LEEDS CITY COUNCIL LOCAL PLAN UPDATE

STUDY ON THE CARBON REDUCTION OF BUILDINGS

University of Leeds

July 2022

EXECUTIVE SUMMARY

This report provides an evidence base to support the development of effective carbon reduction policies through Leeds City Council's Local Plan Update. This is done through addressing four primary LPU objectives: reducing whole lifecycle emissions, requiring net zero carbon during the operational life of developments, implementing sustainable construction standards, and increasing deployment of heat networks.

Definitions for what net zero carbon means in the context of the LPU are suggested, emphasising the need to clearly define between operational, embodied carbon and whole lifecycle emissions. Sustainable construction standards are appraised for what types of developments they are applicable to and how these will support LPU objectives. No currently available standard meets all the LPU objectives and suggested ratings from the various standards appraised are proposed.

To address whole lifecycle emissions, available assessment methodologies are reviewed including the approach already in place in London, and recommendations are made for how whole lifecycle emissions reductions could be approached and implemented in Leeds.

To support the objective of net zero operational carbon emissions, the context of new national building regulations is combined with a decarbonising electricity grid to model and assess how these two factors together impact operational carbon emissions from new developments. This serves as a guide for how much further developments will need to go to reach net zero carbon, highlighting the need for further onsite measures such as energy efficiency and heat pumps, and how energy intensity targets can help maintain focus on fabric efficiency in the context of grid decarbonisation.

An approach to carbon offsetting within the LPU is discussed, noting the true cost of carbon is estimated to be far higher than currently used by planning authorities. The process of local carbon offsetting as a last resort once all possible onsite measures have been taken is explored, and a methodology for setting a local carbon price in Leeds is recommended based on national Government guidelines.

A review of current heating technologies is provided with suggestions around technology eligibility and ineligibility based on technology characteristics and net zero compatibility. A range of low carbon options are suggested including various heat pump configurations and heat networks which make use of local renewable energy sources. Guidance is provided around the implementation of national heat network zoning policies and recommendations are made for a process to require developers to model heating options in new developments, within and outside of heat network zones.

Study undertaken April-July 2022

Version history

Version no.	Version date	Details	Written by	Checked by	Approved by
V1.0	10/06/2022	Draft issue	David Barns	Fleur Loveridge	N/A
V2.0	25/07/2022	Draft issue	David Barns	Fleur Loveridge	N/A
V3.0	11/10/2022	Final issue	David Barns	Fleur Loveridge	Adam Harvatt

Report authored by:

Dr David Barns, Research Fellow
Dr Fleur Loveridge, Associate Professor

School of Civil Engineering
University of Leeds
Leeds, LS2 9JT

Report prepared for:

Martin Elliot, Head of Strategic Planning

Planning & Sustainable Development
City Development
Leeds City Council
Merrion House
110 Merrion Centre
Leeds, LS2 8BB

CONTENTS

GLOSSARY

ASHP	Air source heat pump
BECD	Built Environment Carbon Database
BoQ	Bill of Quantities
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
BS / BSI	British Standards (as implemented by British Standards Institution)
Carbon/CO_2	Shorthand for all greenhouse gas emissions
CE	Circular Economy
CIBSE	Chartered Institution of Building Services Engineers
COP	Coefficient of performance (measure of heat pump efficiency)
CP1	CIBSE Heat Networks Code of Practice for the UK
Developer	Used as an umbrella term to refer to organisations across the development process including developer client organisations, architects, sustainability or energy consultants, building designers, engineers, contractors etc.
EfW	Energy from Waste
EPR	Energy Performance Ratio
GSHP	Ground source heat pump
HEPR	Home Energy Performance Ratio
IES VE	Integrated Environmental Solutions Virtual Environment
ISO	International Organization for Standardization
IStructE	Institution of Structural Engineers
kWh	kilowatt-hour
LCC	Leeds City Council
LBC	Living Building Challenge
LETI	London Energy Transformation Initiative
LPU	Local Plan Update
LPU Policy	Refers to future LPU policies either in direct policy wording or in an SPD
MMC	Modern Methods of Construction
MVHR	Mechanical Ventilation & Heat Recovery
PCDB	Product Characteristic Data Base
PHPP	Passivhaus Planning Package
RIBA	Royal Institute of British Architects
RTPI	Royal Town Planning Institute
SAP	Standard Assessment Procedure
SBEM	Simplified Building Energy Model – the UK Government's building energy model
SGHE	Shared ground heat exchange
SPF	Seasonal Performance Factor of a heat pump
SPD	Supplementary Planning Document
TCPA	Town and Country Planning Association
UKGBC	UK Green Building Council
UoL	University of Leeds
WLC	Whole lifecycle carbon
WSHP	Water source heat pump

1. INTRODUCTION

1.1. Leeds City Council (LCC) has declared a Climate Emergency and committed to achieving net zero carbon emissions across the city by 2030 through adoption of science-based targets[1]. The current version of the targets, the Net Zero Carbon Roadmap for Leeds, identifies and evaluates carbon reduction opportunities and sets out a league table of the most carbon-effective options for Leeds, emphasising the importance of focusing on housing, public and commercial buildings in achieving net zero[2].

1.2. The planning system plays a key role in the city's response to the climate and ecological emergencies by ensuring that development takes place to the highest possible environmental standards[3].

1.3. Recognising the need to update local planning policies in line with these commitments, LCC is currently undertaking a Local Plan Update (LPU), of which reducing carbon emissions is a key objective[4,5]. The University of Leeds (UoL) has been commissioned by LCC to provide evidence that will support carbon reduction aspects of the LPU, focusing on four key policy objectives:

1. Reducing whole lifecycle carbon
2. Delivering net zero operational carbon
3. Implementing sustainable construction standards
4. Increasing deployment of heat networks

1.4. It is intended that the study will form part of an evidence base to support implementation of an effective LPU that will deliver significant carbon reduction associated with the built environment across the city before 2030. The report does not attempt to pre-empt the plan-making process, but explores evidence and proposes measures that would support delivery of the four policy objectives.

BACKGROUND AND CONTEXT

1.5. Science is clear that climate breakdown presents an existential threat to the future of human civilisation[6]. Urgent and drastic action is required to limit global temperature rises to 1.5^{0}C above pre-industrial levels, and every decision we take must count towards securing our long-term survival[2,3,6]. Whilst UK carbon emissions have fallen by 49% between 1990 and 2020, this progress has largely been delivered by the electricity sector through grid-scale renewable generation developments which are remote from households[7–9]. Further reductions will be more challenging as they will involve changes to the buildings in which we live and work. The Net Zero Carbon Roadmap sets out that the built environment is a key contributor to climate emissions and must be a focus if carbon emissions are to fall in Leeds[2].

1.6. According to the latest available data, the city of Leeds emitted 3.8 mtCO_2 in 2019[10], reflecting a 33% reduction since 2005 whilst experiencing an 8% increase in population. Whilst this is good progress, with annual decreases of around 114 ktCO2/year at the current trajectory, carbon emissions across the city would remain around 2.6 mtCO_2 in 2030. Buildings account for around a third of the carbon emissions from the city of Leeds (on a production / Scope 1 & 2 basis)[10]. Significant additional measures are therefore required across the city to deliver the transformational change required. The planning system has a vital role to play in enabling the transition to a resilient low-carbon society which benefits the environment as well as human health and wellbeing[3].

1.7. Because of the cumulative nature of annual carbon emissions, the more rapidly reductions in carbon emissions can be implemented, the greater the cumulative benefit to tackling the climate emergency. Importantly, every building constructed now which is not at least 'net zero carbon ready' will need to be retrofitted, with the disruption and costs borne by the future owner or occupier. Taking appropriate steps to reduce carbon emissions from the outset is a much more cost-effective way of delivering carbon reductions, aside from the significant additional carbon emissions which would be generated unnecessarily through delayed action. Evidence suggests 80% cost savings of designing-in measures in new build properties compared to later retrofitting[11,12]. The UK Government is clear about the need to prevent later retrofit to meet climate targets and the UK's principal planning bodies emphasise that addressing climate change should be the top priority for planning across the UK[3,13].

HOUSING DELIVERY AND FINANCIAL VIABILITY CONSIDERATIONS

1.8. The LPU is taking place in the context of the need for continued development in Leeds, especially for new homes to tackle the UK's housing and cost of living crisis[14]. Leeds has a target set by the UK government to deliver a certain number of new homes per year[15], and if this target is missed, the city can be placed under measures which tilts the balance of development towards approval[16]. In addition, because of the way financial viability calculations impact the price that developers are able to bid for sites, the process tends to favour the lowest cost development[17]. The LPU will need to deliver transformational carbon reduction whilst enabling high quality development for the city. A key part of this will be to implement ambitious carbon reduction requirements which are applied consistently so that developers are clear upfront as to their requirements and can build them in at the earliest opportunity. This will also mean that poorer carbon quality schemes that do not do this are not accepted.

1.9. There is increasing recognition of the role and importance of the financial services sector to supporting the transition to net zero[18–20]. Recognising the urgency of tackling climate change and the importance of the built environment in addressing this, financial investors are beginning to offer products which reward developers for choosing low carbon construction. An example of this type of financial product is Atelier Carbonlite[21] which offers 1.5%-2% reduction in the cost of development finance for schemes which meet the RIBA 2025 or 2030 Challenge v2 criteria[i]. This scheme is primarily aimed at small and medium sized construction companies. Innovative financial solutions and products can potentially change developer viability calculations. It will be important for LCC to be aware of such emerging products and how these may impact on scheme viability, and to support developers to find suitable products.

1.10. In addition, innovative approaches to site design and construction techniques can also affect financial viability considerations, including more efficient Modern Methods of Construction

---

[i] The RIBA 2025 and 2030 Challenges include both operational and embodied carbon limits, and there are discussion in Section 3.

(MMC) and higher density, lower car use approaches[22]. These can also support the delivery of carbon reduction through building form and site design, and from the lifestyles of future occupants. These considerations will be important when commissioning a viability assessment of LPU policies.

REPORT STRUCTURE

1.11. In seeking to support the four key LPU policy objectives and meet the study requirements (see Appendix 1, numbered as Req. 1-8), the report is set out over six main sections (2-7), with Req. 2 and 3 combined into Section 4 and Req. 5 and 8 combined into Section 7.

1.12. Section 2 defines what zero carbon means over the various phases of a building lifecycle and what can be required through the planning processes (Req. 6).

1.13. Section 3 presents an appraisal of sustainable construction standards, assessment of how they would be likely to support LCC policy objectives and recommendations for ratings to apply in the LPU (Req. 1).

1.14. Section 4 analyses approaches to whole lifecycle (WLC) emissions assessments including the approach taken in London, considering what type of developments they may be applicable to, before making recommendations for the LPU (Req. 2 and 3).

1.15. Section 5 focuses on supporting the delivery of net zero carbon developments over the operational life of buildings. An assessment of current and future expected building standards alongside the context of a decarbonising electricity grid are presented through the results of modelling into how far these will go to delivering zero operational carbon emissions (Req. 4). A proposal is made for combining net zero operational carbon with energy use targets.

1.16. Section 6 examines the role of carbon offsetting and makes a recommendation for setting the cost of carbon based on nationally recognised practice (Req. 7).

1.17. Section 7 presents an assessment of currently available heating technologies and provides recommendations as to which should be eligible for inclusion in new developments under a revised heating policy. The role of heat networks is considered in light of the introduction of Heat Network Zones and the role of the planning system in implementation (Req 5 and 8).

1.18. Section 8 concludes the report and summarises the recommendations.

2. NET ZERO CARBON DEFINITION

2.1. To provide clarity throughout the remainder of the study it is first necessary to establish clear definitions for what zero carbon means in the context of new development.

2.2. As outlined in Sections 4 and 5, carbon emissions associated with new developments arise from the embodied carbon (both upfront and during lifecycle including end-of-life) and operational phases of a building's lifecycle.

2.3. Section 4 presents an assessment of various approaches to whole lifecycle carbon emissions assessment which demonstrate that it is possible to measure and take steps to reduce embodied carbon. Key to reducing embodied carbon emissions is to prioritise retention and refurbishment of existing buildings, with new construction being a last resort.

2.4. Section 5 demonstrates how it is possible to measure and minimise carbon emissions from the operational phase of a building's lifecycle.

RECOMMENDATIONS FOR LPU NET ZERO CARBON DEFINITION

2.5. It is important new policies developed through the LPU clearly define whether they are referring to embodied, operational or whole lifecycle emissions. It is not the intention of this study to pre-empt the outcome of LCC's plan-making process, but to provide definitions which help to bring clarity over the stages of a building lifecycle and what net zero carbon emissions might mean in that context. As such, a net zero definition has been provided for embodied carbon emissions, operational carbon emissions, and whole lifecycle carbon emissions.

Net zero embodied carbon emissions definition

2.6. A net zero embodied carbon building in Leeds would be highly resource efficient and:

1. Has taken all possible steps to minimise carbon emissions from materials, construction, repair and maintenance, and end of life, prioritising retention and refurbishment over new construction.
2. Following carbon minimisation in Step 1, uses building materials which sequester carbon to offset emissions internally.
3. As a last resort, all remaining embodied carbon is offset through a £/tonne of carbon cash in lieu contribution to LCC to deliver carbon savings locally.

Net zero operational carbon emissions definition

2.7. A net zero operational carbon development in Leeds would be highly energy efficient and:

1. Has taken all possible steps to minimise carbon emissions through a fabric-first approach and use of the lowest carbon and running cost technology.
2. Following carbon minimisation in Step 1, includes renewable energy onsite to deliver an annual net zero carbon balance (including regulated and unregulated emissions, see Section 5).

3. As a last resort, all remaining operational carbon for a 30 year timeframe is offset through a £/tonne of carbon cash in lieu contribution to LCC to deliver carbon savings locally.

Whole lifecycle net zero carbon emissions definition

2.8. A whole lifecycle net zero carbon building in Leeds would combine net zero carbon embodied and operational phases to achieve whole lifecycle net zero carbon.

NET ZERO CARBON DEFINITION AND LPU POLICY OBJECTIVES

2.9. LCC has undertaken consultation on an LPU policy objective to deliver 'zero carbon development'. This refers to the operational phase of the lifecycle of a development and will require that carbon emissions associated with the building's operational energy are zero or negative. For the remainder of the study, this will be referred to as 'net zero operational carbon' as established in Paragraph 2.7.

2.10. LCC has undertaken consultation on an LPU policy objective to reduce the whole lifecycle emissions of developments. This would involve addressing the embodied carbon emissions associated with a development, in addition to the operational phase as covered by the zero carbon development objective. A development in Leeds which achieves net zero embodied carbon emissions would meet the definition as set out in Paragraph 2.6. A development which addresses both embodied and operational carbon emissions to achieve net zero across the whole building lifecycle would meet the definition as set out in Paragraph 2.8.

3. STANDARDS OF CONSTRUCTION

3.1. One of the priorities for the Local Plan Update is to introduce a requirement for the use of sustainable construction standard(s). To support the objective, this section provides an assessment of some current standards, and one currently in development. Paragraphs 3.2-3.58 provide a descriptive analysis, Table 1 provides a summary of the standards in table format, and Paragraphs 3.60-3.63 provide recommendations for applying standards in the LPU.

UK NET ZERO CARBON BUILDINGS STANDARD

3.2. In May 2022, a project was launched to develop a net zero carbon construction standard[23]. The standard will develop metrics and set requirements for achieving and verifying a building as net zero carbon over its whole lifecycle[24].

3.3. The standard is being developed by a collaboration of key industry organisations including CIBSE, BRE, RIBA and the Institution of Structural Engineers, and is seeking involvement from a range of stakeholders including planning authority officers to develop and test the standard[ii].

Type of building and application

3.4. It is intended the standard will be applicable to all types of residential and non-residential buildings and both minor / householder applications as well as major schemes[iii].

Primary LPU objectives targeted

3.5. **Whole lifecycle carbon** – the scope will include metrics and requirements for reducing upfront and lifecycle embodied carbon.

3.6. **Net zero operational carbon** – it is expected this standard will deliver net zero operational carbon developments.

3.7. **District heat networks** – it is not clear at this stage how the standard will relate to the deployment of district heat networks.

Other LPU objectives targeted

3.8. The standard will focus on embodied and operational carbon emissions and is not expected to impact other LPU objectives.

Analysis of standard

3.9. As the standard is in development, it is not possible to provide an assessment. However, the level of consultation, breadth, expertise and reputability of the organisations involved indicates it will be comprehensive and suitable for implementation in Leeds once launched.

[ii] Further information about the standard and how to get involved is available from https://www.nzcbuildings.co.uk/.
[iii] Clarified in launch event video

HOME QUALITY MARK

3.10. The Home Quality Mark (HQM) certification scheme from BRE awards a 1-5 star rating for new homes against a set of criteria which include living costs, health and wellbeing and environmental footprint[25].

3.11. Indicators include reducing energy and carbon emissions, improving biodiversity, home security and recreational space, flood risk, internal noise and temperature. Promotion of public or active travel options and access to local amenities would support reductions in household carbon emissions outside of the scope of the buildings themselves.

3.12. Credits can be obtained from a range of indicators within three indicator bands - 'my costs', 'my wellbeing' and 'my footprint'. A minimum number of credits have to be achieved in each to obtain a 1-5 star rating.

3.13. The HQM involves a two-stage assessment to ensure principles are incorporated at design stage and to verify the standard has been met post-construction. Assessment is undertaken by independent assessors, trained and licensed by BRE.

Type of building and application

3.14. The HQM is intended to be applicable to household / self-build and larger residential schemes.

Primary LPU objectives targeted

3.15. **Whole lifecycle carbon** – while no WLC calculation is required to achieve the standard, credits are awarded for use of more sustainable materials and construction practices which would help reduce embodied carbon emissions.

3.16. **Net zero operational carbon** - credits are awarded for measures which reduce operational energy requirements and carbon emissions. Whilst credits can be flexed between indicators, a 4 or 5 star HQM rating requires energy savings against current building standards.

3.17. **District heat networks** – if there is potential for future connection to a heat network, credits are awarded for designing to operate with lower temperatures, and internal pipework ready to enable connection.

Other LPU objectives targeted

3.18. The HQM includes a range of performance standards beyond carbon emissions including overheating, flood risk and resilience, biodiversity enhancement, and place-making / 20 minute neighbourhoods.

Analysis of standard

3.19. Implementation of the HQM standard should deliver a better experience and quality of life for residents in HQM certified homes. However because beyond the minimum band rating, credits can be flexed, on its own imposing a star rating requirement would not guarantee a certain energy and carbon emissions reduction. Other planning authorities have implemented a requirement for minor and major developments to achieve a 4 star for the HQM standard alongside energy and carbon reduction standards[26], so this may be appropriate for Leeds.

PASSIVHAUS STANDARD

3.20. Passivhaus Standard is an international energy performance standard developed by the Passivhaus Institut in Germany[27]. Buildings constructed to Passivhaus Standard should deliver a 75% reduction in the need for heating and cooling as well as good indoor air quality[28,29]. It is a highly fabric-first approach to achieving energy and carbon reductions, primarily through passive design features such as insulation, airtightness and solar orientation[29].

3.21. Passivhaus Standard includes a few key energy demand metrics[30]:

- Space heating demand: 15kWh/m^2/yr
- Space cooling demand: 15kWh/m^2/yr
- Primary energy demand: 120kWh/m^2/yr (regulated and unregulated energy)

3.22. Passivhaus requires developers to consider all aspects of the design, materials, and technologies at an early stage. Because of this, the use of certified Passivhaus designers and consultants is critical to a successful project. A specific system, the Passivhaus Planning Package, must be used. Passivhaus Standard is achieved following certification by a registered Passivhaus Certifier[31].

3.23. Mechanical ventilation and heat recovery (MVHR) is usually installed in Passivhaus developments to ensure good internal air quality whilst avoiding the loss of heat. This must be a Passivhaus-certified MVHR to ensure efficient and low cost operation[32]. Whilst heating demand will be very low, consideration must be given to how the home will be heated and hot water provided. One option is to provide heating and hot water via an electric heating element in MVHR ducts. However, direct electricity for both heating and hot water is not normally possible because electricity's high primary energy factor means this usually exceeds the Passivhaus primary energy limit of 120kWh/m^2.

3.24. EnerPHit, a version of Passivhaus Standard for retrofit projects which features slightly less stringent energy demand limits is available if project are unable to achieve Passivhaus[36].

3.25. For all buildings which are built to very high levels of fabric efficiency, care and consideration should be given to minimising future overheating risks[33–35]. In addition, future occupants who will need to be aware of how to ensure appropriate ventilation and operate the controls to ensure a comfortable and healthy environment, and this will need to be bespoke for each building. It may be appropriate to implement a requirement for developers to outline how they will educate future occupants in such issues.

Type of building and application

3.26. Passivhaus Standard is intended to be applicable to household / self-build[iv] as well as larger residential and non-residential schemes[v].

Primary LPU objectives targeted

3.27. **Whole lifecycle carbon** – Passivhaus standard relates to the operational phase of a building's energy demand only rather than focusing on embodied carbon emissions.

3.28. **Net zero operational carbon** – Passivhaus developments require very little energy whilst in use which would go a long way towards achieving net zero operational carbon. Operational carbon emissions would need to be modelled and presented as part of the planning application process to evidence how this will be achieved.

3.29. **District heat networks** – Passivhaus Standard permits heating systems including heat pumps, individual gas boilers, and communal / district heat networks. Heat networks supplying highly insulated dwellings must be carefully designed and operated to the demand characteristic of the homes. Ambient temperature heat networks with individual heat pumps may be suitable (see Section 7).

Other LPU objectives targeted

3.30. Passivhaus Standard focuses on buildings and does not have specific impacts on other LPU objectives.

Analysis of standard

3.31. The low energy demand characteristic of Passivhaus buildings is an ideal way to ensure future occupiers are protected from energy price rises, whatever heating system is used. Schemes must be designed and constructed carefully to address the issue that Passivhaus buildings can suffer from summer overheating[33,34]. Careful consideration must be given to how future occupants will be supported to use the ventilation and other systems effectively to ensure a comfortable living environment.

BREEAM New Construction 2018

3.32. BREEAM New Construction 2018 is the UK version of BRE's international sustainable building standard for non-domestic buildings[40]. This includes commercial, office, retail, education, healthcare, and public buildings, as well as short and long stay residential institutional buildings such as hotels, care homes, and sheltered accommodation etc., and can include part new-build, part refurbishment projects.

[iv] For examples of household schemes[37]

[v] For example of large schemes, see Agar Grove Phase 1a by Camden Council[38] and Goldsmith Street by Norwich City Council[39]

3.33. Assessment and certification must be carried out by a licensed BREEAM Assessor and includes a range of evidence and site inspection. At minimum assessment must be carried out post-construction, with optional design stage and post-occupancy (12-24 months) assessments.

3.34. The assessment scores buildings on a range of nine environmental criteria and awards one of six ratings from 'unclassified' to 'outstanding'. The criteria include reducing energy and carbon emissions, sustainable materials and construction practices, health and wellbeing of building users, accessibility and sustainable transport options,

3.35. For energy and carbon emissions, only 'excellent' and 'outstanding' ratings feature minimum standards. This is assessed against percentage improvements over building regulations, using outputs from an approved building modelling software package (e.g. IES VE, SBEM)[41,42]. Beyond this credits can be flexed and so use of the standard will not on its own deliver net zero carbon developments.

Type of building and application

3.36. This is a non-residential only certification, and is already a requirement in LCC planning policy for non-residential buildings over 1,000m² to achieve an 'Excellent' rating. Other local planning authorities have begun to implement a requirement for buildings over 500m² to aim for an 'Outstanding' rating[26].

Primary LPU objectives targeted

3.37. **Whole lifecycle carbon** – there are two sections in the assessment which should reduce WLC emissions of developments, 9.0 Materials and 10.0 Waste. Credits are awarded for use of sustainable and recycled materials and construction practices, and design for future adaptation and disassembly, which would reduce embodied carbon emissions.

3.38. **Net zero operational carbon** - credits are awarded for measures which reduce operational energy requirements and carbon emissions. The minimum standard for the 'outstanding' rating would deliver a 40% reduction in operational carbon emissions compared to current building standards.

3.39. **District heat networks** – the standard does not require a connection to a district heat network to achieve credits, but notes that air pollution caused by connection to waste incineration schemes would negatively impact BREEAM credits[43].

Other LPU objectives targeted

3.40. The standard also includes requirements for sustainable transport options which would help address the non-building emissions from the development, as well as improving local biodiversity.

Analysis of standard

3.41. Achievement of an 'Outstanding' rating should deliver very high quality non-residential developments which reduce their environmental impact and a much better environment for those working within them. This standard is proposed as long as it is combined with the other requirements set out in the report including net zero operational emissions, reducing whole lifecycle emissions, selection of appropriate heating systems etc.

LIVING BUILDING CHALLENGE

3.42. The Living Building Challenge (LBC) 4.0 is an international construction standard intended to deliver very high levels of environmental and social benefit[44].

3.43. The full standard includes 20 Core Imperatives including nature and biodiversity improvement, promotion of public transport and active travel, onsite water recycling, net zero embodied carbon and net positive operational carbon saving, healthy interiors, and responsible material sourcing. Full certification is possible only after 12 months of building use through demonstration of building in-use performance, although developers can signal their intention to achieve this through a preliminary ruling of LBC Ready Recognition that confirms initial efforts and the intent to certify.

Type of building and application

3.44. The standard is intended to be suitable for application to any building size and type, although the number of certified schemes globally is small.

Primary LPU objectives targeted

3.45. **Whole lifecycle carbon** – projects must demonstrate a 20% reduction in the embodied carbon of primary materials compared to an equivalent baseline, then achieve net zero embodied carbon through the use of carbon sequestering materials and/or carbon offset purchase through an approved carbon offset provider.

3.46. **Net zero operational carbon** – new-build projects must demonstrate a 70% energy demand reduction from building standards, and be net carbon positive through onsite renewable energy generation of 105% of the site needs over a year.

3.47. **District heat networks** – the standard does not consider the use of district heat networks.

Other LPU objectives targeted

3.48. The standard includes requirements around biodiversity and habitat enhancement, access to nature and onsite food growing, flood resilience through onsite storm water management, and place-making through promotion of active travel and public transport over car use. There are also requirements around access and inclusion, and local job creation.

Analysis of standard

3.49. Because of the challenges involved in delivering such an alternative form of development, it is not expected that the LBC would be widely applicable in Leeds or any UK city. However such developments would make excellent case studies and exemplar developments, and would mark Leeds out as a city which encourages bold and progressive developers who can challenge the status quo.

3.50. Because buildings can only be certified after a year of use, at the time of planning application, it would be appropriate for developers to set out how they will achieve the standard and/or LCC could require LBC Ready Recognition. Because numbers of developments aiming for LBC recognition are likely to be very low, the issue of enforcement in the event that a scheme is shown to not comply with the standard is unlikely to represent a major challenge.

RIBA 2030 Climate Challenge

3.51. The RIBA 2030 Climate Challenge is a set of voluntary targets for reducing operational energy use, water and embodied carbon[45]. It is not intended to be a certified construction standard. Whilst the Challenge is officially open to RIBA members only, the standards are open and can be applied more widely.

Type of building and application

3.52. The Challenge is intended to be eligible for domestic and commercial buildings, and includes minimum requirements for offices, schools and residential developments.

Primary LPU objectives targeted

3.53. **Whole lifecycle carbon** – retention and reuse is prioritised, projects must demonstrate a 40% reduction in embodied carbon from building regulation baseline figures, before offsetting as a last resort. The RICS WLC carbon approach and circular economy principles should be adopted.

3.54. **Net zero carbon operational carbon** – operational energy demand should be 50% (residential) / 60% (non-residential) lower than building regulation baseline figures, including regulated and unregulated energy, before offsetting as a last resort. A fabric first approach should be followed with use of low carbon heat generation and onsite renewables.

3.55. **District heat networks** – the use of low carbon heat is required which can include connection to non-fossil fuel based heat networks (or others such as heat pumps).

Other LPU objectives targeted

3.56. The standard focuses on energy and carbon emissions and does not consider wider environmental and social concerns.

Analysis of standard

3.57. As an industry-led voluntary scheme with no certification procedure, the RIBA 2030 Climate Challenge is not a sustainable construction standard per se. Without a certification procedure, developers would need to demonstrate compliance to planning officers through setting out evidence in the planning application for how they will comply with the energy use and embodied carbon metrics (see Table 1).

3.58. Whilst it may be appropriate for LCC to require a certifiable standard only, construction to the minimum standards of RIBA 2030 would deliver significant reductions in embodied and operational emissions, as well as potentially attracting lower cost finance as set out in Section 1.3. For this reason it has been included in the analysis.

COMPARISON OF STANDARDS

3.59. Table 1 shows a comparison of the different standards focusing on their scope, coverage and key metrics.

RECOMMENDATIONS FOR IMPLEMENTATION OF SUSTAINABLE CONSTRUCTION STANDARD

3.60. One of the key objectives of the LPU is to implement a sustainable construction standard or standards. A range of construction standards were presented and discussed in Paragraphs 3.2-3.58. Whilst a direct comparison of standards on identical metrics is not possible, the comparison showed that:

- Some standards focus solely on energy and carbon emissions (UKNZC, Passivhaus, RIBA 2030), whilst others take a wider range of environmental, health and social factors into account (HQM, Living Building Challenge, BREEAM New Construction).
- Some standards are intended to apply to both residential and non-residential buildings (UKNZC, Passivhaus, Living Building Challenge, RIBA 2030), whilst others are focused either on residential or non-residential (HQM, BREEAM New Construction 2018).
- There is no single standard which will deliver on all the primary LPU objectives. The UK Net Zero Carbon Building Standard may be the most likely to deliver embodied and operational emissions reductions, depending on how its development progresses.
- Some standards have formal certification procedures, whilst others are more a set of required targets to aim for.

Table 1 Comparison of Sustainable Construction Standards

	Residential / non-residential	New build / retrofit	Major / minor	Energy reduction metric	Operational carbon emissions	Embodied carbon emissions
UKNZCBS	Both	Both	Both	TBC	Net zero (TBC)	Net zero (TBC)
BRE Home Quality Mark	Residential only	New build only	Both	Energy and operational carbon target together within HEPR (min 28 credits / HEPR 0.630 for 4 star rating)		N/A
Passivhaus	Both	Both	Both	<15 kWh/m²/y	N/A	N/A

	Residential / non-residential	New build / retrofit	Major / minor	Energy reduction metric	Operational carbon emissions	Embodied carbon emissions
BREEAM New Construction 2018	Non-residential only	New build only	Major	Energy & operational carbon target together within EPR (min 0.6 for 'Outstanding')		
Living Buildings Challenge 4.0	Both	Both	Both	70% reduction on building standards	Net positive through onsite generation	Net zero through on and offsite offsetting
RIBA Challenge v2 2025 / 2030[45]	Both	Both	Both	<35 kWh/m^2/y (residential), < 55kWh/m^2/year (non-resi)	N/A	<625 kgCO2 e/m^2

3.61. For these reasons, it may be appropriate to allow developers flexibility in which standard is chosen. Whatever standard is chosen, this should not negate the need for developments to meet the other requirements as set out in Sections 3-8 around reducing whole lifecycle emissions, achieving net zero operational carbon emissions, and following the technology options and review process in the heating approach. But it may be possible for the same evidence to be used to meet both sustainable construction and other requirements, thus minimising burden on developers.

3.62. We recommend that the requirements in Sections 4-8 are met aside from the use of sustainable construction standards, but if the LPU includes the requirement for developers to use sustainable construction standards, the suggested level to aim for is set out in Paragraph 3.63.

3.63. If a range of sustainable construction standards are offered to developers to choose from, appropriate levels to implement from the standards assessed here may be:

- UK Net Zero Carbon Buildings Standard – all development types – certification process to be determined.
- Home Quality Mark – all residential developments - 4 star rating planned at design stage and certified by licensed BRE assessor post construction
- Passivhaus Standard – all development types – certified
- BREEAM New Construction 2018 – +500m2 floor space – Outstanding rating planned at design stage and certified by licensed BRE assessor post construction
- Living Building Challenge – all development types – 'LBC Ready' at design stage and certification post 12 months occupation.
- RIBA 2030 – all development types – evidence provided that standard will be met

4. WHOLE LIFE CYCLE EMISSIONS

4.1. Traditionally much of the focus on tackling carbon emissions from buildings has centred on the operational / in-use emissions from the built environment[46]. However, there is increasing awareness in the development sector of the impact of embodied emissions of construction, and the need to move beyond traditional approaches of demolition and new construction[47,48]. The House of Commons Environmental Audit Committee has recently called on the government to urgently update building regulations and national planning policy to include whole lifecycle carbon (WLC) emissions[46,49].

4.2. WLC emissions result from the materials, construction and the use of a building over its entire life, including its demolition and disposal. As operational carbon emissions are reduced by national building regulations and local planning policy, embodied carbon as an element of whole lifecycle carbon emissions becomes more important. Embodied carbon can represent around 50% of total emissions over a building's lifetime[50,51]. An illustrative example of building emissions at various stages over its lifetime is provided in Figure 1. It is key that action is taken to address embodied as well as operational emissions.

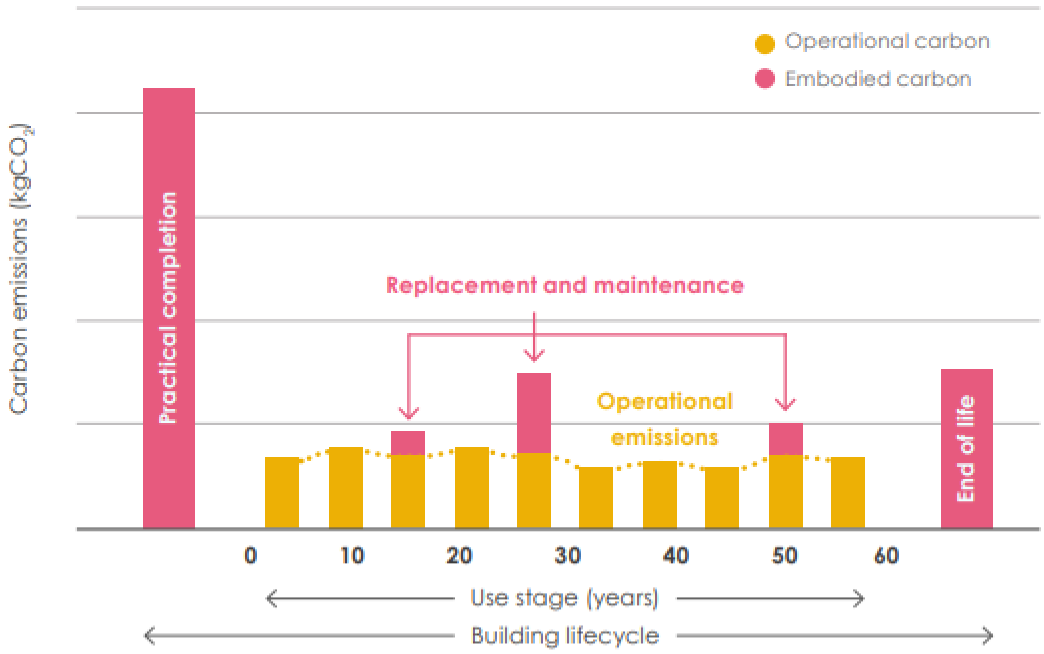


Figure 1 Embodied and operational carbon emissions within the whole lifecycle of a development, indicative. LETI[52]

4.3. Principles for whole life assessment of the environmental impacts from built projects based on life cycle assessments are underpinned by British Standard BS EN 15978 methodology. This defines a standard building's life expectancy as 60 years, and breaks down the lifecycle into five overall stages (further subcategorised into 17 modules) of a standard construction project where embodied emissions should be assessed (see Figure 2).

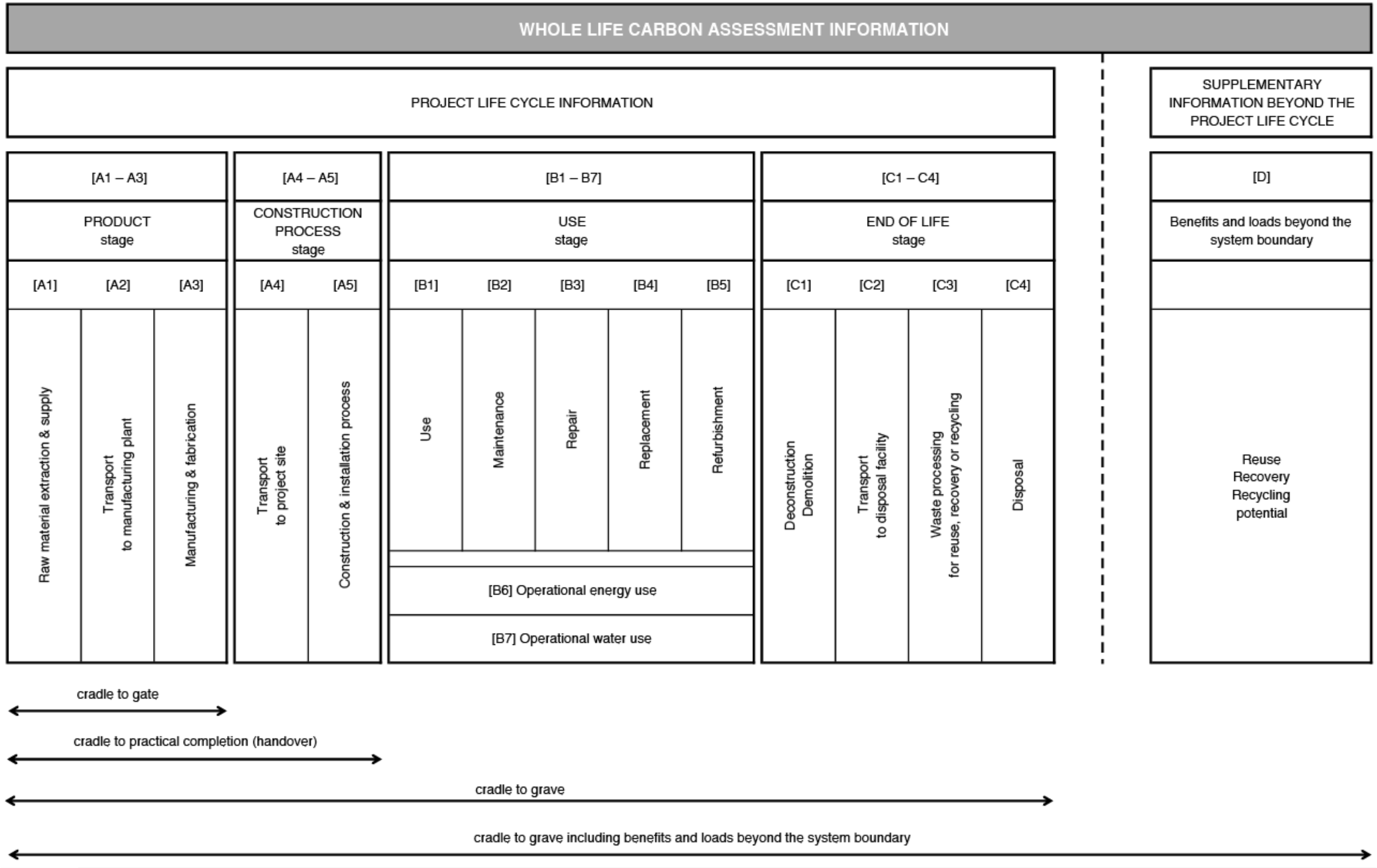


Figure 2 British Standard BS EN 15978, lifecycle stages A-D of a typical project including operational and reuse following disassembly[53,54]

4.4. Table 2 outlines the main elements which cause carbon emissions over a building's life and whether these are included in *embodied* or *operational* emissions calculations.

Table 2 Elements of whole lifecycle emissions as defined by BS EN 15978, with module in [brackets]

Lifecycle stage	Description of emissions activity in lifecycle stage	Embodied or operational emissions
Product stage [A1-A3]	Carbon emissions from raw materials and manufacturing processes	Embodied
Construction stage [A4-A5]	Construction activity including transport to site	Embodied
Use stage [B1-B7]	Repair and refurbishment during use [B1-B5] stage	Embodied
	Operational / in-use emissions including heating and hot water etc. [B6-B7]	Operational
End of life stage [C1-C4]	De-construction, removal, waste processing etc.	Embodied
Beyond life stage [D]	Impacts and benefits from reuse, recovery and recycling of materials and products	Embodied

4.5. The evidence suggests that a primary aim of a WLC policy should be to prioritise refurbishment and the retention of existing buildings, structures and materials rather than demolition and reconstruction[49].

4.6. A focus on embodied carbon emissions of materials and construction practices as part of WLC assessment and emissions reduction is likely to be a challenge for the sector, and supplementing current materials and products with like-for-like replacements will likely result in higher costs[55]. However, taking a WLC approach from the outset may realise potential cost savings through:

- Promoting recovery and reuse of existing structures over demolition and new construction.
- Designing to use less construction material from the outset of a development project[56].
- Construction methods (such as modular construction) which can deliver embodied carbon savings and higher levels of efficiency[22,57].

It will be important that potential cost savings are recognised during viability assessment as well as likely cost increases which occur through the selection of lower carbon products and materials.

4.7. Figure 3 shows how decisions made early in the development process can impact future carbon emissions to a greater extent. Beyond the design decisions, the ability for developers to reduce embodied carbon will be reliant on a supply chain able to deliver the low carbon materials and products. Industry research suggests most supply chain businesses are on this path with 87% implementing or developing carbon reduction strategies[58]. However, significant global focus and investment is required to overcome existing barriers.

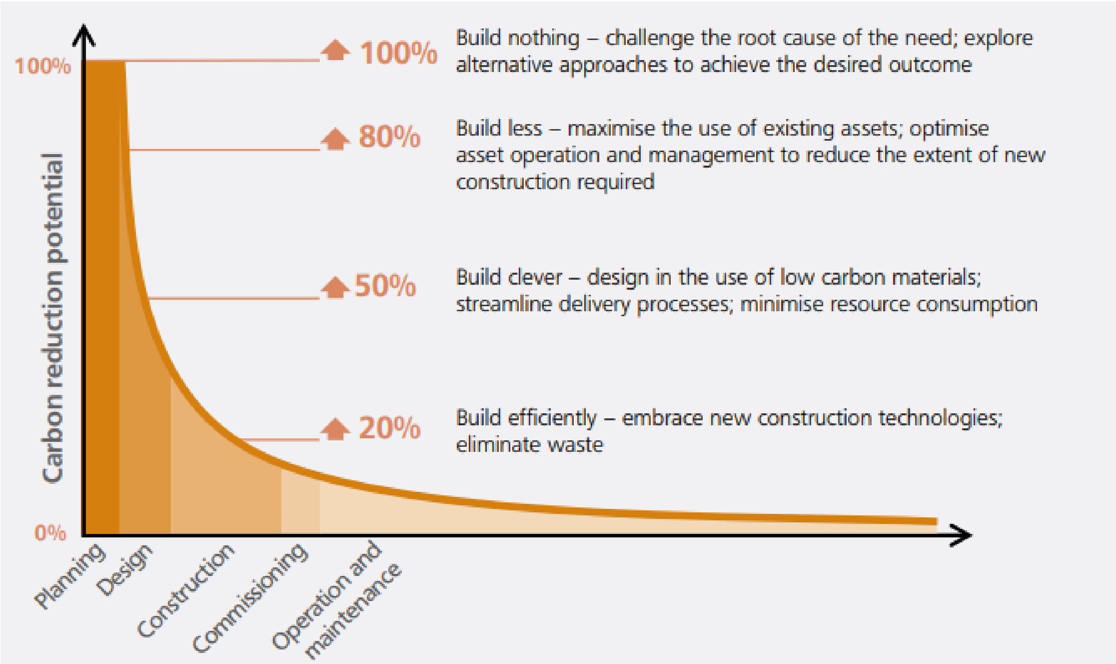


Figure 3 Graphic representation of how opportunities for carbon emissions reductions exist earlier in the development process. UKGBC[59]

Analysis of approaches to whole lifecycle emissions assessment and reduction

4.8. This section sets out some of the key approaches to calculating WLC emissions of a development. They are all based on the core methodology of BS EN 15978 (see Paragraphs 4.3-4.4).

RICS Whole Life Carbon Assessment for the Built Environment

4.9. The RICS 2017 Professional Statement 2017[vi] provides developers with guidance and a methodology for undertaking whole lifecycle emissions assessments[54]. It is based around BS EN 15978 and applicable to all types of residential and non-residential buildings and infrastructure, as well as retrofit projects. The methodology was intended to clarify and standardise inconsistent interpretations and quality of WLC assessment.

4.10. To comply with the RICS methodology, developers are required to consider as a minimum lifecycle stages A1-5, B4, and B6 of BS EN 15978. Modules A-C are encouraged whilst Module D is excluded (this differs from the Greater London Assembly (GLA)

[vi] The RICS Whole life carbon assessment for the built environment, Professional Statement 2017 is available from https://www.rics.org/uk/upholding-professional-standards/sector-standards/building-surveying/whole-life-carbon-assessment-for-the-built-environment/

approach which includes Modules A-D, see Paragraphs 4.19-4.24). To comply with the RICS standard, an assessment is required prior to technical design, and further assessments are recommended (but not required) at further stages in the development process.

4.11. The RICS standard clarifies that a complete whole life carbon assessment should cover all items listed in the project's Bill of Quantities (BoQ), cost plan or as identified in other design information (drawings, specifications, etc.).

4.12. To support developers in calculating WLC emissions, a list of appropriate carbon data sources in line with national (BSI) and international (ISO) standards are recommended. The methodology recognises carbon sequestration of sustainably sourced timber with robust audit trails.

Institution of Structural Engineers

4.13. Recognising the impact of construction on carbon emissions and the urgency of the climate emergency, the Institution of Structural Engineers (IStructE) has produced a guide and tool for undertaking embodied carbon calculations for residential and non-residential buildings[60].

4.14. The guide provides a hierarchy of considerations before any construction takes place:

1. Build nothing – consider first whether new construction can be avoided.
2. Build less – minimise demand for new construction through reuse and repurpose existing assets.
3. Build clever – design to minimum loads and use low carbon products and technologies.
4. Build efficiently – use construction techniques which reduce resource consumption.

4.15. Following BS EN 15978, the IStructE guide prioritises Modules A1-A5, and provides a calculation process to follow based around the fundamental principle of an embodied carbon calculation: to multiply the quantity of each material by a carbon factor for the life cycle modules being considered:

material quantity (kg) × carbon factor (kgCO2e/kg) = embodied carbon (kgCO2e)

4.16. Modules A1-A5 covering materials and construction lifecycle phases of a development are given priority by IStructE because they identify that these stages produce the majority of emissions and because they will be emitted before 2050. Consideration of all stages A-D is encouraged, however.

4.17. To support developers in calculating WLC emissions, the guide provides:

- A free excel-based tool to quantify embodied carbon of materials and construction[vii]. This allows up to 6 schemes using different materials to be readily compared.
- Links to other embodied carbon calculation tools including both free and paid options.

[vii] The IStructE tool is available from https://www.istructe.org/resources/guidance/the-structural-carbon-tool/

- A set of suggested embodied carbon factors for commonly used materials such as concrete, steel, stone and brick etc. (recognising that these will change over time).
- Suggested data sources for obtaining product and material carbon factors.

4.18. IStructE recommends that once it becomes available, the Built Environment Carbon Database (BECD) [viii] should be the source information source for product and material carbon factors.

Greater London Authority approach

4.19. There are two concurrent planning requirements in London relating to whole lifecycle emissions. For developments which are referable to the Mayor [ix], developers must submit both a WLC assessment and Circular Economy (CE) statement[62]. The Greater London Authority (GLA) also encourage the thirty-two London boroughs to implement the two requirements for other (non-referable) types of development[63,64]. This study focuses on the WLC assessment aspects of the GLA approach, but further information is provided on the CE requirements is provided in Appendix 2.

Whole lifecycle carbon assessments

4.20. Policy SI2 F of the London Plan 2021[65] requires that development proposals must calculate whole lifecycle carbon emissions using British Standard BS EN 15978[x] but goes further than the RICS and IStructE approaches by requiring that modules A-D are included in WLC assessments (see Figure 2).

4.21. The GLA's approach to reducing WLC emissions is based around sixteen key principles[66].

1. Existing buildings should be retained and retrofitted before demolition is considered.
2. Recycled or repurposed materials are used wherever possible.
3. New materials should be low carbon (this includes a consideration of durability).
4-5. Operational energy from heating, cooling and water use should be minimised during the operational life of a building (subject to separate net zero policy).
6. Buildings should be designed for disassembly and reuse from the outset.
7. Compact building forms help minimise emissions across the whole lifecycle.
8. Materials can be used which remove carbon from the atmosphere.
9. Buildings should be durable and designed to be flexible for future change of use.
10. Careful consideration of how operational emissions reduction affects embodied carbon.
11. Building life expectancy should be defined and help guide construction choices.
12. Materials sourced locally minimise transport emissions and maximise local benefits.

[viii] The Built Environment Carbon Database (BECD) will be made available at https://www.becd.co.uk/
[ix] Developments are referable when they comprise more than 150 dwellings, over 30m in height or on Green Belt land[61].
[x] : BS EN 15978: 2011 (Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method)[53]

13-15. Efficient (e.g. MMC, modular) and lightweight construction methods can help address WLC emissions. Waste from construction should be minimised & these approaches can help.

16. Circular economy principles should be followed.

4.22. The GLA requires developers to submit WLC assessments at various stages of the development process:

1. Pre-application stage (where relevant).
2. Planning application stage - both outline and detailed stage, as applicable.
3. Post-construction, prior to occupation.

4.23. An excel template is provided to support developers to undertake WLC assessments, with a tab which should be completed at each stage[xi]. In addition, a selection of suitable software tools which include WLC modelling are provided (e.g. Sturgis Carbon Calculator).

4.24. Notably for operational emissions aspects of WLC assessments (module B6), the policy requires developers to not consider future grid decarbonisation unless this is previously agreed with the GLA.

One Click LCA

4.25. One Click LCA[xii] is a suite of automated tools intended to support the completion of WLC assessments including BS EN 15978, RICS and GLA requirements for both WLC assessments and Circular Economy[66]. Assessment can be done at an early design stage to facilitate WLC principles from the outset of a development.

4.26. Data on construction materials is continually updated and verified through a BRE-approved process[67].

4.27. Project types covered include:

- Residential and non-residential developments
- Small and large scale including single house assessments
- New building construction (part or whole) and renovation of existing buildings

4.28. The system operates by allowing a developer to choose the WLC assessment type, development type and construction type, then working through an automated process to select materials with associated carbon emissions.

4.29. The tools can be integrated with building modelling software such as IES VE as well as Excel files so that building designs, material quantities etc. can be imported into the system to generate WLC emissions data[68,69].

[xi] The guidance and excel template are available from https://www.london.gov.uk/what-we-do/planning/implementing-london-plan/london-plan-guidance/whole-life-cycle-carbon-assessments-guidance

[xii] One Click LCA tools are available from https://www.oneclicklca.com

Recommendations for whole lifecycle emissions policy

4.30. As a result of changes to building regulations and electricity grid carbon intensity as set out in Section 5, and the transition away from gas boilers further discussed in Section 7, operational emissions associated with development are reducing. This means the comparative importance of addressing embodied carbon emissions is set to increase. A typical masonry construction dwelling produces around 50 tonnes of carbon to build through materials and construction[67,68]. This would have typically represented 20-30% of a building's emissions over its lifecycle, but in future will mean that embodied emissions become the more prominent source (see Section 5 for typical operational emissions under building regulations scenarios).

4.31. There are currently plans for over 51,952 new homes, over 700,000 sqm office space, and 493ha of new employment land between 2017 and 2033[69]. Considering the impact of the homes only, this could generate in the region of 2.5m tonnes of carbon in construction alone by 2033. Without action taken through to address the embodied emissions aspect of whole lifecycle emissions, this would threaten LCC's science-based targets which will evolve to recognise carbon emissions arising from local activity in Leeds even if materials and processes take place outside the city boundary [2].

4.32. Remedial action starts with measuring and reporting embodied carbon as part of the planning process. This was recognised in the EAC's inquiry as viable now for both smaller and large-scale developments, with marginal costs for larger developers seen to be negligible[49]. Evidence submitted from architects, academics, and industry bodies was found to be positive towards local authorities which had started to introduce planning policy on whole lifecycle emissions.

4.33. As more local planning authorities take steps to address WLC emissions, methodologies, tools and product databases will be developed and will become standard practice for organisations involved in development. Tools to support WLC assessments such as One Click LCA are available to support developers of all types and sizes. However, the requirement to undertake WLC assessments will add additional burden to smaller developers which the LPU process will need to consider.

4.34. Because of the impacts of new construction, an LPU policy would ideally be based on the principle of reuse and refurbishment first, with new construction being a last resort. Elements of the GLA principles for WLC and circular economy would serve as a useful guide for development in Leeds.

4.35. It is recommended that to tackle the significant and increasing issue of embodied carbon emissions, *for all developments*, applicants are required to undertake WLC assessments and demonstrate that they have taken all reasonable measures to reduce embodied carbon. WLC assessments should combine embodied carbon assessments which include Modules A-D of the BS EN 15978 standard as per the GLA approach.

4.36. The evidence found by the EAC suggests industry is ready and willing to tackle embodied carbon emissions if it was given the signal that requirements to do so are going to come. Therefore Leeds has the opportunity to lead the way amongst local planning authorities in addressing this major challenge. This could be done through requiring that *for larger developments* (+10 units, >500m² commercial space), applicants are required to achieve net zero embodied carbon through:

1. Taking all possible steps to minimise carbon emissions from materials, construction, repair and maintenance, and end of life, prioritising retention and refurbishment over new construction.
2. Following carbon minimisation in Step 1, choosing building materials which sequester carbon to offset emissions internally.
3. As a last resort, all remaining embodied carbon is offset through a £/tonne cash in lieu contribution to LCC to deliver carbon savings locally.

5. NET ZERO CARBON OPERATIONAL EMISSIONS

NATIONAL CONTEXT

5.1. The LPU is taking place in the context of national government updates to building standards to reduce the operational carbon impact of the built environment. These are closely linked to any local planning authority's carbon reduction objectives because they set a baseline 'notional building' against which local planning policies will apply to reductions in operational carbon emissions.

5.2. In addition, changes in building standards are important in the context of the UK's rapidly decarbonising electricity grid. Changes to grid carbon intensity will have a significant impact on the future emissions from buildings where heat is delivered by electrified technologies such as heat pumps. Therefore up-to-date standards are essential to ensure appropriate baselines otherwise technologies that are not appropriate for net zero may appear inappropriately favourable (see also Section 7).

5.3. This section sets out the trajectory of electricity grid decarbonisation and provides a description and summary table of the key aspects of current and future building regulations. The combined impact of these two factors on the operational carbon emissions of a typical home is modelled and illustrated in Tables 5 and 6.

UK electricity grid decarbonisation

5.4. UK carbon emissions have fallen by 49% between 1990 and 2020, largely delivered by reductions in the carbon intensity of grid electricity[7,8]. In 2019, carbon emissions from electricity generation were 71% lower than 1990 levels and the UK Government has committed to decarbonise the electricity grid fully by 2035[70].

5.5. Figure 5 presents official UK Government figures on electricity grid carbon intensity for the period 2010-2100. These carbon factors must be used by government decision-makers when appraising projects, and whilst not yet in line with commitments to fully decarbonise the grid by 2035[70], they reflect that by the mid-2030s the grid will be at a very low carbon intensity.

Changes to building regulations

5.6. Building regulations set a nationally required minimum set of standards for buildings. At the time of report production, new building standards are due to come into force. Table 3 summarises some key aspects of Part L 2013 (previous), Part L 2021 Uplift (new as of 15 June 2022) and Future Homes Standard (FHS, expected from 2025 onwards)[71–73].

5.7. Building regulations include fabric efficiency standards such as maximum heat loss through walls, windows etc. (U values), as well as the type of heating system it is expected that buildings will use. Building regulations relate the predicted carbon emissions from a building to the heating system through the Standard Assessment Procedure (SAP) which must be used to calculate building performance[72,74]. As shown in Table 4, the carbon intensity of grid electricity is recognised as being significantly lower under new regulations.

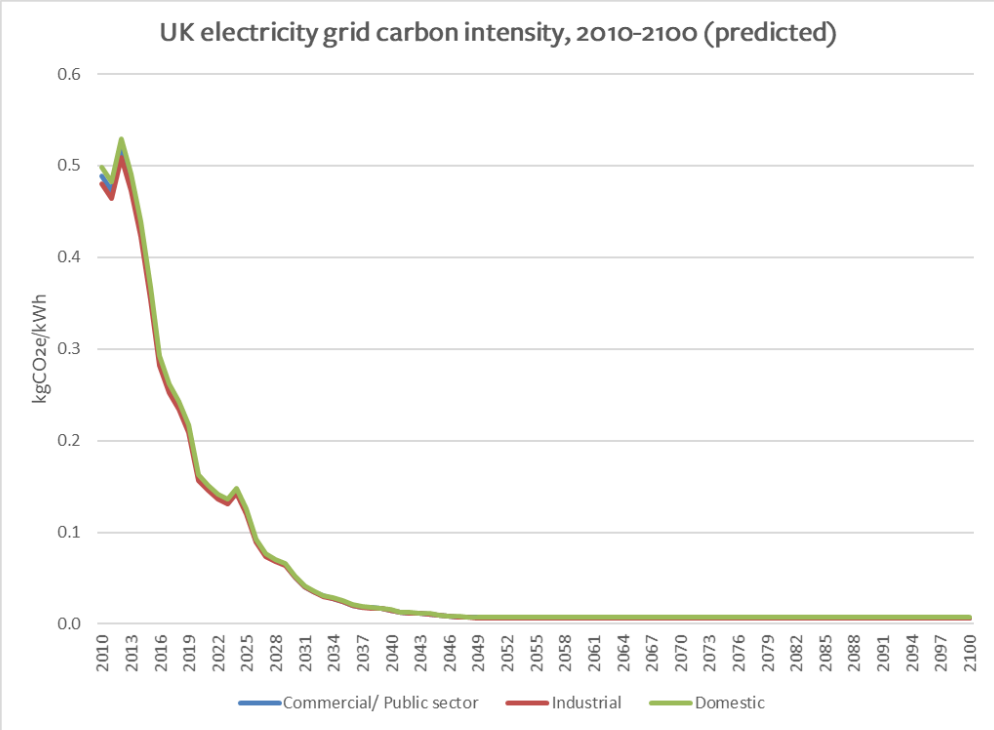


Figure 4 UK electricity grid carbon intensity, 2010-2100, kgCO2e/kWh. Source: BEIS[75]

Table 3 Highlighted aspects of previous (part L 2013), current (Part L 2012 Uplift) and future (FHS) building regulations

	Part L 2013[71]	**Part L 2021 Uplift[72]**	**Future Homes Standard[76]**
	Notable features		
Date in force	06/04/14 (unless submitted prior & on site by 06/04/15)	15/06/22 (unless submitted prior & on site by 15/06/23)	2025 onwards (expected, exact dates TBC)
SAP applies	SAP 2012[77]	SAP 10.2[74]	SAP 11
Grid electricity carbon factor, $kgCO_2/kWh$	0.519 $kgCO_2/kWh$	0.136 $kgCO_2/kWh$	TBC by SAP 11
Mains gas carbon factor,	0.210 $kgCO_2/kWh$	0.216 $kgCO_2/kWh$	TBC by SAP 11
Annual carbon target for typical semi-detached home	16 kgCO2/m2/yr	11 kgCO2/m2/yr	3.6 kgCO2/m2/yr
Notional heating system type	Mains gas boiler	Mains gas boiler	Low-carbon heating (e.g. heat pump)

	Part L 2013[71]	**Part L 2021 Uplift**[72]	**Future Homes Standard**[76]
Heat network loss factor (heat lost between generation and use)	5% - 17% loss depending on age & operating temperature	33.5% - 50% loss if CP1 standard is followed, unless in the Product Characteristic Data Base	TBC
Wastewater heat recovery	No	Yes	No
Solar PV required	No	40% of floor area (all dwellings)	No
Selected 'notional dwelling' metrics which new dwellings should exceed			
U Value – roof, W/m^2K	0.13	0.11	0.11
U Value – ext walls, W/m^2K	0.18	0.18	0.15
U Value – floor, W/m^2K	0.13	0.13	0.11
U Value – window, W/m^2K	1.4	1.2	0.8
U Value – rooflight, W/m^2K	1.4	1.7	TBC
U Value – semi-glazed door W/m^2K	1.2	1	TBC
U Value – opaque door, W/m^2K	1	1	1
Air permeability, $m^3/(h\text{-}m^2)$@50Pa	5	5	5
Ventilation type	Natural	Natural	Natural

Impact of grid decarbonisation and changes to building standards

5.8. To illustrate how changes to building regulations and the reducing grid carbon intensity impact the carbon emissions associated with a building, an excel model for a typical detached 3 bedroom home featuring heating either through an individual gas boiler or heat pump was run for Part L 2013, Part L 2021 Uplift and Future Homes Standard (FHS) design conditions, and heating either through an individual gas boiler or heat pump[xiii].

5.9. In the model, the building performance under the various scenarios was achieved by combining the heat loss impact of the U values on energy required with an average outside temperature of 9.5^{0}C, to maintain an average inside temperature of 20^{0}C. The gas boiler operates at 90% efficiency and heat pump at 3.2 Seasonal Performance Factor (see Section 7). The model reflects the carbon intensity of natural gas as being roughly static at 0.210 / 0.216 kg/CO2/kWh whilst the carbon intensity of electricity starts at 0.142 kg/CO2/kWh in 2022 and reduces as per UK Government predicted carbon factors[75].

[xiii] Model developed by Rod Holt, Otley 2030, and used with permission.

5.10. The results of this analysis are shown in key 2030 and 2050 cumulative emissions figures (Table 4) and graphically for annual and cumulative emissions (Table 5).

5.11. Although the 2021 Uplift to building regulations will result in a small reduction in carbon emissions, the use of a gas boiler (which is expected to be prohibited under FHS) is a more significant factor under any scenario. Because the heat pump uses grid electricity, the very low carbon intensity of the grid from the early 2030s means cumulative emissions do not increase much beyond that point.

Table 4 Summary of cumulative carbon emissions by 2030 and 2050 for a typical 3 bedroom detached house with 'notional dwelling' characteristics under Building Regulations Part L 2013, 2021 Uplift and FHS (expected)

	2030, gas boiler	2030, heat pump	2050, gas boiler	2050, heat pump
Part L 2013	19.5 tCO2	2.9 tCO2	68.1 tCO2	4.24 tCO2
Part L 2021 Uplift	18.7 tCO2	2.8 tCO2	65.5 tCO2	4.09 tCO2
Future Homes Standard	N/A	2.83 tCO2	N/A	4.16 tCO2

5.12. Whilst it is expected that the Future Homes Standard and Future Buildings Standard regulations will be introduced with accompanying bans on gas boilers, this will be subject to future political decisions and cannot be guaranteed.

5.13. Based on the expected dwelling construction figures in the Core Strategy (as referenced in Paragraph 4.31), and assuming a linear housebuilding increase onwards to 2050, the total operational carbon emissions (for homes only) without an LPU policy to require net zero operational emissions in Leeds would be:[xiv]

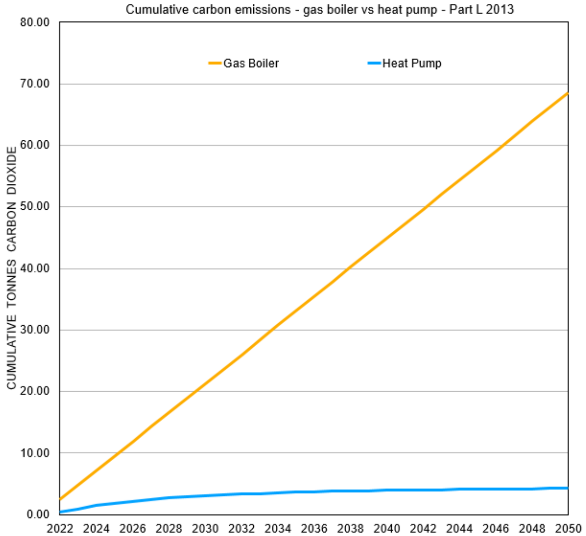
- Scenario 1 – Part L 2021 Uplift remains in force but Future Homes Standard with accompanying ban on gas boilers not introduced: **2.87m tonnes of carbon by 2050**.
- Scenario 2 – Future Homes Standard implemented with accompanying gas boiler ban from 2025 onwards: **104,700 tonnes of carbon by 2050**.

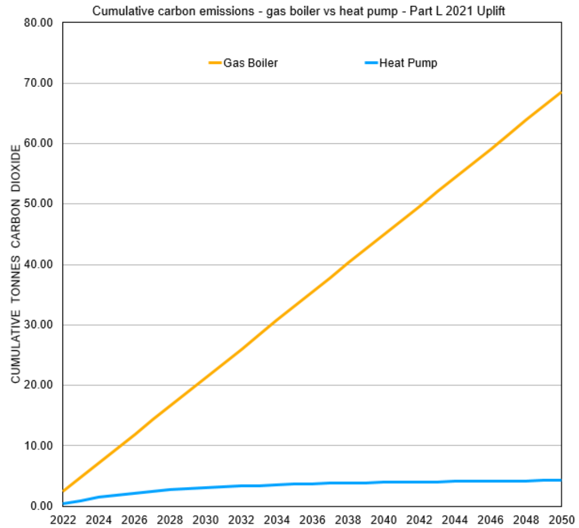
5.14. The cumulative carbon emissions figures in paragraph 5.13 illustrate the importance of a local policy requiring net zero operational carbon emissions from development to ensure that LCC targets can be met. This would become even more important should central government decisions be made not to pursue future upgrades to building regulations.

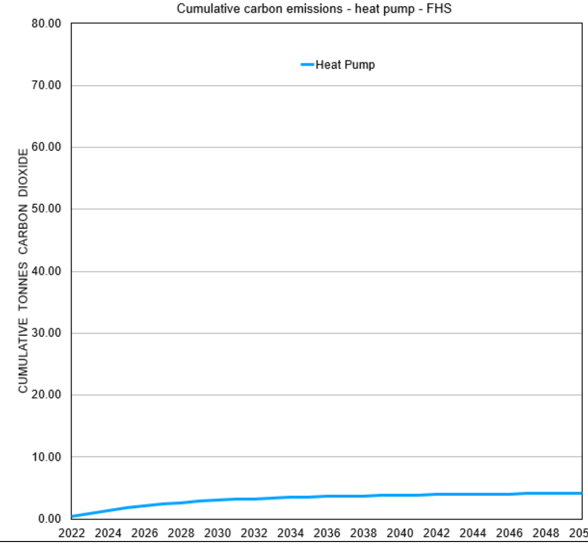
[xiv] As per Paragraph 5.9 these are approximate figures which relate to a standard detached 3 bedroom home.

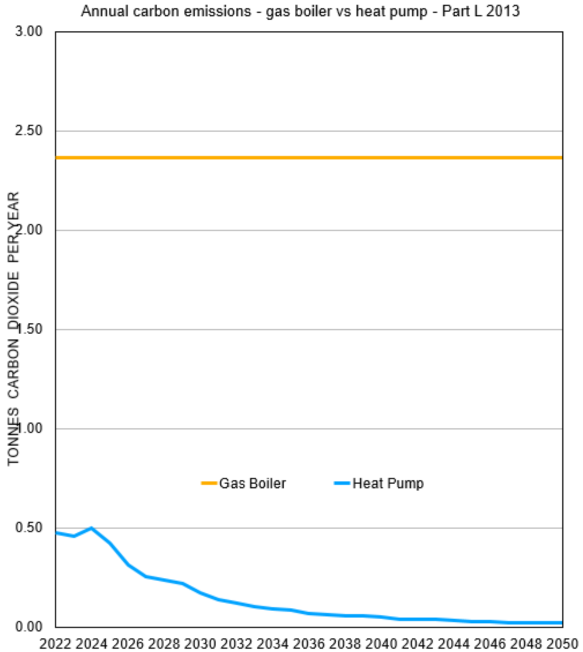
Table 5 Cumulative and annual carbon emissions to 2050 for a typical 3 bedroom detached house with 'notional dwelling' characteristics under Building Regulations Part L 2013, 2021 Uplift and FHS (expected)

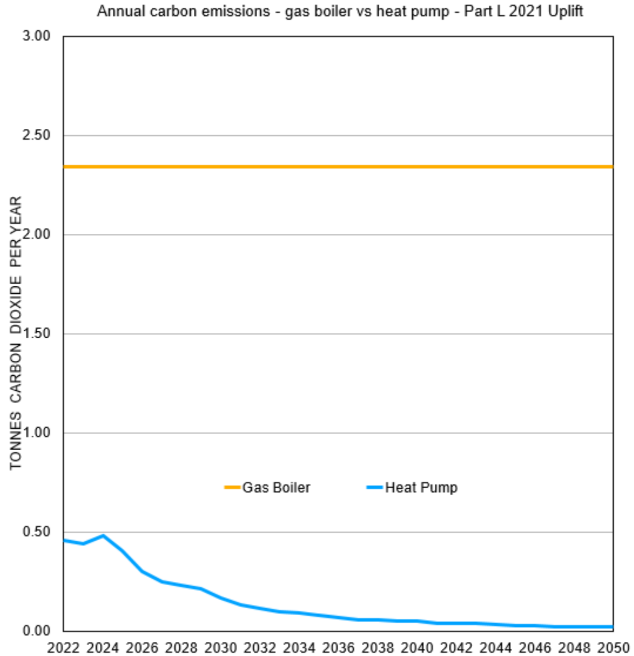
Part L 2013	Part L 2021 Uplift	Future Homes Standard

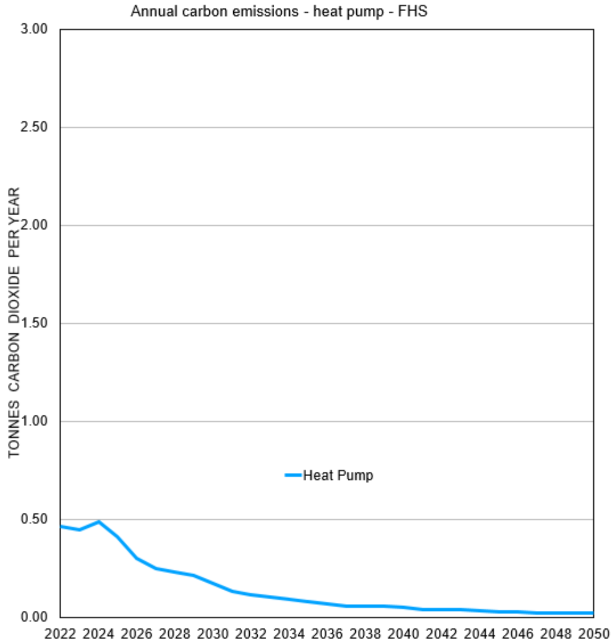












Building regulations updates to address overheating risk

5.15. Evidence suggests that new homes can be vulnerable to overheating[78]. With UK temperatures increasing due to human-induced climate change[79], it will be important that new buildings protect residents and users against overheating whilst being energy efficient and low carbon[80].

5.16. Alongside changes to energy efficiency measures, new building regulations came into force on 15 June 2022 to address overheating in homes[81]. The new regulations, known as Part O, will require that developers take steps to address overheating through:

- Solar gains reduced through limits to glazed areas, especially south facing, and in high-risk areas shading through shutters, overhangs or reduced transmittance glazing.
- An appropriate means of removing excess heat, such as windows which can be opened, ventilation louvres in external walls, or mechanical ventilation.

5.17. The new building regulations emphasise that all reasonable passive measures are used first before adopting mechanical cooling, as well as requiring that sufficient information is provided to building owners to enable them to implement the overheating measures.

5.18. Whilst it is not the focus of this study, the risks of overheating are serious and increasing. It may be appropriate for LCC to support developers to tackle overheating in energy efficient ways through an SPD design guide.

Regulated and unregulated emissions

5.19. It is important to note that building regulations requirements and calculation methodology include regulated emissions only (made up of primary building services like heating, cooling and lighting)[82]. The total operational energy and carbon emissions from a development in reality include unregulated emissions (including computer equipment, fridges, washing machines, TVs, computers, lifts, and cooking, etc) which can comprise up to 50% of a building's total operational energy[52].

5.20. Whilst developers have less control over future unregulated emissions, measures can be taken at design stage to minimise future unregulated emissions. Some local authorities are now including unregulated as well as regulated emissions in their planning requirements[83].

Energy use intensity metrics

5.21. The impact of grid decarbonisation which will be especially important to operational carbon emissions once gas boilers are no longer permitted either through an LPU policy (see Section 7) or by national government through building standards.

5.22. Because a decarbonising grid will mean that carbon emissions will decrease significantly, operational carbon emissions may become less useful over time in assessing the quality of developments in terms of energy efficiency and demand reduction. Other measures of building performance during operational phase are likely to become more important.

5.23. Energy Use Intensity (EUI) targets which describe a buildings operational energy targets on a maximum kWh/m²/year basis are one way of addressing this[3,84]. A set of guidelines for EUI has been proposed by the London Energy Transformation Initiative (LETI), a network of 1,000 built environment professionals, and sets the targets for new developments shown in Table 6[52]:

Table 6 Energy use intensity targets for a range of development types proposed by LETI[52]

Development type	Energy Use Intensity target	Space heating demand[xv]
Small-scale housing	35 kWh/m²/year	15 kWh/m²/year
Medium and large-scale housing	35 kWh/m²/year	15 kWh/m²/year
Commercial offices	55 kWh/m²/year	15 kWh/m²/year
Schools	65 kWh/m²/year	15 kWh/m²/year

5.24. EUI targets can be assessed at design stage through the planning process, as well as measured in-use to support as-built monitoring.

5.25. An important reason for including EUI targets in local planning policy will be to ensure fabric-first design principles of reducing operational energy demand from the outset of a development process endure whilst grid carbon emissions reduce.

5.26. Fabric-first principles such as the list below can help developers meet EUI targets:

- Building orientation to maximise winter heat gain and minimise summer overheating.
- High levels of thermal insulation and air tightness to reduce heat demand.
- Use of Mechanical Ventilation & Heat Recovery (MVHR) in winter to capture internal warmth whilst maintaining ventilation.
- Hot water demand reduced e.g. by limiting shower flow rates.
- Designing out the need for additional mechanical cooling e.g. through optimised glazed area and associated solar gain, and use of natural ventilation in summer.

RECOMMENDATIONS FOR IMPLEMENTING NET ZERO OPERATIONAL CARBON

5.27. LCC have undertaken consultation on a requirement for developments to achieve zero or net negative carbon emissions during the operational phase of a building's lifecycle.

[xv] The maximum space heating demand of 15kWh/m²/yr falls within the overall EUI target for each development type but features a separate target to emphasise the need for developers to reduce space heating demand through building design and fabric measures relating to heat demand.

Such a measure will be critical to Leeds meeting its science-based targets and 2030 net zero carbon goal.

5.28. This section has assessed how far changes to building standards and grid decarbonisation (if a heat pump rather than a gas boiler is installed) will go in delivering that. This was illustrated through the model runs for a typical home presented in Table 5. This evidence demonstrates why gas boilers are not an eligible heating option (this is explored further in Section 7) when zero carbon operational emissions are targeted. Beyond this, Tables 4 and 5 illustrate that under any building regulations scenario, carbon emissions remain which will need to be addressed if net zero operational emissions are to be achieved. For example, under FHS buildings regulations, a typical 3 bedroom home will emit 4.16 tonnes of carbon by 2050.

5.29. To address the gap between the levels of residual emissions and net zero operational carbon, an LPU policy could require:

- All developments to demonstrate how they reduce regulated operational carbon emissions to net zero or net negative.
- All developments to demonstrate how all possible measures will be taken to reduce unregulated carbon emissions to net zero or net negative.
- Energy Use Intensity requirements to be established alongside to encourage energy efficient design and demand reduction measures.

5.30. To enable appropriate enforcement of this requirement, an LPU policy could require that developers demonstrate how the development meets this net zero operational carbon requirement by presenting annual and cumulative carbon emissions for 30 years as part of their planning application. This can be done using an approved building modelling software such as IES VE[xvi], SBEM[xvii], PHPP[xviii], etc., depending on the type of development, the outputs of which would be included in the planning application for officers to review. To reflect the changing grid carbon intensity, developers should employ the official UK government's expected electricity grid carbon intensity figures[xix] rather than the static carbon factors inherent in current Building Regulations / SAP methodology.

5.31. It may be appropriate for LCC to produce a design guide SPD alongside the LPU policies to support developers in meeting new carbon reduction and energy use targets.

[xvi] IES VE: Integrated Environment Solutions Virtual Environment, available from: https://www.iesve.com/
[xvii] Simplified Building Energy Model, available from: https://www.uk-ncm.org.uk/
[xviii] Passivhaus Planning Package: available from: https://passivehouse.com/04_phpp/04_phpp.htm
[xix] As outlined in Section 4.1.3, these are available from https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

6. CARBON COST AND OFFSETTING

APPROACH TO CARBON OFFSETTING

6.1. The legal precedence for local planning authorities to collect £/tonne of carbon cash-in-lieu payments from developments which are unable to meet carbon emissions planning requirements is well established[85]. Planning authorities in London have jointly collected around £130m in carbon offset payments since 2016[86]. Carbon offset schemes have also been established outside of London including in Southampton, Reading and Milton Keynes[87–89].

6.2. The scale and urgency of climate change requires all possible measures to be taken to drastically reduce carbon emissions[90,91]. For an LPU policy to be effective at supporting Leeds in achieving its science-based targets, the option to pay into an offset fund should be a last resort only available once every possible measure to reduce onsite carbon emissions has been taken. This approach is outlined in the London Plan energy hierarchy shown in Figure 6[86].

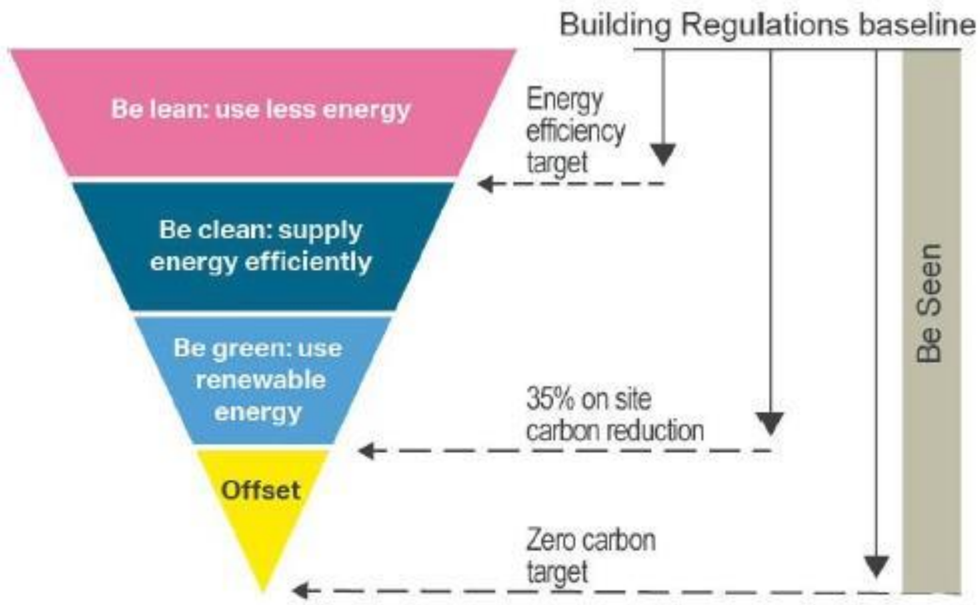


Figure 5 The London Plan energy hierarchy and associated targets showing offset as a last resort[86]

6.3. The £/tonne of carbon cash-in-lieu contribution which LCC may levy to developers will need to be balanced based on the best available science on the true cost of carbon, and on established practice. In London, beyond the minimum onsite 35% reduction in carbon emissions, the London Plan includes a figure £95/tonne for every tonne of operational carbon over 30 years[86]. Outside London, carbon offset payments are less well established, but have been implemented at £60/tonne of operational carbon per year for 30 years (Reading), £200/tonne of operational carbon for 1 year (Milton Keynes) and £210/tonne of operational carbon for one year (Southampton)[87–89].

6.4. The UK Government provides an official £/tonne of carbon emissions which should be taken into account by decision-makers across government when evaluating projects[xx]. This approach is useful because is in line with an approved government methodology[92]. As of 2022, the cost of carbon is set at £248/tonne, and this will increase to £280/tonne by 2030.

COST OF CARBON

6.5. It is important to understand the true cost of carbon if the option of carbon offset payments is to be offered to developers in Leeds.

6.6. Evidence shows however that the real cost of carbon is routinely underestimated[93–95]. Costs of carbon include will arise from many impacts, including but not limited to:

- More frequent and intense floods and droughts
- Sea-level rise
- Destruction of biodiversity and the collapse of ecosystems
- Population displacement and migration

6.7. Although it is very complex to model costs of future climate change and feedback loops, when these costs and the damage they cause to long-term economic productivity are assessed, the latest research finds the true cost of carbon to be over $3,000/tonne[94,96].

RECOMMENDATIONS FOR CARBON COST AND OFFSETTING POLICY

6.8. Because of the urgency of carbon emissions reduction, and the 'true' cost of carbon being significantly higher than current planning authority values, it is recommended that the LPU makes carbon offsetting an option of last resort once all possible onsite measures have been taken to reduce embodied and operational emissions.

6.9. Whilst the true cost of carbon is likely to be many times currently recognised figures, it is important that the LPU requirements are based on legally defensible grounds. Given the uncertainty around the cost of carbon, it is recommended that UK government's valuation could be used as a basis. This is because:

1. It is based on solid evidence and is already used by UK government decision-makers when appraising projects.
2. It reflects an increasing cost of carbon and is updated regularly to reflect the latest data.

6.10. If LCC opt to allow developers to pay a cash-in-lieu contribution, it is recommended that a different approach could be taken for minor/household applications compared to larger developments:

[xx] This is available at https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation

- For minor and household developments – following all onsite measures to reduce embodied and operational carbon to net zero, any further *operational* carbon costs are levied for the total carbon emissions for 30 years, calculated using the UK Government's cost of carbon and grid carbon intensity valuations (see Paragraph 6.4).
- For larger developments (+10 dwellings, +500m² floor space) – following all onsite measures to reduce embodied and operational carbon to net zero, any further *embodied and operational* carbon costs are levied for the total carbon emissions for 30 years, calculated using the UK Government's cost of carbon and grid carbon intensity valuations (see Paragraph 6.4).

6.11. Whilst this marks an increase compared to what other planning authorities currently require, it is justifiable in terms of the true cost of carbon, whilst being rooted in established UK practice in other settings.

7. HEATING APPROACH

7.1. Heating and cooling of buildings accounts for around 38% of total energy consumption and 33% of GHG emissions in the UK[97,98]. The UK's extensive natural gas grid which serves 86% of UK homes has contributed to slow progress in heat decarbonisation[99].

7.2. The choice of which heating technology or approach to choose for a development has been closely tied to national Building Regulations. This is primarily because the carbon reduction a development is required to achieve must be modelled against a standard model of the building which is set by Building Regulations. The building regulations which have been in place to June 2022 (Part L 2013) have featured out-of-date carbon factors which has made natural gas appear to be a lower carbon option than electricity[77,100].

7.3. New building regulations (Part L 2021 Uplift) which came into force in June 2022 updated the carbon factors to reflect electricity being significantly lower carbon than natural gas[72,74]. However the notional building against which a development must compare continues to feature a gas boiler. In practice, the interim standards may lead developers to continue to choose gas boilers and install solar PV panels to reduce the carbon impact[101,102]. Evidence was set out in Tables 4 and 5 which demonstrated the carbon emissions that would result from continued reliance on gas boilers. There are also important reasons to avoid developers switching to direct electric heating to take advantage of the lower recognised carbon factors of grid electricity, and this is discussed in Paragraphs 7.19-7.20.

7.4. Net zero compatible heating solutions are available now and could be mandated through the LPU policies. Heating technology choices made by developers also have ongoing fuel cost impacts for occupants for the lifetime of a building (or until future retrofit). Therefore for the benefit of future building occupants, it would be ideal for a heating policy to require developers to choose not only the lowest carbon but also the lowest running cost system. Such practice has been established elsewhere through local planning policy[26]. The review of heating technologies in Paragraphs 7.5-7.26 examines the different heating technology options with a summary in 7.27. Paragraphs 7.28-7.32 explore impact of the heat network zoning proposals, and Paragraphs 7.33-7.45 make recommendations for LCC's revised heating policy.

REVIEW OF CURRENT HEATING TECHNOLOGIES

Heat pumps

7.5. Heat pumps use electricity to take energy from outside air, ground or water sources to generate heat and/or hot water within a building efficiently[103]. Rather than generate heat directly, electricity is used to power a compression cycle which enables heat pumps to absorb heat energy and transfer it to where it can be used. The instantaneous useful heating delivered per unit of energy input is known as the coefficient of performance (COP)[104,105]. Whilst direct electric resistive heating delivers a COP of 1, heat pumps can deliver COP values of 3-4.5 and higher although in-practice performance will depend on a range of factors including how the technology is operated by building occuptants[103]. In practical applications, many heat pump installations are also associated with other equipment that consumes electricity, such as circulation pumps in wet central heating systems, or ground heat exchangers. The field seasonal performance factor (SPF) which accounts for this will be lower than the COP, and gives a better guide to understanding operating costs[106].

7.6. Because they use electricity to generate heat, and with a rapidly decarbonising electricity grid (as discussed in Section 5) heat pumps are net zero compatible. They are recognised by the Government as being key to the decarbonisation of heat and buildings, especially in new build settings[13]. Although they operate using the same principle, there are several types of heat pump system and the most common are presented here.

Air source heat pumps

7.7. Air source heat pumps (ASHPs) extract energy from the air outside the building via a fan unit and use refrigerant and a compressor to bring heat into the building. They can deliver heat as warm air (known as air-to-air systems) or to a wet central heating system (known as air-to-water or hydronic systems)[107]. If an air-to-air heat pump is chosen, additional direct electric resistive heating is likely to be required for hot water generation and this should be included in carbon and fuel cost calculations. The UK Government does not consider air-to-air heat pumps in its future heat decarbonisation plans[13].

7.8. Whilst they can continue to operative efficiently even in air temperatures well below zero, the SPF will decrease at lower temperatures requiring more energy to run the compression cycle. ASHPs can provide an average SPF of around 3 although as noted performance can impacted by a range of factors[108].

Ground source heat pumps / water source heat pumps

7.9. Ground source heat pumps (GSHPs) and water source heat pumps (WSHPs) are also hydronic systems, which take energy from a range of surface and subsurface sources including shallow and deep geothermal, aquifers, rivers, lakes, buried infrastructure such as tunnels and building foundations, wastewater networks etc. For single building installations, they typically require space for a borehole or horizontal ground heat exchanger, which comprises pipes laid under the ground near the building.

7.10. Because of the more stable temperature of the ground or water sources, GSHPs can typically deliver a higher efficiency than ASHPs, with a SPF of around 4-5 under ideal conditions[108]. This means that although GSHPs are typical more expensive to install than an ASHP, due to the additional construction of a ground heat exchanger, they should be cheaper to run. If set up to do so, GSHPs can recharge the ground or water source with heat from summer cooling or other waste heat sources, to improve long-term performance.

Shared ground heat exchange

7.11. Shared ground heat exchange (SGHE) combines distributed heat pumps across multiple properties connected to a shared ground array via an ambient temperature heat network. SGHE may be particularly suitable for medium-density or semi-urban areas where individual heat pumps or heat networks may not be the best solution[109].

7.12. SGHE can also be installed where there is insufficient space for individual heat pump systems, such as in rows of terraced homes or housing blocks, and can offer the higher efficiency of GSHPs to multiple properties with associated lower running costs. SGHE is currently being retrofitted to existing housing blocks as part of Leeds City Council's plans to improve energy efficiency and tackle fuel poverty[110–112].

7.13. Other benefits of SGHE include[113,114]:

- Ambient temperature operation means heat losses are minimised.
- Can make use of low grade energy such as shallow geothermal and waste heat
- Can support overall energy system balancing
- Each end user has control of their own heat pump and can choose their energy provider (electricity utility) to find the best tariff.
- Can provide both heating and cooling (as other heat pump systems).

7.14. Figure 7 shows where individual heat pumps, shared ground heat exchange and heat networks (see Paragraphs 7.15-7.18) may work best over different scales from single system to city scale.

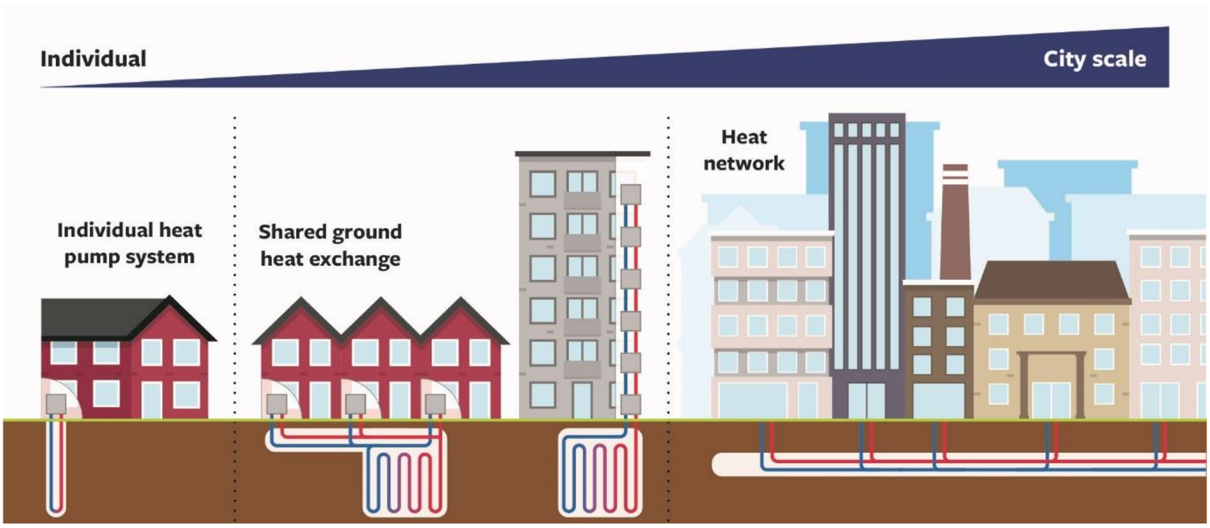


Figure 6 Application of low carbon heating systems over a range of scales. Source Bale et al[109]

Heat networks

7.15. Heat networks are systems in which heating, cooling or hot water is generated at a central source and supplied to multiple users through a pipe network serving either multiple buildings (district heat network) or multiple occupants in a single building (communal heat network)[115]. They offer particular advantages in dense urban areas where many users can be supplied with low carbon heat from the same source or sources, using the shared infrastructure. They are an important part of the solution for heating decarbonisation[13,116–118]. Whilst many heat networks have historically been supplied by natural gas, they can be set on a zero carbon trajectory through replacing natural gas with a low carbon source (see Paragraph 7.8)[120,123].

7.16. It is important that heat networks are well-designed, constructed and operated to deliver heat efficiently with minimal losses between the point of generation and consumption by the end user[119–121]. Careful consideration to both the primary (between generation and the building) and secondary (within building) elements must be given to ensure the system operates efficiently for the building characteristics and at the lowest possible temperature[76,120,122]. Building regulations recognise a 30-55% loss factor where information about actual heat network performance is not available[72,74,81]. No analysis of the efficiency or characteristics of Leeds PIPES heat network has been included in this study, but this information can be obtained from the LCC Heat Networks Team.

7.17. A voluntary industry Code of Practice has been established to try and improve standards in heat network design, construction and operation[128]. The UK Government will require this or similar technical standards to be used for heat networks within zones[116,129]. The government is also introducing regulations to protect heat network customers[130]. In addition, the move towards lower temperature heat networks can enable the use of a wider range of low carbon heat sources[124–127].

7.18. The UK Government recognises that heat networks will play a key role in the transition to net zero[13,131] (see Paragraphs 7.28-7.32). Because they are able to connect multiple users to shared heat source/s, heat networks can make use of abundant renewable energy which would otherwise be wasted or not viable for exploitation. Suitable sources for heat networks can include:

- Rivers and other surface water sources[119,132]
- Subsurface water sources such as abandoned mine workings and aquifers[133,134]
- Shallow geothermal heat[135,136]
- Buried infrastructure such as building foundations, tunnels, and wastewater networks[113,137]
- Deep geothermal[138]
- Waste heat from other sources such as industrial sites or data centres, for example[139]
- Heat captured from pre-existing Energy from Waste (EfW) plants

Direct electric resistive heating

7.19. Direct electric resistive heating uses electricity to generate heat by passing a current through a resistant material which heats up. Direct electric resistive heating features low upfront cost and easy to install, mostly because it does not require wet central heating. With the lower carbon intensity of the electricity grid now being reflected in national building regulations, developers may be likely to opt for this approach unless prohibited by local planning policies[140].

7.20. Whilst direct electric resistive heating will decarbonise in line with the electricity grid, widespread deployment would result in significantly higher energy consumption and could cause additional problems for managing competing demands on the national grid such as from the shift to electrified trasnport[104,105,141]. Low carbon electricity, like any energy source, is a finite resource and will need to be used as efficiently as possible. Direct electric resistive heating will always be comparatively inefficient compared to heat pumps[140]. This is likely to result in significantly higher energy bills for future building occupants. For these reasons it has already been ruled out by planning authorities in other cities such as Bristol[142].

Gas boilers

7.21. Gas boilers combust natural gas (methane) supplied by the gas grid to generate heating and hot water. They are seen as convenient and familiar and experience high levels of user satisfaction. However gas boilers are not compatible with the UK's legally mandated net zero target or LCC's local target[9,143]. Tables 4 and 5 set out the carbon emissions impact of allowing continued gas boiler installation in new developments using an example of a typical UK home.

7.22. Importantly to meet decarbonisation targets, any gas boilers installed now will have to be replaced with a net zero compatible heating technology. This will cause disruption and expense to the future owner or resident. The UK Government has made it clear that new build developments should be futureproofed so that they do not require later retrofit[13] and it is expected that new connections to the gas grid will be phased out from 2024 (non-residential) / 2025 (residential)[13,76]. For these reasons, and to ensure that future changes to national government policy do not threaten Leeds' ability to deliver on its local carbon reduction targets, gas boilers should not be included as options in the LPU heating policy[xxi].

Hydrogen boilers

7.23. The shift to hydrogen for heating could make use of the existing gas grid for delivery to homes and businesses, and in theory hydrogen boilers would operate in much the same way as natural gas boilers do now. Hydrogen is likely to play a key role in decarbonising

[xxi] Gas boilers have already been successfully made ineligible in other areas e.g. Bristol Core Strategy BCS14[144]

sectors of the economy which are difficult to electrify such as industrial processes and long range transportation[145].

7.24. Hydrogen boilers are inherently less efficient than direct use of electricity in a heat pump. This is because to generate the required green hydrogen would require a much larger renewable electricity system[101]. The cost of hydrogen production is also predicted to be far greater than renewable electrcity[145]. There are also concerns about leaks in transmission and the global warming impacts of hydrogen generation and supply[146,147].

7.25. The UK Government is currently gathering evidence to support a decision on the role of hydrogen by 2026[131]. However, given the cost and emissions disadvantages of hydrogen for heating, other countries have already ruled this out[148]. It is also not currently possible for hydrogen to be sourced through the gas grid and it is vital that this does not delay the deployment of low carbon heating options in new developments. For these reasons, hydrogen boilers should not be included as an eligible option in the LPU heating policy.

Biomass boilers

7.26. Solid biomass such as wood in chipped or pelletised form can be burned in individual or networked biomass boilers to provide heating and hot water. However, this approach can cause significant air pollution and associated health issues and is therefore not suitable for urban settings[13,149]. With pollution abatement technologies, biomass could be applicable to more rural areas.

Summary of heating technology options

7.27. Table 7 presents a summary of heating technologies discussed and clarifies which options should be included as eligible options for new developments.

Table 7 Summary of heating technology options

Heating technology	Energy source	Advantages	Disadvantages	Eligible system
Air source heat pumps	Electricity (grid or locally generated) + air	Highly efficient, net zero compliant as grid decarbonises, price competitive with natural gas when designed and operated effectively	High capital costs, requires outside space for fan unit and inside space for thermal storage, efficiency reduces in colder weather	Yes
Ground source heat pumps	Electricity (grid or onsite) + ground heat	Highly efficient, net zero compliant as grid decarbonises, price competitive with natural gas when designed and operated effectively	High capital costs, require outside space for ground heat exchanger and inside space for TES	Yes

Heating technology	Energy source	Advantages	Disadvantages	Eligible system
Shared ground heat exchange	Electricity (grid or onsite) + environmental energy (ground)	Highly efficient, can be installed where there is no or little outside space, net zero compliant as grid decarbonises	High capital costs, requires inside space for thermal storage, requires pipework and borehole installation	Yes
Heat network	Multiple, but going forwards should be on net zero carbon trajectory	Can make use of a range of low carbon heat sources which could otherwise not be exploited, can offer low running costs to users	High capital costs, cost and complexity of metering and billing users	Yes
Individual gas boiler	Natural gas (methane)	Well-liked by users, established supply chains, low capital cost	No path to net zero carbon, will need to be replaced at household expense	No
Direct electric resistive heating	Electricity (grid or locally generated)	Easy to install, low capital cost	Inefficient, can lead to higher energy bills, grid impacts	No
Hydrogen boiler	Hydrogen generated by renewable electricity or methane + CCS	Will be more of a like-for-like replacement for gas boilers	Very low efficiency (c18%), hydrogen leaks could increase global warming, no hydrogen network available	No
Biomass boiler	Wood, wood pellets / chips	Operates in a similar way to a typical gas boiler	Potential air pollution, health impacts	In limited rural settings

HEAT NETWORKS AND PREPARING FOR HEAT NETWORK ZONING

7.28. The UK Government is developing policies to designate *heat network zones* across England by 2025[116,129]. This forms a key part of the Government's strategy to increase heat network deployment and achieve net zero[131]. A heat network zone is defined as, *"a designated area within which heat networks are the lowest cost, low carbon solution for decarbonising heating for an area"*[129]. In practice, zoning proposals will mean heat networks are likely to grow outwards from city centres with their large non-domestic heat demands[109].

7.29. Primary legislation will be required to implement the proposals, and the consultation documents suggest the preferred option would be that within in a heat network zone, *"all new builds, large non-domestic, large public sector and communally heated* *residential blocks would be required to connect to heat networks"*[116,150]. All options under consideration will require new developments within heat network zones to connect to a heat network.

7.30. It is expected that central government will map and assign heat network zones. They will appoint Local Zoning Coordinators to refine, implement and enforce heat network zones. These are likely to be local or regional authorities. However this is arranged locally, the planning system will be integral to implementing heat network zones for new buildings[151].

7.31. The methodology for assigning where heat networks will be the lowest cost, low carbon solution is currently under development. Leeds City Council is one of several pilot sites for heat network zones and LCC is working with Government to support development of the zoning methodology[152]. LCC therefore has the opportunity to help shape this important work to support the development of fossil-free heat networks which make use of renewable energy sources as outlined in Paragraphs 7.15-7.19.

7.32. To avoid the need for later modification, any policy regarding the choice of heating system will need to reflect the introduction of heat network zones to stipulate that any development within a zone must be able to connect to a low carbon heat network.

Recommendations for heating technology policy

7.33. Further to the range of suggested heating technologies included in Paragraphs 7.5-7.27 and the implementation of heat network zones as outlined in Paragraphs 7.28-7.32, the recommendations for an LPU policy on heating are in two parts, for developments outside of and within heat network zones.

7.34. An important aspect of any new heating policy is the effect it will have on decisions made by developers which then impact on energy costs for future building occupants, for the life of the building (or until future retrofit). Therefore, in line with the approach taken in other local plan updates, it is recommended that developers are required to provide figures on anticipated heat unit supply price (£/kWh), annual standing charge and estimated annual maintenance costs of their proposed heating system[26], and that this forms a key part of the technology decision.

Development outside of heat network zones

7.35. For development outside of heat network zones or any site where connection to a heat network is not mandatory under future legislation, it is recommended that the heating policy gives flexibility to developers to choose the best approach for the site within the permitted options above, rather than by setting a strict hierarchy.

7.36. Developers should be supported to consider a range of technology options, and this may be through provision of information and case studies. It is important that the policy doesn't inadvertently prevent the adoption of as-yet unknown low carbon and low running cost heating technologies and so the planning authority should retain the ability to add future technologies to an eligible list.

7.37. In order that LCC officers can properly assess planning applications, the policy could require developers to model a range of options and present the results of that modelling, against two primary criteria:

1. Annual carbon emissions each year for 30 years, using the government's official electricity grid carbon intensity factors.
2. Annual running costs for occupants each year for 30 years, using the government's official retail fuel costs.

7.38. Both (1) and (2) are available from HM Treasury Green Book Supplementary Guidance[xxii] and are updated regularly. The most up-to-date figures should be used.

7.39. The results of the analysis should be presented clearly for planning officers to be able to assess and verify the predicted carbon and fuel cost figures. If a developer choses an option which does not deliver the lowest carbon and cost combination, they must provide a sound justification for this decision, with planning officers retaining the right to refuse on this basis.

7.40. For developments with very low energy requirements, such as where the Passivhaus Standard is met, the same principle should be adopted but some additional technology flexibility may be appropriate if it can be demonstrated that the carbon emissions and fuel costs are lowest.

7.41. Where connection to a heat network is proposed, the developer should attempt to obtain as-delivered carbon factors from the scheme operator and use these in the modelling calculations. If this cannot be obtained, the heat loss factor set out in SAP should be followed to produce a carbon factor for delivered heat (see Paragraphs 5.6-5.7).

Development within heat network zones

7.42. For developments taking place within officially designated heat network zones, connection to a heat network is likely to be mandatory under the legislation to be implemented by 2025. It would be beneficial for future implementation and reducing the need for later revision if the heating policy reflected this requirement, noting the definition that the heat network zone will constitute the *lowest cost, low carbon solution for decarbonising heating for an area*.

7.43. It would be ideal if the policy included a form of words to implement the heat network zoning policy to avoid the need for later revision. However, the same principle could apply for developments within heat network zones as those outside of zones - that

---

[xxii] HM Treasury Green Book Supplementary Guidance https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal (carbon factors: Table 1, grid average; retail fuel prices: Tables 4-8 'High' scenario)

developers need to model a range of options and present the results of that modelling, against two primary criteria:

1. Annual carbon emissions each year for 30 years, using the reported carbon intensity of the heat network and government's official electricity grid carbon intensity factors (as appropriate).
2. Annual running costs for occupants each year for 30 years, using the reported energy costs from the heat network and the government's official retail fuel costs (as appropriate)[92].

7.44. Careful consideration should be given to primary and secondary elements which are designed for the demand characteristics of the new development and operate to as low a temperature as possible. This can be delivered through low and ultra-low/ambient temperature networks, including the shared ground heat exchange approach discussed in Paragraphs 7.11-7.14, as well as mandating the use of technical standards such as the Cope of Practice CP1 as set out in Paragraph 7.17.

7.45. However once these issues are addressed, LCC can take the opportunity through the LPU to support the deployment of heat networks which make use of abundant subsurface and surface renewable resources including shallow and deep geothermal, rivers, abandoned mine workings, buried infrastructure, waste heat from urban processes and pre-existing EfW plants[113,134,135,137,138]. This is likely to involve strategic direction and involvement from LCC in the development of fossil-free heat networks, but the LPU can also encourage developers to seek opportunities to develop and exploit these resources. In addition, the LPU will have a role in ensuring anchor loads in heat network zones support the business case for development.

8. CONCLUSIONS AND SUMMARY OF RECOMMENDATIONS

8.1. This report set out to establish an evidence base to support how the Local Plan Update can deliver four Leeds City Council primary policy objectives:

1. Reducing whole lifecycle carbon in buildings
2. Delivering net zero operational carbon
3. Implementing sustainable construction standards
4. Increasing deployment of heat networks

8.2. As noted in Section 1, key to success of the LPU implementation will be for robust and consistent application of the requirements.

8.3. Section 2 clarified the definition of what the delivery of net zero embodied, operational and whole lifecycle carbon buildings in Leeds might mean.

8.4. Section 3 presented an analysis of sustainable building standards which assessed how implementing a requirement for use of specific standards may impact the key LPU carbon reduction objectives. It is recommended that the LPU include a requirement for the use of an appropriate construction standard from an approved list and rating as specified, providing the other requirements to achieve net zero operational emissions, reducing embodied carbon emissions, and heating approach are met.

8.5. Section 4 set out of a review of approaches to whole lifecycle carbon emissions assessment and explored whether the approach implemented in London would be eligible for Leeds. This section established that reuse and refurbishment should always be first priority, with demolition and new construction being the last resort. Beyond this, the proposal is to implement elements of the London approach. A proposal is set out for smaller developments to use WLC assessments and demonstrate how all measures have been taken to reduce embodied carbon, and for larger developments to achieve net zero embodied carbon emissions through a hierarchy of measures.

8.6. Section 5 focused on operational carbon emissions of developments, in light of the changes to building regulations and the UK's decarbonising electricity grid. A model was presented which showed how these, along with heating technology choices, impact on annual and cumulative carbon emissions from developments. This establishes the gap that further onsite measures are required to address to achieve net zero operational carbon. A requirement and methodology for developments to achieve net zero operational carbon is proposed alongside a set of Energy Use Intensity targets (see Paragraph 8.9 for summary).

8.7. Section 6 explored the issue of the true cost of carbon and the need for offsetting to be the very last resort when all other measures have been taken on site. For sites which cannot achieve zero carbon operational, a £/tonne cost of carbon following UK government guidelines was proposed for minor/household applications and major developments.

8.8. Finally, Section 7 outlined that efficient electrified systems such as heat pumps and low carbon heat networks should be eligible in developments, and proposed that developers model a range of options against carbon emissions and operational costs for building occupants for 30 years as part of justifying the proposed approach. The issues around the development of heat networks, especially in light of the heat network zoning regulations, were set out, and proposals were made for treatment of developments within and outside of heat network zones.

SUMMARY OF RECOMMENDATIONS

Sustainable construction standards

8.9. The use of standards can help deliver better development in Leeds, but with no standard currently available that will deliver against all the relevant LPU policy objectives, these will need to be combined with other requirements. If standards are to be required by the LPU, suggestions are made as to appropriate levels to implement.

Reducing whole lifecycle emissions

8.10. Tools and methodologies for undertaking WLC assessments are available now. The GLA's approach is based on 16 principles and 3 stages of assessment, and employs all aspects of the recognised WLC methodology, and would be appropriate for Leeds. The One Click LCA tool can help developers of all sizes undertake WLC assessments and meets the GLA requirement. It is recommended that a WLC policy would:

- Prioritise retention and reuse over demolition and rebuild.
- Require all developers to assess WLC emissions and take all reasonable measures to reduce embodied carbon.
- Require larger developments to achieve net zero embodied carbon emissions including a last resort option to offset carbon locally through a cash-in-lieu contribution.

Delivering net zero operational carbon developments

8.11. Because new building regulations do not achieve net zero operational emissions, it is recommended that an LPU policy would:

- Require all developments to demonstrate how they reduce regulated operational carbon emissions to net zero or net negative carbon emissions over 30 years.
- Require all developments to demonstrate how they will take all possible measures to reduce unregulated carbon emissions to net zero or net negative.
- Require all developments to comply with local Energy Use Intensity targets.

Increasing deployment of heat networks

8.12. This is dealt with as part of a wider set of proposals for how new developments are heated. The deployment of heat networks is considered in light of Government plans to implement heat network zones. It is recommend an LPU policy would:

- Outside heat network zones
    - Rather than specify a hierarchy, include a list of eligible heat options which are net zero compliant, and prevent developments from adopting heating systems that are not net zero complaint (such as gas boilers).
    - Require developers to model carbon emissions and running costs for 30 years and adopt the best combination unless an alternative can be justified.
- Inside heat network zones
    - Implement heat network zones where new buildings will be required to connect without further policy revisions.
    - Support the deployment of low carbon, high quality heat networks which make use of abundant renewable energy sources.
    - Require developers to model carbon emissions and running costs for 30 years and adopt the best combination unless an alternative can be justified.

Carbon offsetting

8.13. It is recommended an LPU policy makes carbon offsetting via a local cash-in-lieu contribution a last resort option, following a nationally recognised pricing mechanism.

8.14. Overall, the report has set out evidence and proposals to support the development of an LPU which would help Leeds live up to its climate change and carbon reduction commitments. The policies that LCC are developing through the LPU have the ability to put Leeds in the vanguard UK cities taking bold and justified measures to significantly reduce the carbon impact of new development. The carbon reduction and other LPU objectives have the ability to support Leeds' transition to a climate-safe, liveable and healthier city.

References

1. Leeds City Council. Proceedings of the Meeting of the Leeds City Council held Civic Hall, Leeds on Wednesday, 27th March, 2019. at https://democracy.leeds.gov.uk/documents/g8292/Printed%20minutes%2027th-Mar-2019%2013.00%20Council.pdf?T=1 (2019).
2. Gouldson, A., Sudmant, A., Duncan, A. & Williamson, R. F. *A Net-Zero Carbon Roadmap for Leeds*. https://www.leedsclimate.org.uk/leeds-carbon-roadmap (2020).
3. Ellis, H. & Fieth, J. *The Climate Crisis: A Guide for Local Authorities on Planning for Climate Change*. https://www.rtpi.org.uk/media/9379/tcpa-rtpi-climate-guide_oct-2021_final.pdf (2021).
4. LCC. Leeds local plan update: Introduction and summary. https://www.leeds.gov.uk:443/planning/planning-policy/local-plan-update/introduction-and-summary (2021).
5. Leeds City Council. *The Leeds local plan update scoping consultation 2021*. https://www.leeds.gov.uk/docs/Local%20Plan%202021.pdf (2021).
6. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. (Cambridge University Press, 2021).
7. CCC. *Reducing UK emissions: 2018 Progress Report to Parliament*. (2018).
8. HM Government. *2020 UK greenhouse gas emissions, provisional figures*. https://data.gov.uk/dataset/9a1e58e5-d1b6-457d-a414-335ca546d52c/provisional-uk-greenhouse-gas-emissions-national-statistics (2021).
9. Barns, D. G., Taylor, P. G., E Bale, C. S. & Owen, A. Important social and technical factors shaping the prospects for thermal energy storage. *Journal of Energy Storage* **41**, 102877 (2021).
10. BEIS. Emissions of carbon dioxide for Local Authority areas. *Emissions of carbon dioxide for Local Authority areas* https://data.gov.uk/dataset/723c243d-2f1a-4d27-8b61-cdb93e5b10ff/emissions-of-carbon-dioxide-for-local-authority-areas (2021).
11. CCC. *UK housing: Fit for the future?* (2019).
12. Currie & Brown & AECOM. *The costs and benefits of tighter standards for new buildings*. https://www.theccc.org.uk/publication/the-costs-and-benefits-of-tighter-standards-for-new-buildings-currie-brown-and-aecom/ (2019).
13. BEIS. *Heat and Buildings Strategy*. https://www.gov.uk/government/publications/heat-and-buildings-strategy (2021).
14. Barton, C., Booth, L. & Wilson, W. *Tackling the under-supply of housing*. https://commonslibrary.parliament.uk/research-briefings/cbp-7671/ (2022).
15. DLUHC. Housing Delivery Test: 2021 measurement. *GOV.UK* https://www.gov.uk/government/publications/housing-delivery-test-2021-measurement (2022).
16. Planning Advisory Service. *Housing Delivery Test: Preparing Effective Action Plans.* https://www.local.gov.uk/sites/default/files/documents/Housing%20Delivery%20Test%20Preparing%20an%20Effective%20Action%20Plan%20June%202020_0_1.pdf (2020).

17. Homes England. Financial viability for housing-led projects. *GOV.UK* https://www.gov.uk/guidance/financial-viability-for-housing-led-projects (2021).
18. BEIS, DEFRA & HM Treasury. Update to Green Finance Strategy: call for evidence (accessible webpage). *GOV.UK* https://www.gov.uk/government/consultations/update-to-green-finance-strategy-call-for-evidence/update-to-green-finance-strategy-call-for-evidence-accessible-webpage (2022).
19. GFANZ. Glasgow Financial Alliance for Net Zero. *Glasgow Financial Alliance for Net Zero* https://www.gfanzero.com/ (2021).
20. United Nations, U. Financing Climate Action. *Climate Finance* https://www.un.org/en/climatechange/raising-ambition/climate-finance (2021).
21. Atelier Capital. *Atelier Carbonlite Challenge: Product Guide*. https://acp.co.uk/solutions?tab=carbonlite-challenge (2021).
22. Housing, Communities and Local Government Committee. *Modern Methods of Construction: Fifteenth Report of Session 2017-19*. https://publications.parliament.uk/pa/cm201719/cmselect/cmcomloc/1831/1831.pdf (2019).
23. UK Net Zero Carbon Building Standard. Home | UK Net Zero Carbon Buildings Standard. *UK Net Zero Carbon Buildings Standard* https://www.nzcbuildings.co.uk (2022).
24. UK Net Zero Carbon Building Standard. *UK Net Zero Carbon Buildings Standard: An introduction and how to get involved*. https://www.nzcbuildings.co.uk/_files/ugd/6ea7ba_2bd05d6f5d484cc999108e475a9d8c9c.pdf (2022).
25. BRE Global Ltd. *Home Quality Mark ONE: Technical Manual (England)*. https://www.homequalitymark.com/wp-content/uploads/2018/09/HQM-ONE-Technical-Manual-England.pdf (2018).
26. Islington Borough Council. *Islington Local Plan: Strategic and development management policies*. https://www.islington.gov.uk/-/media/sharepoint-lists/public-records/planningandbuildingcontrol/publicity/publicconsultation/20192020/20190904localplanstrategicanddmpoliciesdpdproposedsubmissionregulation19.pdf?la=en&hash=FF3732C05A253BDA47D04FB825CCD3730779D15A&hash=FF3732C05A253BDA47D04FB825CCD3730779D15A (2019).
27. Passivhaus Institute. Passivhaus Institut. https://passivehouse.com/ (2015).
28. Evans, H. *Making 'Net Zero' Happen: How can Authorities target the highest standards in energy performance for new council-led homes?* https://www.publicpractice.org.uk/resources/road-map-to-net-zero.
29. Passivhaus Trust. *Why Choose Passivhaus?* https://www.passivhaustrust.org.uk/guidance_detail.php?gId=15 (2015).
30. Passivhaus Trust. *Technical Guidance - Passivhaus: an Introduction*. https://www.passivhaustrust.org.uk/guidance_detail.php?gId=10 (2012).
31. Siddall, M. & Grant, N. *Technical Guidance - What it means to claim Passivhaus in the UK*. https://www.passivhaustrust.org.uk/guidance_detail.php?gId=25 (2015).
32. Clarke, A. Chapter 5: Building services. in *Technical Guidance - How to Build a Passivhaus: Rules of Thumb* (Passivehaus Trust).

33. McLeod, R. S. & Swainson, M. Chronic overheating in low carbon urban developments in a temperate climate. *Renewable and Sustainable Energy Reviews* **74**, 201–220 (2017).
34. Mitchell, R. & Natarajan, S. Overheating risk in Passivhaus dwellings. *Building Services Engineering Research and Technology* **40**, 446–469 (2019).
35. Fletcher, M. J., Johnston, D. K., Glew, D. W. & Parker, J. M. An empirical evaluation of temporal overheating in an assisted living Passivhaus dwelling in the UK. *Building and Environment* **121**, 106–118 (2017).
36. Taylor, M. *EnerPHit: The new Passivhaus refurbishment standard from the Passivhaus Institute*. https://www.passivhaustrust.org.uk/guidance_detail.php?gId=23 (2011).
37. Passivhaus Trust. Passivhaus goes Personal Custom & self-build Campaign. *Passivhaus Trust - Passivhaus goes Personal* https://www.passivhaustrust.org.uk/competitions_and_campaigns/passivhaus-goes-personal/#Self-build%20case%20studies (2021).
38. Passivhaus Trust. Agar Grove Phase 1A. *Passivhaus Trust - Agar Grove Phase 1a* https://www.passivhaustrust.org.uk/projects/detail/?cId=100 (2018).
39. Passivhaus Trust. Goldsmith Street. *Passivhaus Trust - Goldsmith Street* https://www.passivhaustrust.org.uk/projects/detail/?cId=101.
40. BRE Global Ltd. BREEAM New Construction 2018 (UK) - Issue 3.0. *BREEAM New construction - BRE Group* https://files.bregroup.com/breeam/technicalmanuals/NC2018/#01_introduction_newcon/3breeamuk_nc.htm%3FTocPath%3DIntroduction%2520to%2520BREEAM%7C_____1 (2019).
41. UK NCM. UK NCM: UK's National Calculation Method for Non Domestic Buildings. https://www.uk-ncm.org.uk/index.jsp (2022).
42. MHCLG. *Calculating the energy performance of buildings: Notice of approval of the methodology for expressing the energy performance of buildings in England and Wales*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1073221/Energy_performance_of_buildings_notice_of_approval.pdf (2018).
43. BREEAM. 09-Pollution - BREEAM Knowledge Base. https://kb.breeam.com/wp-content/plugins/breeamkb-pdf/pdf/?c=89 (2022).
44. International Living Future Institute. *Living Building Challenge 4.0: A Visionary Path to a Regenerative Future*. https://living-future.org/lbc/ (2019).
45. RIBA. *RIBA 2030 Climate Challenge: Vesion 2 (2021)*. https://www.architecture.com/-/media/files/climate-action/riba-2030-climate-challenge.pdf (2021).
46. UK Parliament. Emissions must be reduced in the construction of buildings if the UK is to meet net zero, MPs warn - Committees - UK Parliament. *Emissions must be reduced in the construction of buildings if the UK is to meet net zero, MPs warn* https://committees.parliament.uk/work/1147/sustainability-of-the-built-environment/news/171103/emissions-must-be-reduced-in-the-construction-of-buildings-if-the-uk-is-to-meet-net-zero-mps-warn/ (2022).
47. Mayhew, J. *Carbon Emissions (Buildings) Bill - Parliamentary Bills - UK Parliament*. (2022).

48. Partridge, J. Drive for net zero fuels UK boom in retrofitting buildings for new use. *The Guardian* (2022).
49. House of Commons & Environmental Audit Committee. *Building to net zero: costing carbon in construction. First Report of Session 2022–23.* https://committees.parliament.uk/publications/22427/documents/165446/default/ (2022).
50. UKGBC. The New Homes Policy Playbook. https://www.ukgbc.org/wp-content/uploads/2021/01/New-Homes-Policy-Playbook-January-2021.pdf (2021).
51. Röck, M. *et al.* Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation. *Applied Energy* **258**, 114107 (2020).
52. LETI. *LETI Climate Emergency Design Guide.* https://www.leti.london/_files/ugd/252d09_3b0f2acf2bb24c019f5ed9173fc5d9f4.pdf (2019).
53. BS EN 15978:2011: Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method. at https://bsol.bsigroup.com/en/Bsol-Item-Detail-Page/?pid=000000000030256638 (2011).
54. RICS. Whole Life Carbon Assessment for the Built Environment, 1st edition. *Whole Life Carbon Assessment for the Built Environment, 1st edition* https://www.rics.org/uk/upholding-professional-standards/sector-standards/building-surveying/whole-life-carbon-assessment-for-the-built-environment/ (2017).
55. Pitman, K. Lowering embodied carbon: five trends in building design and construction. *RICS World Built Environment Forum* https://www.rics.org/uk/wbef/megatrends/urbanisation/lowering-embodied-carbon-five-trends-in-building-design-and-construction/ (2021).
56. Varriale, F. The other side of the coin: Understanding embodied carbon. *RICS World Built Environment Forum* https://www.rics.org/uk/wbef/megatrends/natural-environment/the-other-side-of-the-coin-understanding-embodied-carbon/ (2021).
57. Delahunty, S. MMC cut carbon emissions by up to 45%, research finds. *Inside Housing* (2022).
58. Balfour Beatty. *Greening the Chain: Overcoming barriers for a Net Zero Supply Chain.* https://www.balfourbeatty.com/media/319122/greening-the-chain.pdf (2021).
59. UKGBC. *Embodied Carbon: Developing a Client Brief.* https://www.ukgbc.org/wp-content/uploads/2017/09/UK-GBC-EC-Developing-Client-Brief.pdf (2017).
60. Gibbons, O. P., Orr, J. J., Archer-Jones, C., Arnold, W. & Green, D. *How to calculate embodied carbon (Second edition)* -. (The Institution of Structural Engineers, 2022).
61. *The Town and Country Planning (Mayor of London) Order 2008. 2008 No. 580* (2008).
62. GLA. MD2962 London Plan Guidance – Whole life carbon and circular economy. *London City Hall* https://www.london.gov.uk//decisions/md2962-london-plan-guidance-whole-life-carbon-and-circular-economy (2022).
63. GLA. *London Plan Guidance: Whole Life-Cycle Carbon Assessments.* https://www.london.gov.uk/what-we-do/planning/implementing-london-plan/london-plan-guidance/whole-life-cycle-carbon-assessments-guidance#:~:text=Whole%20Life%2DCycle%20Carbon%20(WLC,carbon%20impact%20on%20the%20environment. (2022).

64. GLA. Annex Six: Glossary. *London City Hall* https://www.london.gov.uk//what-we-do/planning/london-plan/past-versions-and-alterations-london-plan/london-plan-2016/london-plan-annexes/annex-six-glossary (2015).
65. GLA. *The London Plan 2021*. https://www.london.gov.uk//what-we-do/planning/london-plan/new-london-plan/london-plan-2021 (2021).
66. GLA. *London Plan Guidance: Whole Life-Cycle Carbon Assessments*. https://www.london.gov.uk/sites/default/files/lpg_-_wlca_guidance.pdf (2022).
67. Iddon, C. R. & Firth, S. K. Embodied and operational energy for new-build housing: A case study of construction methods in the UK. *Energy and Buildings* **67**, 479–488 (2013).
68. Empty Homes Agency. *New Tricks with Old Bricks: How reusing old buildings can cut carbon emissions*. https://www.world-habitat.org/wp-content/uploads/2016/03/New-Tricks-with-Old-Bricks1.pdf (2016).
69. Leeds City Council. *Core Strategy (as amended by the Core Strategy Selective Review 2019)*. https://www.leeds.gov.uk/Local%20Plans/Adopted%20Core%20Strategy/Consolidated%20Core%20Strategy%20with%20CSSR%20Policies%20Sept%202019.pdf (2019).
70. BEIS & Kwarteng, K. Plans unveiled to decarbonise UK power system by 2035. *GOV.UK* https://www.gov.uk/government/news/plans-unveiled-to-decarbonise-uk-power-system-by-2035 (2021).
71. MHCLG. Conservation of fuel and power: Approved Document L. 2013 edition with 2016 amendments. *GOV.UK* https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l (2018).
72. DLUHC. *Conservation of fuel and power: Approved Document L: 2021 edition*. https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l (2022).
73. MHCLG. *The Future Homes Standard: 2019 Consultation on changes to Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations for new dwellings*. https://www.gov.uk/government/consultations/the-future-homes-standard-changes-to-part-l-and-part-f-of-the-building-regulations-for-new-dwellings (2021).
74. BRE. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings: Version 10.2 (21-04-2022)*. https://files.bregroup.com/SAP/SAP%2010.2%20-%2021-04-2022.pdf (2022).
75. BEIS. *Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal*. https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal (2021).
76. MCHLG. *The Future Homes Standard: 2019 Consultation on changes to Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations for new dwellings - Summary of responses received and Government response*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/956094/Government_response_to_Future_Homes_Standard_consultation.pdf (2021).

77. BRE. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings: 2012 edition*. https://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf (2014).
78. CCC. *Independent Assessment of UK Climate Risk*. https://www.theccc.org.uk/publication/independent-assessment-of-uk-climate-risk/ (2021).
79. Christidis, N., McCarthy, M. & Stott, P. A. The increasing likelihood of temperatures above 30 to 40 °C in the United Kingdom. *Nat Commun* **11**, 3093 (2020).
80. Environmental Audit Committee. *Heat-related deaths set to treble by 2050 unless Govt acts - Committees - UK Parliament*. https://committees.parliament.uk/committee/62/environmental-audit-committee/news/100427/heatrelated-deaths-set-to-treble-by-2050-unless-govt-acts/ (2018).
81. DLUHC. *Overheating: Approved Document O: 2021 edition*. https://www.gov.uk/government/publications/overheating-approved-document-o (2022).
82. Doughty, K. Unregulated energy – why we should care. *CIBSE Journal* https://www.cibsejournal.com/opinion/unregulated-energy-why-we-should-care/ (2018).
83. Bristol City Council. *Bristol Local Plan Review: Draft Policies and Development Allocations*. https://www.bristol.gov.uk/documents/20182/34536/Local+Plan+Review+-+Draft+Policies+and+Development+Allocations+-+Web.pdf/2077eef6-c9ae-3582-e921-b5d846762645 (2019).
84. UKGBC. *Net Zero Whole Life Carbon Roadmap: A Pathway to Net Zero for the UK Built Environment*. https://www.ukgbc.org/wp-content/uploads/2021/11/UKGBC-Whole-Life-Carbon-Roadmap-A-Pathway-to-Net-Zero.pdf (2021).
85. Stone, D., Coxcoon, R., Holley, M., Lamley, A. & Haycock, R. *West of England Carbon Reduction Requirement Study: Carbon offsetting in the West of England*. https://www.cse.org.uk/downloads/reports-and-publications/policy/planning/west-of-england-carbon-reduction-requirement-study-carbon-offsetting-april-2019.pdf (2019).
86. GLA. *Carbon Offset Funds: Monitoring Report 2020*. https://www.london.gov.uk/sites/default/files/2020_carbon_offset_survey_monitoring_report.pdf (2021).
87. Milton Keynes Council. *Sustainable Construction: Supplementary Planning Document November 2021*. https://www.milton-keynes.gov.uk/sites/default/files/2022-02/2021%2012%2003%20Sustainable%20Construction%20SPD%20adoption%20version.pdf (2021).
88. Southampton City Council. *Southampton City Council's Carbon Offset Fund 2015 Guidance*. https://www.southampton.gov.uk/media/x21pvzzy/carbon-offset-fund-guidance-2015_tcm63-371698.pdf (2015).
89. Reading Borough Council. *Sustainable Design and Construction Supplementary Planning Document (Adopted December 2019)*. https://images.reading.gov.uk/2019/12/Sustainable-Design-and-Construction-SPD-Adopted-December-19.pdf (2019).
90. IPCC. *Global Warming of 1.5 °C: an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission*

pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. (2018).

91. Fuss, S. *et al.* Negative emissions—Part 2: Costs, potentials and side effects. *Environ. Res. Lett.* **13**, 063002 (2018).
92. BEIS. Valuation of greenhouse gas emissions: for policy appraisal and evaluation. *GOV.UK* https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation (2021).
93. Diaz, D. & Moore, F. Quantifying the economic risks of climate change. *Nature Clim Change* **7**, 774–782 (2017).
94. UCL. Economic cost of climate change could be six times higher than previously thought. *UCL News* https://www.ucl.ac.uk/news/2021/sep/economic-cost-climate-change-could-be-six-times-higher-previously-thought (2021).
95. LSE. The missing economic risks in assessments of climate change impacts. *Grantham Research Institute on climate change and the environment* https://www.lse.ac.uk/granthaminstitute/publication/the-missing-economic-risks-in-assessments-of-climate-change-impacts/.
96. Kikstra, J. S. *et al.* The social cost of carbon dioxide under climate-economy feedbacks and temperature variability. *Environ. Res. Lett.* **16**, 094037 (2021).
97. BEIS. Final UK greenhouse gas emissions national statistics: 1990 to 2020. *GOV.UK* https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2020 (2022).
98. BEIS. Energy consumption in the UK 2021. *GOV.UK* https://www.gov.uk/government/statistics/energy-consumption-in-the-uk-2021 (2022).
99. Rosenow, J. *et al. The pathway to net zero heating in the UK.* https://ukerc.rl.ac.uk/UCAT/cgi-bin/ucat_query.pl?UWant=845 (2020) doi:10.5286/UKERC.EDC.000941.
100. HM Government. *The Building Regulations 2010: Approved Document L1A: conservation of fuel and power in new dwellings, 2013 edition with 2016 amendments.* (2018).
101. CCC. *Independent Assessment: The UK's Heat and Buildings Strategy.* https://www.theccc.org.uk/publication/independent-assessment-the-uks-heat-and-buildings-strategy/ (2022).
102. Lord Deben & Baroness Brown of Cambridge. Letter: Future Homes Standard and proposals for tightening Part L in 2020. (2020).
103. Gaur, A. S., Fitiwi, D. Z. & Curtis, J. Heat pumps and our low-carbon future: A comprehensive review. *Energy Research & Social Science* **71**, 101764 (2021).
104. Wilson, I. A. G. *et al.* Historical daily gas and electrical energy flows through Great Britain's transmission networks and the decarbonisation of domestic heat. *Energy Policy* **61**, 301–305 (2013).
105. Chaudry, M., Abeysekera, M., Hosseini, S. H. R., Jenkins, N. & Wu, J. Uncertainties in decarbonising heat in the UK. *Energ Policy* **87**, 623–640 (2015).
106. Gehlin, S. *et al. IEA HPT Annex 52 - Long-term performance monitoring of GSHP systems for commercial, institutional, and multifamily buildings.*

https://heatpumpingtechnologies.org/annex52/wp-content/uploads/sites/60/2022/04/kpiguidesubtask-3-reportfinal.pdf (2022).
107. Carroll, P., Chesser, M. & Lyons, P. Air Source Heat Pumps field studies: A systematic literature review. *Renewable and Sustainable Energy Reviews* **134**, 110275 (2020).
108. Ruhnau, O., Hirth, L. & Praktiknjo, A. Time series of heat demand and heat pump efficiency for energy system modeling. *Sci Data* **6**, 189 (2019).
109. Bale, C., Barns, D. & Turner, J. Shared ground heat exchange for the decarbonisation of heat. https://eprints.whiterose.ac.uk/185509/ (2022).
110. LCC. Decision - Housing District Heating: approval to award a construction contract for Wykebeck Valley and Barncrofts high rise clusters to Cenergist Limited. *Leeds City Council* https://democracy.leeds.gov.uk/ieDecisionDetails.aspx?ID=54400 (2021).
111. LCC. Decision - Authority to procure and spend on a Ground Source Heat Pumps (GSHP project to replace heating systems in four high rise housing buildings with). *Leeds City Council* https://democracy.leeds.gov.uk/ieDecisionDetails.aspx?ID=54462 (2021).
112. LCC. Thousands of Leeds tenants to enjoy cheaper energy bills as council appoints contractor to deliver £24m heating upgrades. *Leeds City Council News* https://news.leeds.gov.uk/news/thousands-of-leeds-tenants-to-enjoy-cheaper-energy-bills-as-council-appoints-contractor-to-deliver-gbp-24m-heating-upgrades (2021).
113. Meibodi, S. S. & Loveridge, F. The future role of energy geostructures in fifth generation district heating and cooling networks. *Energy* 122481 (2021) doi:10.1016/j.energy.2021.122481.
114. Buffa, S., Cozzini, M., D'Antoni, M., Baratieri, M. & Fedrizzi, R. 5th generation district heating and cooling systems: A review of existing cases in Europe. *Renewable and Sustainable Energy Reviews* **104**, 504–522 (2019).
115. BEIS. Regulations: heat networks (metering and billing). *GOV.UK* https://www.gov.uk/guidance/heat-networks (2022).
116. BEIS. *Heat Networks: Proposals for Heat Network Zoning: Government response*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1083318/heat-networks-zoning-consultation-government-response.pdf (2022).
117. CCC. *The Sixth Carbon Budget: The UK's path to Net Zero*. https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf (2020).
118. Daruwala, A., Workman, M. & Hardy, J. Identifying and unlocking the value from heat decarbonisation in the United Kingdom. *Energy Research & Social Science* **89**, 102672 (2022).
119. Millar, M.-A., Burnside, N. M. & Yu, Z. District Heating Challenges for the UK. *Energies* **12**, 310 (2019).
120. Miller, J. *Heat networks - POST*. https://post.parliament.uk/research-briefings/post-pn-0632/ (2020).
121. Mawhood, B. *Heat networks and energy prices (Research Briefing)*. https://commonslibrary.parliament.uk/research-briefings/cbp-9528/ (2022).

122. Sutton Decentralised Energy Network - Hansard - UK Parliament. https://hansard.parliament.uk//Commons/2022-02-04/debates/02841671-B369-4CA1-B0D8-AEA3E66978AD/SuttonDecentralisedEnergyNetwork.
123. BEIS. *Clean Growth - Transforming Heating: Overview of Current Evidence*. (2018).
124. Boesten, S., Ivens, W., Dekker, S. C. & Eijdems, H. 5th generation district heating and cooling systems as a solution for renewable urban thermal energy supply. in *Advances in Geosciences* vol. 49 129–136 (Copernicus GmbH, 2019).
125. Buffa, S., Cozzini, M., D'antoni, M., Baratieri, M. & Fedrizzi, R. 5th generation district heating and cooling systems: A review of existing cases in Europe. *Renewable and Sustainable Energy Reviews* **104**, 504–522 (2019).
126. Wirtz, M., Kivilip, L., Remmen, P. & Müller, D. 5th Generation District Heating: A novel design approach based on mathematical optimization. *Applied Energy* **260**, 114158 (2020).
127. Lund, H. *et al.* The status of 4th generation district heating: Research and results. *Energy* **164**, 147–159 (2018).
128. Jones, P., Woods, P. & Crane, M. *CP1 Heat networks: Code of Practice for the UK (2020)*. https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q3Y00000IMrmGQAT (2021).
129. BEIS. Proposals for heat network zoning. *GOV.UK* https://www.gov.uk/government/consultations/proposals-for-heat-network-zoning (2021).
130. BEIS. UK government announces major expansion of heat networks in latest step to power homes with green energy. *GOV.UK* https://www.gov.uk/government/news/uk-government-announces-major-expansion-of-heat-networks-in-latest-step-to-power-homes-with-green-energy (2021).
131. HM Government. *Net Zero Strategy: Build Back Greener*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf (2021).
132. Queens Quay, Clydebank. District Heating Network. *Queens Quay* https://www.queens-quay.co.uk/district-heating/ (2021).
133. Bailey, M. T., Gandy, C. J., Watson, I. A., Wyatt, L. M. & Jarvis, A. P. Heat recovery potential of mine water treatment systems in Great Britain. *International Journal of Coal Geology* **164**, 77–84 (2016).
134. Sakai, P., Hoffmann, F. & Carver, B. Using geothermal mine water energy for food production in Leeds. https://eprints.whiterose.ac.uk/185993/ (2022).
135. Abesser, C., Busby, J. P., Pharaoh, T. C., Bloodworth, A. J. & Ward, R. S. *Unlocking the potential of geothermal energy in the UK*. https://nora.nerc.ac.uk/id/eprint/528673/ (2020).
136. Barla, M., Mroueh, H., Loveridge, F. & Vieira, A. Editorial: Shallow geothermal energy for buildings and infrastructure. *Environmental Geotechnics* **7**, 223–224 (2020).
137. Loveridge, F. *et al.* The potential for heat recovery and thermal energy storage in the UK using buried infrastructure. *Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction* 1–14 (2022) doi:10.1680/jsmic.21.00018.

138. Gluyas, J. *et al.* Keeping warm: a review of deep geothermal potential of the UK. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy* **232**, 115–126 (2018).
139. Albert, M. D. A., Bennett, K. O., Adams, C. A. & Gluyas, J. G. Waste heat mapping: A UK study. *Renewable and Sustainable Energy Reviews* **160**, 112230 (2022).
140. Rees, S. J. Looking forward to UK low-carbon heating. *Building Services Engineering Research and Technology* **40**, 665–668 (2019).
141. Rees, S. & Curtis, R. National Deployment of Domestic Geothermal Heat Pump Technology: Observations on the UK Experience 1995–2013. *Energies* **7**, 5460–5499 (2014).
142. Bristol City Council. *Climate Change and Sustainability Practice Note*. https://www.bristol.gov.uk/documents/20182/239435/Climate+Change+and+Sustainability+Practice+Note.pdf/d8eb4fee-1c19-7a91-b523-0e038fb1b0b6 (2020).
143. Gross, R. & Hanna, R. Path dependency in provision of domestic heating. *Nature Energy* **4**, 358–364 (2019).
144. Bristol City Council. *Bristol Development Framework Core Strategy*. https://www.bristol.gov.uk/documents/20182/34540/Core+Strategy+WEB+PDF+(low+res+with+links)_0.pdf (2011).
145. Rosenow, J. & Eyre, N. Reinventing energy efficiency for net zero. *Energy Research & Social Science* **90**, 102602 (2022).
146. Howarth, R. W. & Jacobson, M. Z. How green is blue hydrogen? *Energy Science & Engineering* **9**, 1676–1687 (2021).
147. Warwick, N., Griffiths, P., Keeble, J., Archibald, A. & Pyle, J. *Atmospheric implications of increased hydrogen use*. https://www.gov.uk/government/publications/atmospheric-implications-of-increased-hydrogen-use (2022).
148. Kurmayer, N. Austria's new hydrogen strategy slams use in heating, transport – EURACTIV.com. *Euractiv* https://www.euractiv.com/section/energy/news/austrias-new-hydrogen-strategy-slams-use-in-heating-transport/ (2022).
149. DEFRA. *Clean Air Strategy 2019*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770715/clean-air-strategy-2019.pdf (2019).
150. BEIS. *Heat network zoning consultation stage impact assessment*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1024221/heat-network-zoning-consultation-stage-impact-assessment.pdf (2021).
151. RTPI. *RTPI response to BEIS consultation on Proposals for heat network zoning*. https://www.rtpi.org.uk/media/9673/rtpi-response-proposals-for-heat-network-zoning.pdf (2021).
152. Leeds City Council. *Climate Emergency Annual Report*. https://democracy.leeds.gov.uk/documents/s229402/Climate%20Emergency%20Cover%20Report%20310122.pdf (2022).

153. GLA. *London Plan Guidance: Circular Economy Statements*. https://www.london.gov.uk/sites/default/files/circular_economy_statements_lpg_0.pdf (2022).

APPENDICES

APPENDIX 1 – STUDY REQUIREMENTS

1. An assessment of the potential standards of sustainable construction, an assessment of their strengths and weaknesses and provide advice on which standard or standards would meet our policy objectives.
2. An assessment of whole life cycle emissions assessment against a minor or householder application to see how onerous it is for different development types and sizes.
3. What would be the most appropriate whole life cycle carbon assessment methodology to use? Would London's methodology work for Leeds?
4. A model (or example?) that allows development to assess how much CO2 they generate and what they need to do to get to zero carbon using our proposed policies. This would include a comparison of the carbon reduction expected through the current Part L building regulations against the proposed Future Homes/Building Standards.
5. Create a hierarchy of options for heating developments.
6. Advice on what our definition of zero carbon should be, assessed against what we can measure through planning (i.e. what is realistic and implementable).
7. Give an indication of what can be achieved through carbon off-setting and suggest an appropriate £ per tonne of CO2.
8. Recommendations for a revised policy on heat networks with a reasoned justification to support the recommendations. Part of this policy work to include an assessment of the benefit (in saved costs and living conditions) of a development connecting to a heat district network.

APPENDIX 2 – GLA CIRCULAR ECONOMY STATEMENTS

In addition to the requirements for WLC emissions assessments and reductions outlined in Section 4, Policy SI7 of the London Plan 2021 requires developers for referable schemes to undertake a Circular Economy (CE) assessment[153]. This must be evidenced by a written report and completed spreadsheet tool[xxiii].

As per the WLC policy, the CE requirement prioritises retaining and retrofitting existing buildings wherever possible and only constructing a new building as a last resort (see the decision tree in Figure 7).

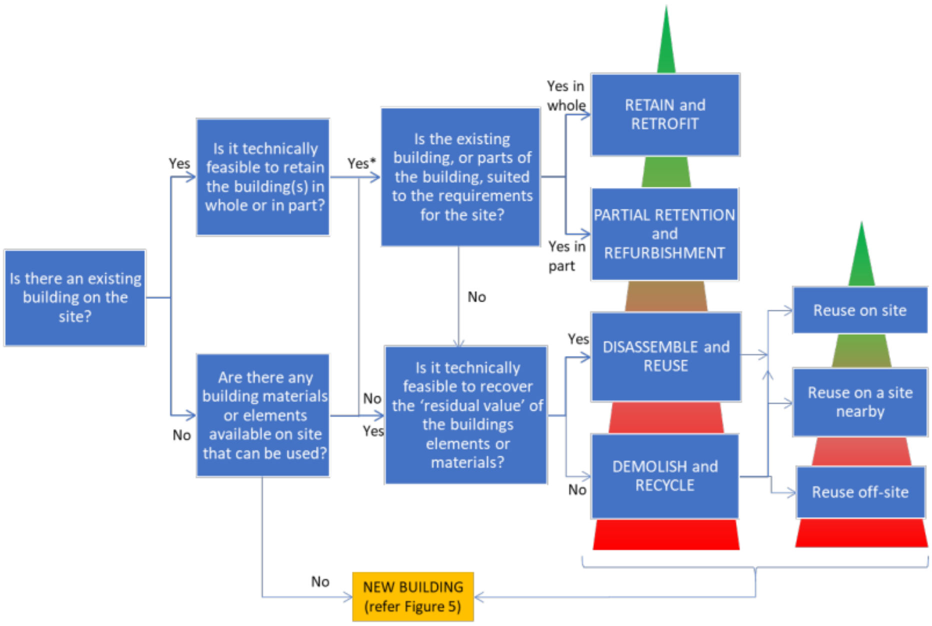


Figure 7 Circular Economy decision tree. London Plan Guidance 2022[153]

The six circular economy principles which underpin the CE requirement are:

1. Building in layers – ensuring that different parts of the building are accessible and can be maintained and replaced where necessary.
2. Designing out waste – ensuring that waste reduction is planned in from project inception to completion, including consideration of standardised components, modular build, and reuse of secondary products and materials
3. Designing for longevity
4. Designing for adaptability or flexibility
5. Designing for disassembly
6. Using systems, elements or materials that can be reused and recycled.

In the same way as WLC assessments, developers must submit CE assessments at various stages of the development process:

1. Pre-application stage (where relevant).

[xxiii] The guidance and excel template are available from https://www.london.gov.uk/what-we-do/planning/implementing-london-plan/london-plan-guidance/circular-economy-statement-guidance

2. Planning application stage - both outline and detailed stage, as applicable.
3. Post-construction, prior to occupation.