DECARBONISING BUILDING OPERATIONS.

Institution of MECHANICAL ENGINEERS

Data as a driving force in reducing greenhouse gas emissions

Improving the world through engineering

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Complex situations require data which is robust, reliable and verifiable in order to support effective decision making.

David Bradley CEng FIET
Professor Emeritus
Abertay University

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Data is the foundation upon which comparisons can be made, best practice identified and improvements implemented.

Eur Ing David Andrews CEng MIMechE
Design Engineer
Perkins Engines

“”

Through collaboration and cultivating an environment of data interchange and transparency, we can truly use data to drive down carbon emissions and steward our glorious earth.

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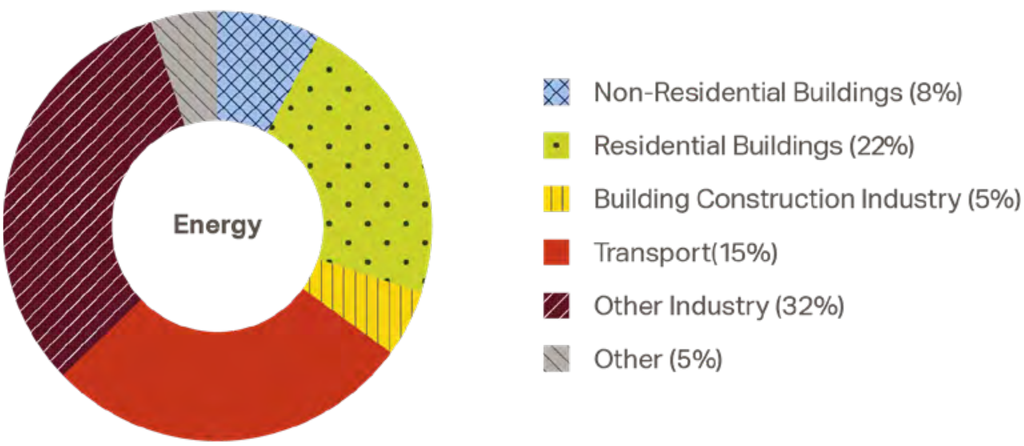
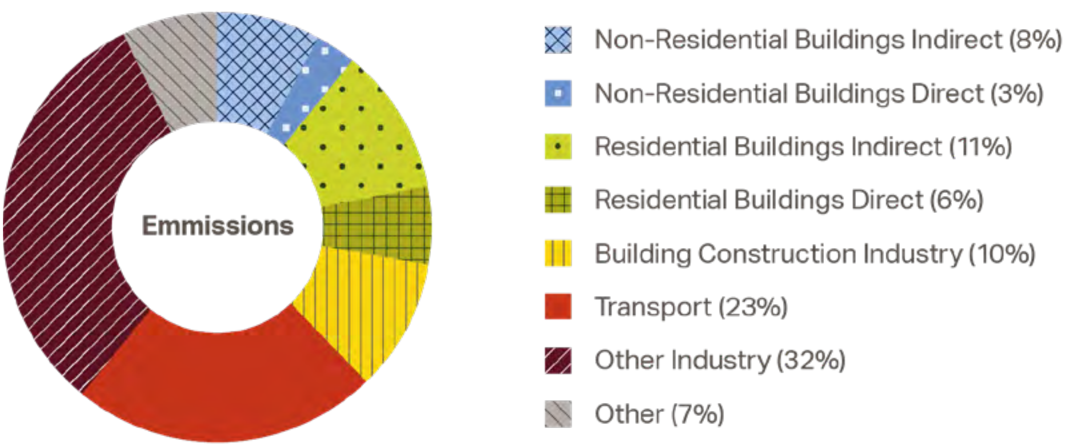
Executive summary

Mega cities, such as London, are currently the source of 52% of the world's greenhouse gas (GHG) emissions. It is projected that by 2050, over 68% of the world's population will be living in urban areas; as of 2020, the figure for the UK is 83.9% of the population, resulting in increasing pressure for a more sustainable use of space and energy within such communities.

The 2020 Global Status Report for Buildings and Construction[1] suggests that in 2019, while the total energy consumption for the sector, whether associated with cities, towns, villages or rural communities, remained unchanged from 2018, emissions associated with building operation rose to around 10 $GtCO_2$, their highest level yet, and to some 28% of global energy-related emissions. If emissions from the construction industry are then included, this share increases to around 38% of global energy-related CO_2 emissions.

Figure 1: Global share of buildings and construction final energy and emissions[1]





It was also noticeable that during the COVID-19 pandemic, when a significant proportion of UK office buildings were closed or at low occupancy, such buildings continued to emit GHG emissions, as building services remained operational for maintenance and non-essential purposes.

When considering the impact of the built environment on GHG emissions and climate change, the entire life cycle of a building must be considered. This includes its construction, operation and demolition.

It is impossible to quantify such an impact, as well as to make a comparison or an informed decision without data. Data is the foundation of any improvement. To be effective, data must conform to common formats and standards and to the definition of protocols to ensure it is collected in a consistent and interchangeable manner.

Such protocols and the associated creation of common data formats and standards to report, for instance, on energy usage during the operation of a building will enable technologies, such as Digital Twins, to be used to optimise both building operation and design in support of reduced GHG emissions.

Further, the exchange of data on building occupancy and environmental conditions will optimise the utilisation of buildings, as well as indoor and outdoor spaces. Non-residential building spaces, such as schools and office buildings, are frequently underutilised and when shared, they have the potential to contribute to the UK economy, support improvements in public health and help make communities more resilient.

The built environment

The built environment encompasses the physical spaces people occupy for living, work and leisure. As such, it includes residential and commercial buildings, as well as buildings used for manufacturing and leisure; the physical components of the transport infrastructure, such as roads and railways; and power generation and utility networks. In 2016, building stock (domestic and non-domestic) accounted for 17.5% of global GHG emissions[2], as shown in **Figure 2**.

This policy paper focuses on the UK, where, in 2019, as shown in **Figure 3**, residential and business sectors represented a significantly higher proportion, at some 32%, of total emissions[3]. **Figure 4** shows the energy consumption by sector in the UK in 2019[4].

By focussing here on energy use according to sector, it is believed that access to appropriately structured and configured information based on robust, validated data will enable a significant reduction in building energy use in the short, medium and long terms.

Figure 2: Global greenhouse gas emissions by sector in 2016[2]

Concerning the goal of achieving Net Zero CO_2 emissions by 2050, as of 2019, it was estimated that in the UK, around 80% of the housing stock that will be in use in 2050 is already in place, much of which is currently highly energy inefficient, largely relying on non-renewable gas in urban areas and oil in rural areas for heating and hot water[3,6,7].

In the UK, social housing represents 18% of all residential units and thus plays a large part in reducing GHG emissions. Most social housing units are owned and managed by private registered providers (PRPs), who may own in excess of 10,000 units, including entire neighbourhoods or streets. New buildings must also be considered, as the UK has a national shortage of housing, especially social housing, yet property developers and house builders are currently not required to build to near zero or zero carbon standards.

Figure 3: UK greenhouse gas emissions for 2019[3]

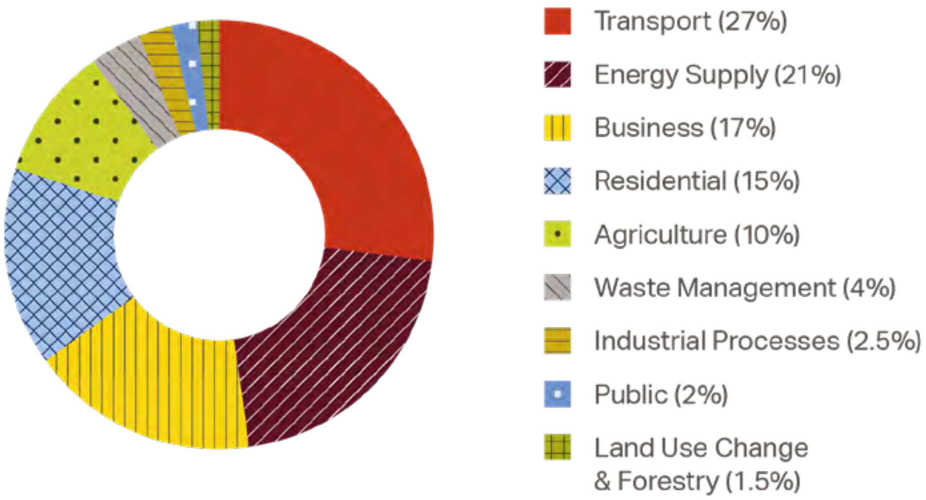
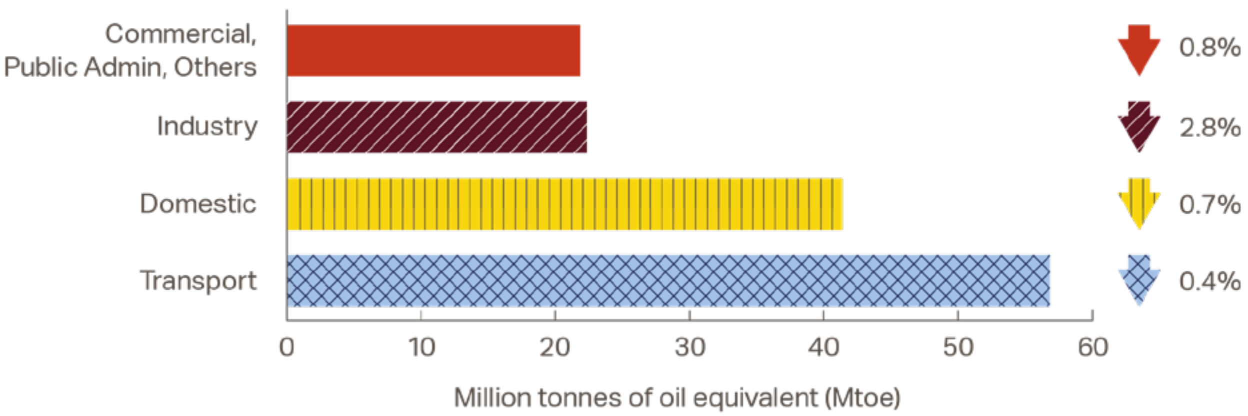


Figure 4: UK energy use by sector in 2019; arrows indicate the percentage changes from 2018[4]



In this context, the Code for Sustainable Homes was withdrawn in 2015. Even while the Code was in effect, lack of knowledge about and an understanding of sustainability were the key barriers to implementation[8,9].

In the short term, data has the potential to be used to report on energy consumption and GHG emissions and, in doing so, provide further knowledge on the operational characteristics within buildings contributing to GHG emissions per sector.

For example, data could be used to demonstrate variations in GHG emissions between providers of social housing, such as local housing authorities and housing associations. This would enable local authorities and others to understand their performance in relation to other similar bodies and organisations[10]. Such an approach would also support the development of more comprehensive and wide-ranging data analyses across the diverse range of housing stock across the UK. It would also inform the development and introduction of similar analyses in the commercial and business sectors of the built environment, including city centres.

However, the data needed to drive this process of innovation must be derived and shared in a manner that is understood by key stakeholders, is transparent and is consistent. Through openly exchanging information on measures for energy efficiency, such as operational carbon and embodied carbon, such stakeholders as home builders can share best practices and develop consistent methods to drive the built environment towards more efficient and dynamic energy systems.

Embodied carbon or embedded emissions represent all the GHG emissions associated with the construction of a building, including those from the extraction of raw material, the subsequent production of building materials and the manufacturing of the finished product and machinery use, the latter being an area in which there is already a significant move to introduce electrically powered machinery using high-energy batteries.

There is increasing demand to collect and measure levels of embodied carbon and hence the GHGs emitted before the building is in operation, which in most cases accounts for the bulk of the GHG production, perhaps as high as 75%, associated with a building over its lifetime[11].

According to the Chartered Institution of Building Services Engineers (CIBSE), to calculate the embodied carbon of products associated with the mechanical, electrical and public health (MEP) systems within buildings, it is imperative that a consistent approach is used to gather data from manufacturers, as well as to calculate and report on the embodied carbon of individual buildings[12].

Similarly, the adoption of technologies used to manage and control energy systems when buildings are in operation has been decelerated by a lack of consistency in the data and hence in the associated derived information required to be collected and exchanged.

Embodied carbon is extremely complex to quantify and measure when compared to operational carbon[11]. Although a variety of technologies and systems, such as the construction carbon scoring tool developed by UKGBC[12], exist to empower UK property developers and housebuilders to calculate and manage their embodied carbon, a consistent approach is still needed.

A short-to-medium-term goal should therefore be to work with building operators to generate more robust data standards, along with the associated protocols for analysis and interpretation of the data to enable the collection, analysis and reporting of operational GHG emissions from within and across all sectors.

The role of data

Access to high-quality and consistent information is an essential component of effective decision-making[13,14,15,16] and is required for the adoption of digitised energy systems[17] targeted at reducing GHG emissions from the built environment. However, the ability to derive the necessary information is dependent on the ability to obtain the necessary data through the provision and use of appropriate sensors, and including issues such as data quality and consistency.

This can be done by ensuring that data collection, analysis and data reporting are consistent across all parties and for all purposes. This will require the definition of the nature of the data to be collected, along with the necessary protocols to set out the means by which this will be done. For example, information on sensor performance parameters, such as the accuracy, resolution and repeatability, will need to be collected and validated, along with the source data.

The collection of such commonly structured and understood data would then be supported by a further set of protocols that set out how the raw data is to be analysed, interpreted and presented in line with the information requirements established and defined for the measurement, presentation and control of energy usage.

The acquisition and derivation of the necessary data and information models to digitalise energy systems requires the engagement and involvement of all stakeholders in the early stages of the process[18]. According to the UK Department for Business, Energy and Industrial Strategy, there is a strong requirement for the coordination of businesses and various stakeholders to develop a shared vision for digitalising energy systems, as well as collectively agreeing on an approach to achieve the system. As of 2021, the UK government has committed to providing leadership and coordination for a collaborative approach[19].

Such technology as artificial intelligence (AI) can be used within dynamic energy system models, particularly to analyse and interpret the large volumes of data gathered, so that over time, the use cases and operational characteristics of energy systems become better understood and defined.

As the models evolve, additional data sets may be integrated with them to understand better the nature of building performance in relation to use and hence support the development of enhanced methods and procedures for improving energy use within buildings. For example, the age of the building, the nature of the occupancy, the associated use of space and the needs of the occupiers could all eventually form a part of the model, along with other physical parameters, such as energy usage and ventilation[20,21,22].

It must also be recognised that action can be taken in the short term based on relatively simple analytic models, such as in the analysis of energy usage and occupancy for commercial buildings. These initial models would form part of the necessary process of learning and understanding associated with the development of the relevant systems, including sensing strategies, enhanced models and the associated responses.

Data must be accessible to allow comparisons and to facilitate planning. For this reason, the IMechE recommends establishing the regular publication, in an appropriate and agreed-upon format, of the requisite data to support effective decision making. This would involve building owners and operators sharing data on energy usage from building operations, in a similar manner to the Royal Institute of Chartered Surveyors (RICS) building a carbon database[23].

Such data then constitutes a collaborative tool that can be used to generate a common set of requirements or data sets for measuring energy emissions from building operations concerning such operating parameters as heating, lighting, occupancy and ventilation. In doing so, the data gathered can be used for knowledge transfer and benchmarking.

Possible data types to be recorded could include:

- Energy consumption (by floor, room, type of space, etc.) to support performance assessment.
- Occupancy levels.
- The nature of the utilisation of building spaces.

It must be recognised that differing spaces and the ways in which they are used will impact energy consumption. Data on energy usage, occupancy and use of space can be integrated to establish profiles of use and hence aid in the identification of outliers in relation to those profiles.

Other operational parameters to be measured and recorded could include:

- Lighting and illumination (both natural and artificial).
- Ventilation and air condition (pollutants, etc.).
- Weather conditions, such as air temperature and wind.

It must also be recognised in relation to all the above that there may be issues with commercial confidentiality and privacy both in the collection of data and in the presentation of the derived information. It is therefore imperative that there is a lawful basis for processing all data under the Data Protection Act 2018 General Data Protection Regulation (GDPR) and that the privacy concerns that building owners may have concerning sharing information are acknowledged and managed. Consequently, it will be necessary for the government to engage with all interested stakeholders to ensure that existing and future issues associated with these areas are properly addressed.


410.23
481.79
152.68
977.65
73.79
120.09
456.52
492.38
742.20
528.54
355.90
789.51
492.38
509.99
789.51

Technologies

Technology plays a role not only in the collection of the data at the source, but also in its interpretation and use. Thus, it is likely that AI will ultimately play a role in determining whether technologies, such as Big Data analytics, Cyber-Physical Systems, Digital Twins, the Internet of Things (IoT) and Smart Grids, will play a significant part in achieving reductions in energy consumption and hence in GHG emissions .

Digital Twin

Digital Twins have been under development in various industry sectors for some time, but they have only relatively recently transferred across into the built environment. In application, they have the potential to:

- Support the enhanced interoperability of technologies.
- Facilitate the integration of real-time data between the physical environment and the digital model.
- Support intelligent interfaces structured around different user needs.

In essence, Digital Twins could operate both at the level of an individual building, of a complex of buildings or even of a town or city. By integrating real-time data with the digital model, the twin, operational decisions can be evaluated in real time while future scenarios can be simulated to determine the most effective strategies.

However, for this to occur, companies, businesses, building owners and operators will need support to test use cases for Digital Twin technology and subsequently adopt the technology where there are opportunities to reduce their operational GHG emissions or improve the utilisation of their energy network.

Technology descriptors

Artificial Intelligence – Machine-based systems structured around the use of complex algorithms and processing methods that generally aim to reproduce aspects of natural or human intelligence with respect to analysing and solving complex problems.

Big Data – Seeks to analyse and extract information systematically from large and complex sets.

Cyber-Physical Systems – These are highly integrated systems, often involving the use of artificial intelligence, to integrate the operation of individual systems, which themselves may in turn be comprised of multiple individual systems, such as sensors and actuators, each with their own processing capabilities.

Digital Twin – This is a virtual representation that serves as the real-time digital counterpart of a physical object or process, enabling the evaluation of performance in real time and the forward prediction of need with respect to specified operating conditions and targets.

Internet of Things – The integration of multiple and distributed objects that themselves utilise a range of sensors and processing capabilities and actuation and that connect and exchange data with other such devices and systems over the Internet.

Smart Grid – These are used to manage the utilisation of shared resources, particularly energy, over multiple locations and environments to maximise the utilisation of said resources by balancing energy use across multiple buildings, rather than, as at present, having individual buildings considered independent, isolated energy consumers.

This should of course build upon current work in this area. For instance, in the UK, the National Digital Twin programme, through its Climate Reliance Demonstrator (CReDo) project, is looking at the use of Digital Twins in the evaluation and management of the response to extreme weather conditions[24,25,26], such as flooding, while considering other studies, such as those reported by the IET[27].

The aim is then to enable access to support the development of system-specific Digital Twins at each and all the system, design, implementation and operational levels.

Smart Grid

Smart Grid technologies can be used to support the integration of local energy systems into the large-scale grid, and they can be used to facilitate such strategies as resource sharing at the level of a cluster of buildings or houses. In such scenarios, the individual buildings would negotiate with each other for access to a shared resource in order to optimise their utilisation.

For example, in Nottingham, a technology platform powered by sensor implementations structured around the IoT has provided an energy-monitoring system for a community energy scheme. The monitoring includes indoor environmental conditions, electric power, thermal energy and heating across the scheme[28].

Other options potentially associated with the adoption of data-driven technologies within the built environment include:

- Using the battery packs on electric vehicles to provide local storage and back-up (once bi-directional battery charging technology becomes common) and applying smart control of vehicle charging to smooth out energy demand.
- Enabling the use of local energy sources, such as micro-CHP and fuel cells, to support the clustering of domestic properties or a larger commercial property around an integrated energy source.

Digital Twins, the IoT, Smart Grids and related technologies could also be used to manage energy consumption across multiple sources, as well as provide such features as energy balancing and tariff control[29,30,31,32,33,34,35,36]. Thus, a single ground-source heat pump installation could be used to supply a group of houses, with energy management and sharing among these houses being undertaken by a smart grid informed by sensors and other systems integrated through the IoT.

Other

Other technologies likely to have an increasing role in achieving the Net Zero goal include Cyber-Physical Systems[37,38,39], which provide enhanced operation at the system level whilst also facilitating resource sharing; Big Data analytics[40,41], which enable the extraction of information across multiple complex sources to determine patterns and identify areas of concern; and AI as means of evaluating complex issues and problems[42,43].

All of these and indeed other technologies have roles to play in facilitating improved operational performance and hence in achieving GHG reduction.

However, it must also be remembered that there are significant lead times associated with the transition of technologies from research to application and changes taking place in the immediate future must therefore be driven by technologies already in place[44,45].

Support and facilitation

Industry, businesses, housing associations, local government and individual households require governmental support to move forward towards achieving Net Zero by 2050.

For this reason, the government should build on work already in place to provide support and advice, as for instance through Simple Energy Advice[46,47], the Energy Saving Trust[48] or Home Energy Scotland[49], to support businesses and property owners in transitioning from their present information and resource models to a robust digital format.

The aim is to enable businesses and organisations to achieve better control of their energy networks and hence to reduce energy usage and GHG emissions. The approach adopted must recognise the need to consider both new builds and refurbishments, as well as refits and changes of use of existing building stock, and it should encourage the adoption of a whole life approach to the operation and management of all buildings[50,51,52].

Within this process, it is suggested that there must be some form of grant provision to encourage transitional actions that may have payback times when using conventional financial models of several years, if not decades, making people reluctant to invest.

However, in line and along with grants to support change, thought must be given to whether there should be some form of penalty associated with an unwillingness to change, particularly after having been given the information and support to enable such change to take place.

Whatever strategy is adopted, it must be recognised that not all buildings are the same, nor are similar buildings necessarily used for similar purposes, and the incentives and/or penalties must therefore be adjusted in line with these differences in use. This is to be facilitated by the provision of support for research into the nature of use, including how this influences and affects energy usage and GHG production.

Enhanced utilisation

As of 2019, office, retail and school buildings accounted for 67% of floor area within London. Many of these buildings are left unoccupied and unutilised for a significant proportion of the day, particularly in the evenings and on weekends.

During these periods of unoccupancy, the buildings are often heated so they are ready at the appropriate temperature when reoccupied. Thus, the School Premises (General Requirements and Standards) (Scotland) Regulations 1967 suggests that teaching spaces, dining rooms, common rooms and staff rooms should be at a minimum of 17°C (62°F)[53]

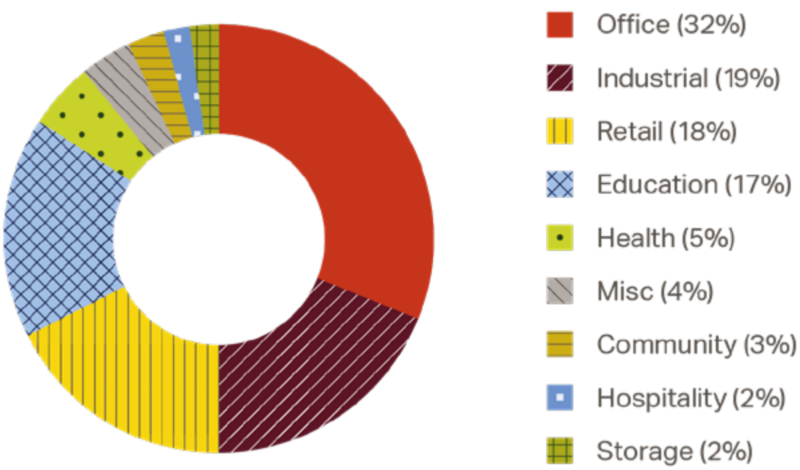
In addition, frequently, the equipment maintains the temperature of hot- and cold-water systems, such as taps left in operation when buildings are closed. Although many buildings are fitted with energy-efficient LED lighting or motion sensor lighting within high street retail spaces, lights may well be left on during the evenings[54], typically for marketing and safety reasons.

Therefore, in summary, energy is wasted through heating, lighting and maintenance in buildings when they are not occupied. However, many of these buildings have facilities and spaces that are used by external businesses and community groups when they are unoccupied.

Adopting measures to report on building occupancy will help to identify the buildings that are unoccupied and utilising energy for the purposes of temperature control. These data can then be shared to enable businesses and communities that can use these spaces when they are unoccupied. In 2020, the Social Market Foundation proposed turning empty shopping parades into residential hubs with local work, care, leisure and retail spaces[55]. A similar idea could be to use these spaces when unoccupied for purposes that do not require changes to the facilities within the spaces.

Deskhop is an international business that provides a web- and mobile-based app for individuals to use areas within hotels, restaurants and cafes to work[56]. A similar model can be utilised for schools, retail companies and offices to share information on the spaces they have available for use when unoccupied on an open-source platform. These spaces could be offered for free or at a reasonable rental price.

Figure 5: A breakdown of non-domestic floor area in London shows offices, retail and industrial buildings as the top three



Moreover, the use of outdoor spaces, such as school grounds and offices, have arguably reduced the risk of damage compared to indoor spaces. A data driven, open source, online marketplaces such as this would enable community groups to make use of the local spaces around them for social activities that promote community integration, integrational activities and improved wellbeing. Thus, at the Antonio Brancati school in Pesaro, Italy, which achieved the highest school energy environmental certification in Europe, spaces such as the library, while recognising relevant security concerns over the control of access, have been configured to enable their public use out of school hours as part of a circular economy strategy for the design and operation of the school[57].

The enhanced use of outdoor places may also encourage community-based groups to cultivate green spaces within these areas that are mutually beneficial to the organisations renting out their spaces. Green spaces have been repeatedly shown to enhance wellbeing and have cooling and shade properties that can help mitigate the effects of overheating.

Sharing data on a publicly accessible and open source can act as a catalyst for both innovation and improved services. For example, Transport for London (TfL) made information on London's transport network available to the public, which enabled apps that rely on such data, such as Citymapper and Waze, to help people to get about the city more efficiently. However, it is important that when information is shared at this scale, appropriate security and privacy arrangements are put in place[58,59].

It is therefore recommended that the UK government, as well as providing grants for SMEs to develop the relevant technologies, provide subsidies for community-based groups to rent these spaces.

Cities and other urban towns are increasingly susceptible to the Heat Island effect, particularly during heatwaves[60]. Research has shown that marginalised groups, such as elderly people, migrants, refugees and those living in poverty, are more likely to live in buildings that overheat during heatwaves.

These residential buildings often have poor insulation, such as the 1960 tower blocks in the UK, relying solely on natural ventilation. In addition, migrants, refugees and the economically poor are more likely to live in inner cities that are more severely affected during heatwaves. At least 104,000 deaths among Europe's elderly population were caused by excessive heat in 2018[61].

Many school buildings, retail shops and offices are installed with ventilation and air conditioning systems that can provide vulnerable people with protection during heatwaves. Sharing data on building occupancy can also help to mitigate the effects of heat waves by mobilising vulnerable people to better ventilated and insulated spaces that are more resilient to external heat gains during heatwaves. As heatwaves are often predictable, local governments can partner with local organisations to notify and arrange transportation of the most vulnerable people when the heatwaves occur.

Temperature and public health data can be used to determine which groups are most vulnerable and when the temperatures are likely to become a threat to their health. Countries such as Spain have installed local temperature sensors to map the urban heat island effect in real time, and use of this data can enable local authorities to be more responsive and alert vulnerable people about the buildings they can access for ventilation and lower ambient temperatures. Cities such as Athens have appointed a chief heat officer to combat the effects of the climate crisis[61].

Government support is required to co-create an open-source platform to share data on spaces that can function for mixed uses and help to reduce the threat of deaths caused by heatwaves. It is recommended that the UK government co-create the platform with organisations with available space and those in need of space during typical times of un-occupation, ie evenings and weekends, to increase the rate at which the data is obtained and organised, identify the key use cases to be initially addressed and lastly ensure the risk associated with renting out unaccounted spaces.

Recommendations

1. The Government should collaborate with industry to define the specific information required when reporting on building energy emissions and subsequently create a common set of information requirements to support informed decision making on the reduction of carbon emissions within the built environment.
2. The Government should introduce a requirement for building owners or operators to report regularly and publicly, in a standard format, on energy usage and GHG emissions.
3. The Government and engineering institutions should collaborate with public and private sector organisations to produce operational guidelines and common data set requirements for the adoption of data-driven technologies, such as Digital Twins, IoT and Smart Grids with respect to the built environment.
4. The Government should continue to develop and support centres of knowledge and businesses in adopting data-driven technology within both new-build and refurbished residential and commercial building stock.
5. The Government should support the development of an open-source platform for the exchange of information regarding the use of indoor and outdoor spaces outside conventional operating hours.

Conclusions

The built environment – in all its forms, from commercial and industrial to residential – through business work, transport and leisure is in both its construction and use a major contributor to CO_2 and other GHG emissions. While there are potential mitigation options available based on current technologies, there is a need to make decisions, whether governmental, individual or organisational, that are driven by robust and reliable data that is defined, collected and interpreted using standard protocols to ensure consistency and comparability while differentiating between different building types and their uses.

The availability of such data can also be used to drive forward a range of data-oriented and data-driven technologies, such as those associated with Big Data, Digital Twins and a wide range of smart technologies structured around the IoT. These technologies can not only enhance the real-time performance of buildings, but also serve to identify areas of concern in support of reductions in energy consumption and hence GHG emissions.

While examples of such technologies and their applications are increasing within the built environment, and while they illustrate the value of collecting consistent data, such as on energy use and occupancy, to guide behaviour and reduce emissions, there must be significant development of both data resources and technologies to enable them to impact on the present situation significantly.

In doing so, it must be recognised that the built environment encompasses not only buildings for work, business and living, but also the associated transport infrastructure and spaces for leisure. All these elements therefore must be considered as part of an integrated whole rather than separately and in isolation.

In taking things forward, it must therefore be recognised that in achieving the Net Zero goal, the built environment presents a complex problem with no easy solutions. It is also an environment in which there is a need to balance incentives and penalties while encouraging organisations that can create best practices and assisting property owners and occupants in the best use of technologies, both current and future.

It is here acknowledged that this not an easy balance to achieve, and it requires the removal of often artificial boundaries between sectors to find solutions.

Finally, it must also be recognised that ultimately, the solutions to achieving Net Zero are not likely solely technological, and there is a need to balance developments in and applications of technology with wider educational approaches aimed at achieving necessary societal changes.

The recommendations associated with this paper were therefore developed to reflect the various issues and concerns identified and set out in the body of the document and aim to facilitate and support a range of issues, including:

- Facilitating the ability to use digital technologies, such as those associated with smart sensors, Digital Twins and Cyber-Physical Systems, to support the better management and use of energy.
- Defining means to identify spaces that can be used when a building is not occupied or is under-occupied and exploring and facilitating other uses for such spaces.

The key to all this is the role of information, and the recommendations move beyond the basic requirements of capturing and disseminating robust, consistent and validated data and the information it then generates. The intention is that this information is used to inform the development and implementation of robust design guidelines focussed on the core issue of GHG emission reductions and based on properly sourced and understood data.

Throughout all this, the role of the government is clear, whether in, as the recommendations establish, facilitating the development of data and information protocols or in bringing together the relevant partners in support of change and development.

Challenges & actions

All the recommendations have implications for the short, medium and long terms, and these are summarised here.

Short Term Now–2025	
Overview	Focus on mitigation using established technologies and establishing an understanding of the key parameters associated with the assessment of building energy consumption and GHG production across the full range of building types and usages.
Actions	• Regulatory approach towards the implementation of short-term actions aimed at mitigation. • Establish research funding for medium and long terms.
Research	• Develop protocols and metrics to enable genuine comparisons between different parts of the built environment in terms of energy use. • Define information needs to support decision making in relation to mitigation activities. • Define sensor requirements in terms of performance (accuracy, resolution, precision, etc.) to generate the data and hence the information. • Define procedures for data validation at the point of collection. • Define and initiate research programmes in association with medium- and long-term goals and needs. • Define an energy hierarchy of buildings to include all business, commercial, industrial and domestic to establish the basic operating criteria for each sector whilst differentiating between current stock and new builds. • Evaluate legislative options and constraints, such as in relation to building energy use and occupancy.
Available Technologies	• Big Data analytics (in some areas) • Cloud technologies • Cyber-Physical Systems • Digital Twins (limited capability) • Industry 4.0 (developing) • IoT • Networked sensors • Smart technologies (relatively limited and basic)
Comments	• Currently not making effective use of technologies already available, partly due to a lack of consistency in how the data is collected, analysed (information) and interpreted (knowledge). • Measurements are often made because they can be, not because they need to be for the creation of the required information and knowledge. • There are privacy issues associated with the integration of data from multiple sources, even when individual data sets are anonymised.

Medium Term 2025–2035	
Overview	Continue work on mitigation but shift emphasis in research towards $C0_2$ reduction/elimination.
Actions	• Migration from fossil fuels. • Implementation of industry support facilities. • Implement data and information protocols. • Introduce legislative incentives/penalties in relation to energy use. • Work towards properly integrated transport systems. • Work towards integrated use of multi-functional spaces and buildings
Research	• Define new research goals based on outcomes of short-term actions. • Continue long-term research activities that now have medium-term goals. • Revise metrics to accommodate changes in status. • Legislation requirements relating to long-term goals
Available Technologies	• Big Data analytics (updated and refined) • Digital Twins (2nd generation) • Enhanced sensor technologies. • Enhanced communications (5G+) • Industry 4.0 • Smart technologies for domestic and industrial energy management

Long Term 2035-2050	
Overview	Final implementation of strategies for achieving carbon neutrality.
Actions	• Complete migration from fossil fuels. • Continued provision of industry support facilities. • Fully integrate transport systems. • Use of multi-functional spaces and buildings established.
Research	• Define new research goals based on outcomes of medium-term actions. • Revise metrics to accommodate change in status.
Available Technologies	• Big Data analytics (established) • Digital Twins (established) • Enhanced sensor technologies. • Enhanced communications (5G +) • Industry 4.0 (established) • Smart technologies (established)

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