, 2010). Unfortunately, while the legal machinery is in place the pressure to change has not resulted in the desired action. If the legislation has failed to bring about change, why should the built environment be more sustainable and why not wait until the regulations develop real teeth?

A unique Ecosystem

The Ecosystem that secures our wellbeing is, as far as we know, unique. Created over 4.5 billion years (4.55 ± 0.01 ; Manhesa *et al.*, 1980), by big bang or some other phenomena the Earth was born. The planet’s Ecosystem fostered life and allowed Homo-Sapiens to start their

2.5 million year period of evolution. However, after the relatively short period of Modern Man, 340,000 years (Barras, 2013), the species started to 'devolve', engaging in detrimental activity that is changing the Ecosystem that Man relies on. From the industrial revolution, in less than 250 years, 'Industrious Man' harnessed the power to impose irreversible change and create ripples in the atmospheric composition the size of which have never occurred in the history of Modern Man (see Met Office, 2009 carbon records). What is often termed 'development' has started to threaten Human wellbeing and existence; with the limitation of natural resource being overlooked. Unfortunately, if Humans destroy the planet's Ecosystem, then there is no obvious place for future generations to escape to. Although we identify galaxies over 13 billion light years away (NASA, 2011), many fail to realise just how precious the Ecosystem is. Earth like planets do exist, some being just 11 light years away (Petigura, *et al.*, 2013), and although explorations look for signs of life (Mazza, 2015) they have yet to find another inhabitable Ecosystem or life-form.

Current Human development imposes threats to the planet's Ecosystem and for some species the situation is acute (World Economic Forum, 2013). Conservative calculations, with evidence based on fossil remains, suggest species extinction is over 100 times the biological norm (Jowit 2010; Ceballos, *et al.*, 2015). Due to the interconnected relationship of the Ecosystem, industrious anthropogenic influence has inadvertently changed the atmosphere and habitats relied on by one or more species, thus affecting biodiversity that Mankind relies on (Ceballos *et al.*, 2015). Some bodies, such as Global Warming Policy Foundation, use the regional variations of biodiversity and climate changes as evidence that the impact is not as great as suggested (Mueller, 2011). While there are some short term regional positives, leading researchers have not changed their position with regard to global warming; the evidence, based on CroSat data, show global change taking place now (Parliament, 2013). How and when the changes will impact on each region is difficult to predict but change is upon us (Met Office, 2009; Hawkins and Sutton, 2009). Disappointingly the solutions are not obvious and the preferred option is to delay change and reduce the impact on people living now, allowing time for mitigation (Joshi *et al.*, 2011).

Since the Industrial Revolution the concentrations of greenhouse gases, have more than doubled, coursing a trajectory that shows no sign of stopping. Over 800,000 years of carbon deposits in the ice caps tell us that Man's actions have vastly exceeded CO₂ production caused by any natural phenomena (Met Office, 2009). The increase in CO₂ is so striking that it is difficult to comprehend. Blame for emissions is often shifted to those nations with the largest populations, although distribution per capita would suggest that the UK provides more than its fair share contributing 7.8 tonnes per head, compared with China's 5.4 and India's 1.4 tonnes (Oliver *et al.*, 2013). Countries contributing the most total emissions are China 29%, USA 16% and European Union 11% (Oliver *et al.*, 2013). Not surprisingly, European development and the built environment sit at the heart of the emissions challenge.

Constructing responsibility

As part of the construction industry, the burden is greater than most; the built environment consumes more natural resources than any other industry and contributes the largest share of emissions (Prism Environment, 2012: Report for the European Commission; Palmer & Cooper, 2013). Reduction in emissions related to the built environment should be a relatively straightforward proposition (Oreszczyn and Lowe, 2010). It is possible to build and retrofit more energy efficient homes (Stafford *et al.*, 2012a, 2012b) and there are particular benefits in focusing attention on homes. Domestic properties use a third of all energy consumed in the

UK, with 65% being used for heating and cooling (DECC, 2014; Palmer and Cooper, 2013) thus, changes to the building stock can create a significant impact.

Building envelopes and performance

For domestic buildings, in Northern European Climates, the main concern is the high energy heating loads required during the winter months. During this and other seasons, reliance is placed on the building envelope to act as a thermal barrier that resists heat losses through the fabric and undesirable air exchanges. However, research has shown that the effectiveness of the barrier can vary and gaps in performance are considerable (Stafford *et al.* 2012a; 2012b). In most cases the thermal barriers are not effective and internal conditions are at the mercy of the external environment, changing rapidly as external temperature and wind changes.

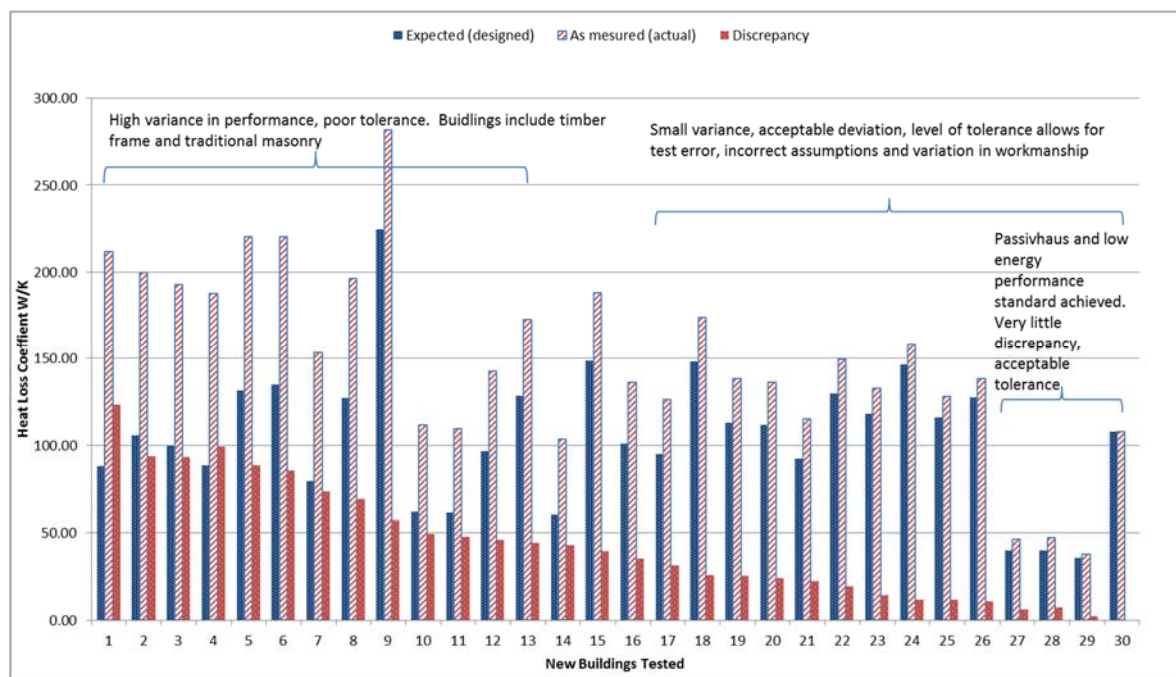


Figure 1: Heat loss studies conducted in the UK – new build (adapted from Johnston *et al.*, 2014)

In light of wasted energy, of real concern is the degree that a building’s fabric performance differs from that specified, especially as current regulation is aimed at design (CLG, 2009). Figure 1 shows the results of heat loss studies, providing an accurate assessment of the building fabrics thermal performance, using a co-heating methodology (Johnston *et al.*, 2013). In most cases, the buildings on the left of Figure 1 show the measured (actual) thermal performance being very different to the predicted resistance (as designed). The evidence from whole building heat loss tests shows, that it is not uncommon for dwellings to experience 60% greater heat loss than designed (Gorse *et al.* 2013; 2014). Where such differences occur buildings do not offer the thermal resistance required and cannot be controlled effectively. The first step towards a change to a more effective building stock is to understand building behaviour, recognise the actual performance, and then to apply appropriate remedies to improve performance. The measurement and monitoring of building performance is important so the building’s energy behaviour can be understood. The results of recent studies, that also include passive fabrics, which align closely with nearly zero energy targets, show that it is possible to achieve performance within acceptable levels of performance tolerance, such as those shown

to the right of Figure 1. However, other simple airtightness tests show how variable performance of existing and retrofitted fabrics can be.

How effective are our building envelopes: why control air penetration?

Simple airtightness tests have been particularly revealing when assessing the effectiveness of the external envelope. In a small airtightness study on a varied sample of existing buildings in the UK, Gorse *et al.* (2015) found some buildings were so 'leaky' that it was not possible to perform heat loss tests using standard electrical heating equipment. The power required to elevate the whole house to a sufficient temperature above its surroundings would have overloaded the property's domestic electric supply. The implications being that such buildings are so poorly constructed or maintained and so 'leaky', that they do not provide an effective envelope. In relatively small buildings, air changes rates of 16 – 29 h⁻¹ @ 50 Pa were found in properties that had been previously occupied. In the leakiest buildings the conditions observed suggested that it would not be possible to adequately heat the whole building during winter conditions.

Air testing in buildings that have been retrofitted can be revealing. In similar building typologies with similar retrofit measures, but installed by different contractors, air permeability results were different. Where thermal insulation was installed, but floor and edge seals were overlooked improvements were limited, changing from 24 to 20 m³/ (h.m²) @50Pa. In properties, where due attention was given to detail and workmanship, ensuring seals were effective, changes from around 19 to 4.73 m³/ (h.m²)@50Pa and 16.77 to 6.43 m³/ (h.m²)@50Pa were achieved. Thus, in some properties, significant improvements were made while in others, for a similar cost, the improvement was minimal. Determining the level of airtightness is a relatively straightforward commercial test and could be used to assist retrofit programmes. Furthermore, the introduction of a thermal survey during the heating season under depressurisation provides valuable information on the building's behaviour and where air leakages occurs. Recognising air infiltration and exfiltration through simple observations and providing appropriate remedies can improve air tightness.

The consequences of underperforming fabrics are not limited to the detrimental impact on energy use and the environment; occupants are directly affected, incurring higher bills and accommodating substandard living conditions, health problems and increasing risk of fuel poverty (Santamouris *et al.* 2014). With some buildings, poor air tightness can mean that adverse weather could strip a building of all of its heated internal air within minutes. Thus, in the midst of winter, exposed to wind pressure, occupants would be unable to achieve an adequate heated environment. Fabric performance is essential for energy control and satisfactory living.

Emerging tests: Measuring whole building thermal performance

To understand how the building fabrics perform researchers have focused on different assessment methods and how to develop the methods so that they become commonly accepted diagnostic tools (Stafford *et al.* 2014; Erkoreka *et al.* 2015). As the assessment methods improve it may be possible to obtain characteristic energy behaviour through in-use energy monitoring enabling the energy efficiency of the building fabric and services to be gathered instantaneously. However, such real time evaluation and energy efficiency control is not widely available. The current focus remains on field test although new tests, as outlined below, are emerging.

During the six stages of a retrofit project within a controlled laboratory, the Saint-Gobain team used a relatively new method to measure heat loss. The Quick U-value of Buildings method (QUB) was used and cross checked with the Leeds team's co-heating test (Farmer *et al.*, 2015). The Energy House facility, a whole house contained within a climate chamber, meant it was possible to perform test separately and sequentially, under the same controlled external conditions, something which is not possible to achieve in the field. The Quick U-value of Buildings (QUB) is a diagnostic method that enables the heat loss coefficient (heat transfer through unit area) to be calculated over one or two nights. It measures the temperature response during a heating and free cooling period. A level of uncertainty is estimated to be $\pm 15\%$ when performed on a single night which becomes less as the test period is extended (Pandraud *et al.*, 2014). The cross checking of the methods showed a close fit (Farmer *et al.*, 2015).

Other methods, based on in-use monitoring data have also been cross checked with the co-heating tests and show comparable results. Methods that use the buildings own heat system with smart meters to check energy required to elevate the building temperature are currently being developed and provide a less resource intensive methods of testing the building's thermal resistance and the heat system's efficiency (Farmer, 2015). As more is understood about the characteristic energy signatures that could be obtained from such methods, both during occupied and unoccupied periods, the potential to assess the performance of buildings and impact of occupant behaviour can be understood. Understanding building performance is only useful if the performance is fed back to a system model. The fabric provides just one aspect of building performance, but it is essential that this aspect is understood and controlled first.

A proposition for better understanding, feedback and control

As over half of a building's energy is attributable to the conditioning of a building's internal environment, fundamental to energy reduction is to ensure that this space is thermally enclosed and can be controlled. Without being able to control the internal environment users are limited in attempts to change to more energy efficient behaviour. Conversely, if the building's envelope provides an effective enclosure and the thermal resistance, capacity and storage is understood then users can, if they desire, adopt appropriate behaviour. It is possible to reduce overheating and eliminate space conditioning during unoccupied periods. However, without effective control and understanding of the building, influencing user behaviour change will be problematic.

Figure 2 provides a schematic showing where energy efficient control and influence can be achieved. If the building space is of a known quantity and the energy demand to condition the building can be accurately predicted and the services properly specified. If services are installed, commissioned and regulated correctly, the building system can provide a functioning facility and, subject to occupant behaviour, the potential energy efficient gains can be realised. With effective feedback, the occupants can accommodate their conditioning demands, so that energy is only used when needed. If the building has good thermal storage capacity and there is potential for pre-heating on a lower energy tariff, reducing peak grid demand, then more effective energy use can be achieved.

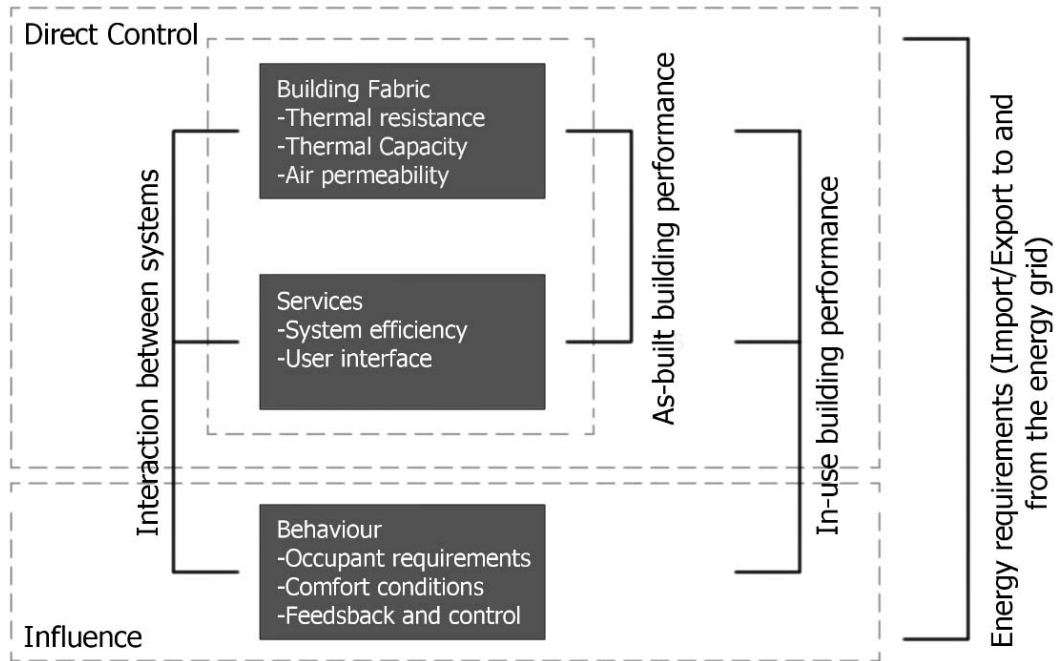


Figure 2. Essential Energy Efficiency Link: Building effective integration

Conclusion

Heat energy is unintentionally lost and wasted through poorly insulated, designed or constructed buildings, resulting in a performance gap. Associated emissions can be reduced by ensuring the envelope is effective, provides the necessary thermal performance and air tightness. Understating the building fabric and enclosure performance is a fundamental requirement if control of the internal space is to be achieved. By understanding building behaviour and gaining control of the building further efficiency gains can be achieved through efficient operation of the services.

The methods used to accurately measure building performance exist, but their use is contained largely to scientific studies, however new less resource intensive test are emerging that show greater potential for in-use diagnostics. As more studies are undertaken and buildings are tested and monitored, knowledge about their actual behaviour will enable change to the way buildings are understood, operated and serviced.

One of the main findings of the forensic analysis undertaken on building fabric is that the most common faults occur where the integrity of the air and thermal barriers are breached. Thus, the connection and continuity of the thermal envelope and the air barrier should be maintained in design and when built. The performance gap work reported shows there is considerable potential to change and reduce associated energy emissions. The work demonstrates that some buildings are achieving considerable reductions in energy use through changes to their thermal properties. The work also highlights buildings that have achieved high standards in design and construction, the findings of such studies providing an important step in achieving low energy and nearly zero energy buildings. Evidence suggests that reductions in energy use and related emissions can be achieved with new and retrofit buildings in the UK.

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