INSULATION FOR SUSTAINABILITY

A GUIDE

Produced by XCO2 for
Insulation Manufacturers Association (IMA)

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EXECUTIVE SUMMARY

Photo: York University, BREEAM 'Excellent' college building insulated with PIR insulation boards

Energy consumption is vital to a dynamic and developing global society. This growth has hitherto been facilitated by non-renewable, primary energy sources such as coal, oil and gas. The insatiable consumption of these fossil fuels has exacerbated anthropogenic climate change through the emission of greenhouse gases, especially carbon dioxide (CO_2).

Greater contemporary understanding of the threat that climate change poses to modern society, as well as the environment, has led to a collective demand for change. The established methods of generating and using energy must therefore be reconsidered in order to limit climate change and the impacts of global warming.

The built environment accounted for over a third of final energy use and approximately 40% of energy and process-related emissions in 2018[1]. Consequently, this sector presents a substantial opportunity to reduce energy emissions quickly and effectively, principally through the implementation of energy efficient building elements – known as a 'fabric first' approach. The considered design and diligent construction of the thermal envelope of a building can dramatically reduce heat loss, reduce energy demand, cut occupant fuel bills and subsequently limit the emission of greenhouse gases and act to stymie climate change.

New buildings should be built to deliver optimum levels of energy efficiency from the outset to result in a space heat demand of 15-20kWh/m^2/yr. Considering these enhanced features from the outset is seen to cost approximately one-fifth of the total cost of retrofitting to the same quality and standard at a later date[2].

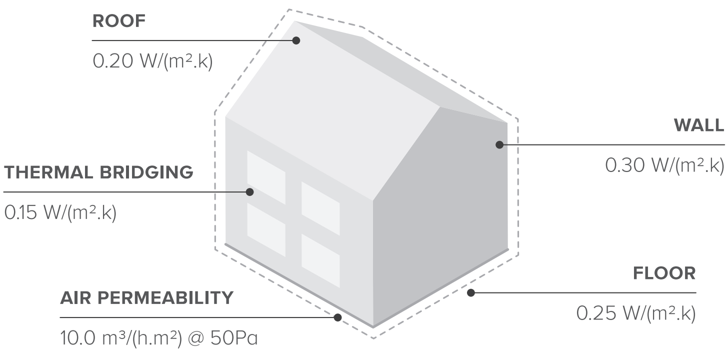
The incremental improvements to fabric performance stipulated within the building regulations are not deemed to be sufficient enough to prompt notable change within the industry. In an era of accelerated global climate change and lagging regulation standards, only urgent and discretionary action will meet the challenge – with the adoption of voluntary design and construction criteria that are seen to surpass the current building regulations. Substantial savings, at the magnitude required to achieve the United Kingdom's (UK) net-zero carbon target by 2050, are typically only realised through adhering to design and construction criteria such as the Passivhaus and London Energy Transformation Initiative (LETI) standards (figure 1).

These elective standards stipulate exacting fabric first parameters that require high performance insulation specifications, as well as maximising the passive design potential of the development. This will reduce demand and ensure the building is built to be future proof and resilient in managing climate change.

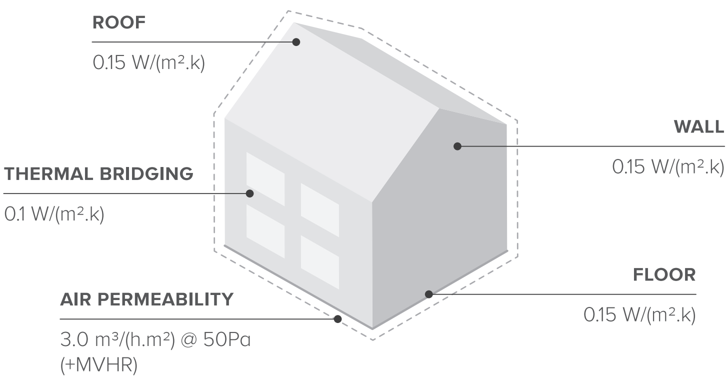
Based on the principal of a fabric first approach, an effective thermal insulation strategy is one of the most successful routes in the realisation of true sustainability and a net-zero society. However, the myriad factors surrounding the choice of insulating materials available, such as, performance, durability, sustainability, health and wellbeing and economic cost, all require critical consideration.

This guide examines and presents an objective evaluation of the principal materials available and at the disposal of authors of the built environment.

CURRENT LIMITING U VALUES FOR ENGLAND



PASSIVHAUS REQUIREMENTS



XCO2 RECOMMENDATIONS

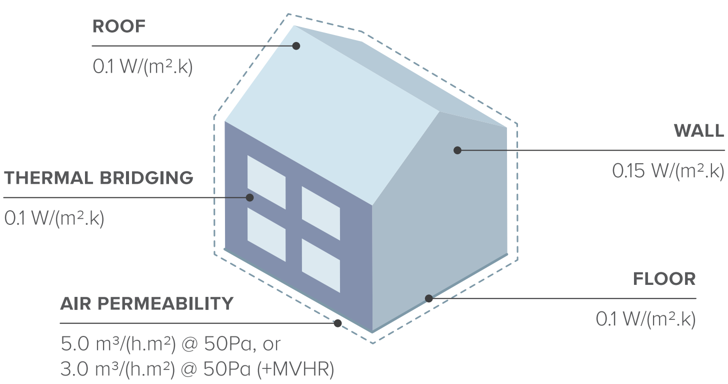


Figure 1: U-values representing the current limiting values for England and the more aspirational voluntary standards such as Passivhaus and XCO2's advisory targets.

SECTION 1

THE GLOBAL CONTEXT

1.1
CLIMATE CHANGE

Human influence on the climate system is indisputable. The mechanisms and processes that have precipitated this change in the earth's natural systems are still occurring at an unmanageable rate, with an ever-diminishing window of possible remediation. The impacts of anthropogenic climate change are now manifest across all of the earth's continents and oceans, such widespread and rapid change – comprehensively documented since the 1950s – is unprecedented in human history, figure 2 illustrates the average global temperature between 1850 and 2019 with warmer years highlighted as red and cooler years blue.

The Intergovernmental Panel on Climate Change (IPCC) concluded in the Fifth Assessment Report (2014)[3], with 95% certainty, that humans are the principal cause of contemporary global warming.

This inescapable reality demands a renaissance in sustainable environmental design, economics and society as a whole, to deliver innovative solutions at pace which can limit and possibly reverse the current projections before a major tipping point in the earth's system is reached.

The continued consumption of fossil fuels for energy generation is perpetuating global warming. Buildings, requiring heat and power, are the largest energy-demanding sector in the developed world[4]. Consequently, this is a key base from which anthropogenic global warming can be quickly and effectively reduced, with readily available technologies – primarily in the form of enhanced insulation strategies and renewable sources.

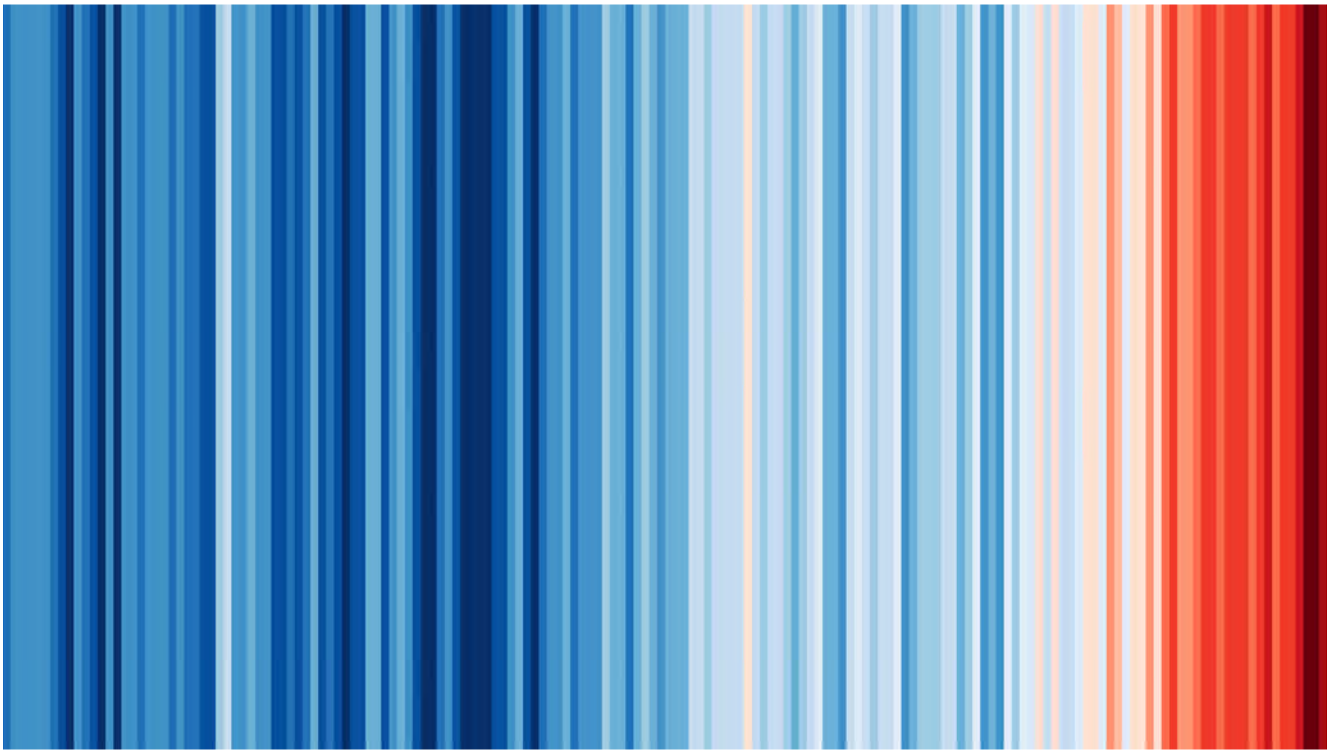


Figure 2: Average global temperatures between 1850 – 2019, illustrated by the 'climate stripes'; showing the relative average surface temperatures for each year (red signifies warmer temperatures and blue cooler) [Ed Hawkins, 2019[5]].

1.2
FUTURE TARGETS

In order for society to continue progressing and to safeguard current advancements, a more sustainable approach to development must be adopted. The general principles for achieving future sustainability are outlined by the United Nations (UN) as part of their Sustainable Development Goals. The most relevant goals for achieving sustainability within the built environment include; 'climate action' and 'sustainable cities and communities'.

Growing public and consumer concern over the impacts of climate change have been seen to drive change to both local and global legislation. As a result, the European Union (EU) has indicated that a target of net-zero carbon by 2050 will be set, which will require Europe's greenhouse gas emissions to be halved by 2030.

The UK Green Building Council (UKGBC) calculate the UK's total carbon footprint at approximately 831 metric tons of carbon dioxide equivalent (MtCO$_2$e), of which 349MtCO$_2$e is attributed to the built environment, with the largest share (139MtCO$_2$e) generated by operational energy uses – including heating (figure 3)[6]. These figures highlight the importance of introducing ambitious legislative measures with respect to buildings and the importance of improving the efficiency of the thermal envelope of a building as a means of reducing carbon emissions.

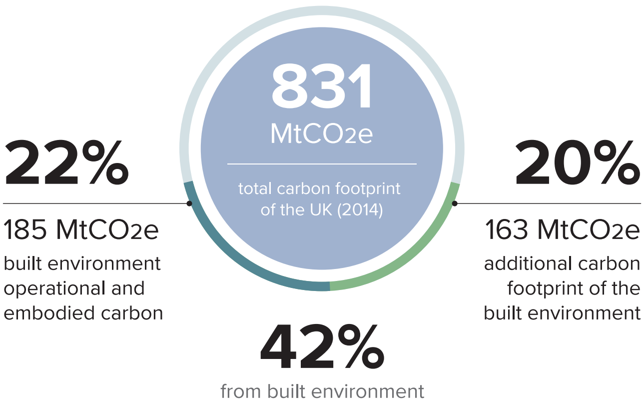


Figure 3: The carbon footprint associated with the built environment [UKGBC, 2014[6]].

In 2019 The UK Government became the first major economy in the world to pass laws to end its contribution to global warming by 2050. Targeting net-zero greenhouse gas emissions by 2050 exceeds the original aim of an 80% reduction from the 1990 levels, stipulated in the original Climate Change Act (2008), following

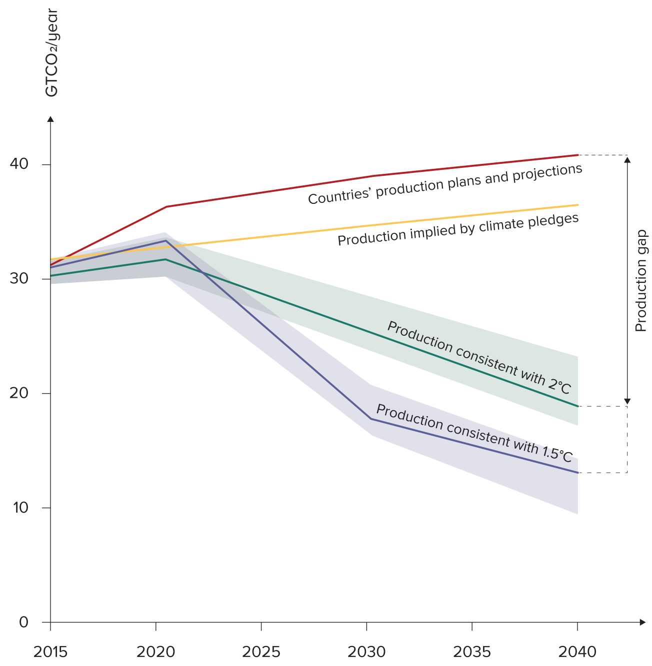


Figure 4: Global greenhouse gas emission scenarios and the resulting increased range in average surface temperature for varying pathways [adapted from the UN Environment Emissions Gap Report 2019[8]].

the objective set out by the United Nations Convention on Climate Change (UNFCCC) within the Kyoto Protocol (2005)[7].

The revised 2019 net-zero target is essential for the UK in order to meet the commitments pledged as a signatory of the subsequent 2015 Paris Agreement with the UNFCCC – limiting the increase in global average temperature to 1.5°C above pre-industrial levels. Figure 4 illustrates how a failure to combat the current production plans and projections will significantly undermine the possibility of achieving the emission reductions required by 2050 in order to limit global temperature increase to below 2°C. The implications of global procrastination with respect to climate action is evident from the data amassed over the past decade of United Nations Environment Programme reporting. The research illustrates that had emissions been tackled in earnest in 2010, the reduction required to satisfy the 1.5°C target in 2030 would have been 3.3% annually. However, as this action did not occur as agreed, the requisite cut in global emissions to achieve the same goal is now considered to be 7.6% annually[8].

Nevertheless, the response in the UK has been apparent – greenhouse gases have reduced by 44% since 1990 and the share of low carbon energy has doubled since 2003. Despite this, 80% of total energy generated in the UK is still derived from fossil fuels[9] and more must be done to ameliorate other key sectors such as agriculture and air travel. Consequently, this is a time which demands major innovation and provides a key opportunity for influencing pivotal environmental change.

1.3 OPPORTUNITIES

There will always be a demand for energy; this is inevitable for a developing modern economy. However, the way in which society uses this resource and the quantity of energy required must change.

The reduction of emissions can be achieved by two general techniques; firstly, by becoming more energy efficient and secondly, by adopting low carbon or renewable fuels. To adhere to the UK's net-zero carbon target by 2050, it is apparent that both of these strategies will be necessary in concert. In addition, actions tackling non-energy related emissions (i.e. methane emissions from livestock and deforestation), will also play a role.

With respect to the construction sector specifically and its wider influence, there are various ways of using energy more efficiently and implementing low carbon or zero carbon alternative fuels.

USING ENERGY MORE EFFICIENTLY

Energy efficiency measures are often low cost and can be implemented immediately at an individual scale by both consumers and in the workplace (bottom-up approach). Relevant examples include;

- Improving the insulation specifications of new-build homes/offices from the outset as well as the implementation of comprehensive retrofitting of the existing housing stock;
- Replacement of outdated, inefficient fixtures and heating systems – light emitting diode (LED) lightbulbs, efficient appliances and specification of efficient servicing strategies, and;
- Substituting conventional gas systems for electric based technologies such as air source heat pumps (ASHP). This will prove to be beneficial as the national grid becomes 'cleaner', utilising a higher proportion of renewable sources.

Figure 5: Examples of energy efficient measures.

SWITCHING TO LOW/ZERO CARBON FUELS

The adoption of energy efficient strategies is an essential, albeit first, step in achieving net-zero carbon.

In the transition from fossil fuels to low and zero carbon energy sources, energy efficiency is a prerequisite. The production of renewable energy relies on an efficient building fabric for optimisation and worth-while implementation. There are various opportunities for reducing dependence on fossil fuels, which have become more feasible and effective with advancements in technology. The adoption of low carbon technologies is dependent on centralised decision making (top-down approach) and therefore has a slower implementation period. Examples of low-carbon/ zero carbon fuels include;

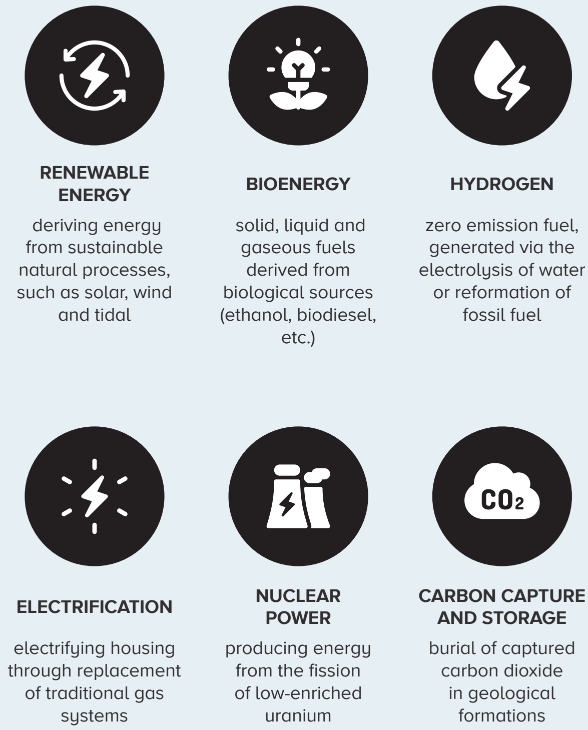


Figure 6: Examples of low and zero carbon technologies.

In order to become a net-zero society by 2050 all of the above techniques are expected to be required in coalition. Eco-centric strategies and technologies such as carbon capture and storage (CCS), carbon credits, carbon offsetting and intrinsically 'green policy' – encouraging investment in climate solutions, carbon saving infrastructure and the creation of new 'green collar' jobs – will also be necessary to support the transition.

SECTION 2

THE BUILT ENVIRONMENT

2.1
THE ROLE OF BUILDINGS

Buildings are responsible for approximately one-third of global energy use and approximately 40% of energy and process-related emissions[1]. Therefore, the scale of influence exhibited by the building sector poses both a substantial risk and opportunity with respect to climate change and its future mitigation.

The influence of the built environment is most apparent in large cities, which are seen to consume 60% of available natural resources and account for 70% of global greenhouse gas emissions[10]. Approximately half of the global population currently reside in urbanised areas, with an estimated 60% (equivalent to approximately 5 billion) forecast to be living in cities by 2030[11]. This forecast growth will add to the existing pressure on urban resources and challenge the services and infrastructures in place.

In order to cope with the rapid rate of population growth, urbanisation must be harnessed as a tool for sustainable development, embedding sustainable strategies at the heart of all new and evolving cities through housing, infrastructure and service developments, in order to reap environmental, social and economic dividends in the future.

The requirement for sufficient and adequate housing in both urban and rural settings must be provided by cost-effective, energy efficient properties that consider enhanced and technological solutions from the outset. In doing so, the construction and retrofitting of buildings to create energy efficient properties will assist in tackling other key UN sustainability goals such as ‘poverty alleviation’, ‘energy/fuel security’ and ‘increased employment’ (the UN sustainability goals are illustrated below in figure 7).

U.N. SUSTAINABLE DEVELOPMENT GOALS

1: No Poverty

2: Zero Hunger

3: Good Health and Well-being

4: Quality Education

5: Gender Equality

6: Clean Water and Sanitation

7: Affordable and Clean Energy

8: Decent Work and Economic Growth

9: Industry, Innovation and Infrastructure

10: Reduced Inequality

11: Sustainable Cities and Communities

12: Responsible Consumption and Production

13: Climate Action

14: Life Below Water

15: Life on Land

16: Peace and Justice Strong Institutions

17: Partnerships to achieve the Goal

Figure 7: The UN Sustainability Development Goals [UN[12]].

The requirement for housing to fulfil the role of traditional office buildings has also been stimulated by the Coronavirus pandemic (2020) with the majority of the UK workforce (approximately 60%) working remotely. In turn, there is a greater need for homes to be more suitable to prolonged periods of occupancy, with particular importance on providing a conducive work environment, providing optimal energy efficiency, air quality, daylight and mitigating overheating risks. This departure from a typical office-centric employment to working from home may provide environmental benefits, such as, reduced transportation associated emissions and a potential long-term reconfiguration of major cities, granting more space for residential development as the demand of a predominately office dominated central business district diminishes.

The triple bottom line framework, illustrated in figure 8 below, identifies the construction industry as an opportune sector from which to instantly begin implementing truly sustainable practices – as it directly relates to the physical environment, provides social comfort and wellbeing and is one of the largest sectors of the economy worldwide.

One key solution for delivering energy efficiency in buildings is via a fabric first approach; specifying insulation and the provision of a high-performance thermal envelope as the foundation of a development.

Insulation is a simple element of construction and a widely available technology, which provides a pivotal opportunity for sustainable development. This is particularly appropriate as many buildings remain insulated to a sub-optimal level, considering the high space conditioning (heating and cooling) demands associated with developed countries.

The adoption of a fabric first approach will create highly engineered buildings offering improved environmental benefits from the outset, as well as bringing enhanced comfort and wellbeing to building occupants. The benefits associated with these buildings will be apparent in terms of sustainability, durability, health and wellbeing and consequently the demand for more resilient homes by consumers is expected to eventually steer the industry into incorporating the enhanced standards as default.

This sea change whereby innovation becomes consumer-driven (led by the public demanding and choosing a premium, highly efficient product over other competitors) and services-driven rather than supplier led – which has traditionally been the case, resulting in slower implementation time – will drive industry-wide transformation and stimulate the investment into green initiatives and projects within not just the construction sector but also potentially the wider economy.

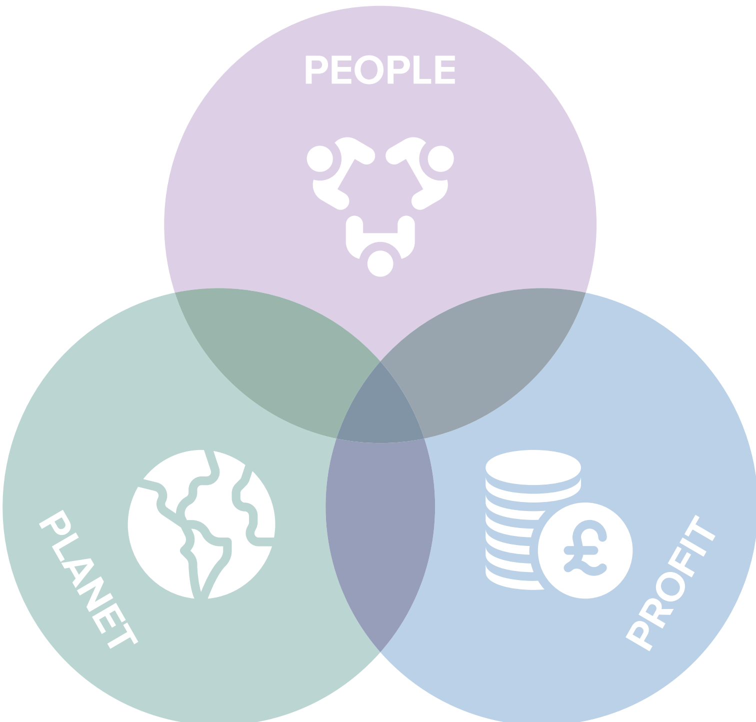


Figure 8: Triple bottom line framework.

2.2
ENHANCED INSULATION STRATEGIES

The Passivhaus Trust notes that:

'Reducing the heating energy demand through a fabric first approach is the only practical way to achieve zero carbon homes in reality[13]*.'*

The purpose of this document is to promote the implementation of enhanced insulation strategies and explore the associated opportunities for environmental sustainability, as well as wider social and economic gains. However, there are some acknowledged factors that need to be overcome in order to realise the benefits, which include:

- Inertia from policy makers with respect to the adoption of more stringent thermal standards and the diminished importance of energy efficiency;
- A gap between the as-designed and as-built performance of buildings; and
- How and by whom is retrofitting of insulation funded.

However, despite these obstacles, there is also a lot of positive activity with many advanced strategies being driven by professional institutions, ambitious construction professionals, social housing providers and mass housing builders who have and continue to, deliver on passive and nearly zero energy building (nZEB) standards. The Royal Institute of British Architects (RIBA) has also launched its own 2030 Climate Challenge to meet net-zero (or better) whole life carbon for new and retrofitted buildings by 2030[14].

Additionally, the industry has worked together with British Standards to develop Publicly Available Standards (PAS2030/2035) to drive up the quality of energy efficiency retrofit projects in dwellings[15].

Photo: Priestley Grove, an example of residential accommodation with an enhanced insulation strategy

2.3 STANDARDS AND REGULATIONS

Photo: Stroughton Primary School, a Victorian school with narrow cavities, refurbished and insulated with injected PUR to meet building regulations

The Climate Change Act[16], introduced in 2008 and subsequently amended in 2019, to target net-zero carbon by 2050, is the basis for the UK's strategy on tackling climate change. This legislation established the independent Committee on Climate Change (CCC) and offers strategies for delivering emission reductions via The Carbon Plan (2011)[17] and carbon budget proposals (The CCC are currently working on the sixth of these reports for publication in December 2020).

Both the Carbon Budget proposals and the most recent Net-Zero Technical Report (2019)[18], produced by the CCC, identify residential and non-residential building efficiency as one of the most important factors in reducing emissions.

The CCC Progress Report to Parliament (2020)[19] illustrates that the building sector has seen limited progress in the past decade, with associated emissions falling by only 14% in the period 2008-2018. The majority of these savings have been attributed to stringent domestic standards implemented between 2008-2015, phasing out non-condensing boilers, along with supplier obligations targeting home energy efficiency.

However, after this policy-driven success in the first half of the decade, there has been minimal progress in recent years. It is therefore apparent that not enough is currently being done with respect to the built environment to maximise the huge potential savings available.

In December 2006, the Zero Carbon Homes Initiative was introduced as part of the Building a Greener Future Consultation[20] and subsequently, in 2007 the Government introduced a policy for all new homes to be constructed to meet a zero carbon standard from 2016. The Zero Carbon hub was founded in 2008[21] and tasked by the UK Government to take day-to-day operational responsibility for defining and achieving the Government's ambitious target and worked extensively to deliver a raft of recommendations in conjunction with industry engagement. Unfortunately, the zero carbon targets were abandoned in 2015 and 2016, with the subsequent closure of the hub, but despite this much of the Hub's recommendations and guidance continue to be utilised on some UK sites, even though the net-zero targets and policy recommendations were not adopted.

The Energy Saving Trust (EST) has proposed a revised national strategy to replace the Zero Carbon Homes Initiative. This would necessitate that all new homes are built to a 2050-ready standard, in order to achieve the net-zero carbon target in the next thirty years. A 2050 ready home is defined by the EST as having minimal energy use and net carbon emissions over a year of operation, as a result of high levels of insulation, low water demands and direct connections to renewable energy systems[22]. Furthermore, the EST identifies energy efficiency as 'the most effective long-term guarantee of a low carbon emission housing stock'. A 2050-ready home would need to meet minimum fabric efficiencies, which would considerably exceed the current building regulations, to help ensure the legally binding targets are achieved.

At a more regional level, the London Energy Transformation Initiative (LETI) has proposed various strategies and influenced policy produced by the Greater London Authority (GLA), in order to generate policy guidance that steers developments in London to zero carbon and which can be eventually applied to the rest of the UK. The recommendations put forward by LETI include the following requirements;

- Requirement that a 10% reduction in carbon emissions for residential and 15% reduction for non-residential development are achieved using an efficient building fabric and systems;
- Inclusion of unregulated energy use within the operational energy demands;
- Energy disclosure, with an additional 'be seen' stage to be incorporated within the energy hierarchy;
- Continual evaluation of the carbon factors used within the methodology to ensure calculations are representative of the national grid, and;
- Maximising potential for renewable technologies.

Furthermore, 67% of local authorities across the UK have responded to the current climate emergency by setting their own stretching planning targets[23]. Local authorities are much better situated to determine local requirements and achievable objectives. The UK's ability to slow climate change depends on individual planning authorities taking ownership of the problem at a local scale, setting ambitious targets in order to precipitate a larger and more co-ordinated response nationally to surpass the more conservative targets administered by the national governments (see figure 9 overleaf).

Exeter City Council and Nottingham City Council have been praised as frontrunners in the arena of setting precedent in the UK with respect to the Passivhaus and Energiesprong standards, respectively. Exeter Council has commissioned new buildings to the Passivhaus standard and required developments to be designed to projected 2030, 2050 and 2080 climate scenarios[24]. Nottingham City Council has been the first in the UK implement the Energiesprong standard in 200 social houses – funded by subsidies from installed renewable technologies and a 'comfort plan' levied on tenants[2].

One of the most influential and most well developed voluntary standards in practice internationally and in the UK, is the Passivhaus standard – through which buildings are designed to use very little heating and cooling energy, with a design focussing on fabric efficiency and airtightness. According to the Passivhaus Trust there are over 1,000 Passivhaus homes in the UK.

The Energiesprong standard is another new-build and refurbishment approach that measures the operational energy consumption as opposed to the modelled performance and stipulates substantial fabric improvements over the current guidelines.

Additional legislative measures must be implemented in order to ensure new developments are built to consider future climate conditions and the risks associated with events such as overheating and flooding. The UK's new National Planning Policy Framework encourages local planning authorities to consider resilience to climate change[25]. However, the UK's national building energy assessment tool; Standard Assessment Procedure (SAP), both the current SAP2012 and the upcoming SAP10 methodology, do not currently require a detailed overheating assessment.

Nevertheless, summer overheating of buildings is beginning to be considered at a local level. The new Draft London Plan (2017) requires major developments to demonstrate how they will reduce the risk of overheating and reduce the reliance on air conditioning.

The UK Government has tasked private housebuilders, housing associations and councils with a target to build 300,000 homes each year by 2025 to tackle the shortfall in housing, a target not met since 1969[26], when approximately half of new build properties were categorised as social housing and were delivered by local councils.

The Government's figures[27] show that 178,800 new homes were constructed in England during 2019, which is the largest number completed annually, since the global financial crisis in 2007/8. The last change to the building regulations energy performance targets was in 2013 and targets were not significantly improved over those introduced in 2010; it is probable that a significant proportion of these will need to be upgraded to help reach the net-zero 2050 target.

The construction targets proposed by the UK Government could provide key opportunities for sustainable intervention in the sector to ensure all properties are built to take advantage of passive design strategies, as well as employing a fabric first approach, with the aspiration and target of achieving net-zero carbon (NZC). This change can be primarily achieved by constructing homes with the most appropriate, durable and resilient high performance insulation to guarantee low future energy demands and reduced associated carbon emissions. However, the focus must not be solely on the optimisation of new build developments in order to create an NZC housing stock for the future. Ensuring the existing stock is retrofitted to improve fabric efficiency and reduce energy demand is also critically important. Nevertheless, low carbon, low demand strategies need to be implemented from the outset for all new constructions, whilst retrofitting to improve the existing building stock is important, there are limitations as to what can be done for many buildings and as such, this cannot be relied upon to compensate for high energy demands (see section 2.4 – retrofitting).

Section 3 of this guide (specifying insulation), investigates and analyses the primary parameters involved in specifying insulation for all applications, both for new builds and for retrofitting schemes.

When choosing the most effective and appropriate insulant for housebuilding on a mass scale, space is typically the overriding consideration. An insulant which provides the greatest performance over the smallest footprint – to ensure development sites are maximised – whilst providing an enduring and long-term solution will typically be the most attractive material.

By specifying an insulant of this nature, not only will space be maximised, but also fewer carbon emissions will be generated by the development due to the enhanced performance and subsequent reduced energy demand. This results in lower fuel bills and greater overall comfort levels for future occupants.

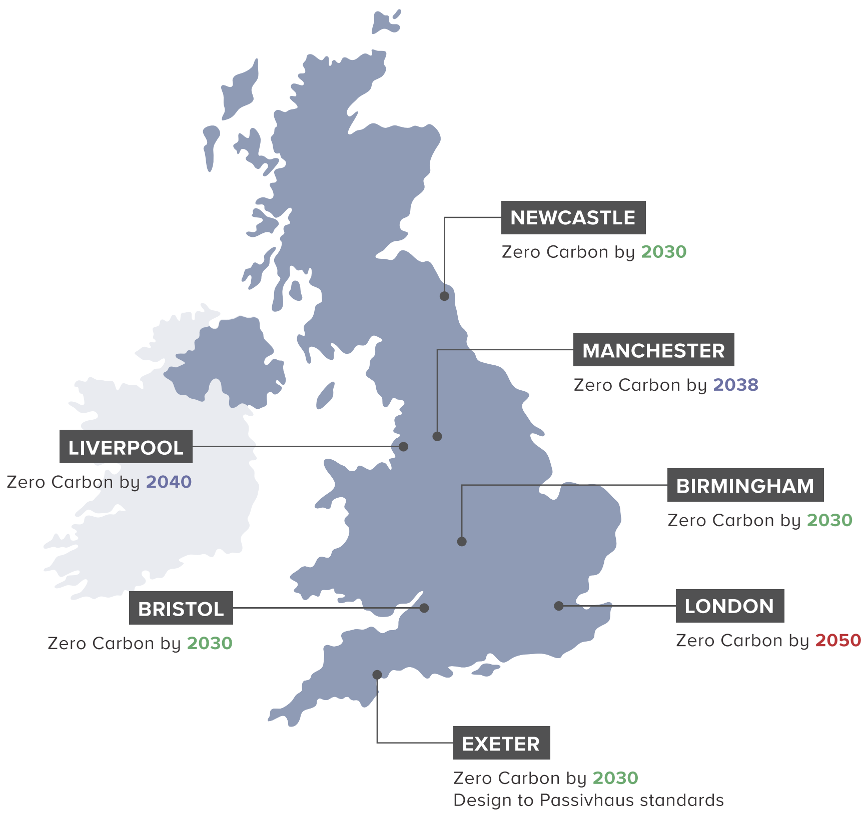


Figure 9: Local Authorities and associated planning targets declared in response to the climate emergency.

2.4
RETROFITTING

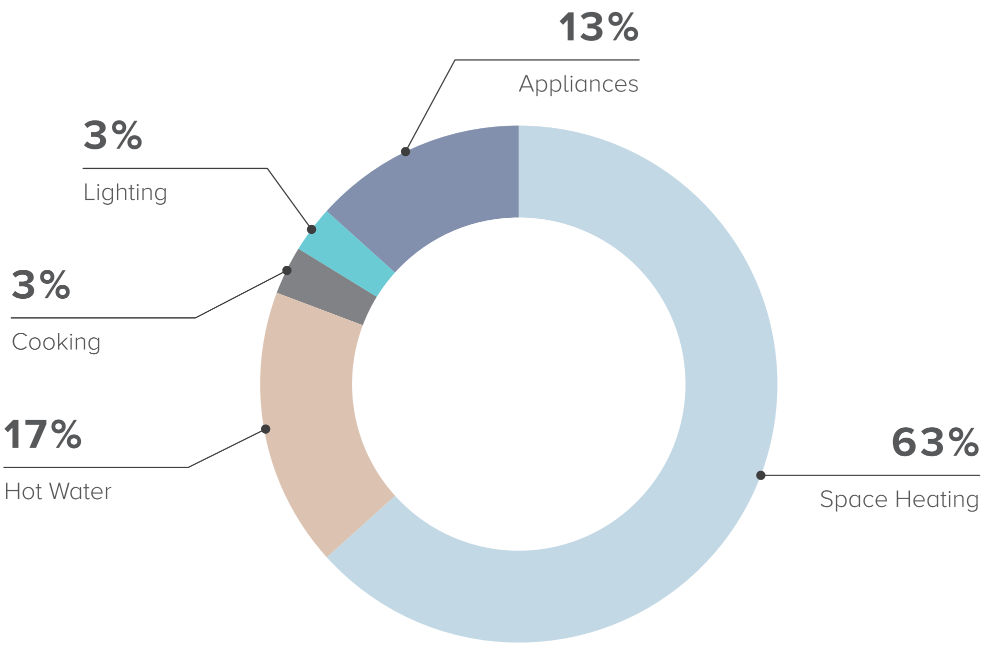


Figure 10: Breakdown of energy consumption in existing homes [CCC Housing Fit for the Future?[2]].

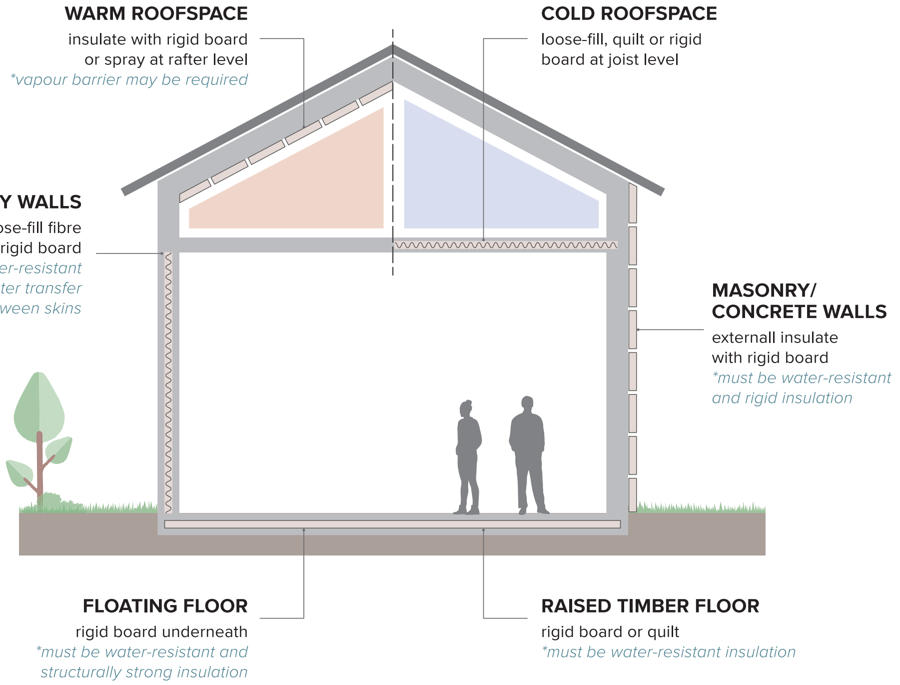
There is currently unprecedented support for the retrofitting of energy efficiency measures in the UK, with building occupants and users calling out in approval of additional measures to be adopted and implemented in the workplace, in rented accommodation and in properties for sale. This universally recognised facet of retrofitting is widely considered worthwhile and as such, these strategies have become expected as standard.

According to the UK Housing Survey Energy Report 2017-2018[27] the three most common energy efficiency measures during the previous 5-year period were seen to be; servicing of the existing central heating system (43%), replacing the central heating system (32%) and installation of enhanced insulation or supplementing existing insulation (18%).

Among owner/occupiers in the UK, 75% had carried out at least one of these energy efficiency measures.

Generally, houses built from 1990 onwards have insulation fitted within the wall cavity to improve the thermal performance of the building. However, homes built prior to 1990 may not have any wall insulation at all. Typically, houses built prior to 1920 are expected to have solid wall constructions with no cavity, whereas residential property built between 1920 and 1990 is most likely to have a wall cavity with no insulation material.

Space heating is seen to be the dominant driver of energy consumption in existing homes (making up 63% of annual energy consumption), followed by hot water demand (17%) and appliance demand (13%)[2] (figure 10).



NOTE: *Where rigid board is used, in-situ sprayed cellular plastic is often also an option.*

NOTE: *Radiant barriers can form a useful strategy in many applications where space is limited. However, maintaining sealed air gaps between and around all layers is essential for performance.*

Figure 11: Examples of retrofitting insulation in existing buildings.

A comprehensive retrofitting programme is therefore a valuable instrument in reducing heating demand as well as curtailing fuel poverty and maximising occupancy comfort and wellbeing (these factors are discussed further in direct relation to insulation in section 3 – specifying insulation).

There are specific design considerations when tackling a retrofit project, especially when targeting savings via a fabric first approach. The most common debate is centred around the best location to position auxiliary insulation. Generally, the most suitable location and insulation type for different building elements are:

- Cavity wall – injection of loose fill or in-situ expanding insulation material;
- Solid masonry wall – external/internal rigid insulation within a weatherproof/protective system;
- Roof space (cold) – loose fill spray or fibrous insulation at roof joist level;
- Roof space (warm) – rigid insulation boards or spray foam insulation at rafter level;
- Solid floor – rigid board under screed or floating floor, and;
- Timber floor – rigid board or quilted batting between floor joists.

Please see figure 11 illustrating the best locations for retrofitting auxiliary insulation.

The Each Home Counts Report (2016)[28] makes the following sector specific recommendations for addressing insulation and fabric, in line with PAS2035/2030:2019 – Retrofitting dwellings for improved energy efficiency, specification and guidance[15];

- All retrofit projects will have an appropriate design stage process which takes a holistic approach and adequately considers the home, its local environment, heritage, occupancy and the householders' improvement objectives when determining suitable measures.
- Put in place a process for gathering information and the design specification ahead of any installation of insulation or fabric measures; store this in a data log for future use and to facilitate continuous improvement; and load aftercare support and quality information into the data log following an installation.
- Ensure that the Insulation and Fabric workstream feeds into the standards, skills and quality assurance development processes and that these reflect best practice and fully take account of the issues specific to the measures.

Nevertheless, retrofitting must only be considered as a solution for existing and historic buildings and cannot be viewed as a panacea to be administered at a later date. Developers must not be allowed to eschew the most appropriate building fabric/solutions available in favour of reducing expenditure – resulting in the responsibility of future-proofing the building to be transferred to the building owners.

The CCC report – UK Housing Fit for The Future?[2] assesses the cost associated with retrofitting a typical building to perform with a space heating demand of 15kWh/m^2/yr. (considered a 'deep retrofit'), illustrating that it is approximately five and a half times more expensive when compared to building a comparable building as a new build. Furthermore, the cost associated with retrofitting strategies to facilitate passive cooling, for example, are also seen to cost approximately four times as much as implementing the same strategies from the outset. This evidence illustrates the importance in considered design of new build developments from the start in order to avoid unnecessary costs and works further down the line.

Supplementary emission savings can be attained where the servicing strategy and supply-side improvements are implemented. This may include the replacement of traditional gas boilers for more efficient alternatives such as an air source heat pump system or connection to a district heat network.

Nevertheless, key considerations when evaluating the potential savings from retrofitting include practical, aesthetic and capital investment constraints, as well as supply side efficiency options being more applicable to new-build projects.

Photo: Rigid insulation boards installed at floor level

2.5
FABRIC FIRST

The fabric first approach places more emphasis on the optimisation and performance of the elemental components and materials that form the building as well as passive design strategies, before designating mechanical and/or active systems.

The key to the success of the fabric first approach is optimising build quality to ensure that the as-built performance matches the design performance.

To ensure that buildings do not suffer with a performance gap it is essential that regulations call for robust assurance regimes, incentives for better buildings and penalties for those that do not perform as predicted.

The Passivhaus Trust report[13] indicates that it is the quality control assurance process of a Passivhaus that ensures that what is designed is built meaning that Passivhaus buildings do not suffer from a performance gap.

Methods for reducing the need for energy consumption via a fabric first approach include;

- Enhanced insulation with low thermal conductivity;
- Improved thermal bridging detailing;
- Maximising air tightness;
- Optimising solar gain and;
- Optimising natural ventilation.

Concentrating on delivering a fabric first solution is generally considered more sustainable than relying on energy saving technologies, or renewable energy strategies, as these latter solutions can be expensive, have a high embodied energy or not be utilised suitably by the occupants. This is apparent when considering fabric enhancements are the most common retrofitting technique implemented in existing properties (including improvements to insulation and glazing efficiency).

Furthermore, the inclusion of a high-performance thermal building envelope reduces the final energy demand to be provided by low carbon/renewable systems, resulting in a reduced dependence on such technologies and improved overall resilience.

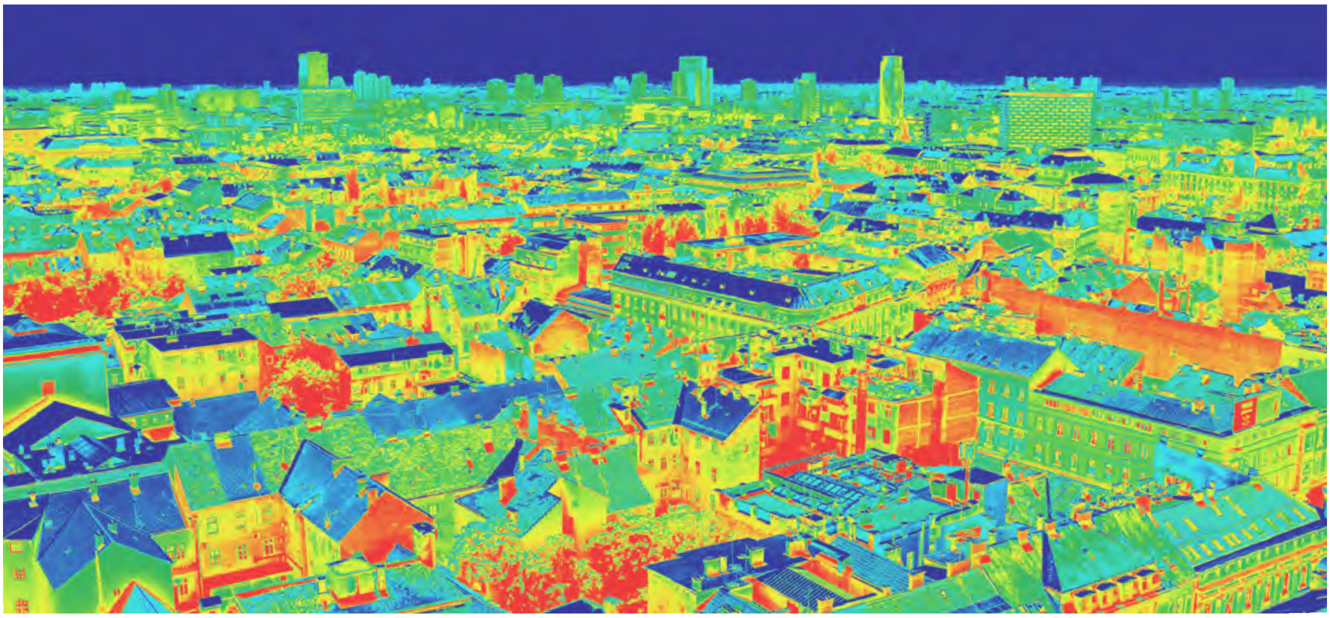


Photo: Infrared thermovision image demonstrating the fabric performance of different buildings

2.6
RESILIENT DESIGN

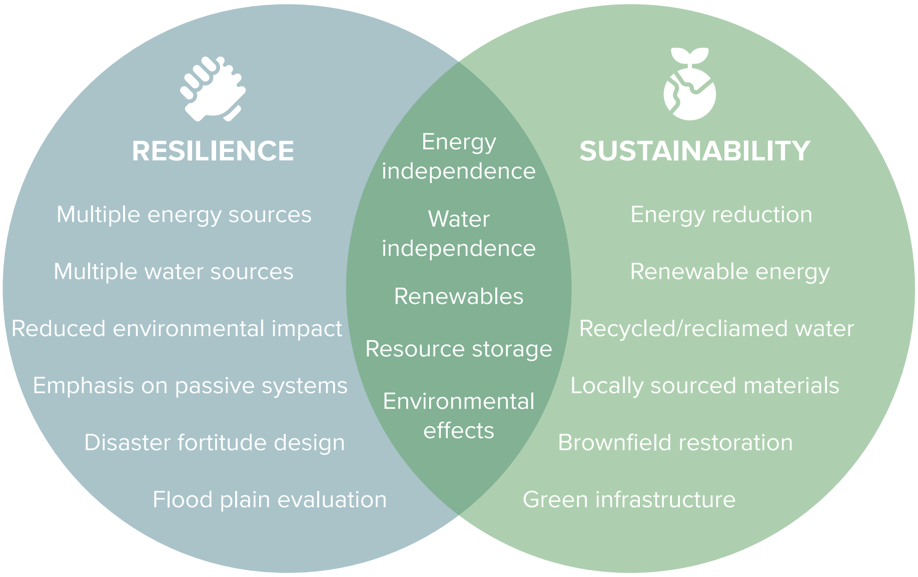


Figure 12: Principles of resilient design and the relationship with sustainability[29].

As previously mentioned, a fabric first approach in new build and retrofit schemes will assist in delivering a resilient housing stock for the future.

According to the Resilient Design Institute[29], resilient design is defined as 'the intentional design of buildings, landscapes and communities to adapt to changing conditions in order to maintain functionality'.

The methodology behind this concept is based on eight key principles:

- Resilience anticipates change and context;
- Passive and flexible solutions are superior;
- Resilience identifies and mimics solutions in nature;
- Local, renewable resources are superior;
- Resilience transcends scale;
- Resilience safeguards basic human needs;
- Resilience incorporates diverse and redundant systems, and;
- Resilience is not absolute.

Resilient design strategies are complementary to the objective of sustainability and the two are mutually reinforcing (see figure 12). However, resilience aims to surpass sustainable and energy efficient design, addressing the relationship between urban development, disaster risk management, climate change and sustainability simultaneously, to provide elegant and enduring solutions to current and future challenges through an assortment of traditional and innovative techniques.

By designing buildings using the fabric first approach, buildings are adhering to the principles of resilient design, highlighting the focus on passive solutions first rather than energy demanding 'quick-fixes', such as, air-conditioning systems. Incorporating passivity removes the dependence of a building on an external energy supply, promoting independence and ultimately, resilience.

The most impactful way in which the fabric of a building can be enhanced to increase energy efficiency is through the incorporation of high-performance insulation. The following section (section 3 – specifying insulation) of this guide provides an appraisal of insulation materials available to achieve these required savings.

2.7
DESIGN PRINCIPLES

Principles incorporated at the design stage of building development can curb the operational energy required by occupants for heating, cooling and lighting in the future.

Optimising features such as layout, insulation, orientation and glazing can all take advantage of passive natural processes and be implemented in the architectural design at an early stage, reducing the collective dependency on low and zero carbon technologies and subsequent active measures from the outset.

Basic design strategies to be included during the architectural conception of a development to optimise efficiency and ensure low energy demand include;

SITE AND BUILT FORM

Site-dependent aspects such as the prevailing wind direction and other microclimatic and seasonal traits may be mitigated through considered design. Earth sheltering and protection of exposed sites by including trees and other soft landscaping features can aid in reducing heat loss and facilitate constant internal temperatures. Wind sheltering has been seen to reduce heating demands by approximately 5% in some urban cases[30]. Additionally, in urban environments the incorporation of green and blue spaces can be specified to combat the urban heat island effect.

Furthermore, the shape and form of a structure has a direct influence on the surface area to volume (SA/V) ratio. Developments with a higher SA/V ratio are prone to greater heat loss as larger surface areas facilitate accelerated heat exchange with the surrounding environment. This theory is exhibited throughout physiological adaptations in nature, the large ears of African elephants are an example of this. Therefore, a compact form such as a cube, should be ideally implemented for buildings in cooler climates where heat loss is undesirable.

It is important to consider daylight alongside the principles outlined above and not neglect the daylighting requirements of a development. See figure 13.1.

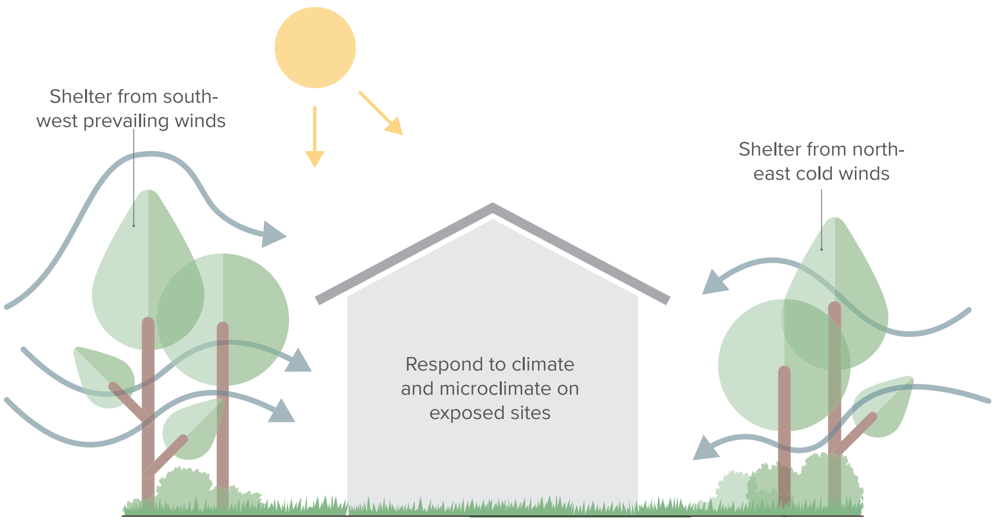


Figure 13.1: Consideration of external site and built form factors in response to minimising heating demands.

OPTIMISED INSULATION AND AIR TIGHTNESS

Typically, heat loss associated with a property is equally distributed between all elements of the thermal envelope; opaque fabric, glazing and background air permeability. Consequently, all factors must be considered. The opaque fabric and glazing should be specified to high-performance standards to minimise the thermal transmittance of the material and avoid unnecessary heat loss (discussed further in section 3 – specifying insulation).

The area of glazing included for a development is a sensitive parameter and a balance between heat loss and satisfactory daylighting must be achieved. Generally, the glazing ratio recommended to strike this balance is a maximum glazed area equivalent to 20-30% of the floor area.

However, this can be increased if external shading elements are integrated within the design of the facade.

Following the stipulation of high-performance building fabric, a controlled and secure ventilation strategy (see ventilation design principle below), must be targeted. This is achieved by comprehensive detailing of the structural build-up and thermal envelope, necessitating a continued quality control of the construction and a high build quality. See figure 13.2.

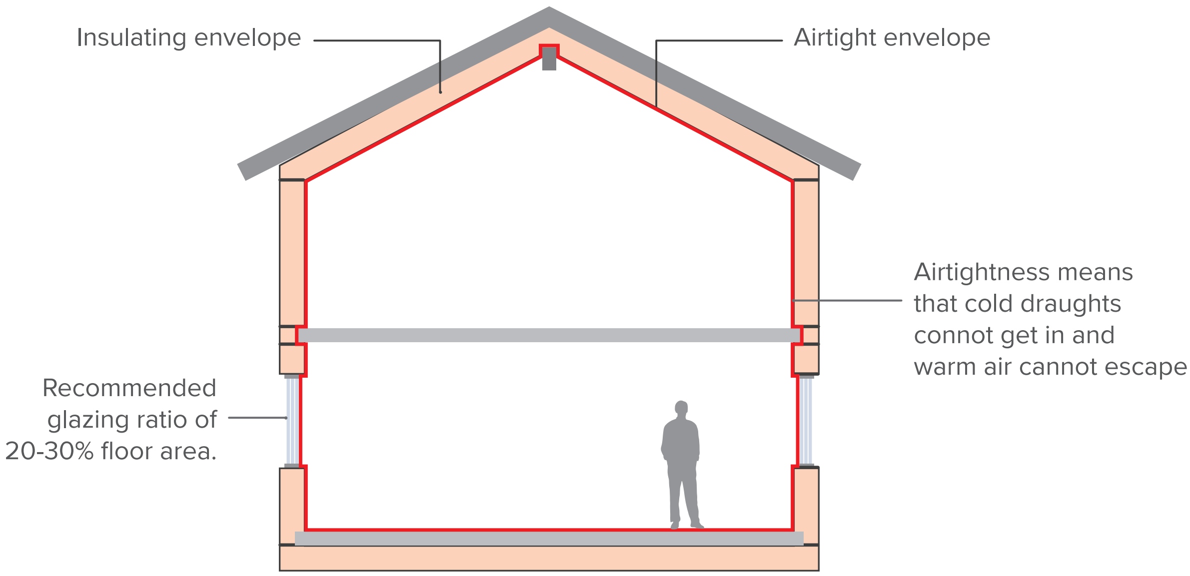


Figure 13.2: Key thermal elements of a building envelope associated with heat loss.

ORIENTATION AND CONSIDERATON OF SUMMER OVERHEATING

Careful consideration to building design is essential to meet the challenges of warmer summers, whilst also reducing the amount of energy that we use in the colder parts of the year.

Passive solar heating requires harnessing the full potential of incoming solar radiation during the winter months when the sun is lower and daylight hours are limited. This demands that glazing areas are maximised and located on the southern façade of the property – orientating the glazing directly towards the greatest available percentage of solar energy.

Limiting solar gain and the associated overheating risk during the summer months must also be considered. This can be achieved via the installation of external shading elements such as louvres, traditional shutters and overhangs to limit the summer sun, which has a higher altitude in the summer relative to the same azimuth (the horizontal angle between the projected vertical vector of the sun and the vertical vector of true north).

Other strategies for reducing summer solar energy include; glazing and film technologies to reduce solar transmittance (g-value), whilst maintaining acceptable levels of light transmittance. Additional structural features include sunspaces and winter gardens which act as thermal buffer zones during the summer – these can be jointly implemented with a thermal mass to store excess heat. See figure 13.3.

VENTILATION

Once a high-performance building envelope has been designed, a controlled ventilation strategy is essential to maintain the integrity of the shell of a building. Mechanically assisted ventilation systems with the capacity for heat recovery (MVHR) should be considered as an option alongside the more conventional approach of natural ventilation, which is still considered to be an effective approach.

These strategies allow minimal air exchange during the winter months, limiting the internal heat loss by preheating incoming fresh air via a heat exchanger, transferring the heat content from the exhaust air. This reduces the space conditioning demand whilst maintaining sufficient fresh air for building occupants. In warmer seasons and climates, MVHR can be employed to control internal humidity and purge heat accumulated during the day via secure night-time ventilation. See figure 13.4.

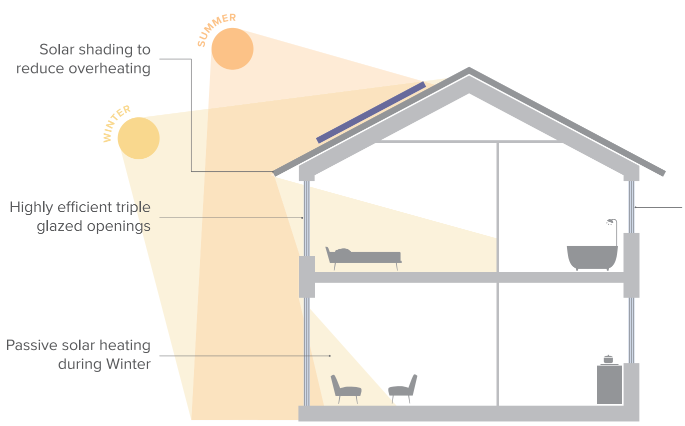


Figure 13.3: Factors associated with maximising passive solar heating and natural daylighting whilst mitigating overheating.

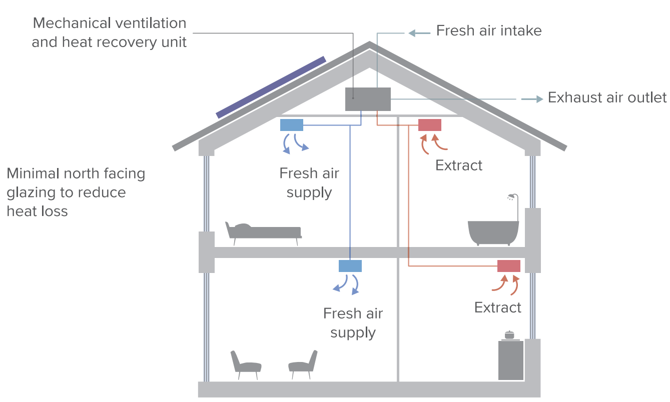


Figure 13.4: Schematic of a controlled ventilation strategy implemented at a residential development.

THERMAL MASS

Thermal mass is the ability of a material to absorb and store heat energy, acting as a 'thermal battery'. In the summer, higher thermal mass constructions can help to reduce daytime temperatures inside a building, absorbing some daytime heat gains (reducing the daytime cooling load), and releasing that heat during the night, which has the effect of making the internal temperature range potentially more stable (but potentially needing more overnight purge ventilation if well insulated).

The downside is that high 'thermal mass' homes are typically considered to be less responsive to heating input during the heating season and require more heat energy to achieve thermal comfort (combined air and surface temperatures) and take longer to reheat once cooled down.

Higher levels of thermal mass buffer the temperature gain to the evening (it is not inter-seasonal), so in a long heat wave it is quite possible for this thermal mass to stay warmer for longer. The embodied energy of materials providing internal heat capacity can be significant and will offset or in some cases negate any saving in space heating energy if such materials are included solely for this purpose. A low thermal mass dwelling tends to have a better heating responsiveness, with less lag, but is less able to buffer the heat from the daytime into the evening. See figure 13.5.

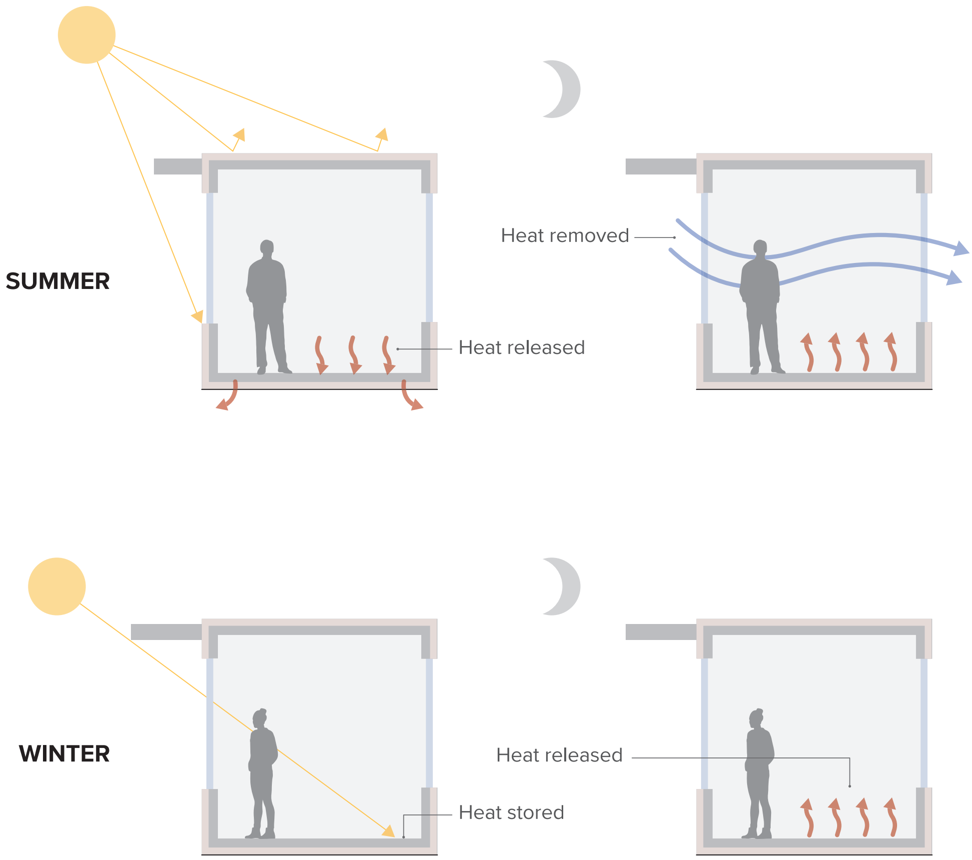


Figure 13.5: The mechanism of a thermal mass during both summer and winter, illustrating the multifunctional application.

2.8
ROUTE TO NET-ZERO CARBON

Considering the significant opportunity the built environment poses in comprehensively tackling climate change, the following framework (figure 14) outlines the most crucial aspects discussed in this guide for future developers to consider implementing at each stage of works to ensure buildings are designed, constructed and operated with the overall goal of net-zero carbon.

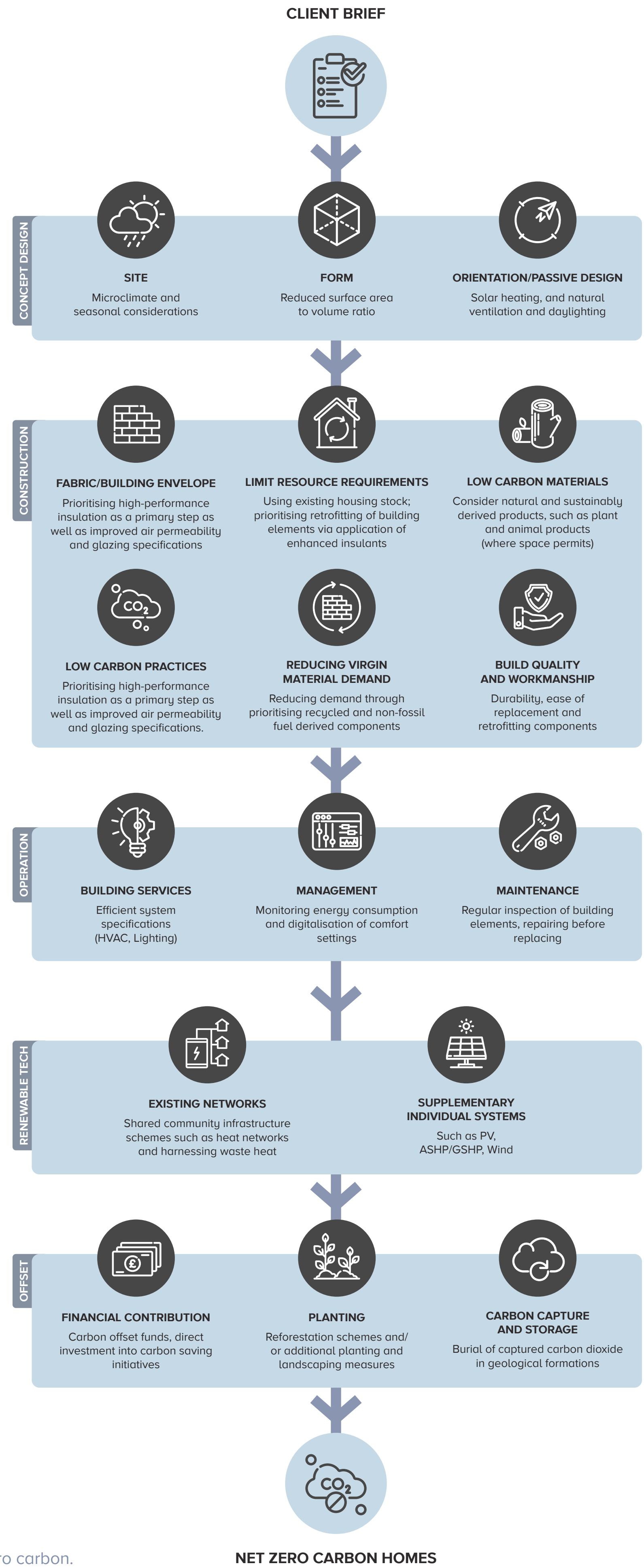


Figure 14: Route to net-zero carbon.

SECTION 3

SPECIFYING INSULATION

The framework provided in the RIBA Plan of Work[31], originally published in 1963, is an industry-wide tool used to provide understanding between project teams during the course of a development. This process map highlights the importance and necessity for consideration of operational and embodied energy, as well as CO_2 emissions from the outset (stage 0 – strategic definition). During stage 3 – spatial coordination, the architectural concept is analysed to determine feasibility in line with the project aspirations such as the sustainability outcomes (i.e. operational energy reduction). As part of this phase, principles of design including form and orientation and as well as details for airtightness, the proposed servicing strategy and insulation are considered.

The agreed approach determined to satisfy the sustainability target is then developed over stages 4 and 5 whereby technical design is carried out with specialist contractors to ascertain manufacturer specifications information to facilitate the desired strategy and the manufacture, construction and commissioning of the building is initiated. Therefore, careful deliberation must ideally be given to the specification of enhanced insulants from the outset in order to result in a development which values sustainability and champions the reduction of operational energy demands.

3.1
CLASSIFICATION

Figure 17: Examples of typical insulants.

Desirable insulating materials must have a low thermal conductivity potential. The second law of thermodynamics states that heat will always travel from a relative area of higher temperature to an area of lower temperature in order to reach equilibrium across the energy differential – this movement of heat energy is defined as 'thermal flux'.

Subsequently, suitable insulating materials have a low thermal conductivity in order to limit heat flux across the thermal gradient and maintain the desired temperature variation, for example, between the internal space and the external environment.

There is a vast array of insulation materials that can be utilised as insulants within the construction industry. These solutions range from advancements in material science and the polymerisation of organic chemical compounds derived from virgin fossil fuels (figure 15), to unprocessed, naturally occurring materials such as wool and flax.

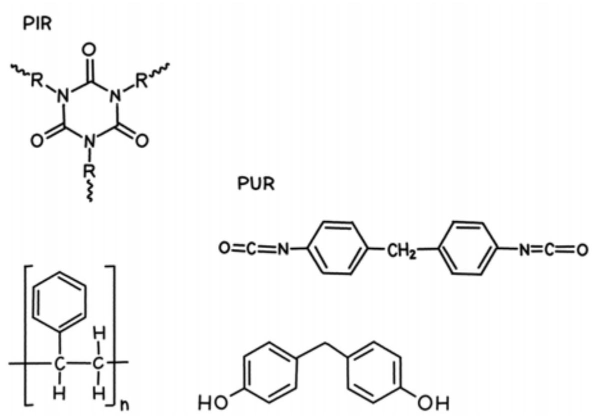


Figure 15: Monomers used in the polymerisation reactions during manufacture of organic synthetic insulants.

Generally, insulation materials can be divided into three main categories: mineral, organic synthetic and natural (plant and animal). Within these three divisions there are two further subcategories, depending on material structure – fibrous and cellular (figure 16). Together, these classifications broadly outline all of the insulation materials currently available for utilisation in the built environment.

Fibrous materials retain air between the individual strands of constituent fibres, preventing heat transmission via convection and also limiting conductive losses by reducing the interaction of gas molecules within the material; these materials are typically flexible owing to their structure.

Cellular insulation materials, on the other hand, are generally more rigid structures with pockets of trapped gas forming in the interstitial spaces when manufactured/installed; these chambers of trapped gas inhibit the process of convection. Gaseous blowing agents have a lower convective potential than air, to further reduce the transmission of heat within the material.

The main insulation materials readily available are presented in the table 1. A detailed summary of the insulants categorised within the table is available in Appendix A.

	FIBRE	CELLULAR
MINERAL	Stone wool, Glass wool	Cellular glass, Perlite, Vermiculite
ORGANIC SYNTHETIC	-	Polyurethane (PUR), Polyisocyanurate (PIR), Expanded polystyrene (EPS), Extruded polystyrene (XPS), Phenolic foam
NATURAL (PLANT AND ANIMAL)	Cellulose, Wool, Flax, Hemp, Wood wool	Expanded cork

Table 1: The general categorisation of insulation materials.

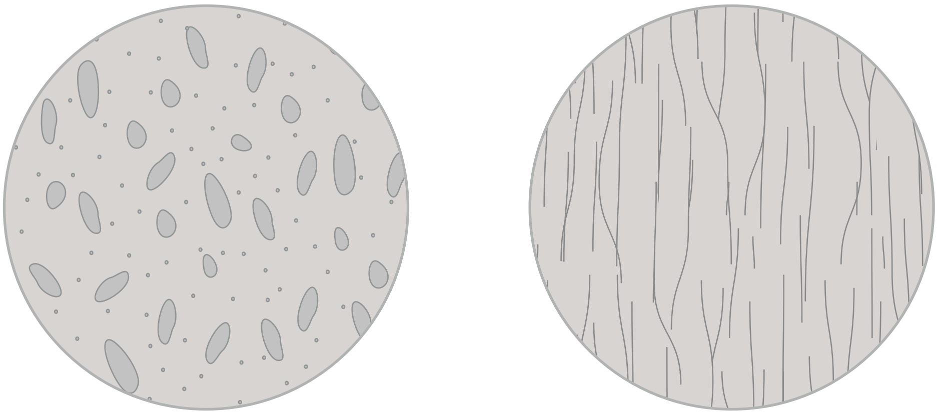


Figure 16: Cellular and fibrous insulants with respective material detail.

3.2
THERMAL ASSUMPTIONS

The energy performance of a building is defined by The Building Regulations Conservation of Fuel and Power Part L1a as 'the calculated or measured amount of energy needed to meet the energy demand associated with the typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation hot water and lighting' [32].

Minimum performance requirements have been set by the Government, these include a target CO_2 emission rate (TER) and a target fabric energy efficiency rate (TFEE). New developments are evaluated against these targets using the Standard Assessment Procedure (SAP) software.

As part of the initial consultation process on the Future Homes Standard (2020)[33] the modifications to the Part L methodology suggest that the fabric energy efficiency standard (FEES) will be abolished, removing the preventative measure of new homes being designed with a fabric worse than the 'notional' building, meaning that homes can be designed using the 'minimum' building fabric U-values as long as the development passes the carbon target. Essentially meaning that a building that would fail to meet the current regulations (Part L 2013) would pass under the new methodology[34].

A letter from the CCC addressing the Future Homes Standard and proposals for tightening Part L in 2020, highlights that without a suitable replacement for the FEES utility and servicing bills may be up to 50% higher for households than under current standards[33]. Furthermore, it states that by 2025, if not before, ultra-energy efficient homes are both achievable and highly beneficial (equivalent to close to Passivhaus standards), but in order to achieve this the workforce must be trained to implement these procedures with immediate effect.

Consequently, in order to facilitate the net-zero target legislated by the Government in 2019, more rigorous building fabrics must be adopted by the building regulation standards or the voluntary adoption of higher standards beyond the current National Building Regulations. One existing example of a voluntary certification process, which encourages and stipulates aspirational target fabric efficiencies and in turn satisfies the net-zero target, is the Passivhaus standard. For the purposes of this certification, the Passivhaus standard requires the space heating demand be <15kWh/m^2/yr. Typical Passivhaus fabric requirements are outlined in the table 2 (please note that these values may be adjusted slightly to best suit the specific location climate). Furthermore, the London Energy Transformation Initiative (LETI) also provides suggestions with respect to targeted minimum fabric standards. The LETI standard also stipulates that the space heating demand be <15kWh/m^2/yr. for all building types, emphasising the important role of building insulation and fabric performance.

In order to meet these aspirational fabric efficiencies and improve the overall performance of a development's thermal envelope, the specification and installation of high-performance insulation is critical and should be considered as the primary mechanism in delivering an energy efficient scheme. This requires scrutiny of the available space within the design to install sufficient insulation thicknesses at the floor, wall and roof elements.

Table 2 below compares the current limiting building regulation fabric parameters in the UK as well as the voluntary Passivhaus and LETI requirements as well as the fabric assumptions suggested and implemented by XCO2.

	BUILDING REGULATIONS						
	UK (2013)	N. IRELAND (2012)	WALES (2014)	SCOTLAND (2019)	PASSIVHAUS REQUIREMENTS	LETI SUGGESTIONS	XCO2 RECOMMENDATIONS
WALL	0.30W/(m^2.k)	0.35W/(m^2.k)	0.21W/(m^2.k)	0.22W/(m^2.k)	0.15W/(m^2.k)	0.15W/(m^2.k)	0.15W/(m^2.k)
ROOF	0.20W/(m^2.k)	0.25W/(m^2.k)	0.15W/(m^2.k)	0.15W/(m^2.k)	0.15W/(m^2.k)	0.1W/(m^2.k)	0.1W/(m^2.k)
FLOOR	0.25W/(m^2.k)	0.25W/(m^2.k)	0.18W/(m^2.k)	0.18W/(m^2.k)	0.15W/(m^2.k)	0.1W/(m^2.k)	0.1W/(m^2.k)
THERMAL BRIDGING (Y-VALUE)	0.15W/(m^2.k)	N/A	BS EN ISO 10211	BS EN ISO 10211	0.1W/(m^2.k)	0.1W/(m^2.k)	0.1W/(m^2.k)
AIR PERMEABILITY	10.0m3/(h.m^2) @ 50Pa	10.0m^3/(h.m^2) @ 50Pa	10.0m^3/(h.m^2) @ 50Pa	15.0m^3/(h.m^2) @ 50Pa	3.0m^3/(h.m^2) @ 50Pa (+MVHR)	3.0m^3/(h.m^2)	5.0m^3/(h.m^2) @ 50Pa or 3.0m^3/(h.m^2) @ 50Pa (+MVHR)

Table 2: The target building fabric performance as outlined by compulsory building regulations as well as voluntary standards.

3.3 ANALYSIS

When assessing insulation, there are several factors which must be considered to determine the overall suitability.

3.3.1 PERFORMANCE

Thermal conductivity (W/m.K) – also referred to as the 'lambda value' (λ) – dictates the insulating ability of a material and is a pivotal factor in designing insulation strategies that achieve stringent building fabric thermal performance. Consequently, minimising energy demand and carbon emissions over the lifetime of a building.

The parameter of thermal conductivity is dependent on two principles: heat flux (W/m²) and temperature gradient (m.K).

$q = -\lambda \times \Delta T$	Where **q** is heat flux, **λ** is thermal conductivity and **ΔT** is the temperature gradient.

The thermal conductivity variable is then subsequently used in determining the overall suitability of an insulation material, which is dependent on the derived 'thermal performance' or 'thermal transmittance' value (U-value – W/m².K), as discussed above. This criterion is calculated based on an insulant's thermal conductivity (W/m.K) and installed thickness (m):

$U = \lambda / d$	Where **U** is thermal performance, **λ** is thermal conductivity and **d** is the installed thickness of the material.

Constructions achieving a low or enhanced U-value minimise the energy demand and associated carbon dioxide emissions of maintaining an elevated temperature gradient between the internal and external environments. This results in not only reduced overall carbon emissions, but substantially lowers the associated fuel bills for occupants and offers greater overall comfort.

The U-value coefficient could theoretically be engineered to achieve a performance approaching zero heat loss, as the thickness can hypothetically be increased indefinitely to achieve the desired U-value. However, as space is typically a constraining factor for developments, materials with the lowest thermal conductivity are often specified to achieve the aspirational U-value targets, whilst maximising the internal space requirements of a development.

A comprehensive breakdown of the insulating materials currently available and their respective U-values, based on typical lambda values and a range of thicknesses, are illustrated in figure 18 below.

It is also worth noting that achieving the quoted theoretical performance of an insulant is dependent on the installation process and good construction practices. Moreover, considerations such as ageing, moisture content and dimensional instability can all have a role on the performance of the insulant (these are discussed in further detail in the following section – 3.3.2 durability).

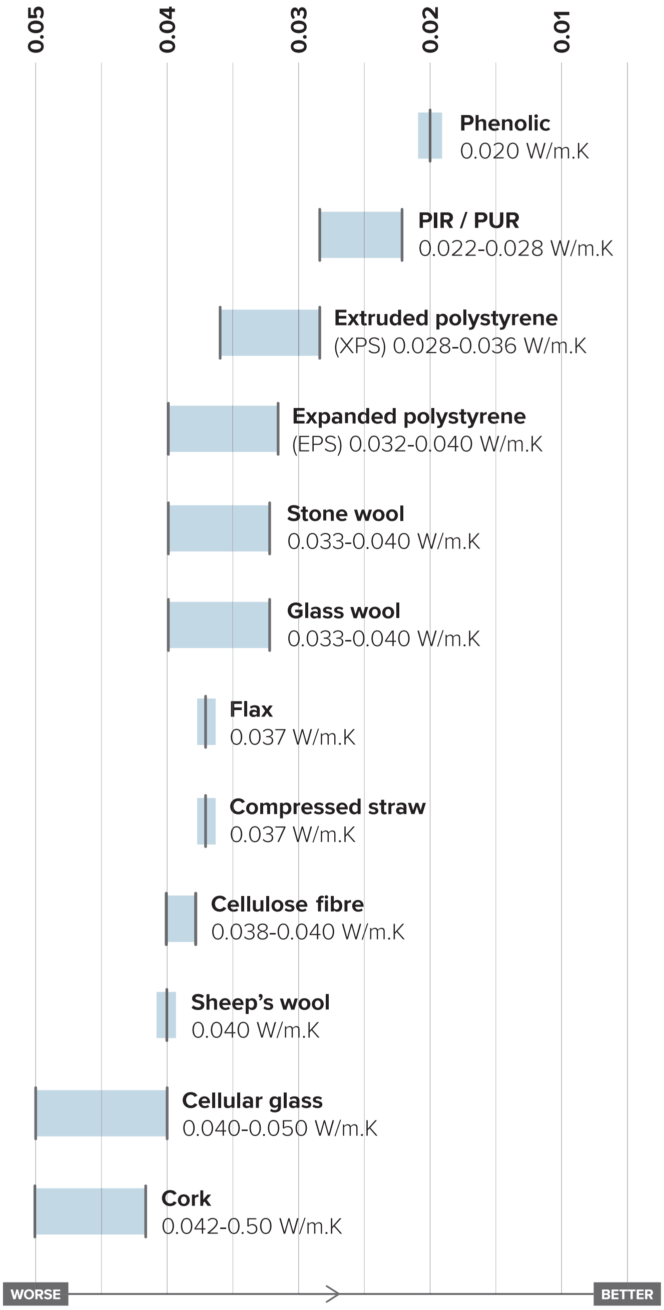


Figure 18: Typical lambda values, illustrating the thermal conductivity associated with popular and readily available insulants.

3.3.2 DURABILITY

Once a suitable thermal transmittance has been specified, choosing an insulant which provides longevity over the forecast lifespan of the development is critical in ensuring resilience and providing the building with the desired target thermal transmittance for the duration of its operation. Insulants must be designed with the aim of outliving the building, as it is not typically easy to replace or repair the materials as remedial works are often intrusive – especially in cases where insulation is fitted within a cavity wall space.

The most consequential risk factor to consider when evaluating the conditions in which optimal functionality can be sustained is exposure to moisture and the potential for condensate accumulation. Vapour permeability and 'wetting' can substantially hinder the thermal performance by dramatically increasing conductivity[35]. Fibrous materials are especially prone to this risk as they are commonly hygroscopic and in some cases the build-up of condensation can cause irreversible structural damage within the material, please refer to figure 20.

An additional consideration for fibrous materials includes 'settling', whereby the insulant slumps and is compressed under its own weight. Settling is commonly a result of insulation not being installed correctly or as a secondary impact following exposure to condensation, whereby insulation becomes saturated and cannot support the additional weight. The result for the building is that pockets of the thermal envelope essentially become uninsulated, consequently increasing the susceptibility to increased thermal conductivity and thus compromising the entire thermal element and in some cases rendering it redundant due to such elevated heat loss.

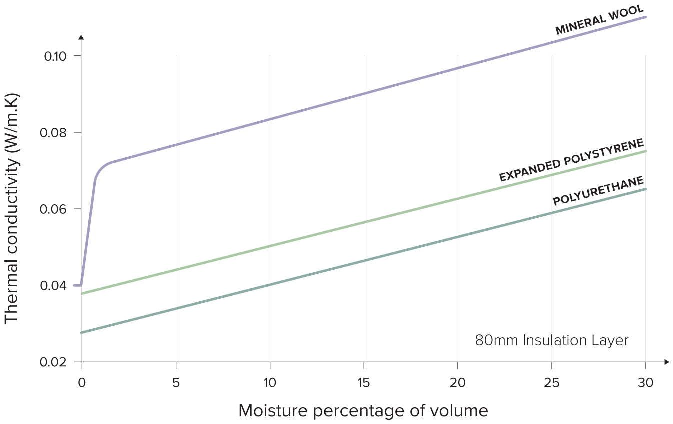


Figure 20: The impact of moisture content on the thermal conductivity coefficient of fibrous and cellular insulants [adapted from Cai, et al., 2014[35]].

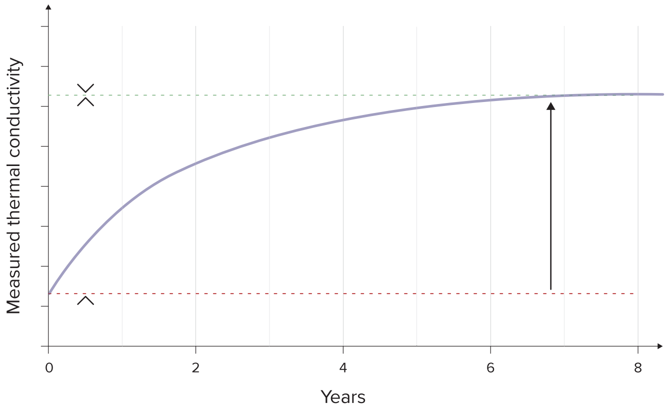


Figure 21: The ageing profile in cellular insulants (specifically PIR/PUR) due to gaseous exchange [adapted from Dedecker et al., 2003[36]].

Furthermore, animal and plant fibres are more vulnerable to cases of vermin infestation and rotting. Pest-resistant and fire-retardant additives such as boric acid and/or ammonium phosphate are commonly applied to natural fibrous insulants. However, if these chemicals leach from the material over time or are not applied correctly, such attacks can again compromise the integrity of the insulant and these processes of degradation will facilitate escalated levels of heat flux.

In blown cellular materials, the process of 'ageing' typically occurs within the first years proceeding installation. Gaseous exchange of the blowing agent within the interstitial spaces of the material and the ambient air causes an increase in the thermal conductivity[36], as ambient air replaces a proportion of the blowing agent until an equilibrium is reached, please see figure 21. However, this 'aged' conductivity must be declared within the manufacturer's details as specified by the relevant European Standards; (EN 13165 for rigid PIR boards[37], EN 13415-1[38] for spray PUR insulation or EN 14318[39] for dispensed PUR products. In some instances, to combat this gaseous exchange, a gas-tight facing may be applied to the insulant. Aluminium sheeting, which inhibits gas transfer is a prime example.

It is worth highlighting the importance of build quality and workmanship in ensuring maximum durability as well as prolonged performance. For example, fibre batting installed in cavity walls may suffer a reduction in lifespan if cavities are not adequately sealed, allowing vapour penetration. Moreover, when considering cellular insulation boards, if gaps are left between panels, then a greater surface area is exposed to the ageing process – which will then not align correctly with the manufacturer's declaration.

3.3.3 SUSTAINABILITY

The impetus for incorporating energy efficiency techniques such as enhanced insulation, is to reduce the carbon emissions associated with the built environment and mitigate the anthropogenic influence on climate change (as discussed in section 1 – the global context).

To ensure that this is achieved sustainably and with the least environmental impact, various aspects related to the entire life-cycle of insulation materials – from 'cradle to grave' – must be factored into the assessment.

ENVIRONMENT PRODUCT DECLARATIONS

Environmental product declarations (EPDs) are tools intended to provide transparency and relative understanding of the impacts of different products, such as insulants, with respect to a range of environmental parameters. However, EPDs are not meant to be an indicator of performance, which should ideally be undertaken at building level rather than product level, in order to account for maintenance, repair, replacement and end of life-cycle requirements.

Within the construction and manufacturing sector EPDs are voluntary certifications. Despite this, their use is growing concurrently with increased awareness surrounding environmental impacts. Both public and private stakeholders are increasingly demanding EPDs and there are various benefits to providing them, including; market differentiation, regulation, legal requirements and subsequent environmental certifications such as LEED and BREEAM.

In the European construction industry, the current EN15804+A1 standard[40] defines how companies should go about generating EPDs. Internationally, the ISO14025 standard[41] establishes the principles and specifies the procedures for developing environmental declarations.

EPDs must be independently verified by a third-party assurance/registration body based on industry standards, to remove bias and provide a fair comparison of different materials from competing manufacturers. The construction product standard EN15804+A1 aims to provide a uniform, comparable manner of assessing and reporting the sustainability of construction products in the EU. Nevertheless, comparisons are difficult to directly draw between different materials as the product category rules vary for different insulation types.

EPDs associated with insulation products report on a range of pertinent sustainability and environmental parameters, including;

- Global warming potential (GWP);
- Depletion of stratospheric ozone (ODP);
- Photochemical oxidant formation potential;
- Acidification potential;
- Eutrophication potential;
- Abiotic depletion potential (non-fossil fuels), and;
- Abiotic depletion potential (fossil fuels).

A further six environmental impact indicators are scheduled to be incorporated into the EN15804+A1 assessment criteria as part of the EN15804+A2 update, which will come into mandatory effect from July 2022. Additional categories covering; biogenic, fossil and total climate change impacts as well as separate eutrophication categories for freshwater, marine and terrestrial environments are proposed[42].

	RELATIVE IMPACT OF EXAMPLE INSULATION TYPES (BRE GREEN GUIDE)		
	PIR	STONE WOOL	STRAW
CLIMATE CHANGE	B	B	A+
WATER EXTRACTION	B	A+	A+
MINERAL RESOURCE EXTRACTION	A+	A	A+
STRATOSPHERIC OZONE DEPLETION	A	A+	A
HUMAN TOXICITY	A+	A+	C
ECOTOXICITY TO FRESHWATER	A+	A+	E
NUCLEAR WASTE	A+	A+	A+
ECOTOXICITY TO LAND	E	E	A
WASTE DISPOSAL	A+	A+	C
FOSSIL FUEL DEPLETION	A	A+	A+
EUTROPHICATION	A+	A+	C
PHOTOCHEMICAL OZONE CREATION	D	A+	B
ACIDIFICATION	B	A+	B
KG OF CO_2 EQ. (60 YRS.)	12	5.1	-53.0
SUMMARY RATING	A	A+	A

Table 3: The relative environmental impacts of common insulants presented in the BRE Green Guide. Source: Adapted from BRE Green Guide[43].

When comparing specific insulation products offered by different manufacturers of the products EPDs should be sought in order to comprehensively compare and contrast products based on environmental merit.

In the UK this information is widely accessible via manufacturers' websites as well as via the Building Research Establishment (BRE) who host the independently certified UK EPD database. Alternatively, the ECO Platform database provides access to verified environmental information on construction products for international markets.

In addition to third party verified EPDs, similar environmental impacts associated with insulation materials are quantified across thirteen main impact categories within The Green Guide[43] – a manual produced by the BRE to examine the relative environmental impacts of construction materials such as insulants through its use of the Environmental Profiles Methodology (2008).

The Environmental Profiles Methodology is a standardised method of identifying and assessing the environmental effects associated with building materials over their life-cycle, including the associated extraction, processing, use and maintenance as well as the eventual disposal.

The results and associated Green Guide ratings for three example insulation materials from each of the three main categories are outlined in table 3 to give a general comparison between typical products.

Historically, the ODP and GWP of insulants has been a key consideration, aerosols associated with the manufacture and installation of cellular plastic insulants were evaluated based on the ODP and GWP of the constituent chemical compounds. However, The Montreal Protocol (1989)[44] identified HCFCs and HFCs as gases requiring emissions control and a subsequent phase-out, due to their high GWP. The Kigali Amendment to the Montreal Protocol (2016) is an international agreement to gradually reduce the consumption and production of hydrofluorocarbons (HFCs)[45]. Furthermore, no ODP products have been used in the UK since 2001. Nevertheless, they have played an important role in insulation practices in the past and may present concerns for buildings constructed prior to the phasing out, considering end of life processing and are consequently outlined below for clarity.

Consequently, low ODP and GWP alternatives such as pentane, CO_2, H_2O and HFOs (hydrofluoro-olefins) are now in use[46]. These compounds have low environmental impacts whilst still delivering an insulant with an enhanced thermal conductivity. Table 4 below outlines the historical phasing out of various blowing agents and illustrates the comparative benefits of the long-term alternatives now in operation.

	BLOWING AGENT	OZONE DEPLETION POTENTIAL	GLOBAL WARMING POTENTIAL	THERMAL CONDUCTIVITY (Λ)
PHASED OUT (UNDER MONTREAL PROTOCOL)	CFC-11	1	3,800	0.0074
	CFC-12	1	8,100	0.0105
TRANSITIONAL HCFCS	HCFC-141b	0.11	600	0.0088
	HCFC-142b	0.07	1,800	0.0084
	HCFC-22	0.055	1,500	0.0099
TRANSITIONAL HFCS	HFC-134a	0	1,300	0.0124
	HFC-245fa	0	820	0.0140
	HFC-365-mfc	0	810	0.0100
LONG-TERM ALTERNATIVES	Pentane (C_5H_{12})	0	<5	0.0140
	Carbon dioxide (CO_2)	0	1	0.0145
	Water (H_20)	0	-	0.0142
	HFO	0	<1	0.0187

Table 4: The historical phasing out of various blowing agents and the associated ODP, GWP and thermal conductivity. BRE Green Guide to Specification. [43].

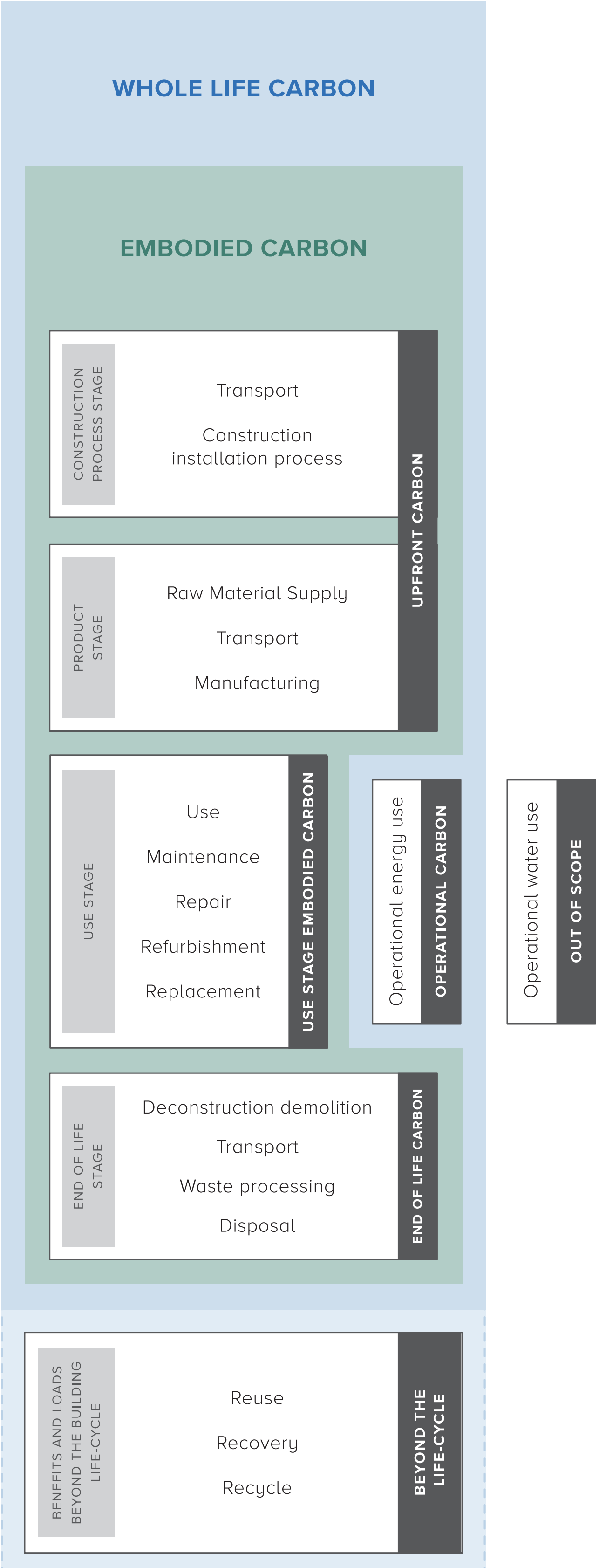


Figure 22: Embodied carbon lifecycle stages as defined by EN15978[47].

EMBODIED ENERGY

Consideration must be given to the raw materials and the energy consumed to fabricate materials. Additional components of the life-cycle must also be analysed in order to attain a truly holistic perspective. These include ancillary factors such as extraction, processing, transport, distribution, maintenance, re-use, recovery and disposal. The life-cycle stages associated with whole life carbon and embodied carbon are illustrated in figure 22, in line with the European Standard EN15978[47].

These wider influences on embodied carbon and energy, although substantial, are not covered in this document as reported figures vary widely between manufacturers and insulants. Therefore, it is recommended that a comprehensive life-cycle assessment (LCA) is completed where possible to gain a high-fidelity understanding of overall embodied carbon and energy associated with these wider variables and provide a more rigorous evaluation.

Assessing the embodied impacts of insulants is pertinent to BREEAM and LEED certifications which require construction materials to be assessed to recognise and encourage the preferential incorporation of materials with a low environmental impact (Mat01; life-cycle impacts and MRc1; building life-cycle impact reduction – applicable BREEAM and LEED credits, respectively). Industry-standard assumptions and the relative impact of these between the major categories of insulants, focussing on the raw materials and manufacturing energy requirements, are outlined below. Figure 23 outlines the manufacturing processes associated with typical mineral, organic synthetic and natural insulants.

MINERAL

Fibrous mineral insulants are produced by melting the constituent elements at high temperatures (>1,600°C) and spinning the malleable material into fibres. A binding material is also added to increase the rigidity (depending on the application). Additionally, a mineral oil or silicone is also added to protect against moisture susceptibility. The high temperature requirements result in a large embodied carbon and energy demand and consideration must also be given to the additives and binding substances required.

Foamed or cellular mineral materials are produced by aerating a granulated raw product such as silica sand or glass in a furnace or with a gaseous agent such as hydrogen sulphide (H_2S). Granulation of the raw product also typically involves crushing and milling in the presence of heat. The processing of the raw materials to produce granules is deemed to be energy intensive, both relating to the mechanical and heat energy required. Furthermore, additional examination of the energy required to produce the gaseous agent must also be reviewed. If an uncontaminated material is retired from a building, it can be recycled, predominantly for use as aggregate.

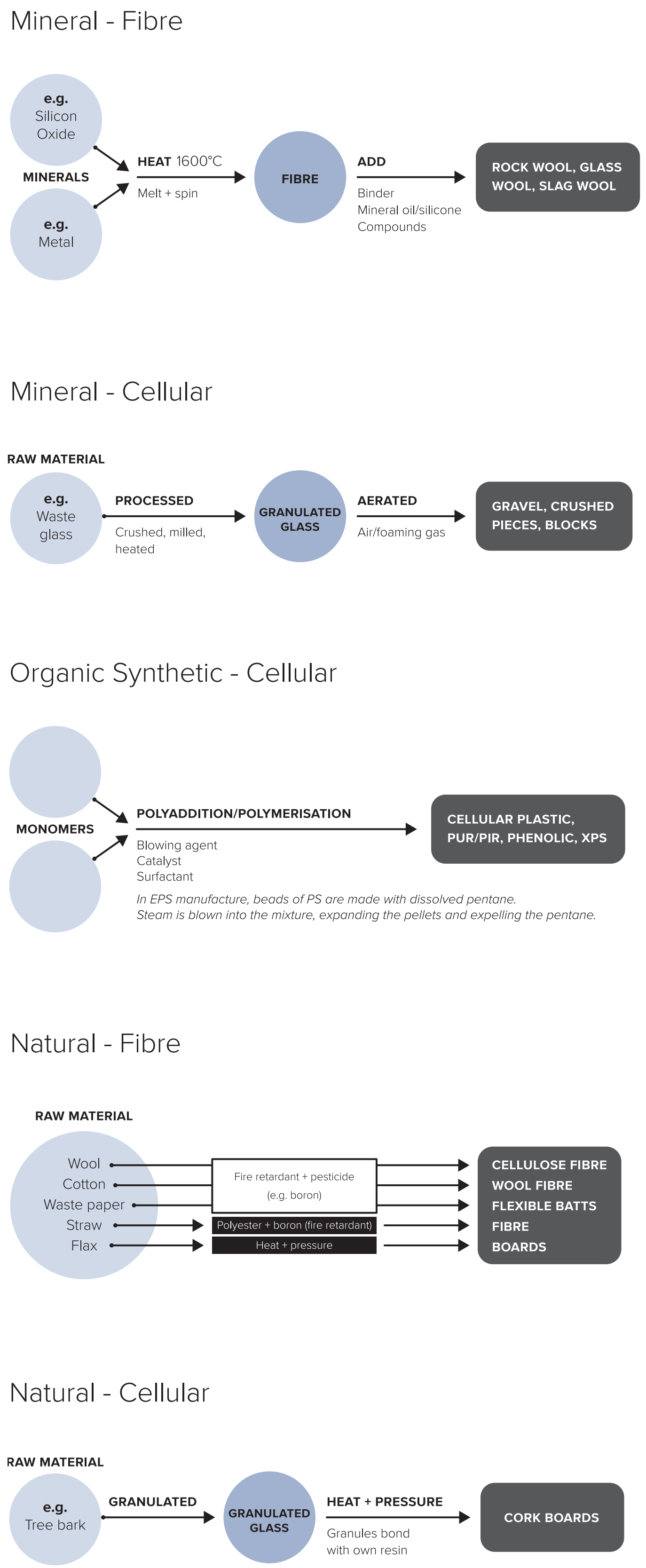


Figure 23: The manufacturing processes associated with the production of typical insulants.

ORGANIC SYNTHETIC

Thermoplastic and thermosetting plastic insulants are typically produced via a process of polymerisation or expansion. Polymerisation involves the reaction of monomer molecules, typically derived from fossil fuels, to form organic long-chain polymer molecules. Polymerisation and expansion techniques both require the presence of a catalyst (such as potassium carboxylate in the case of PIR) as well as elevated temperatures and pressures. The temperature and pressure requirements result in relatively high embodied carbon and energy for these insulants (when compared to the demands associated with the manufacture of natural (plant and animal) insulants – discussed below). When organic synthetic insulants are eventually retired from a building they can be re-used if undamaged.

NATURAL (PLANT AND ANIMAL)

These insulants are generally manufactured by treating naturally derived components to form fibres, batts or boards commonly bound by a plastic netting/wiring. The incorporation of additives to prevent pests and rotting and improve the fire resistance such as boric acid or ammonium phosphate, is also required (outlined in the previous section – 3.3.2 durability).

Plant materials such as cork, hemp, flax and cotton consume CO_2 during development to produce sucrose/glucose and oxygen (as a by-product) via photosynthesis, which results in these materials acting as carbon sinks during growth. Therefore, the associated embodied energy carbon and energy is relatively low and, in some cases, may be negative. At the end of life, the material can be incinerated (depending on the additives incorporated) and the associated heat energy recovered.

The energy demand associated with manufacture is deemed to be relatively low as the materials can be sustainably grown. However, the manufacturing expanded cork boards does require the presence of elevated temperatures and pressures to expand the cork granules. Nevertheless, due to the additives included at the processing stage, including plastic bindings and fire/pest retardants, disposal can be difficult and specified landfills may be necessary.

Further detail on specific insulants and information relating to the manufacturing processes are outlined in Appendix A.

CIRCULARITY

Only 8.6% of the 92.8 billion tonnes of minerals, fossil fuels, metals and biomass that enter the global economy are re-used annually[49]. In order to redress climate change there is a global call for a shift from a 'take-make-waste' traditional linear economy, fuelled by fossil fuels and centred around virgin and finite resources, to a circular model in order to maximise the use of existing assets. Circular economies are intrinsically restorative and regenerative by design, with the dominating objective of keeping products, components and materials at their highest function, utility and value at all times.

In the built environment this theory manifests in practice through:

- Designing out waste and pollution;
- Keeping products and materials in use for as long as functionable (via repairing, maintaining and upgrading where necessary), and;
- Regenerating natural systems.

Designing new developments to be easily modified and maintained to retain function is a key objective of the circular economy, this grants a longer overall lifespan of a building as individual defective elements can be replaced or modified as required without causing systematic failure and complete demolition. The current target lifespan for all new developments is approximately 60 years, however, many buildings are still operational for a much longer period. These lifespan targets can be easily attained via traditional building techniques.

However, the current life expectancy targets for buildings may be extended via implementing modular design strategies and designing for manufacture and assembly (DFMA), which involves subdividing a larger development into smaller constituent parts, which in turn can be independently created, modified, replaced or exchanged whilst maintaining overall function – a prime example of resilient design (as discussed in section 2.7 – resilient design). Designing for disassembly (DFD) is another key aspect of a circular economy, with particular emphasis on the process of designing products so that they can be easily, cost-effectively and rapidly taken apart at the end of the product's life so that components can be re-used and/or recycled.

The overarching goal of a circular economy is to not completely dispose of anything and to reduce the need for purchasing new commodities by re-using and recycling what is available shifting the focus of both the consumer and the manufacture from consumption to function. These basic principles provide a framework that amalgamates myriad methods and approaches such as cradle-to-cradle, biomimicry, industrial symbiosis, ecosystem services, collaborative consumption and, of course, both established and new methods of recovery and recycling of waste.

Consequently, insulation materials that have a long lifespan whilst maintaining performance and can be installed and replaced as individual modules are the most attractive solution in terms of a circular economy. Insulation panels such PIR/PUR and cork boards are possible options for modular arrays which can be easily modified and disassembled as to maintain overall thermal integrity and performance.

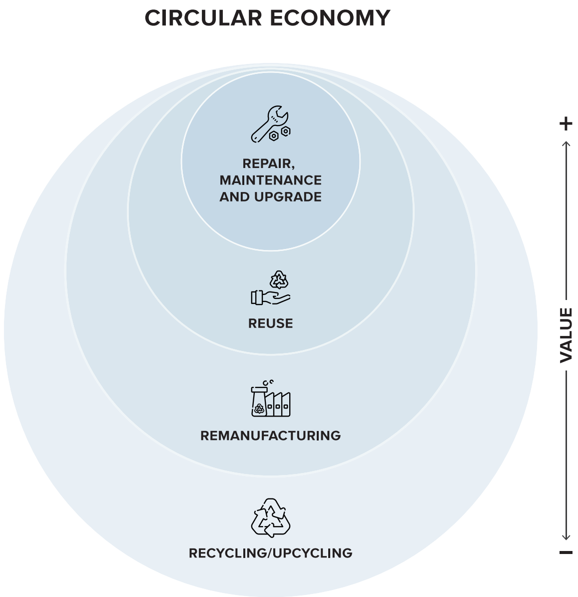


Figure 24: Traditional linear economy compared to the circular economy, illustrating the retention of value – with greater value being associated with products with preserved integrity.

3.3.4 HEALTH, WELLBEING AND SAFETY

The specification of insulation materials can have substantial impacts on the lives of building users and occupants. The importance of thermal comfort, providing pleasant internal conditions during the winter and summer months, is a prime example. This factor is seen to influence performance and productivity as well as the physical and mental health of building users.

Another social benefit associated with enhanced levels of insulation is the reduction and potential elimination of fuel poverty. This issue is alleviated as a greater proportion of heat is retained more effectively in homes when incorporating superior fabric efficiencies. The provision of an enhanced building envelope results in a reduced overall fuel demand needed to achieve equivalent, sustained warmth over the winter months than for a building with lesser thermal performance. Modern lifestyles have come to expect high levels of thermal comfort. 'Affordable warmth' is defined by the World Health Organisation (WHO) as having a sustained temperature of at least 21°C in the living space and at least 18°C throughout the rest of the home when occupied.

Furthermore, the demand and schedule for space heating is considered to be in a transitional state. Traditional heating of residential spaces, generally observed in the morning and evening, is becoming less commonplace as employees are ever more likely to be able to work from home. Moreover, average life expectancy is increasing and therefore older generations are spending more prolonged periods of irregular hours at home during retirement, which generally results in an overall increase in the space heating demand associated with the built environment as a whole.

An increase in space heating requirements will be particularly apparent during incidents that cause prolonged periods of time confined within domestic accommodation. A prime example of this is the 2020 Coronavirus pandemic, which confined residents within households, who would typically be at work or out socialising. This incident, as a result, tested, en-masse, the suitability of the domestic housing stock not only in the UK but across Europe and the majority of the developed world. Considering the increased incidence of mental health challenges associated with isolating, there is now, more than ever, a much greater focus on providing homes which prioritise the wellbeing and health of occupants – this stems from ensuring homes are constructed to provide comfortable and enjoyable places to reside and work for prolonged periods which may not align with the traditional working week as working remotely becomes more common.

The WHO states that climatic conditions directly affect the spread of epidemic diseases and risk to human health[50]. The threats of such outbreaks have also been linked to the wider factors of a developed modern society fuelled by fossil fuels and outlined in section 1 – the global context. As a result, these two features of society – energy consumption and social health – are inextricably linked. Therefore, it is argued that, by reducing energy consumption (through implementing energy efficiency measures such as enhanced insulation) and in turn mitigating climate change has the capacity to influence societal health on a global scale.

Mental health concerns are a growing public health issue, with approximately one in four adults in England being diagnosed with a mental illness at some stage during their lifetime[51]. Understanding how the built environment can influence, improve and support people's overall sense of wellbeing is critical and must be considered as such. Good quality housing, with comfortable indoor conditions facilitated by the correct specification of insulation as well as access to green spaces and recreational facilities, has a direct and positive impact on occupants and building users and in turn has the ability to combat mental health disorders more widely and alleviate some of the pressure on the national health service.

In addition to the wider effects on human health, wellbeing and safety associated with climate change in general and being tackled indirectly by energy efficient measures, there are substantial risk factors directly affiliated with insulating materials. During the installation process of fibrous insulants (such as fibreglass) personal protective equipment (PPE) must be worn to avoid contact dermatitis (irritation of the skin and eyes). Additionally, the materials should be installed in a sealed space to avoid ventilated contamination during occupancy. It must be stressed that fibrous materials such as fibreglass are not deemed to present any risk to human health when properly installed.

In light of the tragedy at Grenfell Tower safety concerns have been raised addressing the behaviour of external wall systems when exposed to fire. Fire safety is a very important aspect to consider when specifying insulation in the built environment but there are also other important characteristics to take into account when assessing whole building performance. At all times the relevant building regulations and codes should be followed. This document is not designed as a tool for advising on aspects relating to fire safety and where appropriate the advice of a suitably qualified fire engineer should be considered.

3.3.5 INVESTMENT AND PAYBACK

Despite the high capital demands, from a homeowner and consumer point of view, insulation is often cited as one of the most cost-effective ways of saving energy and considerably cutting the price of utilities for a property, in turn consequently reducing the energy demand and the associated carbon emissions. The cost of the insulating product as well as the installation service can demand high capital investment. However, the savings associated with the enhanced energy efficiency over the lifetime of an existing building is seen to provide on average a simple payback period (P) dependent on initial capital investment and the annual savings associated with heating and space conditioning.

SIMPLE PAYBACK (YEARS) = **CAPITAL INVESTMENT** (£) ÷ **ANNUAL SAVINGS** (£/YEAR)

This simple formula for calculating a payback period (most commonly in years) is heavily dependent on the type of property and the performance standards of the insulants installed[52].

This payback period is further reduced when the initial enhancements in insulation are administered from the outset rather than post-construction, in the case of new build properties, as discussed in section 2.3 – retrofitting.

Commonly, insulants with more advanced thermal performance, such as organic synthetic materials have a much shorter simple payback period due to the cost-performance ratio and therefore increased potential for saving relative to capital investment.

Natural and mineral insulation materials may become more expensive than organic synthetic materials since a greater thickness (and subsequently overall volume) is required to achieve the same thermal performance and larger fixings may be required. However, considering the benefits of natural insulation, outlined in the previous sections, these factors may outweigh the increased cost and be more attractive to building occupants.

The Energy Company Obligation (ECO) – a government scheme in Great Britain which aims to tackle fuel poverty – is a grant available for UK consumers to help reduce carbon emissions through facilitating the funding and retrofitting of energy efficient measures in the existing housing stock[53].

Photo: A terraced housing scheme incorporating high efficiency insulation products

3.4
INSULATION OPTIONS MATRIX

		PRODUCT CHARACTERISTICS						PRODUCT SUITABILITY											
		THERMAL PERFORMANCE			SPACE REQUIREMENTS			DEVELOPMENT TYPE			DEVELOPMENT SCALE			CLIMATE/WEATHER SUITABILITY			BUILDING ELEMENT APPLICATION		
		HIGH	MODERATE	LOW	<50MM	>50MM	>75MM	NEW BUILD	RETROFIT	MINOR (<10 HOMES)	MEDIUM TO LARGE	MASS HOUSING	PRECIPITATION	SNOW LOAD	HUMIDITY	BREATHABILITY	FLOOR	WALL	ROOF
ORGANIC SYNTHETIC	PUR/PIR	•			•			•	•	•	•	•	•	•	•		•	•	•
	Phenolic foam	•			•			•	•	•	•	•	•	•	•		•	•	•
	EPS		•			•		•	•	•	•	•	•	•	•		•	•	
	XPS		•			•		•	•	•	•	•	•	•	•		•	•	
MINERAL	Stone wool		•			•		•	•	•	•	•					•	•	•
	Glass wool		•			•		•	•	•	•	•					•	•	•
	Cellular glass		•			•		•	•	•	•		•	•	•			•	•
	Perlite			•			•		•	•					•				•
	Vermiculite			•			•		•	•					•				•
NATURAL (PLANT AND ANIMAL)	Cellulose		•			•		•	•	•	•	•				•	•	•	•
	Wool		•			•		•		•	•					•		•	•
	Flax/Hemp			•			•	•		•						•	•	•	•
	Wood fibre			•			•	•		•						•	•	•	•
	Expanded cork		•			•		•	•	•				•			•	•	

3.5
FUTURE POSSIBILITIES

A key consideration for the future is the digitisation of the built environment and the development of a building passport which would give the ability to measure and demonstrate the performance of a building over its lifetime. This could apply to both residential and commercial buildings, with regular checks being made, normalising the concept that buildings, like vehicles, must be judged over time and meet certain standards. This could also provide full traceability of products and services installed into a building, so that each time it is bought, sold, altered or renovated, an accurate log is maintained and updated.

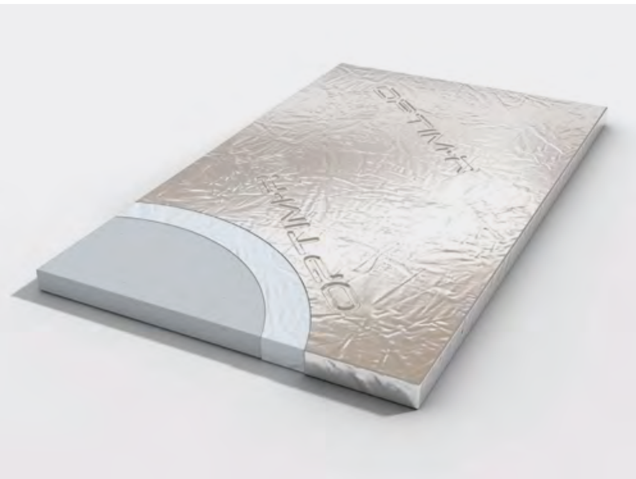
A passport could contain building-related information on elements such as energy consumption/production, maintenance and building plans and could be transferable between building owners. This could go some way to documenting the sustainability criteria of a building and show its performance in relation to the intended standards.

This would be in line with the critical golden thread advocated by Dame Judith Hackitt in her review into the building regulations.

Furthermore, insulation technologies are advancing quickly, as such this is a dynamic field of innovation. As discussed, the application of traditional thermal insulating materials such as mineral wool would require an ever-increasing thickness to meet the energy efficiency requirement to align with the aspirational net-zero targets of the future. Escalated thickness' of insulation are undesirable for many reasons, including limiting internal space and restricting architectural design. Passivhaus levels of insulation, U-values and thermal detailing can already be met via traditional building methods incorporating the utilisation of high performance insulation materials such as PIR, which are able to provide U-values of 0.15W/m².K within a 150mm cavity construction and timber/steel frame.

	EXAMPLE	THERMAL CONDUCTIVITY
VIPS	Kingspan OPTIM-R (50mm)	0.007W/m.K
AEROGEL	Thermablok (5-10mm)	0.015W/m.K
NIMS	Experimental	0.015W/m.K

Table 6: Future insulation materials and their associated thermal conductivity performance.



VIPS

NIMS

Figure 17: Examples of future insulants.

VIPs can achieve extremely low lambda values in theory. The thermal resistance of VIPs is considered to be five times that of conventional PIR/PUR[54]. However, VIPs do not present a robust and adaptable solution, as modifications (including cutting and perforating VIPs) onsite cannot be performed without significantly compromising performance. Moreover, air and moisture will gradually penetrate the VIP envelope over time, resulting in the loss of the vacuum seal and a dramatic increase in the thermal conductivity. The application of VIPs in high performance appliances on a smaller scale (such as refrigerators) is expected to lead to the greater commercial viability of this product in the built environment. Nevertheless, this technology boasts thermal conductivity values of 0.007W/m.K, illustrating the potential for extremely high performance.

Aerogel is a lightweight, low-density material made from silica and air. Aerogel blankets can be integrated as a component in laminate panels and the panels are distinguished by their outstanding insulation properties, with associated thermal conductivity values of 0.015W/m.K[55]. Aerogel tubes designed to emulate the structure and thermal insulation capacity of a polar bear's fur are currently being investigated as a candidate for aerospace insulation. Biomimicry of these hairs is advantageous on many fronts as these individual structures are lightweight, elastic and durable in addition to providing low thermal conductivity. However, this material is also currently very expensive to manufacture at an industrial scale for built environment applications at this point in time, leading to more traditional techniques being more competitive, despite the reduced thermal conductivity potential.

Regardless, both VIPs and aerogels have additional drawbacks besides high cost. Consequently, one major objective for the future of building insulation is to develop a robust material with an enhanced performance coefficient, which has a suitably low carbon footprint and embodied carbon and energy demand.

An example of a future solution to these challenging objectives are nano-insulation materials (NIMs). NIMs consist of hollow silica nanospheres and are in the early stages of development. Hollow silica nanospheres with a typical wall thickness of 10-15nm and a pore diameter of about 150nm can have a significantly reduced thermal conductivity of approximately 0.02-0.015W/m.K[56], comparable to those achieved by aerogels, please see figure 26.

In the context of construction and mass housing projects these technologies, although now established in other sectors, have yet to gain traction. Subsequently, these insulants have had little in the way of a meaningful impact on the built environment thus far and more conventional insulants such as PIR and phenolic foams are still considered the market leading example of high-performance insulation for construction applications.

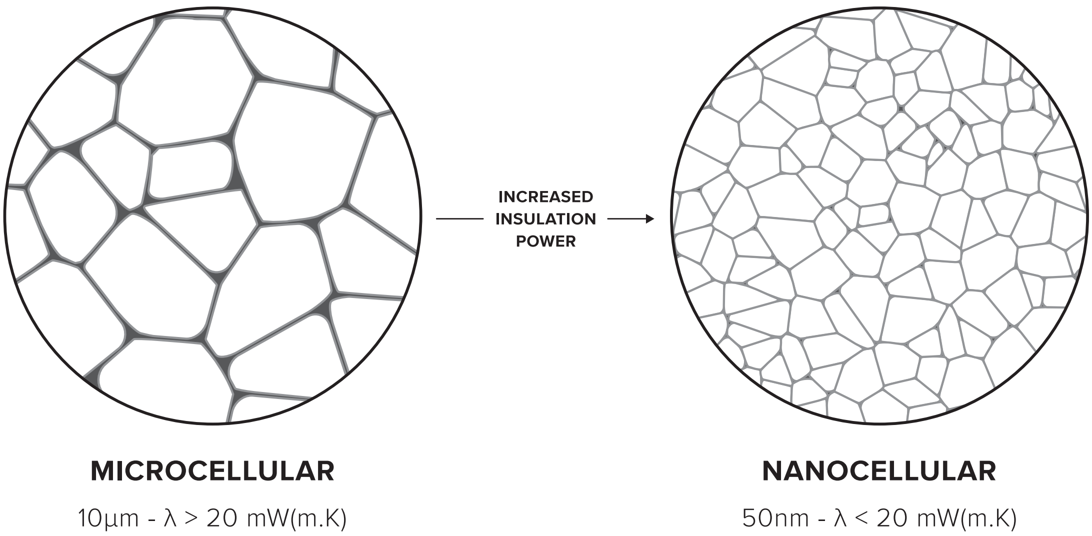


Figure 26: Structure of NIMs in comparison to traditional cellular materials [adapted from Gao, et al., 2012[56]].

CONCLUSION

Photo: Cefn Castell, IMA example of private home with enhanced insulation strategy.

This guide highlights the issues associated with energy demand and the way in which enhanced insulation strategies and energy efficiency measures play a principal role in the built environment to help combat climate change.

The current target lifespan for all new building developments is approximately 60 years, however, many buildings are still operational for much longer. Therefore, reducing the energy demand of a building is of paramount importance, and using a fabric first approach is the most widely recognised way of achieving this.

New build projects should be built to the highest possible standards at the outset, but the focus should not be solely new build developments. Ensuring the existing building stock is retrofitted to improve fabric efficiency and reduce energy demand is also critically important. Improvements to building regulations and codes should be accelerated to some of the levels included in voluntary and regional schemes.

If low carbon strategies are not implemented at the outset for new constructions, expensive retrofitting will be required in the future to compensate for their higher energy demands.

There needs to be greater emphasis on build quality and attention to detail during the installation process and wider phase of construction to achieve the full benefits. This must include checks and compliance to ensure work has been carried out properly and penalties where this does not occur.

There is a number of factors that must be considered when assessing and determining the most sustainable, suitable and resilient insulation material for any given building project. Because these factors are complex there is no “one size fits all” solution. Consideration is required for a range of aspects including performance, durability, sustainability, health and wellbeing as well as checking voluntary environmental product declarations which provide transparency and relative environmental impacts of insulation products.

Insulation products should be manufactured to a harmonised European Standard and have independent third-party certification by an organisation such as The British Board of Agreement (BBA) where possible.

Whilst insulation technology is constantly advancing with solutions such as VIPs and aerogels, these products are not yet available at scale. However, decisions should be dynamic, and assumptions should be re-evaluated periodically to ensure the most effective technique is implemented.

APPENDIX A

SUMMARY OF INSULATION OPTIONS

MINERAL

STONE WOOL

STONE WOOL

Stone wool is derived from quarried igneous lithologies such as dolerite and recycled steel waste. Insulants are fabricated by melting the constituent elements at high temperature and pressure and spinning the melted material into fibres. The insulation is produced in a variety of densities depending on desired function. Varying densities result in varying levels of thermal resistance (λ). Applications include cavity walls, timber frame walls, roof rafter insulation, loft and suspended floor insulation.

GLASS WOOL

GLASS WOOL

Glass wool insulation is made in a similar way to stone wool. Glass wool is generated from silica (sand), glass, limestone and soda ash. The insulation is produced in a variety of densities depending on the desired function. Varying densities result in varying levels of thermal resistance (λ). Applications include cavity walls, timber frame walls, roof rafter insulation, loft and suspended floor insulation.

CELLULAR GLASS

CELLULAR GLASS

Cellular glass insulation is manufactured using crushed glass that is combined with carbon and subsequently heated to temperatures in excess of 1,000°C. The presence of heat leads to the oxidisation of the carbon present generating cellular ‘bubbles’. Foamed glass has a relatively high structural strength and vapour resistance. Applications include flat roofs (including green/blue roofs), walls and floor insulation.

PERLITE

PERLITE

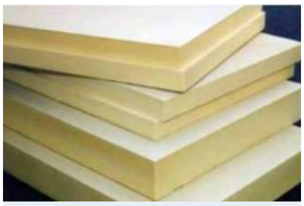
Perlite is a hydrous igneous glass with an amorphous structure. The material can be manufactured via the hydration of obsidian. Perlite expands when exposure to heating. Considering the low density and its inert nature of perlite it is an ideal loose fill insulant. Applications include masonry wall fill, floor and roof insulation.

VERMICULITE

VERMICULITE

Vermiculite is similar to perlite but is not of volcanic origin. Vermiculite is a hydrous phyllosilicate mineral. When heated this material exfoliates to form flaky fragments which additionally expand to fill the cavity spaces. Applications include masonry wall fill, floor and roof insulation. Older examples of vermiculite insulation may be contaminated with asbestos which is a known carcinogenic substance.

ORGANIC SYNTHETIC


PUR / PIR

POLYURETHANE (PUR) / POLYISOCYANURATE (PIR)

PUR and PIR are both synthesised by reacting two monomers in the presence of a catalyst (polymerisation). PIR utilised monomers with different chemical formulas at higher temperatures, whereas PUR employs homogeneous monomers. Essentially these two insulants have a comparable manufacturing process except for the constituent chemical compounds. PIR has a slightly higher thermal resistance (λ). Applications include wall, floor and roof insulation.


EPS

EXPANDED POLYSTYRENE (EPS)

Expanded polystyrene (EPS) insulation is manufactured from small beads of polystyrene, combined with a pentane blowing agent. Exposure to heat expands the polystyrene beads. EPS insulation boards are produced by expanding beads via heat within moulds to achieve the desired shape and fuse the beads. Applications include wall, roof and floor insulation.


XPS

EXTRUDED POLYSTYRENE (XPS)

Extruded polystyrene (XPS) is manufactured by combining polystyrene with a blowing agent under pressure. The release of pressure forces the material to expand into a foam, it is then shaped, cooled and cut to the desired specifications. XPS is relatively stronger than EPS. Applications include wall, roof and floor insulation. XPS is particularly suitable for use below ground or for instances with additional loading requirements.


PHENOLIC FOAM

PHENOLIC FOAM

Phenolic foam insulation is manufactured by combining phenol-formaldehyde resin with a foaming agent. The exothermic reaction of the resin and the foaming agent causes aeration of the resin, generating the foamed structure. An additive to increase the strength of the material is also included in the process. This is followed by rapid setting of the foamed material. Though typically utilised in association with building services, phenolic foam panels are also suitable as insulation for roofs, walls and floors.

NATURAL (PLANT AND ANIMAL)

CELLULOSE

CELLULOSE

Cellulose insulation is made from recycled newspaper. The material is usually treated with a mixture of borax and boric acid to provide fire resistance as well as to repel insects and fungi. Cellulose insulation is available in a loose format for pouring and dry or damp spraying as well as in slab format for fitting within metal or timber frames. Applications include, roof (rafters and joists) and wall insulation, including timber frames.

WOOL

WOOL

Wool insulation slabs and batts are produced from sheep's wool bound with polyester and typically treated for fire and insect resistance by adding boric acid. Applications include roof (joints and rafters) and timber wall insulation.

FLAX AND HEMP

FLAX/HEMP

Flax and hemp insulation slabs are made binding material with a polyester netting or in some cases a natural binder such as potato starch and treating with borates to improve fire resistance, resist rotting and prevent infestations. Applications include breathing wall construction, ventilated pitched roof, ceiling and floor insulation.

WOOD WOOL

WOOD WOOL

Wood fibre insulation is generated from forestry cuttings and sawmill residue. Binding is provided by polyolefin fibres and a typical fire-retardant additive is ammonium phosphate. Applications include breathing wall construction, ventilated pitched roof, ceiling and floor insulation.

EXPANDED CORK

EXPANDED CORK

Expanded cork insulation is made from bark harvested from the Quercus suber (more commonly, cork oak) approximately every nine years. Cork granules are expanded and then formed into blocks under high temperature and pressure conditions, utilising the natural resins to adhere the expanded granules. Applications include flat roof and rendered wall insulation.

APPENDIX B

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Anthropogenic climate change and the accelerating pace of global warming is undoubtedly the most immediate threat to environmental health and global sustainability currently faced by society.

Improving and implementing energy efficiency measures is a direct and influential method of reducing primary energy consumption and in turn quelling the unabated consumption of fossil fuels that has been flagrantly apparent since the industrial revolution.

This guide provides a comprehensive overview of the opportunities presented in the built environment, with respect to thermal design, and analyses the most efficient and effective application of a variety of readily available insulation materials.