Low
Carbon
Innovation
Coordination
Group

Technology Innovation Needs Assessment (TINA)

Non-Domestic Buildings
Summary Report

March 2016

Background to Technology Innovation Needs Assessments

The TINAs are a collaborative effort of the Low Carbon Innovation Co-ordination Group (LCICG), which is the coordination vehicle for the UK's major public sector backed funding and delivery bodies in the area of 'low carbon innovation'. Its core members (at the time of this document's completion) are the Department of Business, Innovation and Skills (BIS), the Department of Energy and Climate Change (DECC), the Energy Technologies Institute (ETI), the Engineering and Physical Sciences Research Council (EPSRC), Innovate UK, Scottish Enterprise, and the Scottish Government.

The TINAs aim to identify and value the key innovation needs of specific low carbon technology families to inform the prioritisation of public sector investment in low carbon innovation. Beyond innovation there are other barriers and opportunities in planning, the supply chain, related infrastructure and finance. These are not explicitly considered in the TINA's conclusion since they are the focus of other Government initiatives.

The purpose of the TINAs is to help policy makers to plan and prioritise innovation support. A report summarising each TINA is published to provide transparency.

The TINAs apply a consistent methodology across a diverse range of technologies, and a comparison of relative values across the different TINAs is as important as the examination of absolute values within each TINA.

The TINA analytical framework was developed and implemented by the Carbon Trust with contributions from all core LCICG members as well as input from numerous other expert individuals and organisations. Expert input, technical analysis, and modelling support for this TINA were previously provided by BRE (Building Research Establishment).

Disclaimer – the TINAs provide an independent analysis of innovation needs and a comparison between technologies. The TINAs' scenarios and associated values provide a framework to inform that analysis and those comparisons. The values are not predictions or targets and are not intended to describe or replace the published policies of any LCICG members. Any statements in the TINA do not necessarily represent the policies of LCICG members (or the UK Government).

Core members of the Low Carbon Innovation Coordination Group (LCICG):

Department for Business Innovation & Skills

Department of Energy & Climate Change

energy technologies institute

EPSRC Engineering and Physical Sciences Research Council

Innovate UK Technology Strategy Board

Scottish Enterprise

The Scottish Government Riaghaltas na h-Alba

This analysis was prepared for the LCICG by:

CARBON TRUST

Key findings

Innovation in the non-domestic buildings sector represents a significant opportunity to help meet the UK's greenhouse gas (GHG) emissions targets, as well as providing value through avoided energy costs, amounting to carbon savings of 70 million tons of carbon dioxide ($MtCO_2$) (30-134$MtCO_2$) and energy savings of c. £14 billion (bn) (£6-27bn) by 2050[1]. Innovation could help create domestic and export opportunities that could contribute total Gross Value Added (GVA) of c. £1.5bn (£0.6-3bn) to Gross Domestic Product (GDP) to 2050, while supporting 1,000 (430-2,000) direct jobs in 2050. Public sector support will be required to unlock this value, as there are significant market barriers across the sector to overcome.

Potential role in meeting UK's GHG emissions targets	• The energy used by non-domestic buildings accounts for approximately 13%[2] of UK carbon emissions, while the buildings themselves are diverse in design and use. • By 2050, total UK non-domestic floor area is expected to increase by 28%, while 60% of existing buildings will still be in use. There is significant potential for energy savings across existing buildings, new builds and major refurbishments. • Innovative energy saving measures in non-domestic buildings could save 19$MtCO_2$ by 2025 and 70 $MtCO_2$ by 2050, depending upon the rate at which the measures can be deployed. • Across the technology areas of integrated design, build process, management and operation, and materials and components, innovations in management and operation would yield savings quickest, while innovations in build process would save the most carbon to 2050.
Value of abatement potential	• The potential net value from energy savings is c.£14bn (£6-27bn) to 2050. The c.8% increase from the original TINA value is primarily driven by the increase in energy prices. • Across the technology areas, innovations in integrated design and build process could deliver the most value, while innovations in materials and components will not provide significant value unless costs come down more rapidly than expected.
Green growth opportunity	• Additional global market value of innovative products in this sector could reach c.£136bn (£46-£255bn) over 2015-2050, of which c.£58bn (£20-106bn) would be accessible to the UK. Of this, innovative products could provide an additional £1.5bn (£0.6-3bn) in Gross Value Added (GVA) to the UK economy by 2050. Additionally, this market can support 1,000 (430-2,000) direct jobs per year in 2050, of which 670 jobs are related to domestic activity, and 330 jobs are related to export activity.
The case for UK public sector intervention	• Market barriers exist across the buildings value chain, which are currently stifling innovation and progress in improving the energy efficiency of non-domestic buildings. • The UK cannot exclusively rely on other countries to develop the innovation needed. The UK is already a world leader in a number of technologies and has unique requirements including climate, diversity of building stock and building usage patterns. • The buildings industry is generally domestically based, meaning the UK will need to build its own capacity to implement energy efficiency measures rather than relying on overseas providers. • Gathering data on actual building performance is vital to understand the value of energy savings, to implement measures effectively, and to overcome split responsibility between different actors in the value chain.

[1] Cumulative (2015-2050) 2015 GBP discounted values for medium (low-high) deployment scenarios and a high innovation scenario.

[2] Factsheet: Buildings, Committee on Climate Change (2015), The original TINA in 2012 mentioned 18%, which was cited from the 2005 Digest of UK Energy Statistics.

Potential priorities to deliver the greatest benefit to the UK	• Public sector support could provide most value in integrated design, where there are significant potential carbon savings and value from energy costs. There are also significant market barriers impeding integrated design innovations, and the UK has a medium-high competitive advantage in the area. • Investment in elements of build process and management and operation measures would also provide significant value, also featuring a number of market barriers and lack of opportunity to rely on others. • Investment in materials and components innovations would provide some benefit, however the potential value and carbon savings would be significantly smaller than from investment in other areas. • Although each area could be treated in isolation, all areas are interconnected, and realising the full benefit of investment will require an integrated approach supporting innovation in each area. • Retrofits represent a significant opportunity for creating low carbon buildings. As well as a robust supply chain, innovation in business models and technologies is needed to enable refurbishment at scale. • More systematic knowledge sharing would be useful in creating and shortening the feedback loop of performance information necessary to drive innovation and improve overall performance across the buildings value chain.

2015 Refresh

Most of the analysis in the original TINA published in 2012 is still relevant today. The original findings on innovative measures, market barriers, and innovation priorities and support remain valid and hence are unchanged. The refresh expands on original findings, updating the original text with specific details in the sections on market barriers and innovation priorities.

External to the buildings boundary, recent technology developments have enabled buildings to play a more active role in the energy system. This refresh also comments on further innovation needs in integration and interfacing with heat networks and the wider built environment. Energy management systems are within the scope of this TINA, although heat management systems are also discussed in the Heat TINA. The specific hardware related to heat (such as heat networks, heat pumps, heat storage) are discussed and analysed in the Heat TINA. The smart controls discussed here in the Non-Domestic Buildings TINA does have some minor cross over with the heating controls element also discussed in the Heat TINA.

The refresh also updates activities/investment that have been happening across LCICG. Examples of international activities that are relevant to the key needs for non-domestic buildings are also mentioned.

The refresh has a revised quantitative analysis on carbon savings and energy savings value with up-to-date emission factors and energy prices. The savings are adjusted to 2015 terms. The refresh also performs additional analysis on the GVA supported by the deployment of non-domestic buildings innovations with domestic and export activity separated out. Jobs supported figures, which were not included in the original analysis, are also provided.

Finally, the multitude of buildings stakeholders and the relatively low current cost of technologies implies that cost reduction in technologies alone is not sufficient, and policy and regulation has a key role to play in encouraging technology uptake. Multiple experts interviewed for the refresh echoed this view, however policy options beyond innovation support are outside the scope of the TINA methodology and will not be discussed here.

Chart 1 - Non-Domestic Buildings TINA summary

Technology area	Value of energy savings (£bn)[3]	Value in business creation (£bn)[4]	Direct jobs supported in 2025/2050[5]	UK competitive advantage	Potential public sector intervention
Integrated design	5.1 (2.1 – 10.4)	1 (0.4 – 2)	1,830/700	Medium - high	• Prize funding challenge to develop tools for enhancing energy modelling techniques. • Collaborative Research and Development (R&D) on ancillary tools (AT). • Early pre-commercial demonstration programme for modelling tools, ATs, and techniques. • Convened consortia for demonstration of ATs.
Build process	5.6 (2.4 – 9.7)	0.3 (0.1 – 0.5)	530/200	Low - medium	• Collaboration for evaluation and demonstration of off-site construction and industrial retrofit. • R&D of standard and community scale retrofit models. • Collaboration to develop online tools. • Development of contractual frameworks and effective means of ensuring builders follow designs and meet standards. • Demonstration of improved commissioning. • Better ways to identify retrofit opportunities, calculating potential market value and devising action plans. • Tools that integrate design across the construction team e.g. taking account of the change of team responsibility as the project proceeds.
Management and operation	2.4 (1.1 – 5.1)	0.2 (0.1 – 0.5)	200/90	Medium	• Collaborative R&D for smart controls with a focus on making them easy to use for the occupiers. • Incubation programme for methods to encourage behavioural change. • Development of new carbon management systems and low-cost diagnosis via convened consortia and directed research, with pre-commercial demonstration and trials.
Materials and components	0.9 (0.4 – 1.8)	0.04 (0.02 – 0.1)	350/40	Medium	• Applied R&D and incubation for low carbon cooling and thermal storage (for heating and cooling), and design of systems to minimise peak loads. • Challenge-based collaborative research and development for advanced façade materials. • Test centres for demonstration of advanced façade materials. • Prize-funding for integration into real buildings across area with pre-commercial field trials (a non-domestic Retrofit for the Future).
Total[6]	**14 (6 – 27)**	**1.5 (0.6 – 3)**	**2,900/1,020**		

Benefit of UK public sector activity/investment[7]	
	High
	Medium
	Low

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[3] 2015-2050 Low-Medium-High deployment with marginal cost of technology included to calculate value.
[4] Total GVA to UK economy with displacement 2015-2050.
[5] Jobs supported in 2025 and 2050 are based on direct jobs only using ONS figures for jobs per £ million turnover for each sub area based on the turnover captured by the UK. Some of the technology areas have a smaller figure in 2050 when compared to 2025 due to reduced uptake as the market becomes saturated in the technology.
[6] Due to rounding, numbers presented throughout this document may not add up exactly.
[7] Also taking into account extent of market failure, UK competitive advantage and opportunity to rely on other countries.

Energy efficiency in non-domestic buildings has an important role to play in meeting the UK's GHG emissions targets

The energy used by non-domestic buildings accounts for approximately 13% of UK carbon emissions[8]. The buildings themselves are diverse in design and use, and are operated by a range of sectors. Overall, the UK's non-domestic building floor area is expected to increase by a third by 2050.

Carbon Trust research has revealed a significant opportunity from existing commercial measures. A carbon saving of up to 75% by 2050 is achievable at no net cost, however these savings, and additional savings from new technologies, will be difficult to realise without innovation[9].

Experience from Carbon Trust buildings programmes demonstrates that design, construction and operation processes have equal or greater influence on carbon outcomes than technology in non-domestic buildings[10].

The actual energy performance of a building will only reflect the design intent if the building is built and operated as designed, and currently there are a number of barriers preventing this. As a result, there is often a significant gap between design expectations and actual performance of a building.

An integrated approach is necessary to take into account the way buildings operate, as a system whose value is greater than the sum of each technology or component used, and in which interaction with users is critical.

Innovative measures could benefit the entire building lifecycle. Ensuring that buildings are constructed and operated as designed will require process innovations (i.e. quality control and compliance arrangements), and innovative tools and systems to enable new processes, while improving the physical performance of buildings will require innovations in building technology.

Also significant, though beyond the scope of this TINA, is the wider context in which low-carbon buildings sit. Other TINAs consider these, in particular those focusing on Heat and Electricity Networks and Storage[11].

We have considered three deployment levels of innovations in non-domestic buildings. The amount of energy saved will depend upon the extent to which innovative measures can be applied to the non-domestic building stock[12] in the UK, so this is the variable that is altered in the scenario analysis.

Regulatory 'push' and market 'pull'

Policy has a key role to play in enabling technology uptake: policy signifies government commitment and encourages private sector investment in innovations by creating additional market demand.

From a market point of view, the feasibility of low carbon technologies depends on a long term sustainable pipeline of demand. Through policy, government can incentivise innovation by providing greater certainty around this pipeline. Standards and regulations are also important to ensure conformity across the buildings value chain.

While appropriate policy support is important, the buildings value chain also needs to respond. Owners and users of the asset need to recognise the benefits of energy efficient buildings. These energy efficiency measures will not just contribute to the bottom line, but also deliver a whole host of co-benefits, e.g. reputation, health & safety, and productivity. The business opportunities available through the uptake of energy efficient technologies will be tremendous, and the buildings industry needs to acquire the skills and tools to address these demands with innovative and robust business models.

The extent of deployment will depend significantly on regulatory 'push' and market 'pull'. The scenarios used in the TINA are based on policy and market needs:

- **Low scenario** – depends on effectiveness of policy measures in existing buildings, new build and refurbishment rates that allow improvement in stock, and perception of measures as low risk (from energy and carbon prices and cost of measures).
- **Medium scenario** – as above, plus strong market demand for low carbon buildings, a supportive legislative framework and structured processes for gathering feedback on actual performance.
- **High scenario** – as above, plus strong political focus coupled with a highly skilled industry, and user cooperation.

These are compared with a counterfactual scenario which assumes that the grid is decarbonised and existing cost-effective commercial measures are implemented.

[8] Committee on Climate Change, Factsheet: Buildings, 2015.

[9] *Building the future, today* (Carbon Trust, 2010).

[10] Carbon Trust Low Carbon Buildings Accelerator (LCBA) and Low Carbon Buildings Programme (LCBP) as well as previous *Energy Efficiency Best Practice (EEBP) projects.*

[11] Other existing work in this area includes DECC's Pioneering Cities programme, and Innovate UK (formerly the Technology Strategy Board - TSB) and EPSRC's Future Cities programme.

[12] The building types considered in the TINA analysis include: Industrial; Retail; Hotels, restaurants and inns; Commercial offices; Schools; Further and higher education; Government estate; Public offices; Healthcare; Sports; Heritage and entertainment; and Transport/communications.

The medium scenario is used as the central scenario for the following analyses.

Buildings in the wider UK energy system

Non-domestic buildings represented 17% of UK energy use with annual emissions of 73MtCO_2e in 2013[13]. Under a business as usual scenario, Non-domestic buildings energy demand will increase by 18% to 269 terawatt hours (TWh) in 2050[14], while innovative measures can deliver up to 411TWh (176-782TWh) of cumulative energy savings by 2050 relative to 2015. Innovation and adoption of new technologies can reduce demand in the energy system by either improving energy efficiency in existing buildings, or reducing the capacity of energy appliances in new buildings through better design.

The buildings energy services – cooling, heating, and lighting – utilise natural gas, grid electricity, and oil with different fuel mixes in different buildings. Electricity emission factors reduce significantly in 2050 due to a decarbonised grid. This TINA analysis incorporates emissions factors reported by DECC[15], but savings from a decarbonised grid do not count towards the energy savings reported in this document.

For heating energy services, better heating networks and the use of storage will reduce demand, and the deployment of heat pumps will further decrease space heating emission factors.

Recent innovations have transformed the position of buildings in the energy system from the conventional energy receiver to a more integrated player. Due to technology advancement, buildings in the future can play multiple roles:

- Power generation, incorporating energy gathering technologies such as solar photovoltaic (PV), combined heat and power (CHP), and heat pumps into the buildings boundary.
- Demand response and storage, shifting or reducing electricity use during peak load to reduce the burden on the external grid. This requires wide adoption of advanced control systems.

These effects are excluded from this analysis due to the scope of this TINA, but are considered in the Heat and Electricity Networks and Storage TINAs.

[13] Factsheet: Buildings, Committee on Climate Change (2014); Carbon Trust Analysis.

[14] BRE Analysis.

[15] Valuation of energy use and greenhouse gas (GHG) emissions: Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government ,DECC (2014).

Chart 2 – Comparison of examples of existing commercial and illustrative innovative TINA measures

	Existing commercial measures	Illustrative innovative TINA measures
Integrated design	• Simplified energy modelling used for new build. • Dynamic modelling applied to selection of new build and refurbishment projects.	• More advanced modelling. • Measures to improve accuracy. • Incorporating building performance data into design tools. • Tools that support decision making.
Build process	• Predominantly traditional construction. • Sample details. • Manual inspection.	• Moves to off-site construction. • Automated surveying and inspection tools, and outcome-based measures of performance, e.g. heat loss measurements. • Improved process for commissioning and handover. • Tools allowing correct sizing of building services.
Management and operation	• Programmable thermostats. • Reduce room temperature. • Optimise start times. • Thermostatic radiator values (TRVs). • Lighting – basic timers, turn off for 1 hour, presence detectors. • Energy management monitors.	• Targeted real time energy usage information. • Greater use of hand-held devices for energy efficiency applets. • New investment and leasing models that overcome split responsibility between designers, contractors and building occupants. • Predictive controls.
Materials and components	• Traditional insulation materials. • Ventilation shafts and stacks. • Light-pipes & sun-pipes. • Triple glazing with coatings and insulating gases.	• Optic fibre daylighting. • 'Switchable' glazing. • Dynamic insulation and thin insulation products. • Free cooling systems (e.g. groundwater).

Description of innovative measures

The innovative measures in this TINA are additional to existing commercial measures, as summarised in ***Chart 2***. Innovations for non-domestic buildings can be split into four major technology areas: integrated design; build process; management and operation, and materials and components.

Integrated design innovations include:

- **Modelling and software tools,** which could become faster and more accurate in using passive design to minimise the need for building services.
- **Design tools and services,** knowledge tools that could be used to close the gap between design intent and actual performance by addressing the wide variety of buildings, incorporating feedback from operational buildings, and **how decisions are made.**
- **Ancillary tools**, such as decision support tools, operational profiles, rating and certification tools, calculator tools for quantitative and qualitative information, and guidelines for the integration of processes.

Build process innovations include:

- **Smart manufacturing processes,** e.g. off-site construction, where individual modules are pre-manufactured and assembled on-site, and modern on-site construction, including products such as tunnel-form concrete and tighter supply chain integration.
- **Industrialised retrofit techniques**, better ways to identify retrofit opportunities, calculating potential market value and devising action plans, new construction methods to reduce the cost of refurbishing existing buildings and improve the performance of refurbished buildings.
- **Commissioning building services**, ensuring that services (heating, cooling, lighting, and ventilation) are put to use efficiently, and new tools to measure performance immediately after construction/installation (e.g. U values, ventilation rates, heat loss factors).

Management and operation innovations include:

- **Smart controls and systems diagnostics,** predictive, intelligent user-oriented building management systems and diagnostic applications that optimise performance of building services.
- **Carbon management services,** integrating landlord-tenant building management through new investment and leasing models to overcome split responsibility and identified lack of action. While these are not technology innovations, they are necessary process innovations.
- Assisting **behavioural change** by providing users with clear information and incentives.

Materials and components innovations include:

- **Advanced façade materials and integration**, improving the functional performance of façades to provide light, insulation, shading and ventilation whilst reducing the need for cooling;
- **advanced daylight technologies,** harvesting daylight from roofs and façades through skylights, fibre optics or other means;
- **advanced natural ventilation systems,** using ventilation stacks, atria and automatic openings combined with automatic control systems, passive cooling such as breathable walls, and the effective thermal mass of buildings to reduce cooling and ventilation energy;
- **low carbon cooling,** a range of technologies combined with building thermal mass and phase change materials to moderate temperature fluctuations.

Calculating the magnitude and value of energy and carbon savings

Innovative measures can provide energy savings additional to those achievable from the existing commercial measures included in the counterfactual.

Total savings achieved from each innovation are derived from a number of assumptions[16]:

- the **uptake** of the innovation, i.e. the maximum proportion of existing floor area to which the innovation can be applied;
- the **energy saving potential** of the innovation as a proportion of existing energy demand for each end use (e.g. 10% saving from lighting);
- the **lifetime**, and **performance at end of life** as a proportion of original performance (known as 'persistence') of the innovation;
- the **time to reach uptake** – a measure of the market's ability to implement the innovation;
- the **year of introduction** of the innovation, and
- the **roll-out period** for the innovation in existing buildings – a measure of the rate at which the innovation can be implemented in existing buildings based on refurbishment cycles.

Innovative measures are not replaced at the end of their life, as these measures will no longer be considered innovative once they are due to be replaced. Attributing further savings resulting from replacement of these measures may be counting savings that would happen anyway, without public sector support.

Uptake rates are defined according to the building type to which the innovations will be applicable – existing buildings, new builds and major refurbishments. For example, integrated design innovations are not applicable to existing buildings; they are applicable to new buildings and major refurbishments.

Energy saving potential is divided into both building type and energy end use (heating, lighting or cooling). For example, build process innovations in new buildings may reduce energy demand from space heating by 50%, but by only 20% from cooling.

Energy savings are calculated by multiplying floor area by uptake rate and energy saving potential. Carbon savings are then calculated from these energy savings using projected carbon emissions factors[17].

[16] Values and rationale for these assumptions are provided in the TINA.

[17] DECC IAG data.

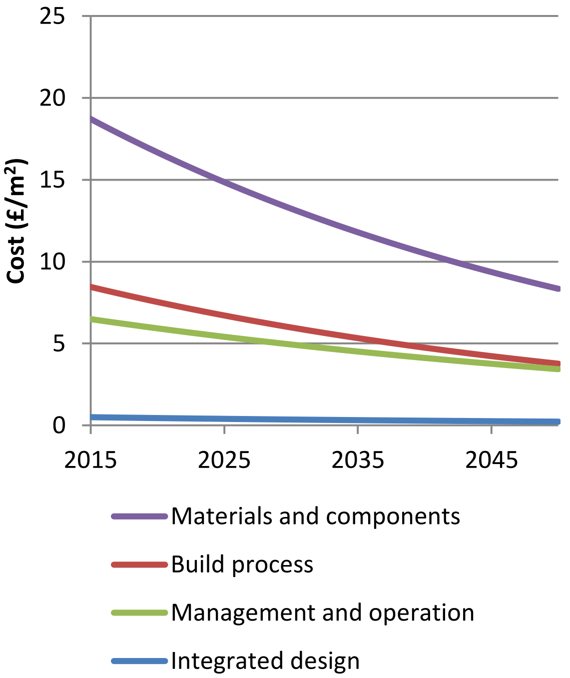
Costs

For most innovations, there is an increase in overall costs associated with additional services or higher quality materials. The cost assumptions used in this analysis are this additional cost. Costs reduce over time with increased levels of uptake and technical advances that reduce the cost of implementation.

- **Integrated design** – additional costs for design tools and software supporting building services.
- **Build process** – costs of new materials and specialist skills anticipated to be marginally more than conventional products.
- **Management and operation** – additional costs for software, controls and information systems.
- **Materials and components** – additional costs for materials (e.g. insulation) and processes (e.g. air-tightness details and commissioning).

Costs are modelled to reduce proportionally to total deployment of each innovation – each time treated floor area doubles, cost reduces by 10%, as shown in ***Chart 3***

Chart 3 - Aggregate costs of innovative measures in non-domestic buildings[18]



[18] BRE, Carbon Trust analysis.

Innovative measures could save an additional c. £14bn and 70MtCO₂ by 2050

These savings would result from energy savings of 411 TWh from 2015 to 2050, or 4% over counterfactual energy demand. The increase from the original TINA value of £13 billion is primarily driven by the increase in energy prices. ***Chart 4*** shows the annual carbon savings resulting from these energy savings. Note that while carbon savings generally decrease with time due to grid decarbonisation, energy savings are still significant out to 2050.

Innovations in integrated design could save £5.1bn and 21MtCO₂ by 2050

Measures in integrated design apply only to new builds and major refurbishments, and so initial savings are small. As more buildings are built or refurbished, carbon savings grow significantly as accessible floor area ceases to be a limiting factor.

Large cost savings are due to a combination of factors: savings continue to 2050, as energy prices are projected to rise; and the costs of integrated design measures are negative, as they reduce the need for costs elsewhere. Note that the ability of integrated design innovations to deliver this value will be influenced by the quality of building performance data.

Innovations in build process could save £5.6bn and 34MtCO₂ by 2050

As with savings from integrated design, build process innovations are initially limited to the new build and refurbishment rates of buildings, however build process innovations could ultimately provide the most significant carbon savings of all technology areas. Cost savings are largely due to significant uptake in new build and refurbished stock.

Innovations in management and operation could save £2.4bn and 10MtCO₂ by 2050

Savings from management and operation measures could realised very quickly as they are applicable to the existing building stock. However, savings decrease rapidly with grid decarbonisation and as more existing buildings are demolished or refurbished. Measures also have shorter lifetimes as they are associated with the lifetimes of building services rather than of the buildings themselves, and tend to be less effective over time as they are subject to user engagement.

The value of energy savings is smaller in comparison with integrated design and build process due to the timing of the savings – most energy savings are made before energy prices are expected to rise significantly. However, the carbon abatement potential is still significant and can be achieved rapidly.

Innovations in materials and components could save £0.9bn and 5MtCO2 by 2050

Savings from innovative materials and components could significantly smaller than other innovations as they are assumed to become effective later and are generally only applicable in specific certain circumstances, and so have very low uptake rates.

Value from energy savings is also low due to the high cost of measures, though would be larger if costs come down faster than modelled.

Chart 4 - Annual carbon savings

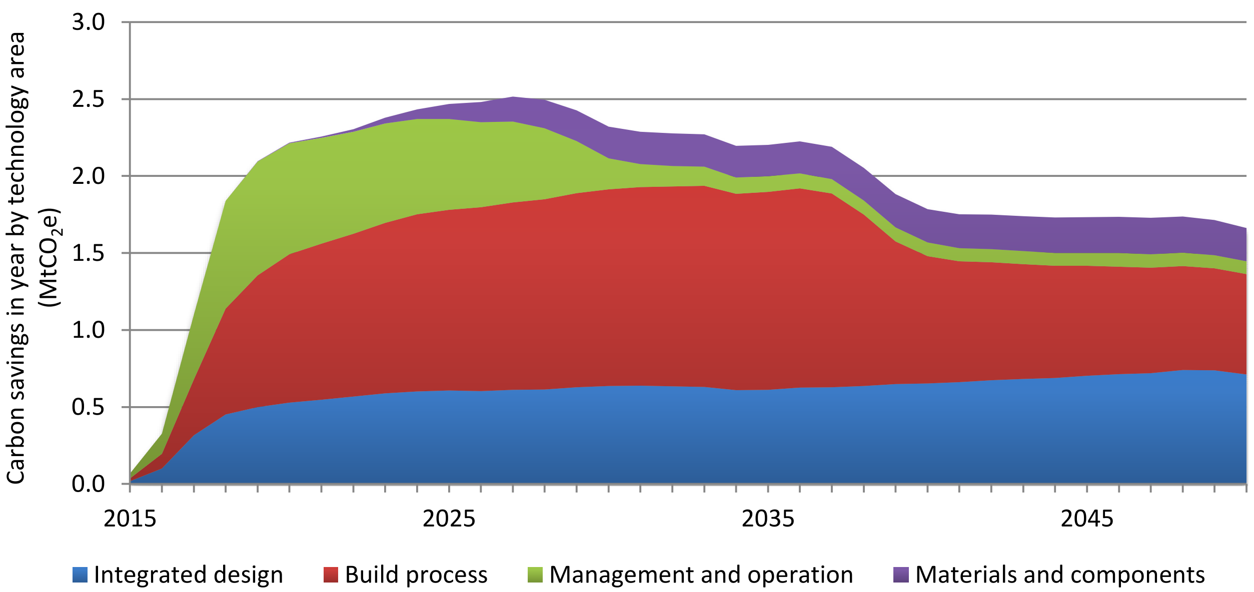


Chart 5 - Summary of abatement potential and value of innovative measures

Technology area	Carbon savings from 2015 to 2025 ($MtCO_2$)	Carbon savings from 2015 to 2050 ($MtCO_2$)	Net Present Value (NPV) of energy savings from 2015 to 2050[1] (£bn)			NPV per tonne CO_2 saved (£/tCO_2)	NPV per MWh saved (£/MWh)
			Low	Medium	High		
Integrated design	5	21	2.1	5.1	10.4	239	38
Build process	8	34	2.4	5.6	9.7	168	30
Management and operation	6	10	1.1	2.4	5.1	244	46
Materials and components	0	5	0.4	0.9	1.8	159	25
TOTAL	**19**	**70**	**6**	**14**	**27**		

Green growth opportunity

The global market[19] for innovative products is estimated to be c. £136bn (£46-255bn)

The global market size for innovations in the non-domestic buildings sector is estimated using the available value from energy savings as a proxy for the additional cost the market would be willing to bear for the innovations. The global market value is scaled up using the ratio of estimated global floor area to UK floor area. It is assumed that developed countries[20] have markets that are similar to the UK, with similar future requirements. It is also assumed that the market for innovative measures in BRIC (Brazil, Russia, India and China) countries will start from 2020 and then evolve at a similar rate as that assumed for developed countries. Developing countries are assumed to have limited markets for technologies that support very low carbon buildings and are excluded from global market calculations.

It is also assumed that the market would be willing to pay 25%[21] of the potential value through energy savings in order to realise them, though in reality this figure will vary by technology.

Only part of the global market will be accessible to the UK, given the generally domestic nature of the construction industry, the accessibility of each technology area varying based on its tradable portion.

The tradable portion for **integrated design** is estimated to be 60%[22] of the global market. Although building energy modelling software and other tools are tradable globally, design services tend to be delivered by local professionals, and some design services are only appropriate for countries with similar climates and construction techniques.

The tradable portion for **build process** is estimated to be 30%[23] of the global market. Building products, components and building services tend to be used in or close to those countries where they are manufactured, though there are global opportunities for exporting intellectual property rights (IPR), skills and specialist tools, specialist components, services and construction approaches.

The tradable portion for **management and operation** is estimated to be 30%[24] of the global market. The export value of many services or associated software and hardware is likely to be low. The market for specialist products and services is global, and for some of these

[19] The original TINA refers to global market value as net present value of technologies deployed, whereas this refresh uses turnover as market value, the like for like figure comparable to the previous TINA's market value of £488 billion is £545bn.

[20] Based on the UN Human Development definition.

[21] Assumption based on expert interviews and modelling.

[22] Assumption based on expert interviews and modelling.

[23] Assumption based on expert interviews and modelling.

[24] Assumption based on expert interviews and modelling.

markets, the English language is an advantage. The provision of some services (e.g. audits) will be largely limited to local providers but there may be some IPR with export value.

The tradable portion for **materials and components** is estimated to be 60%[25] of the global market. Many of the potential innovations, in the form of new products or materials, professional expertise and design tools, have worldwide applications and some technologies are likely to have a large market overseas. There is also significant scope for exportable equipment and IPR.

UK competitive advantage

The UK has various strengths that would allow it to take advantage of the accessible market opportunity in each technology area.

The UK has a **medium-high** competitive advantage in **integrated design**, estimated to be 10% of the accessible market. The UK is a global leader in building information modelling (BIM), there is widespread use of energy modelling amongst UK practices and there is active research and development in energy modelling. Low carbon cities around the world also use UK expertise, standards and best practice tools.

The UK has **low-medium** competitive advantage in **build process**, estimated to be 3% of the accessible market. There is growth in the uptake of off-site construction in the UK together with active government support and research by UK universities, however there is significant competition from other countries in build process innovations.

The UK has **medium** competitive advantage in **management and operation**, estimated to be 5% of the accessible market. The smart controls and systems market is mature in the UK and strongly linked with the IT industry, where the English language is an advantage. There is UK capability in many areas, but services could be carried out locally, though there may be some IPR export value.

The UK has **medium** competitive advantage in **materials and components**, estimated to be 4% of the accessible market. The UK is a leader in many innovations that may have global applications, which could provide value in export of products and IPR.

Contribution to the UK economy

The GVA to the UK economy is calculated by:

1. Multiplying the accessible market by the UK's competitive advantage to give the tradable turnover captured by the UK.
2. Adding the non-tradable portion of the market that relates specifically to UK deployment to give the non-tradable turnover captured by the UK.
3. Turnover figures are then multiplied by a GVA: Turnover ratio[26] (which differs by technology) and a displacement factor[27] to give GVA figures.

The GVA contribution to the UK economy from innovative measures in non-domestic buildings is c. **£1.5bn (£0.6-3bn**), of which export GVA is **£1.0bn (£0.3-1.7)** and domestic GVA is **£0.5bn (£0.2-0.9bn).** Direct jobs in 2025 are estimated at **3,000 (1,200-6,000)**. Due to the exclusion of technology replacement, uptake of technologies will plateau as they reach their maximum uptake, and therefore annual turnover in 2050 will be less than in 2025. The direct jobs supported in 2050 are estimated at **1,000 (430-2,000)**.

There is additional value not captured by this figure, including maintaining (or increasing) UK competitiveness in the construction industry to capture future value, and the value of the energy and carbon savings that would be redistributed within the UK economy.

[25] Assumption based on expert interviews and modelling.

[26] *UK Non-Financial Business Economy (Annual Business Survey), ONS (2012).*

[27] Part of the value created in the buildings sector will be due to a shift of resources from elsewhere in the economy and thus is partly cancelled out by loss of value in other sectors. Expert opinion has roughly assessed this effect to be between 25% and 75%, so we have applied a flat rate of 50%.

The case for UK public sector intervention

To capture the value from these technologies there is a strong case for targeted public sector intervention, especially where there is an evident market barrier. The following section analyses the need for intervention based on the extent of market barriers and on opportunities to rely on others.

Market barriers impeding innovation

There are many overarching market barriers across each technology area, though individual innovations also face specific market barriers. Overarching market demand barriers include:

- **The landlord-tenant divide -** where one party has no incentive to invest in carbon reducing measures as the other party receives the benefit of the investment. This also prevents data sharing from buildings' energy use.
- **Energy costs are not seen as material** – occupiers place a greater premium on the look, comfort and productivity of a building rather than its energy use, so companies are not prepared to pay a premium in rent for a low carbon building. This has had a particular impact in recent years as the prospect of tighter regulation driven by carbon savings appears to be waning. The implication for innovators is that business cases cannot be based on energy cost savings alone.
- **Lack of knowledge** – companies do not have tools or knowledge to identify low carbon buildings, in part as there is no labelling for high performance buildings outside the public sector. It is important to ensure that stakeholders throughout the buildings value chain e.g. vendors, contractors, users etc understand the design, expected performance, and way to use the buildings and are competent in making the right decisions.
- **Existing building regulations are not sufficiently enforced**, or integrated well with planning tools. Non-enforcement could be driven by the costs of enforcement, which could be mitigated by the development of better verification tools. As with much regulation, consistency is often as important as the actual shape of the regulation, for example the lack of enforcement of Display Energy Certificates (DECs).

These barriers lead to a 'circle of inertia'[28], where each party believes they cannot act because of the behaviour of another party.

Contractors might say:

> *"I could build but developers won't specify."*

Developers might say:

> *"I would specify but funders won't provide finance and tenants are not asking for them."*

Funders might say:

> *"I would provide finance but there is no occupier demand."*

Tenants might say:

> *"I might choose a low carbon building but there aren't any and energy is not a material cost of occupancy."*

Additionally, there are a number of supply conditions influencing market barriers:

- **The building sector has a fragmented supply chain**, with multiple sources of impact on carbon performance and hence multiple opportunities for carbon potential to be lost. It is a particularly acute issue in large construction firms, as they contract out jobs to smaller builders rather than performing the job themselves.
- **The building sector is conservative**, and reluctant to adopt new approaches without clear prior demonstration.
- **Lack of necessary skills** to implement novel technologies and solutions throughout the supply chain.
- **Existing conventions around contracting have a negative impact** on low carbon outcome. There is no requirement for the construction industry to fix mistakes, as actual performance may not be a contractual requirement, nor is it easy to measure or prove a cause of worse than expected energy performance.
- **Low carbon measures** generally cost more, which is prohibitive to smaller firms due to lack of economies of scale, and the difficulty in transferring these costs as value added to their customer.

Although these overarching market barriers affect all innovation, there are specific market barriers which vary within each technology area, summarised in Chart 6.

The critical barrier in modelling and software is due to a lack of incentives to share data - neither building owners nor operators provide (or even have access to) the necessary data on building performance. Similarly, developers do not conduct modelling incorporating unregulated demand (demand arising from appliances rather than integrated building services).

Barriers in adopting new technologies

- Considering the need for business cases to be based on more than just energy costs, data collection is failing to capture and feedback co-benefit information (e.g. on reputation, health and safety, productivity benefits).
- Most of the advanced low carbon buildings innovations are from European-based product manufacturers or service providers. Hence their product research will prioritise their home country's

[28] *Building the future, today, Carbon Trust (2010).*

building stocks. This means the UK will require additional demonstration and adaptation trials to integrate innovations.

- Product certification processes are lengthy and expensive, leading to delays in innovative products being applied in the UK. Related to this, contractors are reluctant to accept new technology and insurance providers, and mortgage suppliers are conservative and perceive new technology as adding additional risk.

The UK cannot rely on other countries to drive innovation with the required focus and pace

In some cases, innovation needs may be similar in other countries such that the UK could expect others to develop needed innovations. There are two kinds of innovation activity, which may be needed: research and development, and demonstration and adaptation.

In general, the UK could rely on other countries for some research and development activities, particularly at earlier stages before demonstration and adaptation. However, this is not the case for integrated design innovations where the UK is already a world leader.

Integrated design innovations would also need to be explicitly tailored for UK needs, based on the building stock and climate conditions. This is also true for commissioning building services (part of the build process) and developing advanced natural ventilation systems – the UK has very specific needs, which would require specialist research.

Given that the UK has a unique set of characteristics, and given that buildings are largely constructed by domestic firms, any innovation will need to be demonstrated and adapted specifically for local needs. As the UK cannot rely on other countries to adapt innovations to its own needs, and as it is difficult to import industry learning, UK activity will therefore be required.

Chart 6 - Market barriers in non-domestic buildings innovation areas

	Sub area	What market barriers exist?	Extent of market barrier
Integrated design	Modelling and software	• Split incentives between tenants and landlords • Lack of materiality of energy costs • Diffuse nature of sector	Critical barrier
	Design tools and services	• Split incentives between tenants and landlords • Lack of materiality of energy costs • Diffuse nature of sector	Moderate barrier
Build process	Smart manufacturing processes	• Off-site production is fragmented and dominated by relatively small companies with little effective coordination or partnering with major contractors • Volatility in the demand for factory output. • Imperfect information about benefits combined with high "proving cost" and risk to individual firms	Minor barrier
	Industrial retrofit techniques	• Split incentives between tenants and landlords • Lack of materiality of energy costs • Coordination barrier is also a problem – facilitating cooperation between landlords is very challenging as no single landlord has an incentive to initiate it	Significant barrier
	Commissioning building services	• Existing contractual frameworks do not allow for it • Lack of awareness of need and value • Lack of professional skills needed within trades • No regulatory drivers as innovation sits beyond building codes • Omission of the need in most building energy strategies	Significant barrier
Management and operation	Smart controls and systems diagnostics	• Split incentives between tenants and landlords • Disconnect between the people who procure/design control systems and those who operate them • A lack of information driven by coordination issues in fragmented industry	Significant barrier
	Carbon management systems	• Split incentives between tenants and landlords • Lack of materiality of energy costs • Absence of regulatory certainty • Lack of standardised contractual frameworks • Lack of awareness of the need and value	Moderate barrier
	Behaviour change	• Lack of materiality of energy costs • Lack of strong regulatory certainty • The "valley of death" represents a problem for many technologies in the sector that are in an early stage of development and may lack appropriate capabilities	Moderate barrier
Materials and components	Advanced facades materials and integration	• Inadequate incentives, given the high costs involved • Diverse nature of building stock makes standardisation difficult, constraining potential market size and dis-incentivising investment in production • Lack of knowledge about the systems available and their importance to performance • Product certification processes for new innovations are time consuming and expensive	Critical barrier
	Advanced daylight technologies	• Inadequate incentives to secure investment needed to address technology barrier and reduce costs • Supply chain barrier (with suppliers of lighting systems failing to incorporate daylight systems in their service offers) • Lack of knowledge about the systems available and their importance to performance	Significant barrier
	Advanced natural ventilation systems	• Inadequate incentives to secure investment needed to address technology barrier and reduce costs • Investors and stakeholders perceive high technology risk • Imperfect information about benefits	Significant barrier
	Low carbon cooling technologies	• Significant regulatory barriers: feasibility assessments are expensive and can involve high risk • Inadequate incentives to secure investment needed to fund early stage research, development and demonstration, aimed in particular at finding ways of overcoming significant practical obstacles and to reduce costs • There is a knowledge gap about what is possible and imperfect information based on barrier of past systems	Significant barrier

Potential priorities to deliver the greatest benefit to the UK

The UK needs to focus its resources on the areas with the biggest relative benefit to the UK and where there are no existing or planned initiatives (both in the UK and abroad).

The original TINA illustrated the potential innovation priorities and support needed for the UK. Some of these key needs have been directly addressed by Innovate UK programmes, for example "A digital tool for BIM" addressed the needs for design tools and services. Innovate UK programmes also addressed market barriers identified in the previous TINA, for example "Supply Chain integration in Construction" was intended to address the "fragmented supply chain" market barrier. Public sector activities/investment since the original TINA are summarised in ***Chart 7***.

As a result of these activities, some of the priorities identified in the original TINA have been revised to reflect progress and better capture the aspects of these priorities that remain relevant. The 2015 refresh has also updated the innovation priorities to:

- Focus on specific areas, e.g. smart controls that are more user friendly;
- Capture new aspects of needs due to recent developments, e.g. ancillary tools that support integrated design, interface protocol to enable controllers to communicate with each other; and
- Broaden the scope to include other priorities, e.g. embodied carbon and benchmarking guidance.

Innovation areas with the biggest relative benefit from UK public sector activity/investment

While all technology areas in the non-domestic buildings sector would benefit from public sector intervention, integrated design represents a significant opportunity given the high potential value from energy and carbon savings, medium-high competitive advantage, extensive market barriers, and no opportunities to rely on others to develop needed innovations.

Investment in elements of build process would also provide significant value, as it suffers from a number of market barriers and lack of opportunity to rely on others, particularly in smart manufacturing processes where the industry is already well developed in Germany, Sweden and Austria.

Investment in management and operation innovations would provide value quickly, as measures here can be applied to existing buildings. These are mostly innovations in processes that would allow buildings to be operated as designed.

Investment in materials and components innovations would provide some benefit, however the potential value and carbon savings would be significantly smaller than would result from investment in other areas. ***Chart 8*** summarises the areas that would receive the greatest potential benefit from UK public sector activity across all technology areas.

Chart 7 - Summary of UK public sector activity/investment since the original TINA was published

	Activities	Key needs/market barriers addressing
Integrated design	• Innovate UK "A digital tool for BIM" • Innovate UK "Buildings, better connected" • Green Construction Board "Bigger, Better Data"	• Design tools research development & demonstration
Build process	• DECC/Innovate UK "Invest in Innovative Refurbishment" • Innovate UK "Supply chain integration in construction" • Innovate UK "Digitising the Construction Sector" programme • Innovate UK/EPSRC "Building whole-life performance"	• Industrialised retrofit technique • Fragmented supply chain • Lack of knowledge and skills • Unreliable commissioning
Management and operation	• Innovate UK "Future Energy Management for Buildings" • Innovate UK "User Centered Design"	• Smart controls • User behaviour change

***Chart 8 - Summary of greatest potential impact from UK public sector activity*[29]**

	Sub area	Value from energy savings (£bn)[30]	Value from business creation (£bn)[31]	UK competitive advantage	Extent market barrier	Opportunity to rely on someone else	Benefit of UK public sector activity
Integrated design	Modelling and software	5.1 (2.1 – 10.4)	1 (0.4 – 2)	Medium - high	Critical	No	**High**
	Design tools and services				Moderate	No	**High**
Build process	Smart manufacturing processes	5.6 (2.4 – 9.7)	0.3 (0.1 – 0.5)	Low - medium	Minor	In part	**Low**
	Industrialised retrofit techniques				Significant	In part	**Medium**
	Commissioning building services				Significant	No	**High**
Management and operation	Smart controls and system diagnostics	2.4 (1.1 – 5.1)	0.2 (0.1 – 0.5)	Medium	Significant	In part	**Medium**
	Carbon management services				Moderate	In part	**Medium**
	Behaviour change				Moderate	In part	**Medium**
Materials and components	Advanced façade materials and integration	0.9 (0.4 – 1.8)	0.04 (0.02 – 0.1)	Medium	Critical	In part	**Low**
	Advanced daylight technologies				Significant	In part	**Low**
	Advanced natural ventilation systems				Significant	No	**Medium**
	Low carbon cooling technologies				Significant	In part	**Low**

[29] BRE, Carbon Trust Analysis.

[30] 2015-2050 cumulative, discounted, medium (low-high) deployment.

[31] 2015-2050 cumulative, discounted, medium (low-high) deployment.

Potential priorities for public sector innovation support

In the sections above, we identified the key innovation needs and the market barriers hindering these innovations. The analysis points to a number of priorities for public sector investment in innovation. These include both overarching needs and those specific to each innovation.

Overcoming the various market barriers will require an integrated approach, as illustrated in ***Chart 9***. Although each area could be treated in isolation, all areas are interconnected and realising the full benefit of investment will require a holistic view to solve the numerous market barriers across the entire value chain.

Underpinning all innovations is a need for more data regarding building performance. There is currently a lack of knowledge surrounding the performance of buildings, hindering improvement. Gathering data on actual building performance is vital, and will support efficiency savings in all areas. The BIM task group are developing a unified classification system and data gathering protocol for the operational phase and performance outcomes of built assets. However data collecting mechanisms and data interpretation remain to be addressed.

There are existing government programmes such as NEED (National Energy Efficiency Data Framework, set up by DECC in 2014 to provide a better understanding of energy use and energy efficiency in Great Britain) and ESOS (Energy Savings Opportunity Scheme, established by the Environment Agency and DECC in 2014 as a mandatory energy assessment scheme for qualifying organisations) which represents progress towards more consistent data collection and interpretation. Further consideration is needed to encourage the synergy of multiple schemes and the set-up of purpose-built database platforms.

Systematic knowledge sharing is needed to create and shorten the feedback loop across the buildings value chain. The benefits of an information dissemination platform are:

- Prevents wasted efforts on "reinventing the wheel".
- Enables a more integrated approach by allowing information to flow freely across building stages, e.g. design can incorporate feedback from the construction and operation stage, and the product manufacturer can have better insight into what has worked and what can work better.
- Allows buildings stakeholders to identify suitable products through sharing of product information such as claimed performance, actual performance, and feasibility to use.

Investment is required in research, development, demonstration, and deployment across all technology areas. As the UK is unique in terms of its building stock, usage patterns and climate, investment is also required in adapting innovations to UK conditions and to demonstrate them.

The type of innovation support required and the appropriate support mechanism depends on the technical stage of the innovation need:

- For earlier stage technologies, R&D, testing, and early demonstration for individual components, ranging from new software and commissioning tools, smart building management controls and new products. Support mechanisms include grants, prizes, and "seed" equity investment.
- For mid-stage technologies, controlled demonstration of a suite of technologies or complex processes, involving collaboration between technology/service providers and major contractors/designers or landlords/owner-occupiers, e.g. to achieve innovation in smart manufacturing, industrialised retrofit, smart controls, diagnostics and user behaviour modifiers. Support mechanisms include direct grants, or grants to convened consortia of end-users to select technology/service providers, similar to the "accelerator" model.
- For late stage technologies, integration of technically but not commercially proven technologies into building projects already planning to do something relatively ambitious, e.g. to improve design and observations and measurement on retrofit, or install and "prove" more costly but more effective façade materials.

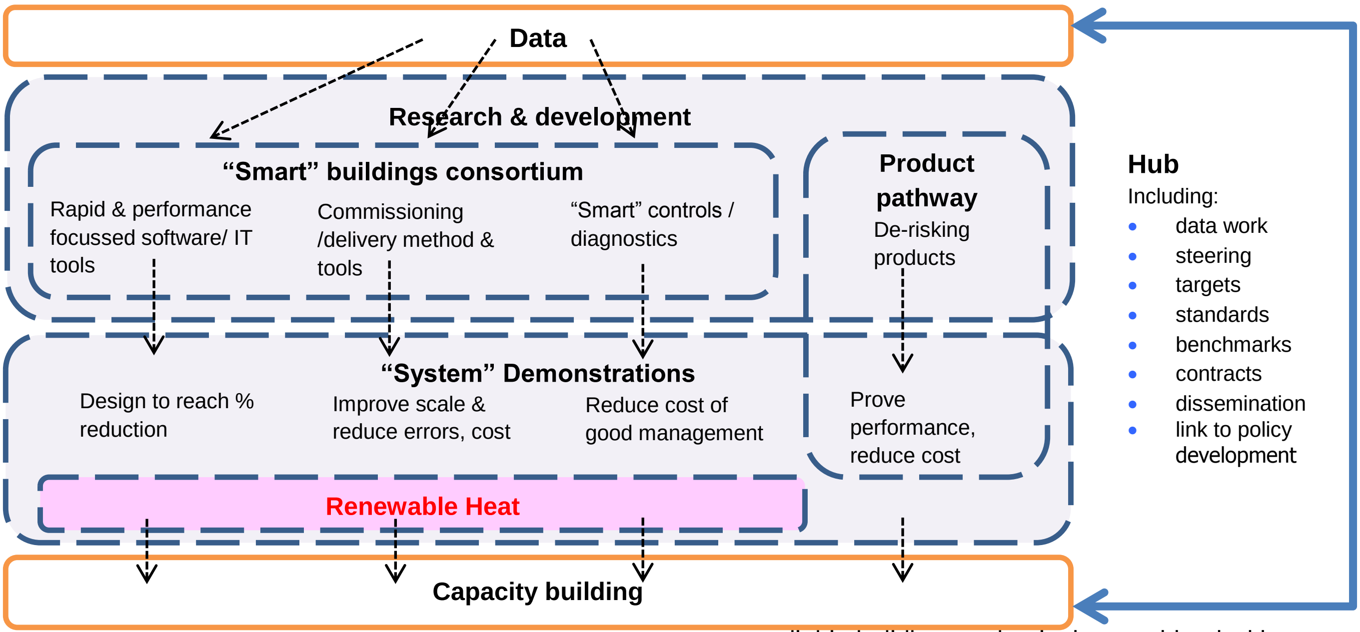
Retrofits represent significant opportunities in low carbon buildings. Aside from a robust supply chain, innovation in business models is needed to enable refurbishment at scale. New business model examples in recent years include:

- In the UK, Low Carbon Workplace, which delivers management and refurbishment of low carbon buildings in which users agree to make use of the building consistent with its low carbon design.
- In the Netherlands, Energiesprong, in which contractors provide a complete refurbishment solution with a guaranteed energy performance that is also insured.

To establish the integrated approach required, a low-carbon non-domestic buildings hub would provide policy direction, set targets, define standards, provide benchmarks, develop contracts and disseminate the latest knowledge across the sector. This hub might be a non-domestic counterpart to Zero-Carbon Hub, featuring:

- A national **non-domestic buildings energy performance database.**
- Systematic gathering of best practice internationally and developed case study insights on best practice.
- Technology and process innovation road-mapping involving industry and government.
- Developing fact-based parameters to support the definition of low/zero carbon requirements, and the creation of aspirational standards for different building types.
- **Prioritise independent, non-partisan research** into specific innovation areas.
- Broader research into what has worked and why.
- Create and coordinate ways to encourage uptake, such as challenges, competitions, and innovative financing schemes.

Chart 9 - Summary schemata of public sector support programme



Buildings integration with the macro system

Apart from investigating the buildings system internally, it is also essential to understand how buildings interact externally with the wider built environment. The roles of buildings need to be explored further. To this end, buildings digitisation is essential. By incorporating big data and IoT (Internet of Things), digitisation will enable controllers to communicate with each other and create feedback loops. This will enable the integration of buildings with macro infrastructure such as energy systems, with benefits such as precision responses to energy demand and balancing grid peak loading with energy storage.

Non-innovative support

There are also a number of overarching needs that require non-innovative but necessary interventions. These include:

- **Exemplar buildings**, e.g. a target for percentage of new and major refurbishments of public sector buildings to be zero carbon.
- **Development of new contractual models** for procurement of low carbon buildings.
- **Knowledge Forum** to disseminate benefits of different buildings technologies to architects and engineers and others in the value chain.
- **Convened fora**, including major landlords and occupiers, to define new practices that integrate best available buildings technologies combined with knowledge sharing activities.
- **Development of essential skills** using learning modules developed in partnership with learning from innovation demonstration programmes.
- **Finance for low carbon refurbishment** and capitalisation of energy efficient new buildings.
- **Quantification of co-benefits** (reputation, health, safety, and productivity) to raise awareness of the wider benefits of low carbon buildings, increase the feasibility of retrofit, and encourage cross-departmental actions.
- Identify ways to **reduce compliance costs** and allow regulation to be efficiently enforced.

Chart 10 - Potential non-domestic buildings innovation priorities and support

Technology area	Key needs	Indicative scale of public funding	Current activities/investments[32]	Future potential activities
Integrated design	• Improve the accuracy and speed of **modelling and software** by better incorporating operational performance data • Lower cost **design tools and services** that better incorporate feedback from operational buildings and the performance of their energy efficiency-related elements • Identify and improve **ancillary tools** that support decision making, such as utilising **operational profiles** to allow comparative design with typical buildings of similar specification • Develop and demonstrate **optimisation tools** for multiple variables, e.g. carbon emission per capita occupier or area • Develop **standardisation and guidelines** for a better integrated design process • Develop and demonstrate **calculator tools** for quantitative and qualitative information	Millions of pounds	• Innovate UK "Design & Decision Tools" programme. • Innovate UK Building Performance Evaluation programme. • *Innovate UK "Buildings, better connected".* • *Innovate UK "A digital tool for BIM" competition*[33]*.* • *Green Construction Board "Bigger, Better Data".*	• Prize funding challenge to develop tools for enhancing energy modelling techniques. • Collaborative R&D on ancillary tools (AT). • Early pre-commercial demonstration programme for modelling tools, ATs, and techniques. • Convened consortia for demonstration of ATs.
Build process	• Develop more flexible and cost effective **smart manufacturing** processes/technologies • Investigate the role of **3D printing and automation** in supporting retrofits • Demonstrate and adapt ***low carbon*** **off-site and modern on-site construction** processes • Develop rapid, cost-effective and feasible **industrialised retrofit techniques** • Research and develop online digital tools enabling carbon **performance-based commissioning** • Scale-up demonstration of improved **commissioning processes** • Share **skills and knowledge** across multi-disciplinary teams, improve workmanship and consistency of outcomes	Tens of millions of pounds	• Build off-site. • Social housing retrofit (e.g. Innovate UK Retrofit for the Future). • DECC programmes. • Building Services Research and Information Association (BSRIA) "Soft Landings". • Royal Institution of Charted Surveyors (RICS) Ska Rating tool. • Chartered Institution of Building Service Engineers (CIBSE) technical manuals for commissioning. • Innovate UK 'Rethinking the Build Process'. • DECC/Innovate UK "Invest in Innovative Refurbishment". • Innovate UK "Supply chain integration in construction". • Innovate UK "Digitising the Construction Sector" programme. • Innovate UK/EPSRC "Building whole-life performance".	• Collaboration for evaluation and demonstration of off-site construction and industrial retrofit. • Research and development of standard and community scale retrofit models. • Collaboration to develop online tools for commissioning. • Development of contractual frameworks for commissioning. • Demonstration of improved commissioning. • Better ways to identify retrofit opportunities, calculate market value and devise action plans. • Tools that integrate design across the construction team e.g. taking account of the change in team responsibility as the project proceeds.

[32] Activities/Investment that happened after 2012 – when the original TINA was published – are in *italic*.

[33] The key need of design tools are currently addressed by Innovate UK programmes. Ancillary tools are identified in 2015 refresh.

Technology area	Key needs	Indicative scale of public funding	Current activities/investments	Future potential activities
Management and operation	• Research, develop and demonstrate **smarter control systems** with a focus on making them easy to use for consumers. • Understand and **demonstrate benefits** (financial and non-financial) to buildings owners and operators. • Research and develop tools and techniques for low-cost diagnosis of energy efficiency measures for **carbon management.** • Early pre-commercial demonstration to test effectiveness of algorithms of diagnostic systems for **carbon management.** • Late stage demonstrations to test/prove **'re-commissioning' services** and methods over a range of non-domestic buildings. • Late stage demonstrations to rest/prove **behavioural change** technologies at scale. • Establish **interface protocols** to enable controllers to communicate with each other. • Develop low cost **Benchmarking guidance** on operational performance based on building profiles.	Millions of pounds	• EPSRC/Innovate UK funding for "user-centred buildings". • DECC programmes. • EU FP7 Energy Efficient Buildings (E2B). • DECC National Energy Efficiency Data Framework (NEED) and Buildings Energy Efficiency Survey. • LDA support for Better Buildings Partnership. • Investment in Low Carbon Workplace Ltd and Standard. • BREEAM In-Use. • *Innovate UK "Future Energy Management for Buildings".* • *Innovate UK "User Centered Design".*	• Collaborative research and development for smart controls with a focus on making them easy to use for occupiers. • Incubation programme for behaviour modifiers. • Development of new content management systems (CMSs) and low-cost diagnosis via convened consortia and directed research, with pre-commercial demonstration and trials.
Materials and components	• Research, development and demonstration of **advanced façade materials, advanced natural ventilation systems** with heat recovery, daylighting and low carbon cooling technologies. • **Late stage demonstrations** that integrate technically proven advanced materials and components into commercial developments to assess and improve commercial viability to meet Green Deal criteria. • Better understanding of **embodied carbon and end of life buildings waste control**, consider the role of buildings in a circular economy. • Faster and cheaper **certification and standardisation** of low carbon materials and components.	Tens of millions of pounds	• DECC programmes. • BRE innovation park. • Tata Centre, Wales. • Sustainable Building Envelope Centre. • University research. • Innovate UK 'Invest in Innovative Refurbishment'.	• Applied research and development and incubation for low carbon cooling. • Challenge-based collaborative research and development for advanced façade materials. • Test centres for demonstration of advanced façade materials. • Prize-funding for integration into real buildings across area with pre-commercial field trials to scale-up (a non-domestic Retrofit for the Future).

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