Guest editorial: Building performance and sustainable infrastructure: unsustainable return to practice

Unsustainable return to practice

The abrupt decline in global carbon emissions experienced during the pandemic was not sustainable. Overwhelmingly, this is evidenced by the advanced economies' swift return to close to pre-pandemic levels and, of greater concern, the total global use of fossil fuels has rebounded to their highest level in history (IEA, 2021; Jackson *et al.*, 2022). Unfortunately, post-pandemic, the anthropic life threating activities have resumed.

Although the International Panel on Climate Change (IPCC) galvanised a global response with Net Zero pledges, the United Nations implementation data presents a sobering picture (UN, 2022). The impact data report reveals that the 2030 Agenda for Sustainable Development is in grave danger (UN, 2022). Many of the sectors in the major economies remain outdated and carbon intensive, with initial commitments not matched by action (Marteau *et al.*, 2021; UN Environment Programme, 2020). The construction industry in this regard, being responsible for 37% of global emissions, carries a considerable share of the burden (Hamilton *et al.*, 2021). A radical transformation is required to decarbonise the sector and buildings (Murtagh *et al.*, 2023). The UK's Net Zero Strategy - "Build Back Greener" (HM Government, 2021), which sets out the polices and proposals for 2050 decarbonisation seeks to address the transition required from the major economic sectors. However, in a recent High Court legal challenge from environmental groups it was held that the Strategy provided insufficient information on how the carbon budgets would be met (Friends of the Earth Ltd., Client Earth, Good Law Project and Janna Wheatly and Secretary of State for Business Energy and Industrial Strategy, 2022). Although early decarbonation of sections of energy supply show progress, other sectors present a sizeable hurdle. This is especially so in the construction sector, which is not maintaining pace towards Net Zero (Hamilton *et al.*, 2021). The Royal Academy of Engineering notes that much more needs to be done (Mitchell *et al.*, 2021). The Academy calls for better design and specification, major developments in construction and reuse of buildings and materials, as well as significant changes to procurement if the sector is to achieve Net Zero by 2050.

The research reported in this special issue of the *International Journal of Building Pathology and Adaptation*, which focusses on building performance and infrastructure, affirms just how wide and varied the challenge is and how critical research is to the solution. Here, even where research is advancing, there are still knowledge gaps.

The contributing academic papers clearly identify transformational challenges both with current practice, existing methodologies and measurement tools. Bruce-Konuah *et al.* (2023) found that all domestic building occupants in their study of heating behaviour manually override their heating system, undermining the use of the thermostat set point. Agyekum *et al.* (2023) showed that even when buildings were sustainably certified using an Environmental Rating framework, occupant satisfaction was not achieved in all Indoor Environmental Quality metrics. In two different studies on ventilation and infiltration by Roberts *et al.* (2023) and Few and Elwell (2023), although advancing the field, they demonstrate that current regulatory methods are not adequately profiling infiltration and estimated heat loss. Whilst all these studies offer significant improvement, there is much

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research and development to do across the built environment if we are to achieve Net Zero. For instance, the current building measurement methods are not as robust as they need to be. There are gaps in knowledge and science are leading to notable performance gaps, which is of concern as attempts are made to move to more sustainable building operation. Reliable in-use performance metrics and base lines are not currently being used.

Whilst admirable, the philosophical Circular Economy and Life Cycle Analysis approaches have data limitations that need to be addressed. Here Feng *et al.* (2023) makes progress and offers a Building Information Modelling (BIM) based framework to iteratively and systematically evaluate embedded building and operational carbon of whole buildings. Peukes *et al.* (2023) also effectively uses Life Cycle Assessment, this time applied to gas heating system upgrades and retrofits. In both studies data on elements of embodied carbon were absent and informed assumptions had to be made. Existing buildings have a myriad of components and due to their history there will be an absence of documents recording extraction materials and production of components. Such information gaps make it difficult to determine the level of energy and carbon embedded. In Peukes' study of heating systems, the more efficient upgrades did outperform existing heating systems, offsetting environmental impact for global warming, ozone layer depletion, aquatic acidification of the oceans, non-renewable energy and carcinogens (a carcinogen being a substance or material of toxic nature capable of causing cancer). However, it was not possible to offset mineral extraction through the operational energy saving. Thus, while such studies and methods are useful, the Circular Economy approach does not represent a utopia moment. There is much work to do to understand the limitations of Life Cycle Analysis and the steps that need to be taken to effectively evaluate materials and performance. All of the work reported in this special issue does demonstrate advancement in science and knowledge, although further research is needed to ensure the methods are reliable and data are robust.

In recent years little has changed in construction and the industry continues to build with traditional carbon intensive materials and processes. Operationally the building stock is no different, most buildings relying on fossil fuels for heating and cooling. The press mocks the industry for its "horribly climate unfriendly" practices and ill-conceived development plans (The Economist, 2022). If the sector is to embrace buildings that reduce embedded carbon and move towards a more circular economy there is much evidence to gather, publish and share. Society needs to be provided with clear evidence of the concerted efforts from the industry and assured that new approaches are being embedded and are having the necessary impact. The failure to act quickly is already having a profound impact.

Urgent sector based action is required

The Earth's Climate system has already changed. Air temperatures have increased over the ice caps, increasing the loss of ice as discharged fresh water resulting in warmer oceans and subsequently a warmer atmosphere (Otosaka *et al.*, 2022). The heat energy that has been accumulated over the decades warming the ocean, land, cryosphere and atmosphere has resulted in unprecedented and committed changes to the Earths' system (von Schuckmann *et al.*, 2022).

The existential threat of climate change is real, dwarfing the pandemic impact. Thus, the role of prototype testing, research and development is crucial to advance building. Although zero carbon targets are in place, including policies to decarbonise energy sources and provide energy efficient and less wasteful building, current action is substantially lacking (Hamilton *et al.*, 2021).

If the construction sector is to play a significant part towards Net Zero emissions then a better understanding of the resources used to construct, service and operate buildings is required. An understanding of the environment from which resources are sourced and the environment in which they are placed is essential if we are to responsibly construct and appropriately reuse. The building system and pathology associated with embedded and operational carbon is complex. The systems that we use for sustainable construction needs to reflect the complexity in order to reliably manage associated emissions. Robust data sets are required to build models and forecast impact. Actors in construction need to make effective decisions and control construction and operation. Quality control of methods, data and production being essential to deliver high quality energy efficient buildings. The work of Peukes *et al.* (2023), Roberts *et al.* (2023), Few and Elwell (2023) and Bruce-Konuah *et al.* (2023) and the other work reported here all adopt very different perspectives, illustrating the complexity of the system that is in use and the gaps that need to be addressed to provide a reliable system.

We are now at an important juncture, the threat has been identified and pledges have been made to respond and develop a more responsive, sustainable and resilient environment – although operationally the sector is lacking in high quality and detailed data to inform the response. Development of such information could take years, but action is needed now – the conundrum means that we must constantly research and evaluate, developing and changing practice. Mistakes are inevitable, but the industry must undertake research alongside prototype and transformational action to ensure research and evidence guides practice.

The UN's overarching framework offering protection to a fragile human and ecosystem

The United Nations Sustainable Development Goals offer an interlinked collection of ambitions that require a united response if they are to reduce the impact of climate change. The goals appropriately embrace social, environmental and economic challenges in a "just and inclusive" framework providing a vision that will hopefully facilitate a united response to the climate change emergency. The global commitment required is immense although undoubtedly necessary. For many, action is already too late as communities have already been displaced. To be effective all nations must act together in a coherent global response. Thus, research must be far reaching, immediate, evidence based and coherent to inform practice and avoid unintentional consequence.

There are significant differences in the way different countries operate and there is much work required to build equivalence in zero carbon infrastructure. The work of Kulmedov and Durdyev (2023), while evaluating furnace and boiler systems commonly used in the post Union of Soviet Socialist Republics' (USSR) countries, also records that the electric grids in these countries are carbon intensive. Thus, in their study, fossil fuel heating systems have less environmental impact when compared to those connected to the grid. Countries and nations are very different, with some countries still increasing coal powered energy supplies. Coal supplies a third of global electricity generation and until newer technologies are available it will continue to play a crucial role in heavy industries (IEA, 2021). There is much to learn and understand from the work across the globe and how the global community can assist and reduce demand on carbon rich processes. While all countries will find the move to Zero Carbon Systems a challenge, those countries with fewer resources at their disposal will find the transition more difficult than those with advanced economies.

The pandemic demonstrated the entwined nature of human activity. Moving from one host to another the virus rapidly crossed international and cultural boundaries, demonstrating how fragile and connected humanity is. The epidemiological nature of COVID-19 indicates the extent that we share atmospheric and physical boundaries.

The reaction to the pandemic also showed how united the race can be in response to global threats. Relatively, the response was mostly quick and sustained for two years. However, the threats posed as a result of anthropogenic climate change are all consuming and to alleviate the impact, action needs to be swift, sustained and most importantly, evidence-based.

The international response to Russia's attack on Ukraine, attempting to restrict reliance on Russian energy is having a global economic impact, making it increasingly difficult for many. Evidence based studies on how events in one community impact on others is fundamental to engender a global response. Urban communities are intrinsically entwined in social systems, physical logistical infrastructure and resources. The work reported here makes a small and important step in helping to inform design and regulate buildings towards a process that has less environmental impact. The papers address different but fundamentally connected challenges and are discussed below, relative to their field.

Summary: A summary of the contributions to this special issue are outlined in the following section

Smart building technologies

In a step to understand and improve operational performance of buildings and reduced embodied carbon, Newton *et al.* (2023) maps out the key components of building energy performance when combined with occupant comfort. A schema is provided advancing the application of smart building technologies. The study demonstrates a viable configuration of available smart building technologies that couple building energy performance with occupant comfort. Although there is potential for smart technologies to transform building energy performance, currently there remain some pragmatic and technical limitations, some of which are highlighted in this paper.

Life cycle analysis

Presently the notion of the construction sector adopting a Circular Economy (CE) where materials and resource are continually used, without waste and minimal carbon emissions offers a conceptual methodology. Observations suggest that there is practical distance between the CE movement and the reality of the energy intensive and wasteful construction processes. For this reason alone, it is essential that steps are taken to address the gap. Here, Feng *et al.* (2023) provide a valuable step as they develop a Whole Building Life Cycle Assessment (WBLCA) methodology aimed at reducing the environmental impacts. The work recognises the complexity and significance of the challenge and, noting a lack of research in this area, they offer an integrated BIM approach to evaluate and optimise designs. The model uses an environmental product declaration methodology. Such interactive systems enable comparisons of various building design upgrades, helping to optimise environmental impact at the design stage. These systems are helpful in identifying those materials and components that are carbon intensive and account for the greatest share of embodied carbon.

The sectors' reliance on traditional practices and materials remains. Many professionals fail to appreciate the combined carbon intensity of materials within buildings. Although many do appreciate that concrete and steel are carbon intensive, having a greater understanding of their dominance coupled with the ability to review and potentially switch products is critical. Understanding the design choices and factors contributing to embedded and operational carbon is essential when evaluating whole building and life cycle carbon.

Recycled grey water

There is a high demand for sustainable solutions across various industries, including construction and hospitality sectors. The aim of Kobeyev *et al.*'s (2023) work was to design and model an on-site grey water treatment system for a hotel building for the effective reuse of sewage water. In arid areas and locations increasingly experiencing prolonged drought, clean and recycled water is a precious commodity. The study considered Los Angeles, California, as a case study location and referred to respective climate conditions and construction standards. The report reviewed and modelled the impact of various options of grey water treatment plants. The modelling proved effective in aiding optimal selection to preserve the eco-system, remaining compliant with the government laws and regulations and offering a financially-viable solution.

Repair maintain and improve

To improve building performance and meet statutory carbon reduction targets, a radical transformation of existing UK building stock is required. Previous research on building performance has tended to focus on large-scale construction. However, retrofit of existing housing stock, which will contribute the majority of the requisite efficiency improvement, will be undertaken by practitioners in the repair–maintain–improve (RMI) sector. Approximately 40% of practitioners in RMI are sole traders and micro-firms. Murtagh *et al.* (2023) examine the factors influencing these practitioners to understand how better to engage sole traders and micro-firms with improved building performance.

Heating control systems

Poor energy efficiency of the building stock and associated emissions has been a subject of considerable research. The dramatic increase in the cost of energy has focussed attention on energy efficiency and building heating systems that optimise performance. The study by Bruce-Konuah *et al.* (2023) focusses on the occupant's interaction with control systems and the impact on energy use.

Few studies have examined the extent that occupants use the heating system thermostat setting to control the temperature of the dwelling and the degree to which occupants manually override the system's set temperature point. In this study, all occupants used the override function to increase the internal air temperature. Without user interference the systems settings will normally control when the heating turns on and off. If assumptions of space heating use are based exclusively on thermostat set points, then real occupant demand and behaviour will be missed. If smart optimal heating is to be realised, further work is required to understand why override functions are used. Smarter controls and better performing homes may be able to accommodate users, but not where manual functions are used to override the system. There is much to gain from research on space heating behaviour, the patterns recognised can be used to inform future energy models. It is important to understand the extent that users interact with control system. There may be some psychological comfort gained through the interface and further research in this area is required.

Building service upgrade

Worldwide, the energy required to operate buildings accounts for 28% of demand. The upgrading of existing appliances to more efficient ones may reduce carbon emissions if the whole life cycle including embodied and operational energy are beneficial when compared with the continued operation of the existing system. Here, in Peukes *et al.* (2023) work, Life Cycle Assessment is used to compare gas heating upgrades in residential properties in Australia. The results suggest that operational energy savings outweigh the embodied energy and therefore contribute positively to the environment, but not all environmental offset impact was met.

Ventilation

Understanding the air change rate due to the mechanisms provided for ventilation and those that occur as a result of leakage through the building fabric is essential if building conditioning systems are to be accurately calculated. Reliable estimates of heat losses from buildings rely on accurate infiltration values. However, infiltration rate is rarely measured directly, and instead is usually estimated using algorithms and from data obtained from fan pressurisation tests. There is a growing body of evidence that the methods used for estimating infiltration rates are inaccurate. Much of the prior research relies on tests conducted during the winter season, when heat energy losses are assumed to be the greatest. The values produced often rely on single measurements obtained on a single day for each dwelling. The work reported by Roberts *et al.* (2023) measures infiltration rates during the summer and spring using tracer gas methods and compares these to infiltration estimation methods. The results show that the infiltration rates were 64–208% higher than measured. The results suggest that current methods are not accurate and have implications for the dynamic modelling of infiltration and associated heat losses and gains. Currently, in the absence of accurate infiltration values, infiltration models may overestimate infiltration. Such inaccuracies are likely to result in buildings with substandard air quality and a risk of summertime overheating.

Few and Elwell (2023) report on the development of two analysis algorithms used to identify occupation periods and infiltration/ventilation. In this study the application of CO_2 concentration decay tracer gas techniques were used to investigate ventilation in occupied homes over time. The methods were successfully applied. The work of Few and Elwell (2023) and Roberts *et al.* (2023) both have important ramifications for assumed ventilation rates.

Building control and regulation

The research undertaken by Dennehy *et al.* (2023) evaluates the compliance of an amendment of the Building Control (Amendment) Regulations 2014 (BC(A)R 2014). The regulation requires a specific sign off process aiming to increase accountability. The study found that this has a positive impact by reducing/eliminating previous bad practice and focussing responsibility and accountability for signing off practical completion of new buildings. The industry has a notoriously poor reputation for delivering and maintaining build quality, as highlighted by Hackett Report (HCLG, 2018), and further work is required in this area to ensure that standards are maintained.

Environmental rating systems

In advanced economies the use of environmental and sustainable building rating systems and assessment tools is almost obligatory, now being required by commercial and public clients alike. The standards are used to help design buildings that perform, while mitigating direct and indirect negative environmental impact as a consequence of construction and operation. Systems such as BREEAM, BCA Green Mark System, CASBEE, CEEQUAL, Energy Star, LEED, EDGE and others are common. Generally, it is accepted that these buildings perform as designed, however, it is essential that the buildings actual performance conforms to expectations and can be demonstrated and measured. Few studies have evaluated the Indoor Environmental Quality (IEQ) of such buildings. Here, Agyekum *et al.* (2021) evaluate occupant perceptions of IEQ metrics for an EDGE certified office building. The expectations of IEQs for noise level, temperature, cleanliness, sound privacy, air quality and humidity failed to reach expected satisfaction measures, all identified as requiring improvement although other metrics either met or exceeded expectations.

While sustainable building rating systems provide useful environmental and sustainable targets, the extent that designs meet predefined criteria should be continually evaluated.

Chemical release and building impact

There is considerable concern with regards to chemicals released during production processes and the impact on the environment. Even the storage and ageing of materials can have an effect on the local environment. The storage and maturation of whisky and associated ethanol losses are said to have little impact. Yet alcohol evaporated during whisky maturation is said to provide carbon nutrition to support black fungal growths. Although the impact and associated growth is localised close to the production areas, the global production of whisky has increased, and many may be unaware of this phenomena and that methods can be used to reduce the impact. Here, Craig *et al.* (2023) investigates the extent and implications of colonisation of the associated fungal growths with the aim of providing evidence of growth and where it occurs. Such information should enable distillers to engage in discussion with neighbours potentially reducing the extent of such occurrences. An evaluation of areas and distances affected was undertaken. The use of radial zoning methodology supported with context information based on distance from the ethanol source and material substrate types and surface textures likely to be affected was considered helpful in understanding and mapping surfaces affected. The research finds that the colonisation of the fungus is non-uniform and dependent on the substrate building material. Rougher-textured building materials often displayed heavier levels of fungal manifestation when compared with smooth surface materials. Aspects such as distance, wind direction and moisture were considered relative to the extent and level of fungal growth.

Boiler system evaluation and different national base lines

Here, Kulmedov and Durdyev (2023) assess selected furnace and boiler heating systems commonly used in the dwellings of seven post-USSR countries. The systems were assessed in terms of their cost and environmental performance, with natural gas and grid electricity used as the main source of energy. Where electricity in such countries is carbon intensive, mostly produced from coal, furnace gas heating systems provided the cheapest source of energy and had least environmental impact. This work exposes not only the differences in heating system effectiveness and operational costs, but also provides a perspective on local energy infrastructure and the ability of homeowners to make eco-friendly decisions with the options available to them.

Conclusions

The papers presented in this special issue report on a wide variety of topics all with a theme of understanding building performance and pathology. All represent a contribution to knowledge, with many questions remaining unanswered. As the sector attempts to interpret the Sustainable Development Goals developing them into more sustainable practice, robust data is required to inform the next steps. As the threat of climate change is so pressing, research will need to be iterative and developed alongside sustainable porotypes, as there is little time to react. Reducing and eliminating wasteful building is an obvious way to reduce environmental impact but to understand which processes, production methods and operational methods are more effective in reducing emissions further research is required. The endeavour to contribute to our sustainable future is an ongoing challenge with the work of those who have made this special issue making positive strides.

Christopher Gorse

School of Architecture Building and Civil Engineering, Loughborough University, Loughborough, UK

Colin Booth
Construction and Property, University of the West England, Bristol, UK, and
Lloyd Scott
School of Surveying and Construction Management, Technological University Dublin, Dublin, Ireland

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