Reduced Resource Consumption in the Built Environment Construction Industry

A scoping-study of the issues to be addressed by the strategic research agenda for the built-environment industry
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>i</td>
</tr>
<tr>
<td>Foreword</td>
<td>ii</td>
</tr>
<tr>
<td>Executive Summary</td>
<td>iii</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Analysis of Existing Studies</td>
<td>5</td>
</tr>
<tr>
<td>3. Identifying Strategic Research Priorities</td>
<td>19</td>
</tr>
<tr>
<td>4. Research Recommendations and Priorities</td>
<td>43</td>
</tr>
<tr>
<td>Appendices</td>
<td>51</td>
</tr>
</tbody>
</table>
We wish to gratefully acknowledge all those individuals and companies that have been involved with the development of this Scoping Study, especially those that volunteered their time to participate in the working group and interviews.

**Funders**

ARUP  
ATKINS  
Balfour Beatty

**Authors**

Ben Stubbs, CE  
Beth Morgan, CE  
Catherine Smith, CE  
Terry Boniface, BERR

Cover image: Earthship Brighton (c) Mischa Hewitt, Low Carbon Trust
Foreword

This report on Reduced Resource Consumption is the final of three National Platform studies into the priority areas defined in the UK Strategic Research Agenda. As has become apparent, it covers an immensely broad subject in which there are a significant number of existing initiatives. We have focused on identifying areas that we believe will add value to industry and its clients, by recommending, for example, that we adopt a broader systems approach to the way in which buildings interact with their surroundings. It is also clear that industry needs to be helped to connect effectively with the range of work being undertaken and to understand the inter-connectivity between them: a decision support tool that identifies comparative costs and benefits of different factors is integral to this.

The challenge of Reducing Resource Consumption is not an optional one: it is an imperative for our industry and clients, as it is for all governments, businesses and individuals. Today in the Built Environment industry we are well aware of the potential we have to make a significant contribution in meeting this challenge.

Our contribution must be a broad one ranging from developing and implementing innovative technical energy solutions that building occupiers use effectively; to the designing and constructing of our buildings, towns and cities to minimise energy consumption and harmful emissions; to addressing the infrastructure that enables more sustainable living. We must appreciate the comparative environmental, social and economic costs and the impacts, and more importantly the benefits of a holistic approach to all solutions.

We commend this report to you. We hope you read and consider it. Most importantly, we hope you contact us about getting involved in the future.

Bob White
National Platform Support Group Chairman; Chief Executive, Constructing Futures

Keith Clarke
National Platform High Level Group Chairman; Chief Executive, Atkins
Executive Summary

The National Platform for the Built Environment aims to establish an industry-led, pre-competitive research programme endorsed by a significant part of the built environment construction industry.

This report is one of three commissioned by the National Platform to determine strategic research requirements for industry based on the issues it will face over the medium to long term (defined as more than 10 years).

Constructing Excellence was commissioned to carry out this study into industry research requirements in the area of reduced resource consumption (RRC). This has become a prominent theme within the industry as demonstrated by the large number of business areas that are now addressing it.

We aim to identify strategic, collaborative, pre-competitive research that industry believes is needed and will add significant value to business in the long term.

Specifically, our research covered the following:

a. The findings from selected existing roadmaps concerned with the subject of RRC
b. Likely future issues related to RRC in the construction industry
c. Priorities for future research on the subject of RRC

General findings and recommendations

• There are currently a variety of organisations developing ideas and initiatives for RRC within the construction industry and this can cause confusion.
  - There is a need for explanation and central co-ordination of these efforts, thus avoiding duplication and improving accessibility and knowledge transfer.
• There is a need to integrate research efforts and understand the most appropriate ways in which industry should be involved.
• In particular, the research community — primarily comprising academics and RTOs — is carrying out a huge range of work relevant to Reduced Resource Consumption.
  - A gap analysis should be carried out to fully understand what work is already underway and highlight potential research partnerships. A comprehensive comparison of this study with existing and planned research initiatives was beyond the scope of this study.
• The implementation of existing RRC technologies and initiatives are particularly underdeveloped: this includes issues such as influencing user behaviour and deployment mechanisms for appropriate technologies.
• Whilst there are a number of promising technologies that appear to deliver realistic prospects for RRC, unfortunately there are others that are currently being promoted but seem to have little prospect of providing meaningful benefits. Disproportionate research on such technologies could draw vital funding away from more valuable initiatives.

• A Decision Support tool for the Built Environment is critically needed that identifies the comparative benefits that are likely to be created by addressing different aspects of RRC.

**Recommended research topics**

We identified a number of recommended research topics for the strategic research agenda on RRC; the results of a subsequent prioritisation exercise are set out in the tables below which summarise the following:

a. The overall top research priorities
b. Research priorities identified as being appropriate for collaborative strategic research enabled by organisations such as the National Platform.

1. **Energy**

**Top Research Priorities – Energy**

- More detailed measurement and understanding of energy consumption and performance in the built environment.
- Improving the thermal performance of building envelopes by addressing issues such as thermal bridging and air tightness.
- Wider use of natural ventilation and/or development of energy-efficient cooling systems.

**Recommended for collaborative strategic research**

- More detailed measurement and understanding of energy consumption and performance in the built environment.
- Improving the thermal performance of building envelopes by addressing issues such as thermal bridging and air tightness.
- Developing implementation mechanisms for energy efficient technologies and renewables.
2. **Materials**

Top Research Priorities – Materials
- Development of innovative, high-performance insulation materials.
- Improving the recycled content and recyclability of construction products and materials.
- Exploring opportunities for RRC at the design stage.

Recommended for collaborative strategic research
- The development of more comprehensive procurement guides backed up by supplier networks and other procurement initiatives.
- Exploring opportunities for RRC at the design stage.
- Developing more advanced waste minimisation solutions – with better baseline data to allow meaningful measurement of progress.

3. **Water**

Top Research Priorities – Water
- Improving the user experience provided by water-efficient sanitary fittings.
- Developing testing and validation of water-efficient technologies.
- Reducing leakage through better modelling of built assets and leak detection, as well as technology to simplify repairs.

Recommended for collaborative strategic research
- Developing water harvesting and recycling for a wider range of building types and applications.
- Better modelling of natural drainage patterns to inform SUDS and storm water management.
- Improving the user experience provided by water-efficient sanitary fittings.
- Developing testing and validation of water-efficient technologies.

4. **Cross-cutting Recommendations**

Top Research Priorities – Materials
- Development of appropriate research and working partnerships – particularly those which span both industry and academia.
- A broader ‘systems approach’ to the way in which individual technologies for RRC interact with each other.

Recommended for collaborative strategic research
- Development of appropriate research partnerships – particularly those which span both industry and academia.
- Mechanisms to ensure effective deployment of technology for RRC.
- A broader ‘systems approach’ to the way in which individual buildings interact with their surrounding environment and community.
• Significant improvements in understanding the embodied energy of construction products and materials backed up by better data provision.
• Decision support tool that identifies the comparative reduction in resource consumed between different factors.

Next steps

Members of the National Platform are committed to taking forward the agenda and recommendations identified in the scoping study. In particular we want to engage other industry and client organisations, academia and RTOs that are interested in the research topics outlined here to define and take forward specific projects of most relevance to them.

There are a number of relevant national and European initiatives that the National Platform believes will be critical in delivering the recommendations of this study. Industry focused bodies include: the pan-European Joint Technology Initiative in Energy Efficient Buildings; the Technology Strategy Board, in particular its Platform in Low Energy Buildings and Knowledge Transfer Network for the Modern Built Environment; and the Energy Technologies Institute. Additionally there is a huge range of academic work being done in this area, supported by the Research Councils, and more specialised initiatives.
1. Introduction

The National Platform for the Built Environment is an industry-led body, dedicated to demonstrating that research is a potential vehicle for industry transformation and a core, business critical issue. It aims to establish an industry-led pre-competitive research programme endorsed by a significant part of the built environment sector.

This report is one of three commissioned by the National Platform to determine research requirements for the built environment construction industry (BECI), based on the issues it will face over the medium to long term (defined as >10 years).

On behalf of the National Platform, Constructing Excellence was commissioned to carry out this study into industry research requirements in the area of reduced resource consumption (RRC). The other two studies are as follows:

- Building a Client-Orientated, Knowledge-Based, Value-Driven Industry: a scoping study of the research agenda relative to the issues facing the built environment construction industry in 2020.
- ICTA (Information and Communications Technology and Automation) Scoping Study: to facilitate knowledge capture and application, and improve understanding of client requirements.

Resource efficiency has become a prominent theme within the industry as demonstrated by the large number of business areas which are now addressing it. A great deal of attention in this area has been politically motivated; however, we aim to take an approach which looks beyond the timeframes of individual government terms.

The motivation behind this piece of work is the need to create an understanding of current and ongoing research on the subject of RRC in order to identify information gaps and future research priorities.

Specifically, we have identified the following:

a. Existing roadmaps on the subject of reduced resource consumption (carried out by BERR).

b. Likely future issues related to reduced resource consumption in the construction industry – specifically addressing the subjects of energy, materials and water. Findings from the recent CRWP (Construction Resources and Waste) Roadmap study, published by BRE in November 2007, will form the basis of information on waste.

c. Priorities for future research in each of the above areas according to a variety of stakeholders across the construction industry.

d. Information gaps/opportunities for research/investment needs.
Our recommendations are intended to prompt an increase in the quantity and impact of research on RRC as well as improving its focus. The detailed mapping of these recommendations against existing initiatives, of which we know there are many, is beyond our scope, but we suggest that this forms the basis of a separate, follow-on study.

**Methodology**

The research carried out for this study can be divided into the following categories:

1. **An analysis of a sample of existing roadmaps and other studies** relevant to the subject of reduced resource consumption in the construction industry. A list of these studies is provided in appendix 1.

2. **Interviews with key stakeholders**

   We spoke to a number of senior representatives from across the construction industry supply chain to establish their opinions about the medium/long term priorities on the research agenda for reduced resource consumption. Some of the interviewees were selected according to their own expertise within the given study topics of energy, materials and water. Others were selected for their holistic or cross-industry perspective. The full list of interviewees is given in appendix 2. Although we drew up a list of semi-structured interview questions (provided in appendix 3), these were only used to guide the discussion and were adapted as relevant to individual areas of expertise.

   Previous roadmapping studies were not discussed as part of the interview process; this would have conflicted with the need to capture clear, independent perspectives. However, comparisons between this roadmapping exercise and those discussed in part one, above, form the basis of our analysis and recommendations.

3. **Industry survey**

   We carried out a survey of a variety of other construction industry stakeholders. This took the form of an online questionnaire and was designed to provide extra evidence and detail about specific research needs.

   The industry survey was designed to provide additional information on research priorities from a variety of available and developing technologies, and other initiatives for RRC.

   A list of organisations involved in the survey process is provided in appendix 5.

   - The survey was sent electronically to representatives from all parts of the construction supply chain.
• Recipients were asked to rate the importance of a number of possible research topics relating to Energy, Water and Materials (on a scale of 1 – 5).

• To have a realistic chance of response, the list of research areas included in the survey had to be limited. However, respondents were given the opportunity to suggest research areas outside this list.

• Research topics included in the survey were chosen following early interviews with experts in the three areas of Energy, Water and Materials.

Sample description

• A total of 21 respondents in 17 organisations completed the survey. Although this is a relatively small sample size, a variety of organisations were involved spanning a wide cross-section of the industry. Perhaps significantly, the majority (62%) of respondents come from large organisations (comprising over 1000 people).

• The resulting data provides a useful extra layer of information to add to the interview results. However, it has not been possible to segment the data for example by company type.

• The respondents were from a range of organisations, including contractors, developers, academia, local government, utilities, manufacturers and cross industry organisations. They typically occupied senior positions.

4. Identification of research recommendations and priorities

• The findings from the three areas of research outlined above form the basis of our key findings and recommendations. We have also identified a number of recommendations which are ‘cross cutting’; they are relevant to all areas of research into reduced resource consumption.

• A summary table of all research recommendations identified by this study and the sample of existing studies is given in appendix 6.

• We recognise that it will not be possible for one body to take forward all of the recommendations from this study. As such, a list of the main recommendations was presented to members of the High Level Group of the National Platform and other stakeholders involved in the research interviews; they were then asked to complete a simple prioritisation exercise.

• The prioritisation exercise was also sent to all those who were interviewed for this study (see appendix 2).
• The exercise involved the following:
  - Respondents were asked to score each of the main recommendations according to how they should be prioritised on the strategic research agenda for the built environment construction industry.
  - For each of the recommendations, respondents were asked who should take forward research initiatives – industry, government or the National Platform (or a combination of these).
  - Respondents were also invited to comment on the list or recommendations.
  - A full copy of the results of the prioritisation exercise is presented in appendix 7.
2. Analysis of Existing Studies

This part of the study attempts to analyse and draw synergies from a number of existing studies relevant to the Reduced Resource Consumption (RRC) theme of the National Platform’s Strategic Research Agenda (SRA).

- The sample studies were completed by panels drawn from UK industry, academia and government and developed to meet differing forward priority-setting needs.
- The studies selected for this exercise are listed in appendix 1 (headline themes and priorities). We are aware that there are additional roadmaps and other studies covering this subject area.
- To allow for effective comparison with our own primary research findings, the most consistent and/or key emerging priorities relevant to RRC have been divided between Energy, Waste and Materials and Water. To avoid duplication, elements which may address more than one of the priorities (e.g. Waste and Energy) will appear only where they have most impact.
- Reference has also been made, where appropriate, to some key recommendations on reduced resource consumption made by the Callcutt review. This review into housing and regeneration in England was led by Sir John Callcutt, a former Chief Executive of English Partnerships, and was published in November 2007.
- A separate section analyses implications of the Government's Sustainable Construction Strategy on the research agenda for RRC and details some of the responses made during the consultation period for the document.

The majority of the source roadmaps concentrate heavily on the reduction of energy usage and carbon emissions. This is not surprising given the emphasis on development of Zero Carbon Buildings – and the regulatory measures now in place through the Department for Communities and Local Government’s ‘Building a Greener Future: Policy Statement’ published in July 2007. This policy statement confirmed the Government’s intention for all new homes to be zero carbon by 2016 with a progressive tightening of Building Regulations to reduce energy consumption - by 25 per cent to 2010 and by 44 per cent to 2013 - leading to the zero carbon target by 2016. There are, however, a number of important issues emerging within the subject of waste/materials, and to a lesser extent water conservation, which also form part of this analysis.

This analysis also recognises, but does not draw on, the European Construction Technology Platform’s (ECTP) Implementation Action Plan (IAP) which aims to explain how research themes defined in the ECTPs Strategic Research Agenda should be implemented. The IAP of the ECTP SRA is based on a selection of the most important and urgent research areas of the SRA which should be strategically dealt with in the period 2007-2013. This selection resulted from a prioritization process organised in the framework of the ECTP and its comprehensive Network of National Technology Platforms. It identified a set of 9 major priorities with a number
of associated research items.

Two of these areas are clearly related to the Reduced Resource Consumption theme:

• New Technologies, Concepts and High-tech Materials for Efficient and Clean Buildings, and;

• Reduced Environmental and Man-made Impacts of Built Environment and Cities

A proposal to set up a Joint Technology Initiative - E2B (Energy Efficient Buildings) - to coordinate the first of these priorities is in preparation. The overall objective of E2B JTI, through a systemic approach, is to deliver and implement building and district concepts that have the technical, economic and societal potential to cut the energy consumption in existing and new buildings by 50% within 2030. This will require new technologies and materials; development of new business models, services and partnerships; proof by demonstration that these concepts work.

1. Low Energy / Low Carbon in the Built Environment

The major research and development challenge for the industry on energy is to react to the need for low energy, low carbon developments and refurbishment, while equally acknowledging the potential thermal and air quality issues likely to be exacerbated by climate change scenarios. The industry will need to find ways to provide environmentally and economically affordable solutions for both domestic heating/insulation and workplace cooling. Buildings, and potentially infrastructure, will need to become platforms for building or local area renewable energy; building controls will need to become more user-friendly, or automatically controlled through building management systems.

The wide variety of roadmapping activities to date have uncovered a large number of energy-related issues covering construction practices right through to buildings in use. However, this work has largely concentrated on buildings and, so far, there has been little evident roadmapping which sheds light on infrastructure priorities.

1.1. Energy in materials production

Priorities for materials production have focussed on reducing embodied carbon in a number of areas:

• Mineral extraction.
• Drying techniques.
• Coatings and surface engineering - i.e. to improve the thermal properties of existing materials.
• Development of new materials with both advanced thermal properties and renewable or low
embodied carbon (e.g. Vacuum and phase change materials, controlled insulators, SMART glass, FSC timber) and/or breathable surfaces.

- Standards and Quality Assessment for new materials.

**Key Issues:**

There has been particular concern about materials for retrofitting – particularly in the form of acceptable, affordable, non-disruptive insulation for both warmth and cooling.

There also needs to be better understanding and measurement of the properties of new and traditional materials in whole life terms and this will require advanced testing, monitoring and demonstration.

### 1.2. Component Production/ Renewables

Energy efficient building products have received a great deal of attention in previous studies on RRC. The following have been highlighted:

- Energy-efficient lighting.
- Natural ventilation and other low energy cooling.
- Renewable energy generation systems (especially heat pumps/solar thermal).
- Energy-efficient domestic appliances.
- Development of advanced sensors, thermostats and building controls as well as comprehensive building management systems.
- Understanding the interactions between different renewable energy sources.
- Integrating renewables into building elements.

**Key Issues:**

The main concern here has been with the deployment of renewables – for heat as well as electrical energy. Information is particularly lacking on the measurement of embodied carbon and the relative whole life value (WLV) of renewables (e.g. Whole life cost/benefit of CHP, wind-turbines etc.) Work has been suggested to improve understanding of appropriate scales for renewables: at the building level, community level or from centralised generation. Advanced testing, monitoring and demonstration is required.
1.3. Design

Detailed consideration of resource efficiency at the design stage can have a dramatic impact on a project, during both construction and operation phases. Suggested priorities in this area have been as follows:

- Advanced modelling and simulation of designs and decision tools to include U-value modelling, compliance-checking and Platforms to digitally test innovations. This could be through Building Information Modelling, via advanced CAD plug-in design tools.
- Use of design for thermal room separation and exchange, to include better understanding of passive cooling, thermal mass, heat-loss paths and natural ventilation balanced with air-tightness.
- Models of Building performance and holistic whole-building U-value design.

**Key Issues:**

It will be vital to have platforms to effectively model and test designs. Demonstration, monitoring and extraction of data on performance of completed buildings will also be necessary. Greater understanding of natural or passive building design elements is required.

1.4. Construction Process

With sound planning, a number of efficiencies can be achieved during the construction process. Previous studies have suggested that the following should be taken into account.

- Integration of renewables into standard modular, off-site solutions.
- New joining technologies, including a better understanding integration and interface technologies for both new materials and refurbishment of existing properties.
- Tools to aid specification and surveying of existing buildings.
- Error-proof assembly.
- Understanding skills needs.
- Accreditation, Building Control or warranties for low energy buildings.

**Key Issues:**

Of particular concern here is the need to develop error-free construction techniques and technologies, which can maximise the potential offered by low energy design and minimise health and safety issues. To achieve this, the future associated skills needs must be properly understood.
1.5. Occupation

Once a building is occupied, the systems for maximising energy efficiency need to be fully understood and constantly under review; opportunities for further efficiencies should be recognised and appropriate action taken. In particular, the following need to be properly addressed:

- Procedures for constantly improving better occupant feedback.
- User-focused/user-friendly control systems for both new build and retrofit - to include smart metering, remote control.
- The creation of information models for large-building managers as a way of better operating the built asset, and identifying effects of any post occupation alteration on energy/carbon burden.
- Fail-safe DIY construction products for domestic applications (e.g. insulation without mould growth).
- Sampled post-occupancy evaluation of homes to ensure they conform to specification.

**Key Issue:**

The main emphasis here has been on the development of building products and controls which make occupants more aware of the building’s energy use, and better able to regulate it. Mechanisms for feedback should be developed to improve the understanding of how occupants interact with buildings so that appropriate design improvements can be achieved.

1.6. Other areas for consideration

Outside the areas mentioned above, the existing roadmaps have highlighted the following needs:

- Further clarity on the benchmarks the industry is trying to achieve in creating low energy and low carbon communities.
- The development and publication of an agreed definition of “Zero Carbon”: without such a definition the industry’s real target will remain uncertain.
- Greater clarity in planning and Building Regulations: this has included a specific call for research to help fully understand local barriers to the introduction of sustainable building designs and community energy schemes.
The Callcutt Review

The Callcutt review suggested that a clear definition of Zero Carbon performance needed to be in place by the end of 2008 and that SAP (standard assessment procedure) is updated to reflect the definition of zero carbon. The review also supported the notion that zero carbon credentials be tested through building control and that Local Authorities participate in demonstration programmes.

2. Low Waste / Low Materials Usage in the Built Environment

The industry faces a number of significant research and development challenges in the drive towards reducing its material resource consumption. These include improving lean construction methods, better utilisation of existing materials and the development of recycled or renewable materials. There are also a number of issues concerning the way waste can be minimised during design, construction and demolition phases. However, some of the most significant challenges involve understanding how to make the most of the existing building stock.

2.1. Development of construction products and materials

Priorities suggested by previous studies for materials development are as follows:

- Development of new ranges of lighter, stronger and more durable materials. There should be particular emphasis on advanced materials and coatings which can improve the longevity or capacity of the existing built environment; a key theme from the infrastructure sector board of the KTN is the need to extend the life of existing assets (e.g. Victorian bridges, tunnels).
- Increasing the availability of a wider range of stock sizes of solid materials (e.g. timber, plasterboard).
- Renewable, recycled and bio materials being developed should be subject to proper assessment, validation, characterisation and demonstration.
- New technologies should be developed to enable real time, in-situ monitoring of new materials.
- The development of appropriate codes and standards may be required.

Key Issues:

For materials production, the stress has been not only the development of new materials (whether traditional, recycled or renewable), but also on ensuring market confidence in their use by developing a level playing field of demonstration, testing for WLV and certification.
2.2. Design

The following areas of research have been proposed for reducing materials requirements as part of the design process:

- Advanced IT-based modelling and decision support technologies are needed to aid specification as well as introducing concepts such as design for demountability, disassembly and low waste reconfiguration (design for flexibility is a priority for both the Health and Offices sector boards of the KTN).
- Adoption or development of improved client-designer-contractor visualising tools.
- Systems to allow internal fit-outs to be refreshed without replacement.
- Standardisation of sizes and interfaces used in asset design – and gearing product suppliers to these requirements.

Key Issues:

It is particularly important to encourage the development of forward-looking design and IT tools to aid the process of improving materials efficiency. The development of codes, standards and generic building models is likely to assist in the standardisation process.

2.3. Construction Process

The construction process itself offers significant opportunities for materials savings. Previous roadmaps have suggested the following:

- A shift to increased and advanced off-site modular or volumetric construction is seen as key to developing a tighter control on material waste on site and the transfer of materials to other projects. This might involve mass customisation, or building element production.
- Open building standards and systems may be key to bringing this forward. Otherwise, the further development of research to enhance and accelerate the take up of lean construction and supply-chain integration/partnering is seen as key to avoiding construction waste at source.
- Development of novel joining/separating technologies and advanced measurement techniques - to aid dimensional accuracy of manufacture and setting out - are required for both new build and retrofit.

Key Issues:

The main concern here has been with the need to have greater control of the construction process, either through the advancement of greater on-site integration and specification or by advancing technologies and underpinning standards to assist the move to factory production.
2.4. **Deconstruction**

A number of technology advancements are required to accelerate the recycling and re-use of deconstruction waste:

- Smart technologies will need to be developed for material and component separation and segregation.
- Technologies will also be needed to identify the material properties of deconstructed materials to enable recycling and potential re-use of traditional materials within the same site or elsewhere.
- Acceleration of RFID tagging of building elements going into new build for eventual re-use would be desirable.
- In addition, advanced procedures for the sustainable disposal of deconstruction waste must be developed.

**Key Issues:**

There is an urgent need to increase the volume of deconstruction material which can be re-used in subsequent building or transferred to other markets. Deconstruction of existing buildings can be particularly problematic and requires site-based technologies to identify properties of materials and potential for re-use. For new build there needs to be labelling of construction elements, as well as smart separation built in from the start.

2.5. **Other areas for consideration**

Beyond the more technical areas mentioned above, there was a clear call for the following:

- Much clearer, approved definitions of biodegradability, compostability and renewable materials, potentially leading to the development of codes and standards.
- Research may be needed to examine whether increasingly stringent component specification regulations inhibit re-use (e.g. for window units).

2.6. **CRWP – Construction Resources and Waste Roadmap**

The CRWP Roadmap, published in November 2007, focussed particularly on the materials wasted in the construction, refurbishment and demolition of buildings in England. It aimed to provide a baseline for current evidence, policy and activities relating to construction resource use and waste management, capture the views of stakeholders on the subjects and present a longer term perspective and vision for improvements in these areas. As part of this agenda, it identifies relevant knowledge requirements and the actions that can be taken to achieve a longer term vision.
The target audience for the resulting roadmap includes central, regional and local government; government agencies and delivery partners; and the construction industry, their advisers and trade bodies.

Recommended actions from the study were as follows:

- Set baseline data for construction-related waste.
- Measure performance consistently in terms of waste reduction, reuse, recycling etc per company, sector, process and product.
- Extended producer responsibility for all key construction products OR industry-agreed voluntary commitments.
- Supply chain commitments in place for all government procured projects.
- Relevant professional training/education to include modules on resource efficiency.
- Strengthen the Code for Sustainable Homes to require significant waste reduction at level 3 upwards.
- Develop consistent method of measuring carbon impacts relating to waste and resources.
- Develop consistent method of measuring whole life cost impacts relating to waste and resources.
- Encourage the reduction of waste in preference to recycling.
- Encourage the reuse of products and materials in preference to recycling.
- Simplify resource efficiency support to the construction sector.

3. **Low Water Usage in the Built Environment**

The major research and development challenges for the industry in terms of water efficiency are in reducing waste and better exploiting water already supplied to, or falling on, building structures. Improving leak detection and non-invasive, non-disruptive repair is critical at both the infrastructure and asset level, and smart ways need to be found to re-use water within buildings for non-drinkable applications. At the building level, the development of low-water domestic devices will be crucial in reducing overall demand.

3.1. **Reducing loss from water infrastructure**

Making the necessary improvements to minimise water loss from infrastructure will require a much clearer understanding of how and where leaks occur. This must also be accompanied by improvement in technology to simplify repairs. Specifically, research will be required in the following areas:

- High resolution modelling of buried assets.
• Smart deployment of sensor technology on pipework to provide data on location, performance and leakage from water infrastructure.
• Non-invasive and trench-less repair technology – mechanised/robotic, or exploiting liquid and material micro- and nanotechnology.

Key Issue:
Modelling and sensor technology must be better employed to identify sources of leakage whilst improving technologies to repair pipework without major disruption and problems with local consent.

3.2. Development of water-efficient products
Efforts in product development for reduced water consumption should be in the following areas:

• Development and wider adoption of low-water toilets, baths and shower appliances which don’t involve compromise on performance.
• Water-less technologies.
• Super critical liquids reducing water used in cleaning.
• Self-sealing domestic pipework.

Key Issue:
The overarching theme is to provide products which are acceptable to the occupier and provide a similar experience compared to standard appliances.

3.3. Design for water efficiency
Opportunities for reducing water use from the design stage are as follows:

• Specification of technologies to advance domestic rainwater harvesting – for use in gardens, toilets, washing machines etc.
• Development of industrial-scale rainwater harvesting systems - process water, irrigation and humidification usage.
• Development of failsafe greywater systems for domestic re-use of water for non-potable use.
• Longer-term consideration of collection and treatment of all domestic grey/backwater for general re-use.
• Better understanding of conditions appropriate for the use of green roofs. Specifically, this should include work to understand the potential for vegetated building roofs to store, treat and reduce rainwater run off.
• Improved storm water management – including local surface water run-off collection and treatment.

**Key Issues:**

There are major opportunities in making better use of the water falling on, or already within a building by designing in separate water systems (i.e. pipework for potable and grey/harvested water). Testing, validation, demonstration and standards development for such systems will be crucial.

NB: The Callcutt review also supported the need for testing validation and demonstration of water recycling technologies and water saving building design.

### 3.4. Water-efficiency for buildings in use

For buildings in use, opportunities for improving water efficiency are as follows:

• Mechanisms for better occupant feedback.
• Smart water metering.
• In-building leak detection at the level of individual buildings.
• Larger building operators will need information models to operate the unbundled water systems to show working without shortfall or smart automated systems to increase mains supply if needed.

**Key Issue:**

To develop systems which are cost-effective, easy for users to understand, and which can be managed simply without health risk.

### The Sustainable Construction Strategy and the RRC Agenda

The Government’s new Sustainable Construction Strategy\(^3\) was launched on 11th June 2008 and includes a series of commitments aimed at dramatically changing the industry’s approach to sustainability. The completion of this study is listed as one of the key deliverables listed in Chapter 5: Innovation.

The strategy aims to bring together targets from industry and government in a single document and spans a variety of aspects of sustainable construction; it will undoubtedly have a major impact on the strategic research agenda for the industry. A number of the targeted areas within the strategy are of particular relevance to RRC agenda covered in this study and reflect some of our own research findings:

Design:

Action and deliverables identified within the Strategy include the use of Design Quality Indicators; a BREEAM ‘excellent’ target for new build and ‘very good’ for refurbishments on projects procured by central government; and all public sector funded housing to be built to Lifetime Homes Standards. Specific opportunities for RRC through the design process were identified throughout our research for this study (Section 3).

Innovation:

As well as the completion of the National Platform Strategic Research Agenda, the Strategy makes specific reference to a variety of specific research initiatives which are relevant to RRC. These include the Low Impact Building Innovation Platform (R&D and Design Challenge competitions; development of demonstration and procurement opportunities); developing the third phase of the Sustainable Urban Environment Research Programme; and the Carbon Challenge Programme. Other targets include development of zero-carbon eco-towns and partnership working through the new European Construction Research network (ERACOBUILD).

People:

An emphasis on recruitment and upskilling within the industry was also highlighted by our own research (Part Two, Section 4.2). The Strategy includes targets for recruitment and training; apprenticeships; promotion of the value of CPD; and facilitating access to other sustainability training. It also calls for a fully trained, qualified and competent workforce, with a reduction in accident rates and fatalities – this also has a knock on effect for resource efficiency.

Climate Mitigation:

Implementation and improvements of technologies, backed up by a strong regulatory regime, will be vital to achieve the Strategy’s commitment to zero carbon (new) homes by 2016 and consultations on similar initiatives for other types of buildings. Specific actions are also listed for improvements in energy efficiency and reductions in carbon emissions on the government office estate; there are also broader aims of reducing emissions from construction processes and associated transport. Our research has identified a number of research areas which have the potential to contribute towards these goals (Part Two, Section 1).

Climate Change Adaptation:

As well as mitigation, the Strategy also includes a chapter specifically on climate change adaptation. Stated actions include the completion of the Adaptation Policy Framework (DEFRA), a National Programme on Adaptation and UK Risk Assessment. Regional spatial and economic strategies should also take account of adaptation. However, of particular relevance to the RRC agenda are the reviews of Building Regulations and Water Fittings Regulations to make allowances for a changing climate.
**Water:**

The review of Water Fittings Regulations is repeated in the water chapter and the need to set new performance standards for key fittings was also highlighted through our research - particularly in terms of the testing and validation of water efficient technologies (Part Two, Section 3.4). Other areas of action relevant to the RRC agenda for water use include meeting Code for Sustainable Homes targets for water efficiency, water consumption targets for the government estate, reductions of water usage in manufacturing and construction work, and changes to Building Regulations to improve the water efficiency of new homes.

**Waste:**

Targets for the reduction of construction, demolition and excavation waste to landfill represent a huge opportunity for RRC. Work by BRE on the CRWP Roadmap (see Section 2.6, above) has highlighted a number of recommended actions which could help achieve success in this area. Specific areas for action which the Strategy highlights for achieving W2L reductions include the following: development of relevant guidance for small builders; preparation of sector resource efficiency plans; setting of targets for the diversion of demolition waste from landfill; extension of the Plasterboard Voluntary Agreement to the rest of the supply chain; and reduction of packaging waste (20% target by 2012).

**Materials:**

The Strategy’s overarching materials target ‘that the materials used in construction have the least environmental and social impact as is feasible both socially and economically’ is of direct relevance to the agenda for RRC. Specific actions include the development of pilot product roadmaps to assess product impacts across their full lifecycle, developing Responsible Sourcing Schemes and improving access to Life Cycle Inventory information. Our own work also reflects the need for these actions, as well as identifying particular areas of research to improve RRC (Part Three, Section 2.3).

**Consultation Process**

In addition to the main document, the following suggestions are drawn from the responses received during the consultation stage and indicate additional areas for strategic research and development which are of relevance to the RRC agenda. These also mirror a number of issues emerging from previous roadmapping activity.

1. **Definitions**

   - The development of agreed definitions was a recurring theme of the responses – these include ‘waste’, ‘zero carbon’, ‘carbon neutral’, ‘sustainability’, ‘whole life costs’ and ‘whole life value’.
Industry also needs a better understanding of the breakdown of construction, demolition and excavation waste.

2. **Measurement & certification**
   - Effective comparison of new and traditional products, materials and processes is required – this is reflected in the majority of roadmaps considered for this study.
   - We need independent testing, demonstration and certification of systems accompanied by standardised definitions and metrics to enable meaningful comparisons between products and processes.
   - The development of standardised approaches to Whole Life Costing (WLC).

3. **Understanding requirements**
   - Improving understanding and consistency of regulatory enforcement with the development of national, rather than local, building standards.
   - A need to further integrate sustainability into Building Regulations, planning standards and the Common Minimum Standards.
   - Development of benchmark standards in areas such as resource use, impact assessment and post occupancy evaluation.

4. **Best Practice and sharing of information**
   - Disseminating better practice knowledge and more openly sharing information between companies to help set higher common threshold standards.
   - Development of post-occupancy evaluation of projects with feedback mechanisms so future projects could learn from previous experience.
   - Learning from overseas exemplars.

5. **Process**
   - Greater standardisation of contracts, processes and designs.
   - “Inter- operability” between the different elements of construction should be more visible. A high-level road-map would be helpful indicating roles and responsibilities across each stage of the construction process and tools available.

6. **Technologies**
   - Some participants in the consultation process supported the development and validation of a number of technologies for reduced resource consumption.
3. Identifying Strategic Research Priorities

In order to build on the findings from existing studies on the subject of RRC, we also carried out our own primary research. This allowed us to:

a. Compare the findings from existing studies;
b. Add more detail to the findings from existing studies; and, most importantly
c. Identify potential new research areas not covered by existing studies.

As well as the broad themes of energy, materials and water, we identified a number of cross-cutting themes that are common across the whole RRC agenda for the construction industry.

1. **Energy**

Summary of Research Requirements – Energy

1. Further developments of high performance glazing technologies and insulation.
2. Improving measurement/understanding/knowledge of energy consumption in buildings – including the development of more sophisticated modelling techniques.
3. Better coordination of the implementation of appropriate energy saving/generating technologies. Development of robust, integrated systems.
4. Understanding buildings as part of whole systems, including the impacts they have on their surrounding environments.
5. Appropriate retrofitting to improve the thermal performance of existing buildings.
6. Improving the efficiency of delivering electricity by developing localised energy generation options and reducing loss in transmission.
7. Waste heat recycling (from industrial processes to domestic level).
8. Location of IT data processing installations offshore/abroad where they can be powered by renewables.
12. Developing understanding of air tightness.
13. Life cycle analysis of renewables generation (including embodied energy).
15. Optimising the scale and location of renewables.
16. Innovative ways of incorporating renewables into construction projects (e.g. energy piles; solar panels within glass/roof tiles).

17. Developing mechanisms to improve the uptake of proven renewables such as solar thermal and ground source heat pumps.

18. Increasing the efficiency of biomass production – including research on photosynthesis and possible production at sea.

19. Improving energy storage technology.

20. Detailed understanding of embodied energy in buildings and their individual components.

1.1. Background

There will be £2billion of funded research on energy within the UK over the next 10 years. This is a major step up compared to previous funding levels and will involve the various funding bodies within the UK and beyond pulling together to coordinate the agenda. This progress is, in part, prompted by the launch of the Energy Technologies Institute which will work alongside the existing research councils in the management of research funds.

The consideration of energy use in buildings requires a major step change if government carbon reduction targets of 60% by 2050 are to be met. However, the capacity of existing technologies should not be underestimated and it is crucial that these are managed and applied appropriately; herein lies a major challenge for stakeholders from government level down. For the vast majority of buildings it should be possible to improve thermal performance using existing high performance glazing technologies and insulation. In fact, there is no technology that people are currently talking about that hasn’t been around in some form since the 1970’s or earlier.

That said, reducing energy use in buildings will not be simple. Some argue that we have yet to develop buildings for the mass market which can confidently be described as being ‘zero carbon’ in whole life terms. There is also a serious lack of information on the energy consumption of domestic dwellings. It may well be inappropriate to aim for zero carbon homes, particularly at the level of single units. Far greater energy savings might be achieved if all homes, new and existing, were to achieve level four of the Code for Sustainable Homes; the extra effort required to achieve level six will require a disproportionate investment in resources.

Coordinating technologies will also be a major challenge; problems caused by a lack of compatibility of individual building components represent a major barrier to the development of low carbon buildings. We need robust integrated systems which are easy to install in both new and existing homes.
However, the deployment of technology has not been a traditional research topic and involves very complex, multidisciplinary systems; more concerted efforts in this area will be crucial if progress is to be made. In addition, buildings cannot be treated in isolation but must be considered as part of a whole system which includes their surrounding environments and the entire supply chain involved in their creation. In order to achieve this, it will be necessary to create much closer working relationships between academics and industry in order to tie together research and industrial capability.

Competition for existing and emerging fuel sources will also have a major impact on the construction industry as oil and gas become increasingly scarce and, therefore, less economically viable for certain applications. We will need to make decisions on how we provide heat and power for buildings and this will have a major impact on the number and type of power stations which are required: at a national level, the nuclear debate is pressing but there must be much more research into remediation and clean up; meanwhile, hydrogen fuels are at an early stage of development and their future could follow many different and complex paths.

The complexity of the issues involved in ongoing energy provision means that a clear roadmap is needed to coordinate energy supply and demand at the same time and this will have major implications for all construction activities.

1.2. Energy Efficiency

It is a commonly held belief that efforts to reduce carbon emissions should begin with efforts to generate ‘cleaner’ energy. However, whilst this will undoubtedly play an important role, a much greater emphasis should be placed on saving energy through efficiency improvements rather than generating more of it; this also has greater potential for long-term cost savings.

It is vital to remember that improving energy efficiency should begin right at the specification and design stage of all construction work.

Some of the ways in which greater energy efficiency could be achieved by the construction industry are outlined below:

- The construction industry has made considerable progress in improving thermal performance, largely driven by the regulatory framework. However, efforts on new build have not been matched for retrofitting existing buildings and this needs much more attention.
- The way we move electricity around involves significant loss in transmission and this should be reconsidered. Options include more localised generation (perhaps at community level) or improving
transmission efficiency, perhaps with a move from AC to more efficient DC currents.

- Systems for the reuse of waste heat from industrial processes could also have huge potential for a variety of applications ranging from simple on-site water heating to more complex local community heating schemes. In glass production, for example, 40% of the energy used in melting goes ‘up the chimney’.

- The use of energy in IT is also a significant area for consideration which is often overlooked whilst demand is rising dramatically. Data processing requires huge amounts of energy and corresponding waste heat. However, processors don’t need to be based at the point of use and might be better located offshore/abroad where the energy they require could more easily be generated from renewable sources. Where this isn’t possible, there may be options for recycling the waste heat.

- Moving away from air conditioning in buildings will be vital; in London more energy is now used for cooling in the summer than for heating in the winter. Natural ventilation systems need to be developed to reduce the need for air conditioning; however, there needs to be an acceptance amongst building occupiers that there will be some seasonal variation of internal temperature.

- The construction of ‘labyrinths’ under certain types of buildings may be one solution for reducing dependence on mechanical air conditioning. These involve the construction of an ‘undercroft’ with a series of parallel ‘corridors’ through which air can be fed and then used for air conditioning. However, the necessary infrastructure could only be created for a limited number of building types – large public venues such as theatres, for example.

- Intelligent Building Management Systems will be crucial, particularly where facilities management services are inadequate. BMS should be developed and simplified for use in an increasingly wider variety of buildings types and so that they can easily be operated by all potential users.

- Work is required to develop modelling techniques which can accurately represent energy use in buildings; this will require much more detailed consideration of all aspects of energy use and energy loss. Elusive but simple solutions can have an enormous impact on energy use. Whilst current knowledge about the performance of domestic buildings is severely lacking, for the majority of non-domestic buildings it is even worse. Models will become increasingly accurate as they are compared to measured reality and refined accordingly (as reflected by improvements in weather forecasting over the past decades).

- The potential for energy efficiency improvements through the use of insulation are dealt with separately under ‘Materials’ (section X).
1.3. Thermal Bridging and Air Tightness

Any efforts to improve the insulation levels in buildings must be accompanied by research on reducing heat loss due to thermal bridging and poor levels of air tightness – otherwise we are missing a huge opportunity to provide more holistic solutions.

- To reduce thermal bridging the emphasis should be on developing forms of lintel support that don’t create cold bridging issues.
- A much better understanding of air tightness of buildings within the UK is required. Current Building Regulations specify a value of 10m³/h/m² for air tightness whereas passive house technology in other countries has already achieved 0.7 and it will be possible to improve levels even further. However, it will be unfeasible to achieve the lower levels if we continue to demand bespoke buildings using traditional techniques.

1.4. Renewable Energy

As well as improving efficiency, renewable energy will also provide appropriate alternative energy in many cases. However, more work is required in the following areas:

- Accurate data about the embodied energy of generating equipment and infrastructure for renewable energy is needed to ensure that whole life benefits can be achieved both economically and in terms of carbon reductions.
- Clear information about the generating potential of different renewable energy technologies will also be required. A number of products clearly don’t provide useful amounts of energy and we need an independent group of scientists to identify these so that efforts can be concentrated in more valuable areas of research.
- The potential of different locations to provide useful amounts of renewable energy must be investigated properly. This will help to prevent inappropriate installations (e.g. wind turbines in urban areas; PVs in cloudy areas).
- As well as location, the scale of installation is also vital; work will be required to ensure that this is optimised and to discourage inappropriate investment in certain micro-generation technologies. Arguably, there needs to be a move away from a focus on individual buildings towards more community-based renewable energy generation. And on a larger scale, theoretically, the North Sea could provide all our energy needs by optimising the use of wind and wave power; however, this would require massive investment and financial mechanisms within a regulatory framework.
• It may also be possible to develop innovative ways of incorporating renewables into construction projects, particularly if opposition to visible additions on existing buildings continues. However, it may not be wise to incorporate technologies that can’t be easily replaced; renewable electricity technology is likely to evolve faster than we think and the need to replace entire sections of buildings (e.g. facades) to keep systems up to date would clearly be counter-productive. Facades with integrated PV cells, for example (as has happened already) may not provide good value in whole life terms. Building materials should be designed to last a very long time; renewable technologies should only ever be put into a long life materials and products, or onto detachable elements.

• Energy piles incorporate ground source heat pumps into building piles and have become increasingly common in Switzerland and Austria; the technology involved is particularly appropriate given UK (and London) targets for onsite generation. However, they have not yet become widespread within the UK so far and work will be required to investigate their performance potential including the heat conduction of soil, ease of installation and durability.

• Improvements in the efficiency of PVs may be possible so that they become viable in terms of cost and their whole lifecycle – perhaps even in Northern Europe.

• Renewables which are seen as offering the most potential are solar thermal technology and heat pumps (particularly ground source) for heating. Mechanisms to encourage cost reductions and to ensure their uptake should be investigated. Solar thermal technology, in particular, is currently overpriced and underutilised. Heat pumps are generally more suited to new build projects where the efficiency of the building envelope can be more easily optimised.

• Wind turbine technologies are very old – efforts should be concentrated on developing super-light gearing and transmission systems. Urban wind turbines are generally seen as inappropriate.

• The consideration of biomass as a carbon neutral energy source arouses a wide variety of opinions and there are disagreements over the scale on which it will be appropriate. There simply isn’t enough land to provide enough biomass to meet all our energy needs and food production should be prioritised in any case. However, work could be carried out to increase the efficiency of photosynthesis and therefore raise the potential; there may also be potential for increasing biomass production at sea, perhaps by harvesting algal blooms.
1.5. **Community ('nearsite') Generation**

Community-based schemes for energy generation may also provide significant resource efficiency improvements and, therefore, carbon reductions.

- The potential for community-based energy generation is rising up the agenda, particularly in the form of combined heat and power systems; however, there will be issues surrounding acceptability and management issues and research will need to establish optimum scale. Such schemes will need collective servicing systems and unit-by-unit metering to keep costs low and fair.

- Our research also revealed some optimism for a future hydrogen-based economy, which might also be developed at a district, as well as at the building level.

- Community-based systems may also be appropriate for cooling, as well as heating, applications.

- The energy relationship between buildings and vehicles was also put forward as a potential area for research. Cars could potentially be designed to be integrated with the power systems of houses, getting electricity to run them partly, or wholly, from the house’s system. Equally, hybrid vehicles could provide houses with the power they accumulate whilst running. There is a huge electrical capacity under the bonnets of the country’s cars and current urban patterns are likely to continue to demand car use.

1.6. **Energy Storage Technology**

One of the main issues with renewable energy is that its supply is often unpredictable. Work is urgently needed to find effective ways of storing the energy from the sun and the wind to make up for natural variations; this should include the development of materials which can effectively store heat without taking up excessive space (i.e. development of phase change materials for thermal storage; thermal storage chemistries).

The capture and use of methane from dairy farms may also be feasible and is currently the subject of a study by Faber Maunsell for Cambridge University as part of their drive towards meeting 10% of energy requirements onsite. The gas could be used to provide energy for CHP installations as an alternative to less sustainable biofuels.
1.7. **Survey Findings**

From the cross-industry survey, the following issues were identified as being the top five most important research priorities for RRC in the area of energy use (based on the mean average of responses).

<table>
<thead>
<tr>
<th></th>
<th>Provision of appropriate training and professional education for reduced energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Smart metering or Building Management Systems</td>
</tr>
<tr>
<td>3</td>
<td>Improving the energy efficiency of cooling systems</td>
</tr>
<tr>
<td>4</td>
<td>Educating users about how to make the most of sustainable features / technologies</td>
</tr>
<tr>
<td>5</td>
<td>Provision of better performance figures for individual building components</td>
</tr>
</tbody>
</table>

2. **Materials**

Summary of Research Requirements – Materials

1. Reducing the over-ordering of materials.
3. Developing glass technologies to improve U-values for windows.
4. Vacuum technologies for insulation.
5. Use of waste organic material for insulation and fillers.
6. Acceptable external cladding solutions (including work to change public attitudes and make them acceptable).
7. Improving opportunities for reuse and recycling.
8. Developing recycled products which can achieve guaranteeable quality. (e.g. especially for window manufacturing).
9. Developing standards which don’t hold back the use of recycled content.
10. Widening the reuse of structural frames.
11. Less energy-intensive concrete formulas.
12. Incorporation of waste materials into concrete.
13. Increasing the use of pre-stressed concrete.

2.1. Background

It is important to remember that reduced resource consumption in the areas of construction materials and energy are closely tied together because of the energy requirements of manufacturing, processing and transportation (i.e. embodied energy). Efficient use of materials should generally lead to parallel energy savings.

Some of the opportunities for materials efficiencies are as follows:

- **Good design**: This is a major part of materials savings, both in terms of minimising materials use as well as designing out waste. However, progress is hampered by a desire to create something new and different all the time.

- **Predictable processes**: Making manufacturing and construction processes more standardised and, therefore, predictable can have enormous potential for the reduction of waste; this is clearly demonstrated by offsite manufacturing processes.

- **Innovative products and materials**: The development of new products and material can lead to reduced resource consumption. However, developing new products and materials takes time and technological progress in the construction industry is well behind other sectors.

- **Recycling and Reuse**: Reducing the consumption of virgin raw materials by recycling, or better, reusing whatever can be salvaged. However, making changes in these areas represents a major challenge for an industry which has traditionally been slow to respond to calls for efficiency improvements: large manufacturers and industry organisations spend huge amounts of money promoting their products and have a great deal of influence; construction companies are loathed to abandon tried and tested procedures, sometimes even when the potential for cost savings are identified.

The traditional over-ordering of materials within the industry will also be difficult to change. This has been seen as necessary to ensure prompt delivery and reduce penalties and is likely to continue until offsite manufacturing is embraced more widely - and even offsite there is a huge stock of unused materials.

It is commonly suggested that improvements in materials consumption within the industry will require an increase in regulation. The introduction (and increase) of the landfill tax, for example, has had a bigger impact on waste reduction than any initiatives generated within the construction industry itself.
However, an increasing scarcity of virgin raw materials and fossil fuels, and corresponding cost increases, are likely to prompt new approaches to materials use. To take full advantage of the options available, much better links and knowledge transfer between academia and industry will be required.

Some of the potential opportunities for improving materials efficiencies are outlined below:

2.2. Embodied Energy

Recent efforts to reduce energy in the construction sector have focussed on the operation of buildings – minimising energy use for end users. Government targets for zero carbon dwellings don’t take into account the significant energy requirements of the design and construction phase. Materials such as concrete (see below) and steel have particularly high levels of embodied energy; however, each interest group obviously plays up its advantages and it is difficult to find reliable data.

Theoretically, the consideration of embodied energy should rise up the agenda as energy use falls elsewhere. However, there is a danger that it will be eclipsed by the drive for buildings which are zero carbon in use.

The following research would be appropriate:

- This embodied energy and carbon involved in creating buildings and their individual materials and components is not well understood; accurate, standardised measurement procedures for use in LCA techniques must be developed as a matter of urgency. This will allow proper comparison of different products and materials.

NB - Embodied energy can also be reduced by developing and extending recycling processes, and products should be developed accordingly (see below).

2.3. Life Cycle Analysis

In the development and adoption of new building products and materials, it will be necessary to have a comprehensive understanding of how each of them behaves throughout their entire lifetime.

- It is particularly important to improve understanding of the potential of products and materials as pollutants throughout their lifetime, and the possible costs of remediation.
- LCA should be used to prioritise the development of products and materials which have low maintenance requirements.
- There needs to be clarity on the realistic design life of new and innovative products and materials.
2.4. Insulation Materials

Improving insulation is one of the quick wins for improving energy efficiency in buildings. Traditionally, this has involved increasing the thickness of internal insulation to reduce heat loss. However, this can create major issues, particularly in existing buildings: the resulting reduction of floorspace can have a negative effect on lifestyle and property prices; there can also be problems with over-heating during summer months and increased condensation.

The need to optimise levels of insulation often seems to conflict with architects’ fondness for using more and more glass in buildings. However, it may be relevant to balance any loss in U-values with the potential for increasing solar gain; this will vary from one building design to the next.

Some of the research requirements for improving insulation materials are as follows:

- There is an urgent need to develop new, cost effective insulating materials which are super thin, super light and durable - and yet still have good U-values. These may include aerogels (low density, silicatious solids which are used on space shuttles) and multifoils but these will only be viable options for the mass market if costs can be reduced substantially. Significant progress could also take between 10 and 20 years. Work on developing new insulation materials must also be accompanied by initiatives to reduce heat loss through thermal bridging and air leakage (see section 1.2).

- Vacuum technologies, as currently used for insulation by the refrigeration industry, may be adaptable for use in buildings; however, work must be carried out to reduce the risk of puncturing and improve overall durability – this will also need to be accompanied by a major leap of faith within the industry.

- The external façades of existing buildings are often protected and the addition of insulating cladding is generally seen as undesirable and problematic, particularly for heritage buildings. A great deal of work will need to be done to change attitudes if we are to come to terms with the idea of putting new materials on old surfaces. Even for new buildings, acceptable solutions remain elusive. Research will be required to develop a much better understanding of surface technologies which offer significant resource savings as well as achieving broad acceptance.

- Although coatings to maximise the efficiency of double glazing are already well optimised, there may still be further opportunities for the development of vacuum glazing to further improve U-values.

- Investigations should be made into the potential use of waste organic material for insulation and fillers; however, there will need to be careful consideration of fire regulations.
NB - The design life of buildings needs to be carefully taken into account when considering which insulation materials to use. For existing buildings, in particular, it may not be sensible to add new insulation which will not have the opportunity to pay for itself economically or environmentally.

2.5. Recycled and Reused Materials

The specification of reused and recycled materials is likely to continue to rise up the agenda as the use of virgin materials becomes more expensive and increasingly frowned upon. However, there will have to be corresponding improvements and refinement of the market for them to ensure sustainable supplies.

The recycling and reuse of a variety of construction products and base materials presents a number of challenges, not least in the form of legislation which discriminates against them, often without justification. Questionably, things have gone too far in the area of health and safety, for example, putting serious pressure on materials usage (e.g. it is unacceptable to reuse fire doors that are more than capable of doing the job). There is a very real danger that some future construction products will be less sustainable if regulations continue to be tightened inappropriately.

Moving away from products which are manufactured using virgin oil-based materials (i.e. plastics) is likely to become increasingly pressing as resources dwindle; recycled and non-oil-based polymers are likely to play an increasing role.

Research in the following areas would be beneficial:

- Initiatives to improve opportunities for the reuse of construction materials. Reuse offers greater opportunities for reduced resource consumption than recycling.
- The reuse of structural frames: This is already done but many construction companies prefer to ‘play it safe’ and build new, thus missing out on the opportunity for major potential materials savings. Guidance is also lacking and more research is required to provide accurate surveys.
- Innovation to develop materials which incorporate high levels of recycled content and can also achieve ‘guaranteeable’ quality. This is needed to overcome the often inaccurate perception that recycled = inferior. However, this will also require a serious cultural shift within the construction industry to move away from a ‘new is best’ attitude.
- Window manufacturing is an example of one area where increasing recycled content is particularly problematic; high quality window glass can’t be produced from the contents of a mixed bottle bank. This highlights a need for much more refined segregation processes to isolate very specific types
of glass or, alternatively, the development of manufacturing processes which allow the incorporation of materials with more impurities. Coatings used on high quality window products make them difficult to recycle and this may also be an area for future consideration.

- Work will be required to develop appropriate standards which don’t hold back the increase of recycled content in a variety of construction products.

### 2.6. Concrete

Concrete has particularly high levels of embodied energy; cement-making is responsible for 5% of world manmade CO$_2$ emissions on its own (twice as much as the aviation industry)\(^4\); mammoth efforts will therefore be required to reduce this impact if it is ever to be considered sustainable. The problem is aggravated by the current trend towards specifying higher than necessary levels of strength.

Concrete substitutes, such as those which incorporate specially prepared hemp with a lime binder, have provided promising alternatives for smaller buildings; however, they are unsuitable for high rise construction.

Efforts should be concentrated in the following areas:

- Research into the development of new concrete formulas which require less energy in production.
- Accelerating the development and take-up of concrete products which incorporate a higher proportion of waste materials (e.g. waste aggregates, fly ash, slags from industrial processes and even diced tyres). Work will be required to ensure quality is maintained and to achieve wider acceptability. To date, efforts to incorporate recycled content have often conflicted with the need to provide long-term guarantees and this is compounded by a reluctance from the concrete industry to adopt new methods.
- The increased use of pre-stressed concrete. This offers the potential for huge savings in the amount of materials which required (up to 30% less concrete and ¼ as much steel). Pre-stressed concrete is already in use and is seen as competitive in cost terms.
- Initiatives to capture and sequestrate the carbon emitted from concrete production; this is particularly important given the rapid rate of development in South and East Asia.

### 2.7. Waste Management in Manufacturing

The introduction of mandatory Site Waste Management Plans in April 2008 should lead to significant reductions in waste at a site level. However, attention will also need to be focussed on waste management

\(^4\) www.guardian.co.uk and Wikipedia
in the manufacturing of construction materials. Even steel manufacturing, which boasts an average 90% recycling rate, there is still significant waste; slags, for example, have previously been seen as a waste product but can successfully be incorporated into concrete to reduce cracking.

- Efforts will be needed to ensure the development of manufacturing processes which minimise the waste or materials. This will need to be accompanied by appropriate legislation and awareness-raising.

2.8. **Procurement Guides**

Procurement guides will play an important part in encouraging the uptake of products and materials which have been produced more efficiently. However, these will have to be further developed to provide a much better understanding of a wide variety of potential environmental impacts. Procurement issues are dealt with very much on an ‘ad hoc’ basis at the moment and templates should be developed to cover all types of building fabric separately.

Care must be taken to ensure that the environmental profiling of materials isn’t seen as being in conflict with EU competition rules.

2.9. **Survey Findings**

From the cross-industry survey, the following issues were identified as being the top five most important research priorities for RRC in the area of materials (based on the mean average of responses).

<table>
<thead>
<tr>
<th></th>
<th>The need to develop recycling facilities for a wider range of materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Understanding and consideration of the whole life impact of products (from extraction / manufacture to disposal)</td>
</tr>
<tr>
<td>3</td>
<td>The development of products with lower environmental impact</td>
</tr>
<tr>
<td>4</td>
<td>Encouraging or enabling local sourcing of materials</td>
</tr>
<tr>
<td>5</td>
<td>The development of supplier networks / procurement initiatives</td>
</tr>
</tbody>
</table>
3. Water

Summary Of Research Requirements – Water

1. Understanding the conflicts and synergies between water and energy efficiencies. Measuring the carbon footprint of supplying water.
2. Developing the potential for recycled/harvested water for use in a wider range of applications.
3. Developing waste heat recycling from grey water and water used in industrial processes.
4. Technologies which reduce domestic water use whilst offering the same level of experience as less efficient systems.
5. Exploration of the potential of waterless sewerage systems for domestic use. Understanding the ongoing sustainability of water-borne systems.
6. Development initiatives to encourage the uptake of flow-controlling devices.
7. Protecting water courses: controlling what can be discarded into drainage systems (including developing more benign products).
8. Better modelling and understanding of natural drainage patterns to develop SUDS.
9. Exploring the practicalities of water redistribution.

3.1. Background

Recent studies on mitigating and adapting to the effects of climate change have been dominated by research into the management and supply of energy – perhaps at the expense of other resources. And yet it is becoming increasingly obvious that major water management problems will present huge challenges, both globally and within the UK. The incidences of unusual and extreme climate events are on the rise and in northern Europe these have included both water scarcity and flooding in recent years.

In Northern Europe, water has been seen as a ubiquitous and plentiful resource and reducing its use has not been a high priority for the general public. Water companies will have an important role to play in managing future supplies and have a responsibility to educate and inform consumers to increase the uptake of efficient technologies and discourage wasteful behaviour. More progressive companies are already beginning to run information campaigns and offer advice to raise awareness of domestic water management issues. However, any changes to the way water is supplied are bound to be controversial and there must be demonstrable benefits compared to traditional systems.
Water utilities also have to be seen to be setting an example through their own practices; domestic users are reluctant to make what they see as minor water savings whilst the companies that supply them seem to be failing to tackle excessive leaks.

The knowledge and technologies we need for dramatically reducing water consumption are already largely available and the main challenge will be to encourage widespread uptake. This should be made much easier as water metering becomes more common although work will need to be done to ensure that affordability, reliability and maintenance benefits are made clear.

3.2. Relationship between energy and water use

We must make sure that reducing water consumption isn’t at the expense of large increases in energy use to compensate:

- Research efforts need to take into account the conflicts and synergies between water and energy efficiencies.
- Efforts will be required to increase the understanding of the carbon footprint of supplying water; there is an acute lack of data on the footprints of existing water supply and management technologies. Without baseline data it will be difficult to justify further investment in conceptual or prototype systems.

3.3. Recycled and harvested water

Increasing the uptake of systems which utilise recycled and harvested water will require efforts to improve their acceptability. These sources have traditionally been seen as ‘polluted’ whilst utilities have generally been able to provide plentiful supplies of clean, potable water. A move towards using mains water for a much narrower range of household activities will require a significant cultural shift. However, as summers get hotter and drier due to climate change, restrictions on the use of mains water are likely to become increasingly common.

Dual supply systems are currently seen as a huge overhead, particularly at the level of individual buildings, but they are likely to become increasingly cost-effective as the cost of supplying and consuming water rises.

The following research areas have been suggested:

- Using recycled/harvested water in a more creative way: There has been too much emphasis on reusing it within buildings; perhaps it would be more appropriate to use non-potable sources in the landscape (particularly in the South East) where it doesn’t need so much treatment.
- The possibility of using grey water recycling systems for thermal storage should be explored;
recycling waste heat from bath and basin water presents a major opportunity for energy saving. There may also be potential for thermal storage using rainwater harvesting tanks.

- At a commercial level there is even greater economic and environmental potential in recycling the water (and waste heat) used in manufacturing processes.

### 3.4. Water efficient systems and products.

Major strides have been made in the development of a range of water efficient sanitary fittings and appliances; these have provided significant benefits at both domestic and commercial levels. However, moving away from baths and power showers will require a major cultural shift which could take at least a generation unless driven effectively.

- To achieve consumption of 80l/person/day (as required for the higher levels of the CSH) efforts must be made to ensure users feel like they are using much more. Nebulisers are one potential solution for dramatically reducing the amount of water used in showering.
- Waterless systems for sewerage may also offer potential. Vacuum systems, as used on ships and planes for example, offer one potential solution but would probably be prohibitively expensive for use at a household level at the moment and their introduction at a domestic level would likely encounter resistance.
- In parallel with the above, work must be carried out to establish the sustainability of water-borne sewerage systems into the future. This issue needs to be considered at RDA or government level; the possibility of protecting our waterways as unpolluted resources would provide clear environmental, social and economic benefits.
- Efforts should be made to promote a wider take-up of flow controlling devices at both domestic and commercial levels. Ideally this will be driven from the EU level through relevant regulations.
- Industry standards and certification systems for water efficient sanitary fittings should be established.

### 3.5. Reducing contamination from domestic sources

The disposal of cleaning products and other domestic waste into our water courses represents a major cause of pollution.

- Action is required to control what we discard into drainage systems and how it can be processed.
• It will be necessary to develop, and increase the uptake of, more benign products.
• It is important that we start to take on board that it is not only the chemical impacts of discharges, but increasingly the impact on biological/ecological and physical processes in line with the EU Water Framework Directive.
• Human behaviour is a key area to target with regard to sanitary waste. Scotland’s national ‘Bag It and Bin It – Don’t Flush It’ campaign asks residents to carefully wrap sanitary items and throw them in the bin rather than simply flushing them away. Around 340 million items of sanitary waste are flushed down Scotland’s toilets each year causing blockages and damage to the sewerage infrastructure.

3.6. Understanding and managing the movement of water

Improving the understanding of natural and man-made drainage systems will also be key to the sustainable long term management or water resources. SUDS are increasingly being considered as part of planning conditions – particularly in the South East of England.

• Further research into understanding natural drainage patterns will be required to maximise the potential of sustainable urban drainage systems.
• Consideration must be given to the amount of energy (and embedded carbon) required to create man-made drainage systems.
• Distribution of water from areas of plenty to areas of scarcity may become inevitable. The practicalities and cost of providing the necessary infrastructure will need to be further explored.

NB: It should be noted that some of those interviewed stressed that the research agenda for energy is many times more important than that for water. This is because the implementation of energy solutions is much more complex.

3.7. Survey Findings

From the cross-industry survey, the following issues were identified as being the top five most important research priorities for RRC in the area of water use (based on the mean average of responses).

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Use of rainwater harvesting systems</td>
</tr>
<tr>
<td>2=</td>
<td>Designing buildings for lower water consumption</td>
</tr>
<tr>
<td>2=</td>
<td>Further improvements of sanitary fittings to minimise water consumption and wastage</td>
</tr>
</tbody>
</table>
4. Cross Cutting Themes

As well as the issues which fall into the specific categories above, the research process also revealed a number of cross cutting themes; these include issues which are relevant to, and should be considered across, the whole RRC agenda for the construction industry.

4.1. Timeframes and Priorities

This study has aimed to look at the strategic research agenda over the medium/long term which we defined as 10 years+. However, for many of the research areas discussed above, results over this timeframe will require immediate commitment and planning; the process of prioritisation will be crucial.

However, there is some confusion about who should be driving the agenda forward and this is not helped by the current fragmentation of organisations which claim responsibility for construction sustainability/resource efficiency.

It has also been suggested that the construction industry is currently waiting for government to provide the leads; however, this is a clear abdication of responsibility. The sector should be working collaboratively with government and academia to experiment and find appropriate solutions; long term improvements in resource efficiency will involve an iterative process which will see many technologies and processes come and go. There will have to be some acceptance of risk.

Addressing the energy and emissions reduction targets (as set out by the government) provides one of the most pressing requirements for research and development. However, the challenge of zero waste to landfill by 2020 is also pressing and will require concerted action if it is to be achieved.

Technological changes will be largely incremental and we shouldn’t anticipate any huge step changes in the coming years; however, we already have most of the technology that we need and this needs to be introduced more effectively.
4.2. **Skills and Training**

Compared to previous generations, there is now a much broader range of people coming through the University system and a wider variety of subjects available. However, there is still a shortage of skills for research on RRC; we noted, for example, that research on environmental engineering at many universities isn’t considered to be of a high standard.

There are particular shortages within the subjects of construction-related physics and mathematics which are crucial for industry research and development; expanding research in the area of building fabric design and M&E systems for renewables was mentioned as being especially important. Further shortages are apparent in the area of logistics, where better understanding would eliminate a wide variety of waste-related problems, and engineering, where rapid upskilling will be essential if we are to achieve government targets in areas such as renewable energy generation.

As well as increasing skills for specific research disciplines, there is also a clear need in both academia and industry for people who can develop more holistic solutions and therefore efficiencies across the whole of a project.

In order to coordinate the research agenda, it will be necessary to form more suitable research partnerships, in particular between the industry and academic institutions – but this is difficult. Current ‘knowledge transfer’ mechanisms can be blighted if industry doesn’t feel that it gets the full benefit of research initiatives. Furthermore, private companies sometimes feel that they are missing out on external funding to carry out their own research at a more practical level and that unilateral private initiatives are difficult to justify with limited internal research budgets.

Better partnerships will also be required to optimise skills at the site level where it is felt that more and more people are unwittingly in control of things that they don’t fully understand. Areas of specialism may be split across several different trades which may fail to work in collaboration and blame each other for lack of progress. And for all who have specialist skills, ongoing training and CPD will be essential to ensure that they keep abreast of developments in technology, processes and site management.

To provide the necessary impetus to expand the skills base, the industry will undoubtedly have to sell itself better. Co-ordinated initiatives will be required to ensure that construction-related careers are viewed as interesting, rewarding and different.
However, despite a clear skills shortage across the construction industry, it is also important to remember that a great deal of what needs to be done isn’t necessarily technically complicated; it is more a case of changing long-term habits.

### 4.3. User Behaviour

Influencing the behaviour of building occupants is seen as a major challenge in the drive towards maximising resource efficiency. The benefits of resource efficient design and technology cannot be fully realised unless the end users are empowered to make the most of them.

Whilst awareness raising campaigns and education initiatives certainly have their part to play for people of all ages and backgrounds, it is also imperative that technologies are made as simple as possible. Users also need to be able to clearly understand the benefits, particularly in terms of cost savings, which can be achieved – the widespread adoption of smart-metering systems will be particularly beneficial for this.

The impact of user behaviour on energy use is generally more obvious and, arguably, easier to measure; however it is also important to bear in mind the implications for water usage and sanitary waste.

In buildings where it is particularly difficult to influence user behaviour, intelligent building management systems may be able to provide improved operating efficiency.

### 4.4. Systems Integration

The full potential of individual RRC initiatives cannot be fully realised if they are considered in isolation. It is essential that all research, methodologies, technologies, materials and processes which are developed to improve resource efficiency are considered as part of the wider systems in which they operate.

For example,

- at the project level, it is important to consider how different products and materials interact with each other. Benefits can be lost if the design of a building fails to take into account its individual components or if those components are not compatible with each other.
- at the macro-scale, the function of a building or structure within the wider community should be carefully planned in advance. Measures to improve resource efficiency may fall down if the necessary wider support systems are not in place (e.g. recycling efforts must be accompanied by appropriate local recycling facilities). Alternatively, new initiatives to improve resource efficiency may negatively impact on resource efficiency elsewhere (e.g. operational energy savings from the installation of...
renewables infrastructure may be cancelled out by the embodied energy required for manufacturing and installation).

4.5. Embodied Energy

Although embodied energy has already been covered under materials (2.2 above), there are clear overlaps with energy use and water management. It is also worth re-emphasising that there is currently a shortage of data and understanding in this area.

Current environmental assessment methodologies concentrate on the energy consumption and carbon emissions of buildings in operation and fail to properly consider all the energy required to bring products and materials to site – including mining, processing, manufacturing and transportation. There also seems to be precious little information on the energy involved in upgrading and maintaining our water infrastructure.

Better understanding of embodied energy (and the related embodied carbon) will be essential in efforts for RRC.

4.6. Deployment of Technology

It was broadly agreed that a number of the materials and technological knowledge required for RRC already exist and have done for some considerable time. Serious efforts must therefore be made to ensure effective deployment.

Some common excuses for failing to adopt new technologies include costs, availability and lack of skills (i.e. for installation and servicing) – so it will be particularly important to develop appropriate support mechanisms to ensure wider uptake, both at government level and within the industry itself.

4.7. Land Use

Land use wasn’t considered separately as part of the research process for this study – largely because of the linkages and overlap with other areas of resource efficiency. However, it is important to note that land use management has a fundamental influence on resource consumption in the construction industry and specific research requirements are noted below:

- The implications of the location of new developments on resource consumption. Opportunities for reduced resource consumption are often compromised by locating buildings in inappropriate locations.
- Establishing optimum densities to maximise resource efficiency – both in construction and operational phases. Vertical zoning is particularly important.
4.8. Overall Survey Findings

Over all three of the research areas surveyed, the following issues were identified as the top five research priorities for RRC:

<table>
<thead>
<tr>
<th>Rank</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Provision of appropriate training and professional education for reduced energy consumption (Energy)</td>
</tr>
<tr>
<td>1</td>
<td>The need to develop recycling facilities for a wider range of materials (Materials)</td>
</tr>
<tr>
<td>3</td>
<td>Smart metering or Building Management Systems (Energy)</td>
</tr>
<tr>
<td>4</td>
<td>Understanding and consideration of the whole life impact of products (from extraction / manufacture to disposal) (Materials)</td>
</tr>
<tr>
<td>5</td>
<td>Improving the energy efficiency of cooling systems (Energy)</td>
</tr>
</tbody>
</table>

4.9. Conclusion

Although it is common sense to build efficiently and to reduce resource consumption to a minimum, if only to reduce costs, our research suggests that the variety of unexploited opportunities remains huge. And whilst legislation and standards seem to be demanding ever increasing resource efficiency, regulatory policy changes very slowly and some suggest that there is significant reluctance within the industry to provide adequate funding to meet challenging national targets.

During the course of our research, the construction industry was variously described as follows:

- secretive, adversarial and conservative;
- risk averse - needing to be driven by regulatory drivers;
- impervious to learning; and
- highly fragmented.

Where they exist, such traits clearly represent a major barrier to progress on RRC.

Cost is likely to remain the major issue – whether real or perceived. The industry needs to find low-cost ways of producing sustainable products and materials at high volumes, whilst also communicating their economic benefits to both constructors and building users. The majority of house buyers will avoid buying
sustainable houses if they are more expensive than equivalent unsustainable options – even if there is potential for long-term operational savings.

Also, there are currently a variety of organisations developing ideas and initiatives for RRC within the construction industry; this can cause confusion. Decisive action is needed to coordinate these efforts and so avoid duplication, as highlighted by a number of participants in our research process. Social, political and technological progress is rarely synchronised but a more holistic, systems-based approach would be beneficial.

Whilst there are a number of promising technologies which offer realistic prospects for RRC, unfortunately there are others that are currently being promoted but have little prospect of providing meaningful benefits; examples cited during our research included certain applications of wind turbines and PVs. Although further research on such technologies could yield improvements, it could also draw funding away from important initiatives and a balance must be carefully considered.

There is broad consensus that we have some of the knowledge and technologies needed to dramatically reduce resource consumption within the construction industry. However, catalysing the regulatory process, organising the required investment, funding essential research, coordinating implementation and changing the behaviour of building users all still represent major barriers to the rapid progress which is required.
4. Research Recommendations and Priorities

The analysis of previous roadmapping studies, together with the interviews and survey carried out as part of this study, led to the identification of a large number of recommended research topics for the strategic research agenda on RRC. However, we recognise that it will not be feasible for the National Platform to take all of these forward; indeed many of them will be appropriate to the work of other research organisations.

The final part of our research process involved a prioritisation exercise to identify the following:

a. The overall top research priorities (responsibilities not identified).

b. Research priorities identified as being appropriate for collaborative strategic research enabled by organisations such the National Platform.

However, it should be noted that, outside the list of the top three or four research priorities in each section (energy, materials, waste and cross-cutting) a number of other recommendations were also rated quite highly and these are also outlined at the end of each section.

1. Energy

Top Research Priorities – Energy

- More detailed measurement and understanding of energy consumption and performance in the built environment.
- Improving the thermal performance of building envelopes by addressing issues such as thermal bridging and air tightness.
- Wider use of natural ventilation and/or development of energy-efficient cooling systems.

Recommended for collaborative strategic research

- More detailed measurement and understanding of energy consumption and performance in the built environment.
- Improving the thermal performance of building envelopes by addressing issues such as thermal bridging and air tightness.
- Developing implementation mechanisms for energy efficient technologies and renewables.

The identification of measurement and understanding of energy consumption as a priority for research reflects a broad range of views expressed during the interview process for this study. Although such measurement has improved markedly in recent times, the need to develop more sophisticated modelling techniques to represent energy use more accurately and in more detail was highlighted. It was felt whilst that current knowledge about the energy performance of domestic buildings is severely lacking, for the majority of non-domestic buildings, it is even worse.
Improving the thermal performance of building envelopes was highlighted as an important research area which could be taken forward by the National Platform. It was stressed that any efforts to improve insulation levels in buildings should be accompanied by research into reducing heat loss due to thermal bridging and poor levels of air tightness. The understanding of air tightness is still seen as lacking in the UK, which is well behind other countries in this area.

Whilst the wider use of natural ventilation accompanied by development of energy-efficient cooling systems was identified as an important research area, it was felt that research in this area should be taken forward by individual companies.

However, it was felt that organisations such as the National Platform could have an important role to play in the development of implementation mechanisms for energy efficient technologies and renewables. This may involve a move away from a focus on individual buildings towards more community-based energy generation initiatives and there will also have to be consideration of how to improve cost-effectiveness. A number of further issues affecting the implementation of renewables are outlined in part two, section 1.4, below.

Other research recommendations for energy included the following:

- Improving understanding of the embodied energy of construction projects down to the level of individual products and materials.
- Improvements in energy-efficient lighting and appliances.
- Addressing the loss of energy in electricity transmission.
- Exploring the potential for waste heat recycling at domestic and industrial levels.
- Better life cycle analysis of renewables including solid understanding of their energy-generation potential as well as consideration of optimal scale and location.
- Further improvements in the generating potential/energy conversion of certain renewables (e.g. wind turbines, biomass).
- Developing acceptable/innovative ways of incorporating renewables into buildings/building components.
2. Materials

Top Research Priorities – Materials

- Development of innovative, high-performance insulation materials.
- Improving the recycled content and recyclability of construction products and materials.
- Exploring opportunities for RRC at the design stage.

Recommended for collaborative strategic research

- The development of more comprehensive procurement guides backed up by supplier networks and other procurement initiatives.
- Exploring opportunities for RRC at the design stage.
- Developing more advanced waste minimisation solutions – with better baseline data to allow meaningful measurement of progress.

A number of participants in the interview process for this study emphasised the need for ongoing research into the development of innovative, high performance insulation materials; however the prioritisation exercise suggested that this is something that should be taken forward by individual companies. Specific solutions in this area are covered in part two, section 2.3.

The National Platform may be better placed to take forward the exploration of further opportunities for RRC at the design stage which have been highlighted by some previous roadmapping studies. This might include advanced modelling and simulation of designs and decision tools to include u-value modelling, compliance checking and platforms to digitally test innovations. Design initiatives could also improve passive cooling, thermal mass, heat loss paths and the balance of natural ventilation and air tightness.

It was also suggested that procurement guides need to be further developed and backed up by supplier networks and other procurement initiatives. It is felt that procurement issues connected to RRC are dealt with very much on an ad hoc basis at the moment.

Research into further progress in the area of waste/materials minimisation was also seen as being within the remit of the National Platform. Manufacturing processes were highlighted as an important area where significant progress could be made. Great potential is seen in the improvement of reuse of some materials and recycled content or recyclability of others. Reducing the resource consumption involved in concrete manufacturing was singled out for particular attention.

Other research recommendations for materials included the following:

- Achieving the ‘guaranteeability’ of recycled construction products.
• Reducing the energy intensity (and carbon emissions) of concrete production (e.g. developing new formulas, using recycled content)

3. Water

Top Research Priorities – Water

• Improving the user experience provided by water-efficient sanitary fittings.
• Developing testing and validation of water-efficient technologies.
• Reducing leakage through better modelling of built assets and leak detection, as well as technology to simplify repairs.

Recommended for collaborative strategic research

• Developing water harvesting and recycling for a wider range of building types and applications.
• Better modelling of natural drainage patterns to inform SUDS and storm water management
• Improving the user experience provided by water-efficient sanitary fittings.
• Developing testing and validation of water-efficient technologies.

Although there are a wide variety of options for improving the resource efficiency associated with water supply and usage, we noted that research in this area is seen as less important than that for energy and materials.

However, areas for highlighted for attention included improving the user experience provided by current water-efficient sanitary fittings; it was also felt that water-efficient technologies need appropriate testing and validation processes to assist in the assessment of their relative benefits.

It will also be possible to develop water harvesting and recycling for a wider range of building types and applications; it was felt, for example, that opportunities for non-potable use of water are currently being missed and that these could offer significant benefit – particularly in the south of England. The feasibility of using harvested and recycled water for thermal storage should also be explored and could potentially offer significant energy savings. At the commercial level there is even greater economic and environmental potential in recycling the water (and waste heat) used in manufacturing processes.

The ongoing challenge of reducing leakage was seen as an important priority but it was felt that this is the responsibility of water utilities, rather than being an issue for government or the National Platform.

Other research recommendations for water included the following:

• Exploring the practicalities of water redistribution.
• Protecting water courses by controlling domestic, industrial and agricultural discharge.
• Exploring the potential for heat recovery from grey-water.
• Exploring the feasibility of domestic waterless sewerage systems.

4. Cross-Cutting Recommendations

Top Research Priorities – Cross Cutting

1. Development of appropriate research and working partnerships – particularly those which span both industry and academia.
2. A broader ‘systems approach’ to the way in which individual technologies for RRC interact with each other.
3. A broader ‘systems approach’ to the way in which individual buildings interact with their surrounding environment and community.

Recommended for collaborative strategic research

1 = Development of appropriate research partnerships – particularly those which span both industry and academia.
1 = Mechanisms to ensure effective deployment of technology for RRC.
3 = A broader ‘systems approach’ to the way in which individual buildings interact with their surrounding environment and community.
3 = Significant improvements in understanding the embodied energy of construction products and materials backed up by better data provision.

As well as research recommendations in the specific areas of energy, materials and water, our research also highlighted a number of cross-cutting opportunities.

It was felt that the development of appropriate partnerships, spanning both industry and academia, is particularly relevant to the work of the National Platform. It is felt that current knowledge transfer mechanisms can be blighted if industry doesn’t feel that it gets the full benefit of research initiatives.

Better partnerships will also be required to optimise skills at the site level where it is felt that more and more people are unwittingly in control of things that they don’t fully understand. Areas of specialism may be split across several different trades which may fail to work in collaboration and blame each other for lack of progress.

The design of mechanisms to ensure the effective deployment of appropriate technologies for RRC was also suggested as being appropriate to the work of the National Platform and has implications for partnership working. It was broadly agreed that such technologies have existed, in some form or other, for some considerable time. However, effective deployment is, once again, dependent on the cooperation of various stakeholders, particularly those within government and industry.
All of these recommendations are based strongly on the idea that full potential of individual RRC initiatives cannot be fully realised if they are considered in isolation. As well as ‘stakeholder integration’ for the development of partnerships, the concept of ‘systems integration’ was also a strong theme within our interview process. It is seen as essential that all research, methodologies, technologies, materials and processes which are developed to improve resource efficiency are considered as part of the wider systems in which they operate. For the National Platform, the consideration of how individual buildings interact with their surrounding environment and communities is seen as particularly relevant. At the project level, it will also be important to consider more carefully how individual products and materials interact with each other.

We have also identified improvements in the understanding of the embodied energy in construction products and materials as being a priority cross-cutting theme. Whilst some see this as a ‘materials’ issue, there are clear cross-overs into energy efficiency and the development of water infrastructure. Current environmental assessment methodologies concentrate on the energy consumption and carbon emissions of buildings in operation and fail to properly consider embodied energy; we noted that there is currently a major shortage of data in this area.

Other cross-cutting research recommendations included the following:

- Improvements in the provision of ongoing training and CPD at the site level.
- Better marketing of the broad built environment construction industry to attract the necessary skills base.
- Changing the behaviour of building users to ensure that they maximise features designed for RRC.
- The simplification of technologies for RRC and the development of intelligent building management systems to eliminate human error.

5. Research opportunities

It is hoped that the findings of this study can be used to influence major national research initiatives such as those listed below:

**European Joint Technology Initiatives (JTIs): implementing large scale research activities**

“JTIs aim to achieve greater strategic focus by supporting common ambitious research agendas in areas that are crucial for competitiveness and growth, assembling and coordinating at European level a critical mass of research. They therefore draw on all sources of R&D investment - public or private - and couple research tightly to innovation.”

---

Further Information: http://ec.europa.eu/information_society/tl/research/priv_invest/jti/index_en.htm

**Intelligent Energy - Europe Programme**

The Intelligent Energy – Europe Programme is the EU’s tool for funding action to improve market conditions to take advantage of opportunities to save energy and encourage the use of renewable energy sources in Europe.

Further information: http://ec.europa.eu/energy/intelligent/call_for_proposals/index_en.htm

**Technology Strategy Board**

The Technology Strategy Board is an executive non-departmental public body (NDPB), established by the Government through the DTI. Its task, operating across all important sectors of the UK economy, is to stimulate innovation in those areas which offer the greatest scope for boosting UK growth and productivity.

With a business-led panel of board members, an executive team and a business focus, the Technology Strategy Board will play an increasingly important role in the development of the Government’s innovation strategy. Its primary aim is not the creation of knowledge - where Government separately invests over £3 billion per annum - but the translation of knowledge into innovation and new and improved products and services.

The vision:

“For the UK to be a global leader in innovation and a magnet for innovative businesses, who can apply technology rapidly, effectively and sustainably to create wealth and enhance quality of life.”

The activities of the Technology Strategy Board are jointly supported and funded by the DTI and other Government Departments, the Devolved Administrations, Regional Development Agencies and Research Councils.

The TSB has launched the Low Impact Building Platform in May 2008 to assist business to harness the growing market for environmentally sustainable buildings. Initially this will focus on new build, through markets affected by changes to Building Regulations, the Code for Sustainable Homes and Scottish targets for zero carbon buildings. The first call on ‘Components and Materials for Low Impact Buildings is open for expressions of interest until 16th July 2008.

Further Information: http://www.innovateuk.org/
UKERC – UK Energy Research Centre

The UKERC is the focal point for UK research on sustainable energy. It takes an independent, whole systems approach, drawing on economics, engineering and the physical environmental and social sciences.

The centre’s role is to promote cohesion within the overall UK energy research effort. It acts as a bridge between the UK energy research community and the wider world, including business, policy makers and the international energy research community and is the centrepiece of the Research Councils Energy Programme.

Further Information: http://www.ukerc.ac.uk/Home.aspx

UK Research Councils’ Energy Programme

The UK Research Councils’ Energy Programme brings together engineers and physical, natural, social and economic scientists not just to create the technologies but to examine their social and economic consequences. EPSRC is taking the lead on energy research on behalf of all the UK Research Councils.

Further Information: http://www.epsrc.ac.uk/ResearchFunding/Programmes/Energy/default.htm

EPSRC (Engineering and Physical Sciences Research Council)

The EPSRC is the government’s leading funding agency for research and training in engineering and the physical sciences. Full details of their funding opportunities are available on their website at http://www.epsrc.ac.uk/ResearchFunding/Opportunities/default.htm

IMRCs (Innovative Manufacturing Research Centres)

IMRCs are based at a number of UK universities including Imperial College, Bath, Cambridge, Reading, Salford and Loughborough. They receive five year block grants which are flexibly allocated between projects. This provides the UK’s leading manufacturing researchers with a base of stable yet flexible funding.

“The IMRCs cover a broad spectrum of research topics required to create or improve value adding processes, from business strategy and construction management to free-form fabrication processes and bio-processing. Individual IMRCs vary in width of remit from those with a narrow focus on a single topic, such as e-business, to those covering the full range of manufacturing research.”

Further information: http://www.epsrc.ac.uk/ResearchFunding/Programmes/BetterExploitation/IMRCs/default.htm
Appendices

Appendix 1

Sample for Analysis of Existing Studies (headline themes and priorities only):

- Roadmapping for the Modern Built Environment – work commenced by the former DTI in 2007
- Technology Strategy Board’s Roadmapping for the Innovation Platform on Low Impact Buildings
- The National Centre For Excellence in Housing – 2016 Zero Carbon Research Map
- National Physical Laboratory’s Roadmapping of Measurement Priorities for the Built Environment.
- MAT-UK’s emerging Materials R&D Priorities for Housing/Buildings
- Elements of The National Composites Network’s Technology Roadmap for Composites in the Construction Industry
- Also presented is an outline of the relevant sections of the ECTP Strategic Research Agenda Implementation Plan. This plan has not however been used as input for the analysis.
- CRWP – Construction Resources and Waste Roadmap – Produced by BRE for the DEFRA-funded Business Resource Efficiency and Waste (BREW) programme

Appendix 2

Interview participants:

- Stuart Alexander (Group Technical Coordinator, WSP)
- Keith Clarke (Chief Executive, Atkins)
- Prof. Mark Fletcher (Director, Arup; Visiting Professor, Engineering Design for Sustainable Development, Bradford University)
- Steve Hunt (Corporate Social Responsibility Manager, Taylor Woodrow)
- Prof. Tadj Oreszczyn (Professor of Energy and Environment/ Director of Environmental Design and Engineering Studies, The Bartlett, University College London)
- Ian Ritchie (Director, Ian Ritchie Architects; Co-founder, Rice Francis Ritchie)
- Richard Saxon CBE
- Lynne Sullivan (Executive Director, Inbuilt)
- Prof. Jeremy Watson (Global Research Director, Arup; Visiting Professor, Southampton and Sussex Universities)
- Bill Watts (Senior Partner, Max Fordham)
- Prof. Chris Woods (Research and Development Director, Wates Group; Visiting Professor, School of the Built Environment, Salford University)
- Senior representative from Pilkington (Name supplied)

**Appendix 3**

Semi-Structured Interview Questions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>With regard to reduced resource consumption, which topics should be prioritised on the strategic research agenda for the construction industry in the medium/long term (i.e. 10 years +)?</td>
</tr>
<tr>
<td>2.</td>
<td>Which specific technologies will lead to the biggest overall reductions in resource consumption?</td>
</tr>
<tr>
<td>3.</td>
<td>What are the prospects for the widespread adoption of each of the technologies mentioned above?</td>
</tr>
<tr>
<td>4.</td>
<td>What are the realistic timeframes for these technologies to be developed and fully implemented?</td>
</tr>
<tr>
<td>5.</td>
<td>Which technologies are likely to be able to attract the most investment?</td>
</tr>
<tr>
<td>6.</td>
<td>Where are the most obvious information gaps at the moment? Who will fill these gaps? Who will do the necessary research?</td>
</tr>
<tr>
<td>7.</td>
<td>Do you consider any current technologies or research initiatives to be inappropriate? (i.e. in that they don’t offer any realistic prospect of measurable benefits) Why?</td>
</tr>
<tr>
<td>8.</td>
<td>Who will be responsible for driving the adoption of technologies for reduced resource consumption? (building users? investors? developers? to contractors? clients? politicians?)</td>
</tr>
</tbody>
</table>
| 9. | What will be the barriers to the uptake of these technologies  
   a. economically?  
   b. technologically?  
   c. socially?  
   d. politically?  
   e. environmentally? |
10. What are the prospects for encouraging behavioural change to maximise uptake and fully realise the benefits of these technologies?

11. Are the necessary skills available
   a. for R&D?
   b. for manufacturing?
   c. for installation?
   d. for maintenance?

**Appendix 4**

**Survey Questions**

Please rate, on a 1-5 scale, the extent to which you believe the following issues impact on your business, and the timeframe within which you think you will need new knowledge or methodologies to address these issues when they arise.

**ENERGY**

1. Incorporating energy efficient technologies into the construction of buildings can contribute to reducing carbon emissions.
   A. Improving the energy efficiency of cooling systems
   B. Improving the energy efficiency of heating systems
   C. Improving the energy efficiency of electrical appliances
   D. Other

2. Reducing carbon emissions of buildings partly depends on the ability of buildings to retain heat.
   A. Installing insulation on the outside of buildings
   B. Reducing the amount of heat lost through external facades of properties
   C. Installing high performance/integrated glazing technologies
   D. Improving the thermal mass of building structures
   E. Other

3. Sustainable building standards promote technologies that help to generate a building’s energy supply from renewable sources.
   A. Use of ‘onsite’ renewable technologies (micro-renewables)
   B. Use of ‘hearsite’ renewable technologies (i.e. community schemes)
   C. Development of ‘offsite’ renewable technology
D. Use of Solar Thermal technologies
E. Use of Solar Photovoltaic technologies
F. Use of wind turbines
G. Use of Ground Source Heat Pumps
H. Use of Biomass Boilers
I. Using district heating systems
J. Using combined heat and power systems
K. Using fuel cell technology
L. Other

4. Integrating energy technologies with other components of a building can affect the efficiency of technology and its and ease of use.
   A. Ensuring inter-compatibility of energy technologies with wider building components
   B. Other

5. Improvements in techniques to model and measure a building’s supply and demand of energy can affect the overall use of energy in its
   construction and end-use.
   A. Improving modelling techniques to better understand energy use in buildings
   B. Provision of better performance figures for individual building components
   C. Other

6. An important element in the effectiveness of energy technologies is the way in which they are used.
   A. Simplifying technology to make it accessible to a wider range of users
   B. Educating users about how to make the most of sustainable features/technologies
   C. “Smart metering” or Building Management Systems
   D. Other

7. The ability of people and businesses to reduce their energy consumption can rely on their level of relevant knowledge and skills.
   A. Provision of appropriate training/professional education for reduced energy consumption
   B. Other

8. Policies and regulations regarding energy consumption can have an impact on the way in which buildings are designed and energy is
   used.
   A. Tightening regulations for energy efficiency in buildings (e.g. through building regulations)
   B. Providing tax incentives to reduce energy use
   C. Other
9. Other comments on ENERGY

WATER
1. With water supplies becoming increasingly scarce the construction industry has a role to play in managing its water usage.
   A. Developing and introducing building management systems to minimise water consumption
   B. Introducing "Smart Metering" systems to monitor and manage water usage
   C. Extension of water metering so that it reaches more buildings and estates
   D. Better understanding of fluctuations in water demand
   E. Designing buildings for lower water consumption
   F. Other

2. Conservation of water supplies can be aided by a number of technologies to improve consumption efficiency and minimise its use.
   A. Use of rainwater harvesting systems
   B. Use of greywater recycling systems
   C. Introduction of Sustainable Urban Drainage Systems
   D. Further improvements of sanitary fittings to minimise water consumption and wastage
   E. Other

3. Certain policies and regulations can affect the design and construction of buildings to improve the efficiency and conservation of water.
   A. Developing appropriate regulations for water efficiency in buildings (e.g. through building regulations)
   B. Other

4. Improvements in techniques to model and measure the supply and demand of water can affect the use of water in construction and end-use of buildings.
   A. Accessing measurement data on performance of existing water efficiency technologies
   B. Modelling domestic water use (e.g. to help achieve higher levels of the Code for Sustainable Homes)
   C. Other

5. Water supply can incur a carbon footprint in the processes of supply and consumption, as well as in the maintenance of water supply systems.
   A. Accessing information on carbon footprinting for the supply and consumption of water
   B. Minimising vehicle movements by reducing the requirements for water system maintenance
   C. Other

6. The ability of people and businesses to reduce their water consumption can rely on their level of relevant knowledge and skills.
   A. Developing the appropriate skills for implementing sustainable water supply and management
   B. Other
7. Buildings and construction materials require varying amounts of water in the process of producing them.
   A. Reducing water used in manufacturing processes
   B. Other

8. Other comments on WATER

MATERIALS
1. The manufacturing process of construction materials causes the production of carbon dioxide emissions which need to be reduced to reach UK carbon reduction targets.
   A. Measuring energy usage and carbon emissions produced during the manufacturing process
   B. Measuring energy usage and carbon emissions produced through the transportation of products
   C. Reducing energy usage in the manufacturing process
   D. Reducing the vehicle movements needed to transport products
   E. Use of consolidation centres to reduce the number of vehicle movements required to transport products
   F. Encouraging or enabling local sourcing of materials
   G. Other

2. Consideration of the whole life cycle of products can affect and reduce the environmental impact of a project.
   A. Understanding and consideration of the whole life impact of products (from extraction/ manufacture to disposal)
   B. Other

3. The construction industry consumes a significant amount of natural resources each year and steps can to be taken to reduce this through reuse, recycling and the use of recycled products.
   A. The need to develop recycling facilities for a wider range of materials
   B. The need to incorporate more recycled materials into construction products
   C. The need for buildings to be designed so they can be easily deconstructed and the components reused
   D. The need for improved mechanisms for the reuse of materials
   E. Other

4. The sourcing of construction materials can have an important impact of the overall sustainability of a project.
   A. The need to improve mechanisms for responsible sourcing of materials (ie through certification schemes)
   B. The development of products with lower environmental impact
   C. The development of supplier networks/ procurement initiatives
   D. The use of local suppliers to reduce vehicle movements and improve the sustainability of the projects
   E. Other

5. Other comments on MATERIALS
Appendix 5

Organisations participating in the online survey:

- BSRIA
- Construction Industry Council
- Dept. of Finance and Personnel (Properties Division)
- Forticrete
- Future Conversations (Consultants to the Concrete Centre)
- HBG UK Ltd
- Institute of Directors
- Lend Lease Corporation
- Manchester City Council
- Nationwide Building Society
- Saint Gobain Building Distribution UK
- Taylor Woodrow
- Thames Water
- University of Salford
- VINCI PLC
- Wates Construction
- Wates Group
## Appendix 6

<table>
<thead>
<tr>
<th>Research Recommendations</th>
<th>Identified by previous roadmapping studies</th>
<th>Identified as a priority through interviews and survey</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measuring and modelling energy consumption</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Better energy performance data for individual building components</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Systems/holistic approach to understanding energy use in buildings</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Benchmarks for creating low energy/low carbon communities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understanding and reducing embodied energy in buildings and building components</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Intelligent building management systems</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Improving thermal performance of building envelope</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Reducing thermal bridging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Better understanding of air tightness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improving natural ventilation/efficient cooling systems</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Implementation of energy saving/generating technologies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy efficient lighting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improving energy efficiency of domestic appliances</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Waste heat recycling</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Improving energy storage technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improving the efficiency of electricity delivery (i.e. local generation/ reducing loss through transmission)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improving renewable energy generation technologies</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Better understanding of the potential of renewables, including better measurement</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Life cycle analysis of renewables</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Optimising scale and location of renewables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Innovative incorporation of renewables technologies (including offsite manufacturing)</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Category</td>
<td>Item</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Improving the uptake of proven renewables technologies</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Increasing the efficiency of biomass production</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Relocating IT data processing (to make use of renewables)</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td><strong>Materials/Waste</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standardisation of sizes and interfaces used in asset design</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Standards and quality assessment for new materials</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Design for deconstruction</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Lighter, stronger, more durable materials</td>
<td>• •</td>
<td></td>
</tr>
<tr>
<td>Better performance data for ‘sustainable’ products</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Improved life cycle analysis of materials</td>
<td>• •</td>
<td></td>
</tr>
<tr>
<td>High performance glazing technologies</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>High performance/innovative insulation</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Developing vacuum technologies for insulation</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Use of organic waste for insulation and fillers</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Developing acceptable external cladding solutions</td>
<td>• •</td>
<td></td>
</tr>
<tr>
<td>Improving opportunities for reuse and recycling of construction products</td>
<td>• •</td>
<td></td>
</tr>
<tr>
<td>Developing recycled products of ‘guaranteeable’ quality</td>
<td>• •</td>
<td></td>
</tr>
<tr>
<td>Developing standards to encourage/allow the use of recycled content</td>
<td>• •</td>
<td></td>
</tr>
<tr>
<td>Smart technologies for material and component separation and segregation</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Identification of the material properties of deconstructed materials to enable recycling or reuse</td>
<td>• •</td>
<td></td>
</tr>
<tr>
<td>Increasing the reuse of structural frames</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Developing less energy intensive cement formulas</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Incorporation of waste materials into concrete</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Carbon capture and sequestration from concrete production</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Increasing the use of pre-stressed concrete</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Advanced procedures for sustainable waste disposal</td>
<td>• •</td>
<td></td>
</tr>
<tr>
<td>Measuring carbon impacts relating to waste and resources</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Waste minimisation in manufacturing processes</td>
<td>• •</td>
<td></td>
</tr>
<tr>
<td>Topic</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>More comprehensive procurement guides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of supplier networks and other procurement initiatives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encouraging local sourcing of materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanisms to reduce overordering of materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modelling/understanding of natural drainage patterns to inform SUDS and storm water management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exploring the practicalities of water redistribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protecting water courses - controlling discharge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Better water metering - including smart metering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understanding the carbon footprint of supplying water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designing buildings for lower water consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developing water harvesting/recycling for use in wider range of applications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste heat recycling from grey water/water used in industrial processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic water efficiency technologies which allow same level of experience</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Testing and validation of water conservation technologies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developing waterless sewerage systems for domestic use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increasing the uptake of flow-controlling devices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understanding conditions appropriate for the use of green roofs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved leak detection including high resolution modeling of built assets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology to simplify repairs</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developing appropriate training and professional education for RRC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empowering building users to make the most of sustainable features</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understanding how occupants interact with buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tools to aid specification and surveying of existing buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accreditation, building control or warranties for low-energy buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sampled post-occupancy evaluation of homes to ensure they are performing to specification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The impact of location on resource consumption</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Establishing optimum population densities to maximise resource efficiency</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Error-proof assembly</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Better client-designer-contractor visualising tools</td>
<td>•</td>
<td></td>
</tr>
</tbody>
</table>

**Appendix 7**

**Results of prioritisation exercise**

- For each of the recommendations listed below, respondents were asked to give a score according to how they should be prioritised on the strategic research agenda for reduced resource consumption (RRC) in the construction industry. (0=not a useful area of research; 1=low priority; 3=medium priority; 5=very high priority).
- They were then asked to indicate which of these recommendations should be taken forward as part of the National Platform’s strategic research agenda, or whether they are the responsibility of industry or government (more than one could be selected if appropriate).
- Additional comments were also recorded.
- Scores in the table below represent the total scores given by all those who responded to the prioritisation exercise (10 respondents for energy and cross-cutting issues; 9 for materials and water). The top scores are highlighted.
- The final three columns show the number of respondents who suggested that the individual priorities should be taken forward by industry, government and the National Platform respectively. The top scores for the National Platform are highlighted.
<table>
<thead>
<tr>
<th>Research recommendation</th>
<th>Score</th>
<th>Industry</th>
<th>Government</th>
<th>National Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More detailed measurement and understanding of energy consumption and performance in the built environment.</td>
<td>46</td>
<td>4</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Improving understanding of the embodied energy of construction projects down to the level of individual products and materials.</td>
<td>36</td>
<td>7</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Improving the thermal performance of building envelopes by addressing issues such as thermal bridging and air tightness.</td>
<td>39</td>
<td>7</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Wider use of natural ventilation and/or development of energy-efficient cooling systems.</td>
<td>39</td>
<td>10</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Improvements in energy-efficient lighting and appliances.</td>
<td>30</td>
<td>10</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Exploring the potential for waste heat recycling at domestic and industrial levels.</td>
<td>33</td>
<td>6</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Addressing the loss of energy in electricity transmission.</td>
<td>26</td>
<td>6</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Developing implementation mechanisms for energy efficient technologies and renewables.</td>
<td>38</td>
<td>5</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Better life cycle analysis of renewables including solid understanding of their energy-generation potential as well as consideration of optimal scale and location.</td>
<td>33</td>
<td>6</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Further improvements in the generating potential/energy conversion of certain renewables (e.g. wind turbines, biomass).</td>
<td>31</td>
<td>8</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Developing acceptable/innovative ways of incorporating renewables into buildings/building components.</td>
<td>35</td>
<td>8</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
### Materials

<table>
<thead>
<tr>
<th>Activity</th>
<th>Support</th>
<th>Interest</th>
<th>Contribution</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploring opportunities for RRC at the design stage.</td>
<td>37</td>
<td>5</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Development of innovative, high-performance insulation materials.</td>
<td>40</td>
<td>9</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Improving the recycled content and recyclability of construction products and materials.</td>
<td>38</td>
<td>9</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Achieving the ‘guaranteeability’ of recycled construction products.</td>
<td>28</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Reducing the energy intensity (and carbon emissions) of concrete production (e.g. developing new formulas, using recycled content).</td>
<td>35</td>
<td>8</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Developing more advanced waste minimisation solutions – with better baseline data to allow meaningful measurement of progress.</td>
<td>32</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>The development of more comprehensive procurement guides backed up by supplier networks and other procurement initiatives.</td>
<td>29</td>
<td>3</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

### Water

<table>
<thead>
<tr>
<th>Activity</th>
<th>Support</th>
<th>Interest</th>
<th>Contribution</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better modelling of natural drainage patterns to inform SUDS and storm water management.</td>
<td>31</td>
<td>3</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Exploring the practicalities of water redistribution.</td>
<td>28</td>
<td>3</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Protecting water courses by controlling domestic, industrial and agricultural discharge.</td>
<td>27</td>
<td>1</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Developing water harvesting and recycling for a wider range of building types applications.</td>
<td>33</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Exploring the potential for heat recovery from grey-water.</td>
<td>20</td>
<td>7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Improving the user experience provided by water-efficient sanitary fittings.</td>
<td>38</td>
<td>8</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Developing testing and validation of water-efficient technologies.</td>
<td>35</td>
<td>6</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Exploring the feasibility of domestic waterless sewerage systems.</td>
<td>25</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>----</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Reducing leakage through better modelling of built assets and leak detection, as well as technology to simplify repairs.</td>
<td>34</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

**Cross-Cutting**

<table>
<thead>
<tr>
<th>Development of appropriate research partnerships – particularly those which span both industry and academia.</th>
<th>43</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvements in the provision of ongoing training and CPD at the site level.</td>
<td>34</td>
<td>8</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Better marketing of the broad built environment construction industry to attract the necessary skills base.</td>
<td>30</td>
<td>8</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Changing the behaviour of building users to ensure that they maximise features designed for RRC.</td>
<td>30</td>
<td>6</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>The simplification of technologies for RRC and the development of intelligent building management systems to eliminate human error.</td>
<td>33</td>
<td>6</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>A broader ‘systems approach’ to the way in which individual technologies for RRC interact with each other.</td>
<td>42</td>
<td>5</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>A broader ‘systems approach’ to the way in which individual buildings interact with their surrounding environment and community.</td>
<td>39</td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Significant improvements in understanding the embodied energy of construction products and materials backed up by better data provision.</td>
<td>38</td>
<td>7</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Mechanisms to ensure effective deployment of technology for RRC.</td>
<td>37</td>
<td>4</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>