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Environment Agency

Evidence

Energy and carbon implications of rainwater harvesting and greywater recycling

Report: SC090018

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Miranda Kavanagh

Miranda Kavanagh

Director of Evidence

Executive summary

This report presents the findings of a study into the energy and carbon implications of rainwater harvesting (RWH) and greywater recycling (GWR) systems. The Environment Agency (EA) commissioned the review jointly with the Energy Saving Trust (EST) and National House Building Council (NHBC) Foundation.

This study quantifies:

- Lifetime carbon footprints of RWH and GWR systems, consisting of embodied carbon and the carbon emitted from operational use; and
- The contribution of RWH and GWR systems to reducing carbon emissions associated with mains water demand and foul water volumes.

The key messages from this study are:

1. **Buildings using harvested rainwater or treated greywater typically increase greenhouse gas emissions compared to using mains water**, where total cradle to gate embodied and operational carbon are considered. For example over 30 years, where an 'average' 90m^2 house has a RWH system with a polyethylene tank, the **total** carbon footprint is approximately 1.25 – 2 tonnes of carbon dioxide equivalent (CO_2e). This is similar to one year of energy-related emissions from a house built to Code for Sustainable Homes Level 3 energy efficiency standards. The footprints of systems applied to commercial buildings vary widely, but over a 30 year lifespan were found to represent around one month's operational energy-related emissions in the hotel, office and schools studied.

2. **With one exception, the operational energy and carbon intensities of the systems studied were higher than for mains water** by around 40 per cent for a typical rainwater application, and over 100 per cent for most greywater applications. The exception is short retention greywater systems which are around 40 per cent less carbon intensive than mains water supply. The assumed operational intensities of rainwater and greywater systems are based on the limited measured data and information available to this study.

3. **There is scope to improve the efficiency and design of systems to reduce their carbon footprints.** Storage tanks account for a large proportion of the embodied carbon footprint of rainwater systems; slightly less so for greywater. Pumps also make up a large proportion of rainwater and greywater embodied carbon and pumping determines net operational carbon. Direct feed rainwater systems have a large operational footprint because both rainwater and mains backup are pumped to end uses via the storage tank. Innovation in these and other areas could reduce carbon footprints. Manufacturers and suppliers should work quickly to reduce the footprints of their systems, and particularly to reduce the energy intensity of pumps and treatment systems.

This study focuses on the energy and carbon implications and mains water savings of rainwater and greywater systems that supply water for non-potable use in buildings and are commercially available in the UK. It does not include any other environmental, social or economic costs and benefits assessment. Emerging gravity-fed rainwater systems, and all systems exclusively supplying water for external uses, including rainwater butts, have not been considered in this study.

To conduct the study, RWH and GWR system suppliers were contacted to identify a number of generic systems to analyse. These systems were assessed against selected building types including houses, flats, a hotel, an office building and a school. The systems were sized using standards and industry practice. Carbon footprints were then calculated over 15, 30 and 60 year system lifetimes. Four scenarios were used to explore the effects of future changes. The scenarios considered changing water demand, mains water leakage and carbon intensity, emissions factors for UK grid electricity, and annual rainfall. These are based on the 'future scenarios' Uncontrolled Demand, Innovation, Sustainable Behaviour and Local Resilience which we developed as part of our 'Water Demand in the 2050s' project. The analysis of these scenarios found that only grid decarbonisation had a major impact on the carbon footprints of the systems studied.

There are a wide variety of greywater system types and six were analysed: small membrane bioreactors, short retention systems serving one or two WCs, small biological systems, multimedia filters, and larger membrane bioreactors. Footprints for smaller greywater systems, applicable to the average home, range from 0.5 - 2.8 tonnes. This is similar to the range for rainwater systems but, with the exception of short retention systems, these systems have higher carbon footprints per unit of water saving. Footprints for the larger systems applicable to non-domestic and multi-residential buildings range from 13 – 47 tonnes for the building types studied.

This study identifies a 'carbon gap': a building with RWH and/or GWR systems has an increase in carbon emissions and so a larger carbon footprint. However, for a complete picture this should be considered alongside reductions in mains water demand and foul water volumes, and other benefits such as reduced rainwater run-off, and increased 'resilience' to water shortages from on-site collection and storage. The value of water demand reductions and the wider benefits of rainwater and greywater systems was outside the scope of this study. Bringing together the results of this study with work valuing water-related benefits could establish a basis for deciding when such benefits bridge the 'carbon gap'.

The findings of this study suggest that decision makers should review the current situation where rainwater and greywater systems are essentially universally encouraged and take account of the multiple drivers to cut carbon emissions, conserve resources and achieve wider benefits, recognising that relative priorities may vary with location and context. For example, policies that strongly encourage rainwater and greywater systems could be targeted at areas where the water savings and wider benefits would be of most value. Where there are drivers for these systems, checks on their applicability in a given location could help to ensure that, where there is a 'carbon gap', systems have wider environmental benefits that bridge the gap.

Decision makers need to work with the industry to improve the evidence currently available. Manufacturers and suppliers need to get an understanding about the lifetime carbon impacts of their systems and publish this information for consumers and decision-makers. The EA, EST and NHBC Foundation will support the industry to speed up the process of producing, disseminating and raising awareness of such information.

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In addition we would like to thank the members of the UKRHA, rainwater and grey water system manufacturers and suppliers that supported the project by providing information and data on their systems, and the University of Technology Sydney, Institute for Sustainable Futures for responding to queries about their research in this field.

The Project Partners

The NHBC Foundation was launched in 2006 in partnership with the BRE Trust. Its remit is to provide the necessary data and intelligence to develop long-term solutions to the challenges for the house-building industry which lie ahead and lead debate and thinking among industry experts. The NHBC Foundation facilitates research and development, and shares pragmatic and relevant guidance and good practice to the homebuilding industry. Much of the NHBC Foundation's research is focused on the challenges of the Government's 2016 zero carbon homes target.

Further details on the NHBC Foundation can be found at www.nhbcfoundation.org.

The Energy Saving Trust (EST) are an independent, UK-based organisation focused on promoting action that leads to the reduction of carbon dioxide emissions - a key contributor to man-made climate change.

The Energy Saving Trust are the source of free advice and information for people across the UK looking to save energy, conserve water and reduce waste. They are impartial, and not tied to any particular commercial organisations or driven by political or corporate motivations.

The Energy Saving Trust work with like minded organisations and groups who wish to tackle climate change, both in the public and private sector. They have teams based in Scotland, Wales and Northern Ireland, whilst in England there is a regional structure. This approach allows EST to deliver UK-wide programmes on a country and regional basis, as well as country-specific programmes in each of the individual nations in the UK. It means they are able to offer people help tailored to their home type, circumstances and household budget. EST direct people to the right grants to make change happen, from cavity walls, to loft insulation and installing more renewable energy sources.

Contents

1 Introduction

1.1 Background

1.1.1 The climate challenge

The challenge of climate change and the need to reduce greenhouse gas emissions and stabilise their levels in the atmosphere was globally recognised in the Copenhagen Accord in December 2009 (UNFCCC 2009). Transition to a low carbon society is increasingly supported by a range of policy, legislation, targets and implementation plans at international, national and local level.

The UK is committed to meeting CO_2 and energy targets, agreed between the European Commission and Member States. The European Union has agreed to reduce CO_2 emissions by 20 per cent on 1990 levels by 2020.

The UK Climate Change Act (2008) sets a legally binding target to reduce UK emissions by at least 80 per cent by 2050. It established the Committee on Climate Change, which advises the government on statutory 5-year carbon budgets. The first three budgets for 2008 to 2022, announced in 2009 (HM Treasury 2009), aim for a 34 per cent reduction in emissions by 2020.

1.1.2 UK water resources

The need to act to reduce CO_2 emissions, and to tackle climate change and its consequences sits alongside the need to use resources in a sustainable manner.

Water stress

There are significant pressures on the UK's water resources as highlighted in the Environment Agency report, *Water resources in England and Wales – current state and future pressures* (EA 2008b). There are many catchments where there is little or no water for additional abstraction during dry periods, with pressures observed at their greatest in the South East and East of England. Increasing stresses on the water system such as rising population and climate change could have a significant impact on water availability and management.

Drivers for resource management and water efficiency

Future Water (DEFRA 2008) describes the previous Government's water strategy for England looking ahead to 2030. It considers the water cycle as a whole, from rainfall and drainage through to discharge and treatment. The strategic vision for 2030 includes:

- Reduced per capita consumption of water through cost effective measures, to an average of 130 litres per person per day by 2030[1], or possibly even 120 litres per person per day depending on new technological developments and innovation; and

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[1] 2007/08,148 litres of water were used on average in per person per day (EA 2009)

- Water efficiency playing a prominent role in achieving a sustainable supply – demand balance, with high standards of water efficiency in new homes, and water-efficient products and technologies in existing buildings.

Future Water emphasises the key role of the water sector in mitigating climate change by taking action to reduce their greenhouse gas emissions arising from water and wastewater treatment and supply, and from water use by customers wherever possible. Section 93A of the *Water Industry Act* (1991) requires water companies to promote the efficient use of water by consumers. OFWAT announced in *PN 36/08* (OFWAT 2008) that water companies must increase water efficiency savings by 40 percent from 2010. The targets must be delivered by behavioural change and promoting water saving devices and exclude savings from supply pipe replacement and repairs. The targets were introduced on a trial basis in April 2009, coming into full effect in 2010.

The devolved nations, Northern Ireland, Scotland and Wales, have their own policies and strategies for water management. Northern Ireland historically managed water on a local council basis and the move to a country-wide management strategy has been facilitated by the Northern Ireland Department of the Environment. The Scottish Climate Change Adaptation Framework (2009) refers to water efficiency measures but not specifically to the use of rainwater or greywater. The Framework document is a broad outline and there are plans to develop a comprehensive Sector Action Plan for Water Resource Management in 2010 with prioritised actions.

In 2006 CLG and DEFRA published a joint consultation on *Water Efficiency in New Buildings* (CLG/DEFRA 2006). This proposed a whole-building performance standard for water efficiency in new homes in England and Wales. The subsequent joint CLG / DEFRA policy statement (CLG/DEFRA 2007), proposed that new homes should have a calculated water use of less than 125 litres / person / day. This was implemented through changes to Part G of the Building Regulations, which came into effect in April 2010. The *Water Efficiency Calculator for new dwellings* (CLG 2009) is used to determine compliance with the mandatory internal water credits in the Code for Sustainable Homes (the Code)[2]. *Future Water* refers to the proposed Part G water efficiency requirement for new homes and to the Code as mechanisms for achieving its vision. Scotland and NI often adopt the principles of Building Regulations developed for England and Wales; they have not yet announced any intentions to introduce Building Regulations covering water efficiency.

Policy support for rainwater and greywater systems

Existing mechanisms generally reflect the view that rainwater and greywater systems could play a role in future management of water resources and in the solutions required to address water stress. They are explicitly encouraged within the Code and are widely accepted to be necessary to achieve higher Code levels (5 and 6). They are at least implicitly encouraged in BREEAM and in other sustainability standards and policies for buildings, for example in local planning policies. The Code and BREEAM are applied across the UK without any variation in their compliance criteria to account for differences in location. The awarding of ‘credits’ for water savings from rainwater and greywater systems in these assessments invites the assumption that they are more sustainable than using mains water in all areas.

The Code (including a range of minimum performance standards) has been adopted as a key requirement for publicly funded affordable housing and for homes built on previously publicly owned land in England, Wales and Northern Ireland. The Code has not been adopted in Scotland. It is increasingly used alongside BREEAM as a measure

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[2] Levels 1 & 2: 120 litres / person / day, equivalent to the Part G proposals; levels 3 & 4: 105 litres / person / day; levels 5 & 6: 80 litres/person/day

of the sustainability of new development and introduced as a development requirement by planning authorities.

The increase in references to rainwater and greywater systems and the drive for low water use targets in new homes and non-domestic buildings have resulted in an observed increase in interest in these systems from developers.

Potential for conflict: carbon savings vs. resource management

Both the Environment Agency and Energy Saving Trust's corporate strategies recognise the need to act to reduce climate change and its consequences and to use resources in a sustainable manner. In pursuing these aims it is important to understand potential conflicts, such as promoting resource efficiency at the expense of increasing carbon emissions.

There are often trade-offs and conflicts that need to be considered in sustainable design, which are not always apparent when looking at specific design options for separately improving performance on energy, water, materials use, etc. Rainwater and greywater systems should be considered both in terms of water management and energy and carbon implications. Their carbon footprints vary depending on system design, site considerations and installation arrangements, and on rainfall which depends strongly on location. Emissions from using mains water also vary depending on the nature of the regional or local supply network.

Characterising conflicts, exploring whether and when they exist, and quantifying their scale is vital to informed decision-making. This study explores these issues. It follows and builds on previous work by the Environment Agency and Energy Saving Trust. An Environment Agency study, *Greenhouse gas emissions of water supply and demand management options* (EA 2008), looked at the energy and carbon implications of a wide range of water supply and demand side water efficiency options and this report makes frequent reference to it. An Environment Agency / Energy Saving Trust study, *Quantifying the energy and carbon effects of water saving* (EA/EST 2009) looked in greater detail at water efficiency measures in homes and particularly the relationship between hot water use and carbon emissions. While the material in the latter report is less directly relevant to rainwater and greywater systems, some of the formats for presenting carbon saving information have influenced this study. Relevant material from these previous studies is discussed in more detail in the methodology and results sections of this report.

1.2 Objectives

This study was commissioned by the Environment Agency, in partnership with the Energy Saving Trust and NHBC Foundation with an overall objective to help improve understanding of the energy use and associated carbon emissions of rainwater harvesting and greywater recycling systems applied to homes and non-domestic buildings, and the role of these technologies in achieving low carbon lifestyles. It aims to develop a better understanding of the potential environmental trade-offs involved in applying rainwater and greywater systems. It specifically aims to quantify:

- The increase or savings in energy use and related emissions, relative to the reduction in mains water demand (and wastewater to be treated).

The results of the study will support the formulation of sustainability advice within the sponsoring organisations. The study is also expected to be of interest to carbon and water policymakers in national and local government departments.

Other specific objectives defined in the brief are:

- “To review existing evidence on energy and carbon implications of domestic and commercial greywater recycling and rainwater harvesting.
- To develop an evidence-based view of what role these technologies should play in sustainable water management and a low carbon future (and in what circumstances).”

In addition to its role in informing water, energy and sustainable building design policy it is hoped the project results will encourage manufacturers to identify opportunities to improve the balance of environmental outcomes of rainwater and greywater systems. The study results may also help developers, engineers and other building professionals to make more informed decisions about the appropriate application of these types of system within a holistic sustainable design strategy. However, this was not a specific objective of the project and results have not been tailored to support system selection and design.

1.3 Report structure

This peer reviewed report sets out the work undertaken within the project, and the project findings, conclusions and recommendations. The remainder of the report is organised as follows:

Section 2	Introduction to systems and review of existing evidence.
Section 3	Calculation approach and methodology.
Section 4	Results of an assessment of the energy and carbon implications of a range of rainwater harvesting and greywater recycling systems.
Section 5	Conclusions and recommendations for further work.

2 System types, applications and evidence review

2.1 Outline

A literature review was undertaken to gather information of relevance to this study. The review looked at academic research, standards, case studies and general reports on systems in the UK, and elsewhere in the world where relevant. Based on the review, this section outlines the concepts of rainwater and greywater in terms of their sources and potential end uses. It then introduces system types, applications, general performance issues, and summarises available data on operational energy use. There are separate introductions for rainwater (section 2.2) and greywater systems (section 2.3). Supporting information gathered as part of drawing up system component and materials inventories during the study is included where relevant.

Previous studies that specifically looked at or reported the energy use and carbon footprints of rainwater and greywater systems are of particular interest to this study and are discussed in section 2.4.

A literature review report prepared during the study is available as a separate Annex.

2.1.1 Collection sources and end uses

‘Rainwater’, ‘greywater’ and other related terms are sometimes used interchangeably or confused. For the purposes of this report, the following definitions have been used:

- Rainwater – Water flowing off roofs or hard surfaces after precipitation.
- Greywater – Water that has been used once for bathing (baths, showers and basins) and other relatively ‘clean’ processes; considered suitable for recycling in the greywater systems considered in this study. (This excludes kitchen wastewater, which often contains high levels of grease or food particles and is considered ‘blackwater’.)
- Blackwater – Wastewater containing sewage, grease, oils, process chemicals, or other contamination that might be deleterious to health; not suitable for recycling in the greywater systems considered in this study.
- Harvested water – Filtered rainwater.
- Treated water – Treated greywater.

Rainwater, greywater and blackwater can all be recycled and, following treatment appropriate for the intended end use, be used in buildings. The Water Supply (Water Quality) Regulations (1989) includes a classification of suitable end uses for potable and non-potable water, as summarised in Table 1.

Use Class	Class A	Class B
Definition	Potable	Non-potable
Suitable end uses	Supplies to kitchen taps, drinks machines etc, basin taps, baths, showers or Jacuzzis, any spray systems such as cooling towers, pressure jetting etc.	Other water uses including WC flushing, irrigation and laundry.

Table 1. Water use classes (from Water Supply (Water Quality) Regulations 1989).

A Water Regulations Advisory Scheme Information and Guidance Note on ‘Reclaimed Water Systems’ (WRAS 1999) recommends levels of treatment according to intended end use. Class A uses require much more stringent treatment and quality checking.

This study only considers systems that:

- Harvest rainwater and treat greywater, and
- Supply non-potable water for ‘domestic’ water uses in buildings such as flushing WCs and urinals, washing laundry and potentially additionally (but not exclusively) for external use, such as garden watering.

These are considered the most common and widely replicable types of rainwater and greywater system in terms of source collection and intended end uses.

The study excludes systems that:

- Treat blackwater, and
- Exclusively serve external uses such as garden watering / irrigation.

2.2 Introduction to rainwater harvesting

2.2.1 System types

At their most basic, rainwater systems need to do two things: collect and store rainwater and transport stored rainwater to points of use. Systems that supply water in buildings have a mains backup system. This ensures an uninterrupted supply to the end uses connected to the system whenever rainwater is not available.

BS 8515 (2009) categorises rainwater systems into three basic types:

- Direct Feed systems,
- Header Tank systems, and
- Gravity systems.

The review identified around thirty-five companies supplying at least ninety rainwater systems, some on a supply-only basis for DIY or third party installation, through to full-service offerings including installation, commissioning, and after sales maintenance. Systems are marketed for a range of home, non-domestic, and irrigation uses.

Direct feed (DF)

The key characteristic of direct feed systems is that water is supplied to end uses under pressure provided by a demand driven pump. This is usually a submersible pump within the main storage tank or can be a pump outside the tank or in a small secondary storage tank in the ground floor or basement of the building. The mains backup system supplies mains water to the storage tank when required. (Note that this means the mains backup water for connected end uses has to be pumped from the storage tank.)

Header tank (HT)

This type of system uses a header tank – so called because it is located above the points of use, usually within the roof space or on the roof. Instead of harvested water being pumped directly to end uses, it is pumped to the header tank. The mains backup system supplies mains water to the header tank when required, usually under mains pressure. Water is then supplied to end uses under gravity.

Header tank system controls often enable automatic draining and refilling of the tank if insufficient water is drawn off over a period of time. This reduces the potential for building users to come into contact with water that may have degraded while stored in ambient temperate conditions.

Gravity Systems

Gravity systems consist of an above ground tank, typically located outside the building and at a level above the points of use so that collected water can be fed to end uses under gravity. These systems require no pump and no (or only basic) controls. They normally have a small storage capacity and a limited range of application for water supply in buildings.

System types considered further in this study

This study focuses on systems that commonly supply non-potable water for use within buildings. For rainwater, these are usually variations of the direct feed and header tank systems described above.

Garden watering systems, water butts, etc. that mainly supply external and process uses, are outside the scope of this study. Opportunities to apply gravity systems to buildings are currently limited (the review found no systems being marketed), and they were not included in the study for that reason.

2.2.2 Rainwater storage tanks

All rainwater systems include a storage tank that receives rainwater from the roof and any other suitable collection areas via a filter and calmed inlet. Tanks can be installed fully or partly underground, at ground level, or within the building, usually in a basement or ground floor plant room.

Installing underground tanks is more resource intensive than installing tanks within basements or at ground or roof level. However, with the exception of garden irrigation systems, the overwhelming majority of systems supplied in the UK incorporate underground storage tanks because:

- Keeping the rainwater storage out of direct sunlight helps to maintain water clarity and prevent premature water degradation,.
- It is uncommon for homes in the UK to have basements. Many systems in Europe, especially Germany, locate tanks in basements which are a more common feature of European homes.

The vast majority of tanks are made from:

- Reinforced concrete (RC),
- Glass reinforced plastic (GRP, often called ‘fibreglass’), or
- Polyethylene (PE), which for tanks can be medium or high density polyethylene (MDPE or HDPE).

RC tanks can be manufactured in a wide range of sizes and installation does not require an additional concrete shell or base. GRP tanks can also be manufactured in a wide range of sizes including very large tanks; they require backfilling with concrete to provide a stable and protective shell. PE tanks are generally available in many discrete sizes up to approximately 6,000 litres beyond which multiples of smaller tanks are used. Some PE tanks may require a concrete shell, but an increasing number targeted at home rainwater systems can be installed with a sand base and backfill.

PE tanks are often selected for single-home applications. GRP tanks are more often applied as part of larger scale (multi-residential and non-domestic) systems, but small tanks for single-home applications are also available. Concrete tanks are less prevalent in the UK at present but are marketed as part of both single-home and larger systems.

2.2.3 System applications

Homes often depend on mains pressure to supply water to the point of use. Mains water is typically supplied either via a header tank (common in older homes and still fitted in the roof space of some new houses) or more commonly now through direct feed under mains pressure.

The main differences in design and operation of rainwater systems are between small, single and low rise home or non-domestic applications, and systems for larger multi-residential and non-domestic buildings. Rainwater harvesting systems fitted to new build or retrofitted to existing homes can use a header tank type system, direct or indirect systems to supply to WCs and washing machines. The different arrangements will affect the pumps specified, their operational usage and the arrangement of the internal pipework design.

Rainwater systems designed for communal residential and non-domestic applications are fundamentally only dependent on the scale of the system needed. The non-potable water, supplied through internal non-potable rainwater pipework, can be pumped directly via a submersible pump or on demand through a dual pump system with a submersible pump in the main tank and a secondary tank and demand driven pump in the building.

Communal and non-domestic systems normally have bespoke specifications and the pumps and tank can be optimised to suit the building size and height, demands and pipework design.

2.2.4 Other performance issues for rainwater systems

Service life

The majority of rainwater tanks for systems sold in the UK come with a manufacturer’s warranty of 15 years. However, the tanks have no moving parts and are made of inert materials. If they remain undamaged by impacts or movement, the service life of rainwater tanks is likely to be significantly longer than the warranty period. Tank life up to and over a hundred years was estimated by some suppliers in discussions during the study. Suppliers commonly offer 2 year warranties for other static parts, relecting the warranties offered by manufacturers. Again, suppliers estimate that actual service life is likely to be significantly longer.

Pumps experience operational wear and tear and most manufacturers offer a warranty for only 1 year. The actual service life of a pump is likely to be in the region of 10 years.

Reliability & maintenance

System reliability and maintenance are closely linked and are of interest in this study for several reasons. Reliability affects the reputation of a technology, its desirability and suitability to each group of potential users, uptake, failure rates, and hence the quantities of operational water savings, energy use, and related carbon emissions. The maintenance programme will also contribute to the cumulative embodied carbon footprint of systems as a result of travel to site by technicians for periodic inspections, routine maintenance and replacement of parts, or to replace failed parts.

Studies that model rainwater and greywater system performance often need to make assumptions about maintenance frequency. Roebuck R., et al (2006) assume a shortlist of annual tasks (maintain pump, clean roof, gutters, etc.) and cleaning of the tank ("desludging") every three years. This broadly agrees with assumptions elsewhere and with BS 8515:2009 (which suggests additional annual inspection and maintenance tasks, including a more conservative annual tank cleaning schedule). CIRIA (2001) and CIBSE (2008) also provides relevant guidance on common time intervals for the replacement of components. The maintenance frequencies recommended in BS8515 are shown in Table 2.

Component	Notes	Frequency*
Gutters/ downpipes	Check that there are no leaks or blockages due to build up of debris; clean the gutters if necessary	annually
Filter	Check the condition of the filter and clean, if necessary	annually
Storage tank/cistern	Check that there are no leaks, that there has been no build up of debris and that the tank is stable and the cover correctly fitted drain down and clean the tank	annually
Storage tank/cistern		Every 10 years
Pumps and pump control	Check that there are no leaks and that there has been no corrosion; carry out a test run; check the gas charge within the expansion vessel or shock arrestors	annually
Back-up water supply	Check that the back-up supply is functioning correctly, that there are no leaks and that the air gaps are maintained	annually
Control unit	Check that the unit is operating appropriately, including the alarm function where applicable	annually
Water level gauge	Check that the gauge indication responds correctly to the water level in the tank	annually
Wiring	Visually check that the wiring is electrically safe	annually
Pipework	Check that there are no leaks, that the pipes are watertight and that overflows are clear	annually
Markings	Check that warning notices and pipework identification are correct and in place	annually
Support and fixings	adjust and tighten, where applicable	annually
UV lamps	Clean and replace, if necessary	Every 6 months

* These frequencies are recommended if no information is given by the manufacturer.

Table 2. Rainwater system maintenance schedule (based on BS8515:2009)

A BSRIA study (2001) that collated detailed case study reports including summaries of maintenance logs found that the pump was the most likely point of failure in a rainwater system, often due to fouling by debris or because of electrical issues. Of the individual case studies reviewed, the majority required higher maintenance frequencies than those stated in guidance documents. This is partly due to unplanned maintenance to correct faults, some of which are likely to be related to installation.

2.2.5 Operational energy

Rainwater harvesting systems use electricity to run pumps and control systems. This operational energy use, mainly for pumping, contributes a significant proportion of the carbon footprint of a system, with the remainder as embodied carbon in system materials, and arising from transport for system delivery and maintenance,

Pump selection depends on the amount of water to be pumped, the height it needs to be lifted, frictional losses in pipework. Pump performance varies and there is scope to optimise systems to meet requirements, work efficiently and minimise losses such as stop – start and standby losses.

The review identified a range of reported operational energy use of ~0.6 – 5 kWh/m^3 for rainwater systems. This does not include UV disinfection, which increases the upper band of reported energy intensity to 7.1 kWh/m^3. Reported values for rainwater system energy intensity are plotted in Figure 1. Also shown is the line of median energy intensity for delivered mains water in the UK, and bands showing the quartile ranges between minimum and maximum energy intensity for mains water. (Section 3.2.2 explains how quartile bands for mains water carbon intensity were derived in this study. A notional value for mains water energy intensity is calculated from the carbon intensity figure using the same Defra (2009) carbon emissions factor of 0.54667 kgCO$_2$e/kWh that is used in this study to convert rainwater and greywater system electricity use into a carbon footprint.)

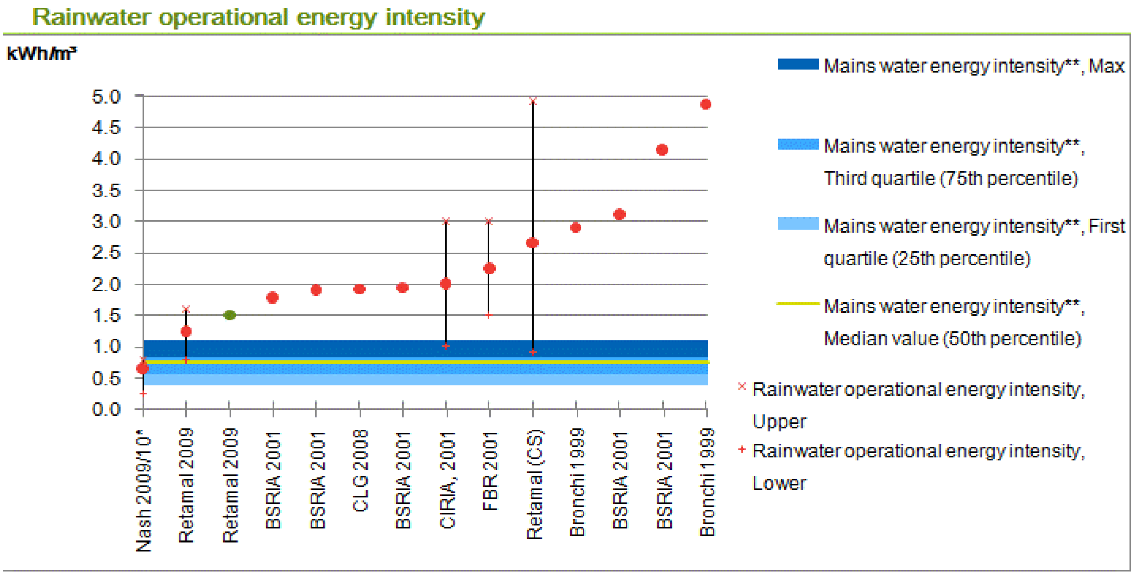


Figure 1. Review of reported energy intensity of rainwater systems.

It is clear that the mid-range figures and individual reported figures for rainwater system energy intensity lie above the range of mains water energy intensity. Assuming these results exclude any energy use for UV treatment (as intended), this means that for the majority of the systems monitored, pumping water from the rainwater tank to end uses gave rise to higher carbon emissions than those arising from the supply of mains water to buildings in the UK.

Homes

A recent study in Australia by Retamal et al. (2009) compared theoretical models of pump energy use for single home rainwater systems with monitored pump energy use, which was collected as part of the same study (monitored results were included in Figure 1). The pump energy models were found to provide a reasonable estimate of the operational energy use of rainwater systems. The pump model results shown in Table 3 illustrate how the pump energy demand in direct feed systems varies depending on the end use being supplied.

Pump model:	Constant power model	Pump 1	Pump 2	Pump 3	units
Nominal motor power	750	500	770	890	W
Average whole house	**1.5**	**0.9**	**1.1**	**1.4**	kWh/m^3
Faucets	2.9	1.8	2.1	2.6	
Toilets	2.7	1.7	1.9	2.4	
Clothes washer	0.9	0.5	0.7	0.9	
Irrigation	0.8	0.4	0.6	0.8	
Showers	1	0.6	0.8	1	
Baths	0.8	0.4	0.6	0.8	
Leaks	96.4	64	67.9	80	

Table 3. Energy intensity of home rainwater pumping by end use (Retamal et al. 2009)

The theoretical whole house averages range between 0.9 and 1.5 kWh/m^3, which is at the lower end of the range of monitor energy intensities for rainwater systems, but mostly above the range of mains water energy intensities, and clearly above median mains water intensity in the UK.

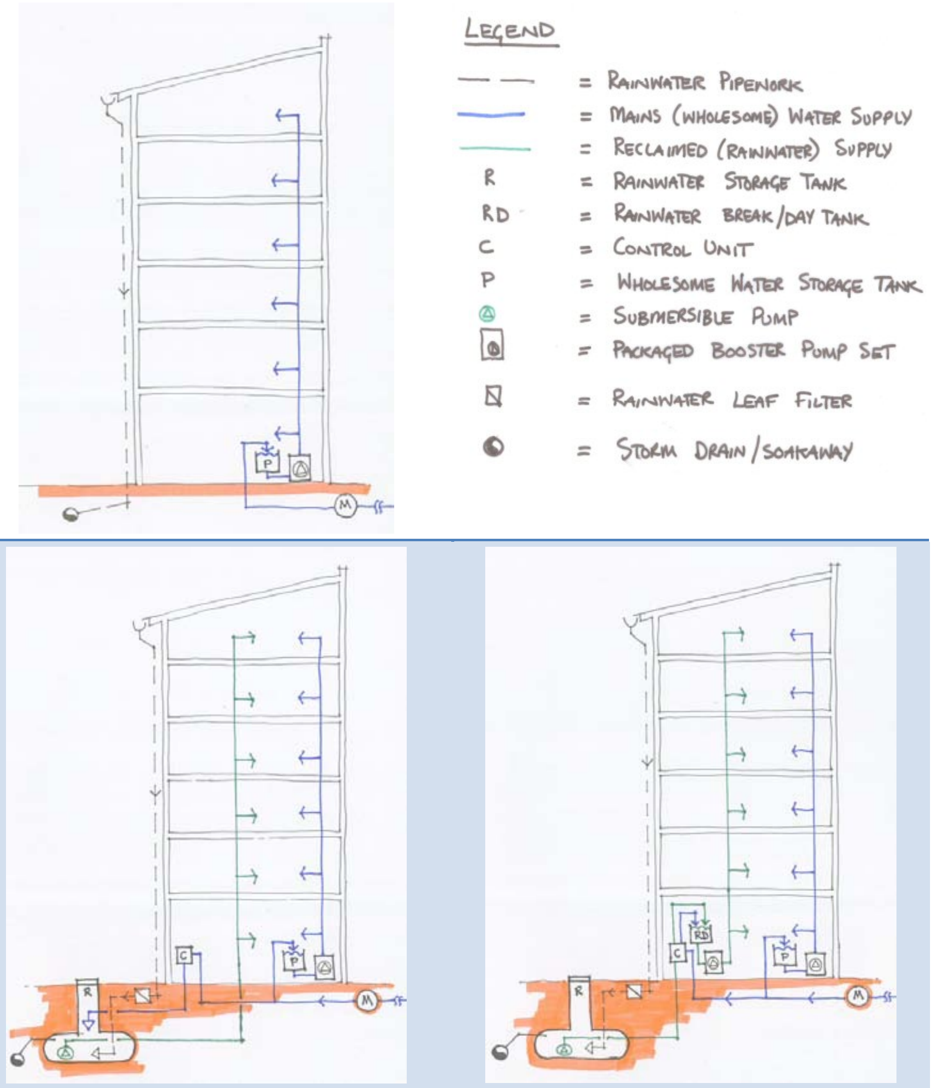
Larger systems

In absolute terms, more pumping is required to supply water to end uses in larger and taller buildings. However, these types of buildings would often have a pumped mains water supply in any case (in contrast to most homes where water is supplied under mains pressure). Therefore a judgement must be made about what proportion of pumping in larger buildings is considered additional.

The base case (pumped mains supply) and two options for rainwater supply in large buildings are illustrated below.

Base case

Rainwater options



Direct Feed **Secondary Break / Day tank**

Figure 2. Options for pumped supply in larger buildings

The direct feed option is identical in concept to direct feed in single home systems. The break tank option has some similarities with the single home header tank, in that water is pumped from the main storage tank to an intermediate vessel to reduce the number of pump starts and related inefficiency. However in this case the break tank is at low level and is a pressurised hydraulic accumulator that can satisfy small draw-offs without the pump needing to start.

2.3 Introduction to greywater recycling

2.3.1 System types

Greywater recycling systems vary greatly in their complexity and size from small systems with very simple treatment to large systems with complex treatment processes. Systems typically consist of:

- A pre-treatment tank to collect greywater from baths, showers and bathroom taps via a diverter valve, with excess greywater yield going to the wastewater drain;
- Some form of treatment system, with the sludge going to the foul drain and treated water to:

- One or more treated water storage tanks; and
- A pump to supply treated water to points of use.

Systems can supply to end uses using direct feed or a header tank and implement mains backup accordingly in a similar way to rainwater systems.

Storage of untreated greywater must be kept to a minimum and reasonable use must occur each day so as to avoid creating a nuisance or health concerns due to unpleasant odours or appearance (WRAS 1999). Storing the water underground in a cold dark environment reduces the rate of deterioration of stored water. Large scale greywater recycling systems are often based on scaled down sewage treatment systems designs and therefore can treat large quantities of water to a very high quality.

Greywater systems can be grouped according to the type of treatment they use (EA 2008c), as follows:

- Direct reuse systems (no treatment)
- Short retention systems
- Basic physical and chemical systems
- Biological systems
- Bio-mechanical systems

Each of the system types is described briefly below with occasional reference to commercially available systems. (NB. The Environment Agency, Energy Saving Trust and NHBC Foundation do not recommend any particular manufacturer or system. Specific systems are discussed in this report for illustration only.)

Direct reuse systems (no treatment)

Direct re-use systems involve no treatment and the greywater is only stored for very short periods of time to minimise bacteria growth and deterioration in water quality. For example, cooled bathwater can be used directly for garden watering. These systems are simple but not normally applicable for uses such as WC flushing within buildings.

Short retention systems

Short retention systems involve very basic treatment. A proportion of the wastewater drained from the bath or shower is collected and stored. The storage vessels include simple treatment techniques such as particle settlement and surface skimming to ‘treat’ the water. These storage vessels provide a supply of greywater for toilet flushing only. Systems are normally located in the same room as the source of greywater (or within close proximity), reducing the need for building wide dual-network plumbing. A typical short retention system is illustrated in Figure 3.

Potential water savings are dependent on quantity and timing of greywater yield from shower or bath relative to WC usage pattern and demand and the storage vessel capacity.

One example is the Ecoplay[3] system which closely integrates the treatment tank, storage and WC cistern. To prevent potential water degradation, systems have a self draining mechanism that replaces greywater that is not used within a certain time with mains water. Supplier marketing emphasises that with ‘no filters to clean or replace’ the systems are ‘maintenance free’.

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[3] http://www.ecoplay-systems.com

Greywater options

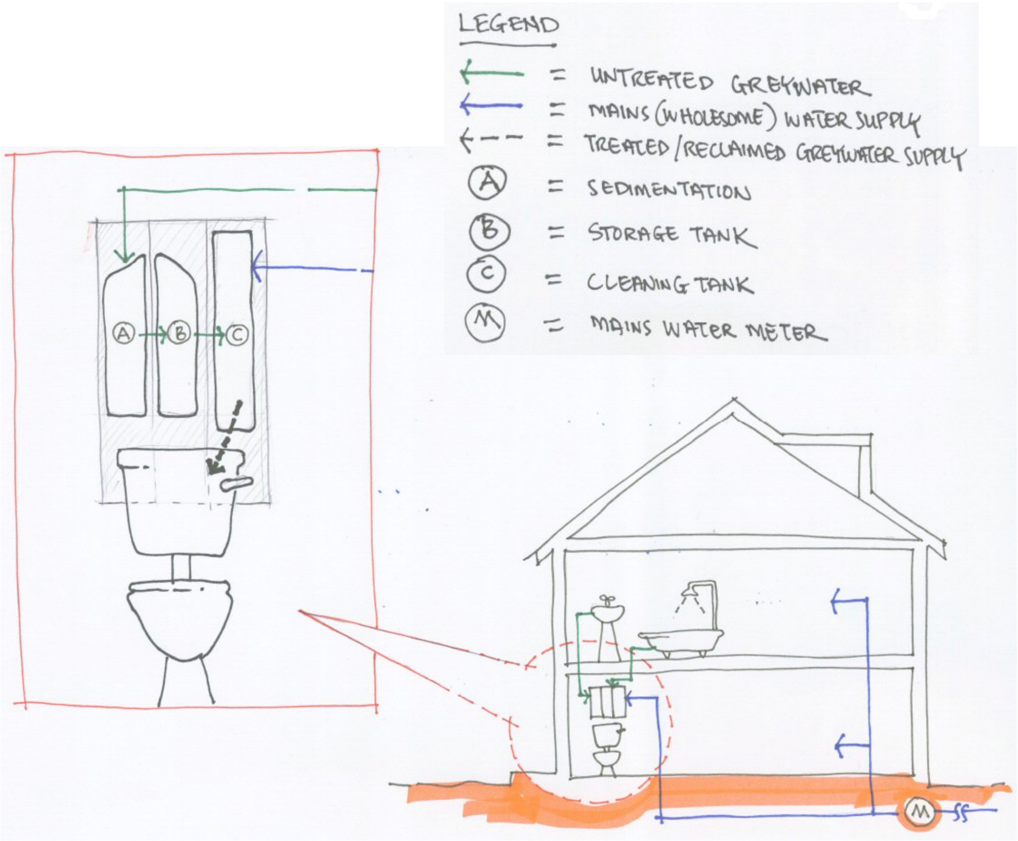

Figure 3. Example short retention systems schematic

Basic physical and chemical systems

Historically the most common type of domestic greywater system, these types of system use a filter to remove debris from the greywater prior to storage while chemical disinfectants (e.g. chlorine or bromine) are used to stop bacterial growth during storage. The use of disinfectants has an environmental impact and often require manual replacement of the disinfectant. The ongoing cost and maintenance implication of this type of systems have resulted in its decline in the market.

A study by the Environment Agency (EA 2008c) reported:

- water savings could be made by the use of greywater systems, ranging from less than 6 to over 32 per cent of total water use
- variable reliability of the systems
- filters required regular cleaning to avoid blockages
- odour problems due to either poor water quality or high levels of disinfectant
- instances where the system had failed and switched to mains back-up with users unaware of the failure.”

Several other studies have looked at the water saving potential of these systems and have also encountered similar reliability issues[4].

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[4] See EA 2008c for further details

Biological systems

Biological systems have overtaken chemical systems in popularity. Biological systems vary in their treatment mechanisms but the basic concept is the same, bacteria are used to remove the organic partials from the greywater. An example of this system type is illustrated in Figure 4.

The biological process is based on principles employed for large scale sewage treatment. The greywater is aerated, providing a supply of oxygen to encourage bacteria growth and the decomposition of the organic contamination in the greywater.

Some systems are entirely mechanical based using pumps to draw air through the grey water which is stored in tanks (see Bio-mechanical systems); others have a more natural element using reeds to provide additional naturally occurring aerobic and anaerobic micro-organisms for the biological digestion and to help aerate the greywater.

Reed beds are an established method for treating wastewater and sewage and can also be used to treat greywater. The wastewater is usually passed through a series of treatment stages including settlement, solids filtration and biological digestion. The waste water is finally passed through the specialist sub-base in which the reeds are growing, and the symbiotic bacteria on the reed roots, fed by oxygen help digest the organic contaminants in the greywater (EA, 2008c).

Traditional reed beds require a relatively large outside area and are therefore often not applicable for new and existing buildings in urban and sub-urban areas. The GROW systems[5] (Green Roof Water Recycling) aims to bypass this issue as it uses a series of treatment troughs located on the building roof. The troughs include a settlement trough, filter and a series of reed and plant filled troughs. The system includes additional mechanical aeration to assist the plant oxygenation and a trace heating wire to prevent the system from freezing in very low temperatures.

An additional treatment stage sometimes included in biological systems is the passing of the treated water through an ultraviolet (UV) filter to kill any remaining bacteria.

The potential water savings are dependent on the design and individual system. Treated water yields relative to the greywater supplied to the system may be lower than other systems as a result of evaporation, plant transpiration and (if the system is open to the ground) infiltration.

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[5] http://www.wwuk.co.uk/grow.htm

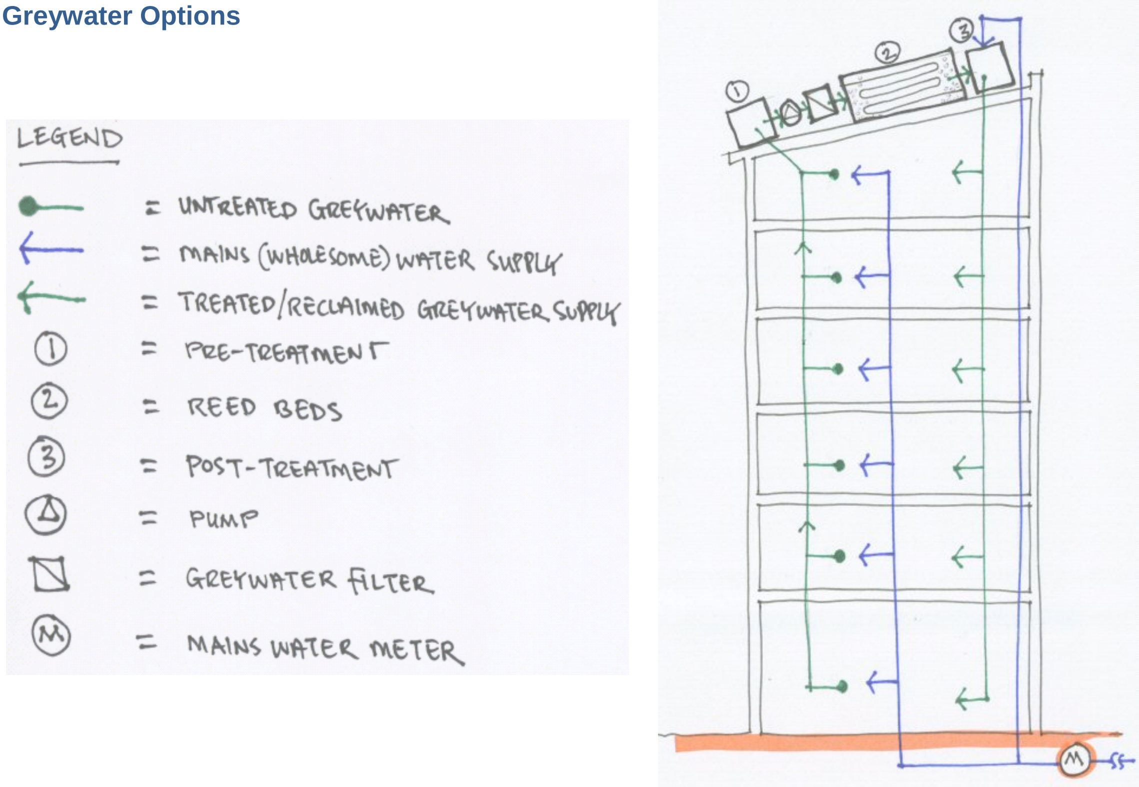

Figure 4. Example biological systems schematic

Bio-mechanical systems

These types of systems usually rely on self cleaning filter or membrane technology, a series of treatment tanks and biological treatment. They are advanced in their treatment and the resulting water quality often meets and exceeds EU bathing water standards. (See Figure 5 for an illustration of this system type.)

One such domestic system is the ‘AquaCycle® 900’[6] an ‘all-in-one’ unit which treats and stores water in three enclosed tanks. Greywater is filtered as it flows between storage tanks and organic matter is removed by bacteria (microbial cultures) formed on rubber chips. Solid material is allowed to settle to the bottom of the tank and is removed automatically. The system encourages bacterial activity by bubbling oxygen through the water using aerating pumps. The final stage of the system is UV disinfection to remove any remaining bacteria. (EA 2008c)

Larger scale communal and commercial bio-mechanical systems utilise biological pre-treatment using pump aeration and then membrane filtration to produce high quality treated greywater. These types of systems often use a four stage, four tank, process which includes:

- 1. Pre-treatment - larger dirt particles are taken out of the process by sedimentation
- 2. Aerobic treatment - bio-degradable substances are degraded by cleaning bacteria
- 3. Membrane filtration - all particles larger than 0.00005mm are retained by the membrane
- 4. Treated water storage - the end water is stored for future reuse

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[6] http://www.freewateruk.co.uk/domestic-greywater-IV.htm

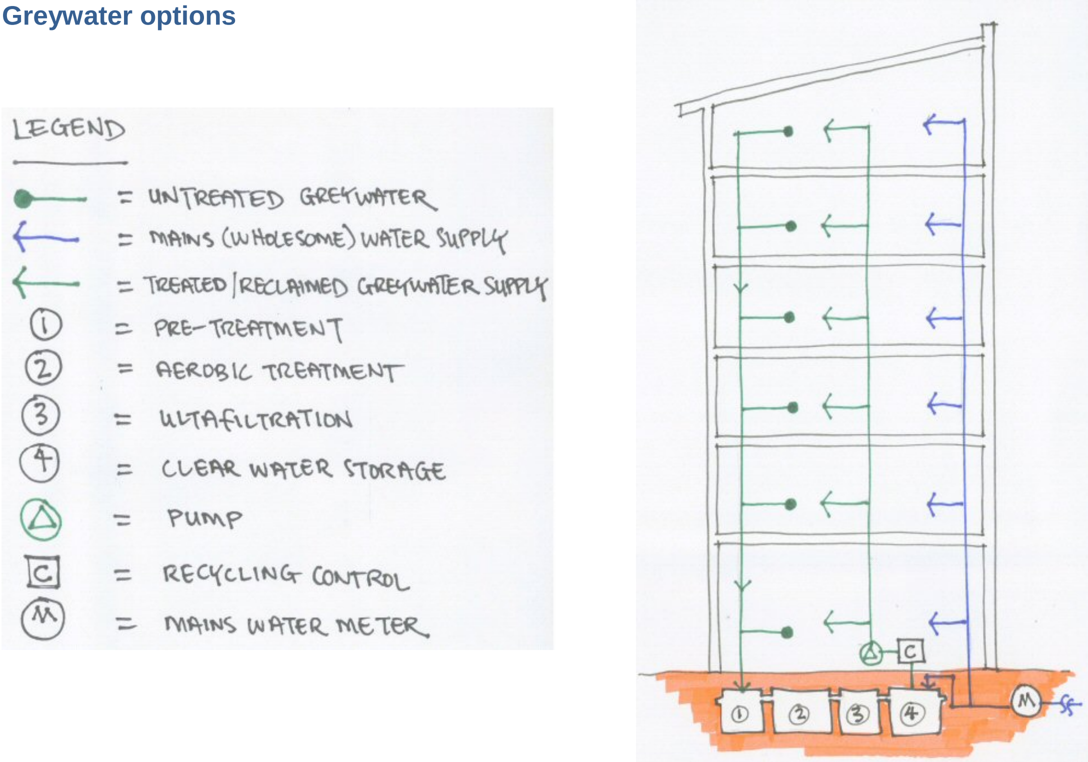

Figure 5. Example bio-mechanical systems schematic

Another type of large scale communal or commercial system used is deep bed multi-media filtration. An example is the Spruce filter[7], which consists of a multi-layer filter bed comprising four layers of inert particulate material with decreasing coarseness and size. The final layer is a naturally charged, fine magnetite media that attracts organic particle-digesting bacteria, which reduce or eliminate the pathogenic micro-organisms in the water. The final stage of treatment is optional UV disinfectant.

Bio-mechanical systems are usually efficient on treating grey water and systems can normally be easily sized to meet the non-potable water demands.

2.3.2 System applications

Different types of greywater systems, their scale and their different treatment levels make them suitable to specific applications. Low level treatment systems, such as, short retention systems are applicable to homes and hotels and may have some degree of application in non-domestic buildings. They are less applicable in buildings such as offices that have lower yields of greywater.

Different biological and bio-mechanical systems are designed for applications to different building and development scales. For example the Aquacycle system is designed for single residential dwellings; biological membrane systems to communal and commercial applications; and medial filtration to significantly larger applications such as high rise buildings, mixed use and multiple building developments.

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[7] http://www.sprucefilter.com/

2.3.3 Other performance issues for greywater systems

Service life

Like rainwater systems the pumps within greywater systems are vulnerable to substantial wear and tear due to the mechanical nature of their operation and the variable loading they may be subjected to. The warranty offered by most manufacturers is 1 year, however the lifespan of pumps is likely to be in the region of 10 years.

Some treatment related parts, such as membranes in some greywater systems and the bulbs in UV disinfectant units have relatively short expected service life, requiring replacement every 1 or 2 years.

Reliability

The reliability of water recycling systems will impact the maintenance schedule of a system.

Many greywater systems were found to suffer from some form of operational fault, with a number eventually being abandoned. In one particular case study (Unpublished 2004), individual systems suffered from high failure rates; more than 50 per cent. The most common fault was insufficient water flow to flush the toilet, potentially related to the backup potable water supply.

Chemical greywater systems require a constant, low dose of disinfectant. Failures of this type of system have been commonly reported and compounded by the fact that householders were often unaware that the system was not functioning (Birks 2002).

Modern greywater systems tend not to rely on chemicals and are often designed with fail-safe mechanisms. The mechanisms are often designed to cut the supply of greywater reverting to mains water supply where filtering, treatment or another process is not operating properly. Poor installation has led to long periods of in operation, often without the users' knowledge (BSRIA 2001). More sophisticated systems are equiped with mechanisms to alert the user of failures. Communal systems can be expected to have an alert system, made available through economies of scale.

Biological greywater systems contain bacteria which metabolise the 'grey' elements in the effluent. They are vulnerable to contamination by chemicals and other agents which can reduce the assimilative capacity of the system. Although no instances were reported in the case studies, it is important that users are made aware of what cannot be put down drains for recycling to avoid unnecessary system failures or reduced service life of parts.

Good design and installation are crucial to the reliable operation of rainwater and greywater systems. The lack of reporting on monitored systems and the potential bias of existing reporting would make modelling specific system reliability difficult and it is likely that it would require the inclusion of unsubstantiated assumptions. However this study makes assumptions for the replacement and maintenance requirements of systems based on the British Standard suggested maintenance regimes (see section on system maintenance below).

System maintenance

The maintenance programme will contribute to the energy and carbon impact assessment as a result of technician's transit to the site for periodic inspections and from replacement parts. See Table 4 for indicative maintenance requirements.

The draft British Standard for greywater recycling BS 8525-1 (2009) includes inspection and maintenance schedules with estimated replacement frequencies. A set of detailed case study reports including summaries of maintenance logs were collated by BSRIA (2001). Best practice guidance from CIRIA (2001) also provides common time intervals for the replacement of components.

System component	Notes	Frequency*
Filters, membranes, biological support media and strainers	Check the condition of the filter(s) etc and clean or replace, if necessary	Annually
Biocide, disinfectant or other consumable chemical	Check that any dispensing unit is operating appropriately; replenish the chemical supply if needed	Monthly
UV lamps (where fitted)	Clean and replace, if necessary	Every 6 months
Storage tank/cisterns	Check that there are no leaks, that there has been no build up of debris and that all tanks and cisterns are stable and the covers are correctly fitted	Annually
Storage tank/cisterns	Drain down and clean the tanks and cisterns	Every 10 years
Pumps and pump controls	Check that there are no leaks and that there has been no corrosion; carry out a test run; check the gas charge within any expansion vessels or shock arrestors	Annually
Back-up water supply	Check that the back-up supply is functioning correctly and that the air gaps are maintained	Annually
Control unit	Check that the unit is operating appropriately, including the alarm functions where applicable	Annually
Water level gauge (if fitted)	Check that any gauge indication responds correctly to the water level in the supply tank or cistern	Annually
Wiring	Visually check that the wiring is electrically safe	Annually
Pipework	Check that there are: no leaks, the pipes are watertight and any overflows are clear. This includes the collected and treated greywater supplies, any backwash supply and the back-up water supply.	Annually
Markings	Check that warning notices and pipework and valve identification are correct, visible and in place	Annually
Supports and fixings	Adjust and tighten, where applicable	Annually
Backwash	Check functionality	Annually
*** These frequencies are recommended if no information is given by the manufacturer.**		

Table 4. Greywater systems maintenance schedule (BSI 2009b)

Of the individual case studies reviewed, the majority have higher maintenance requirements than those stated in the guidance documents, although part of the increase is due to unplanned maintenance to correct faults and other issues of reliability.

2.3.4 Operational energy

Greywater recycling systems use electricity for pumps, treatment (such as aeration), disinfection and control systems. This ongoing operational energy requirement can be responsible for large proportions of a system's life cycle impact.

A case study reported in the BSRIA document reported operational energy use of 1.9 kWh/m^3 (BSRIA 2001), consistent with predictions of operational energy use in the German greywater standard (FBR 2005), which suggests a range between 1.5-3 kWh/m^3.

Even compared to the paucity of data on rainwater system energy and carbon intensity, the availability of reported data for greywater systems was low. For this reason, the study team relied on the generic indications of energy intensity for greywater systems along with information provided by suppliers. The data received (with minimal range information where available) are plotted in Figure 6, with the value used in this study shown as a bold dot.

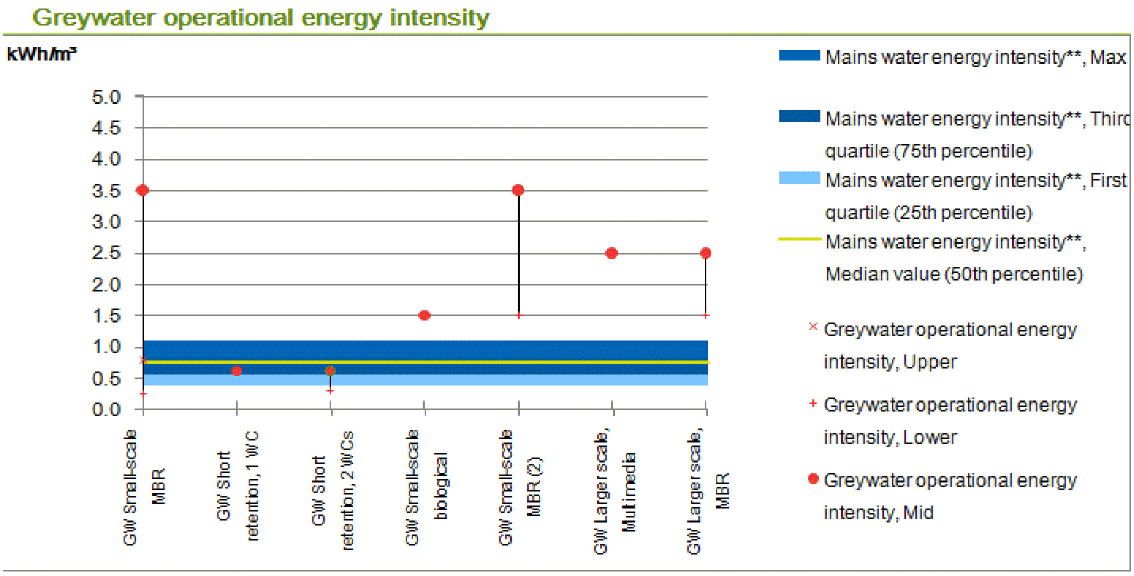


Figure 6. Review of reported energy intensity of greywater systems.

With the exception of short retention systems for both single and two WCs, the minimal data (much of it received from suppliers) shows that the energy intensity of greywater systems is higher than the energy intensity of mains water. This remains true even when potential savings from offsetting foul water pumping (effectively pushing mains intensity up by 0.19kWh/m^3) are taken into account.

Short retention systems clearly stand out as they lie both well within the bands of mains water energy intensity, and below the median intensity. Adding the effect of offsetting foul water pumping means that these systems produce net carbon savings for each unit of water supplied under current assumptions. The size of this saving relative to embodied carbon emissions can be seen in the final presentation of baseline against ‘uncontrolled demand’ scenario results in section 4.7.

2.4 Previous energy and carbon footprint assessments

Previous assessments of the energy and carbon impacts for rain and greywater systems potentially provide comparison data for this study. However, studies often use methodologies tailored to the particular system(s) being investigated or to the research focus. While this makes direct comparisons of results difficult or potentially misleading, the qualitative trends can be observed.

In 2008 Halcrow was commissioned by the Environment Agency to assess the greenhouse gas emissions associated with a range of water supply and demand management options (EA 2008). This study looked at the energy and carbon implications of a wide range of water supply and demand side water efficiency options including individual and communal grey and rainwater systems applied to 1000 homes.

The study found that greywater recycling systems had the potential to save more water compared to other demand management options but with significantly higher life time carbon emissions. Individual domestic systems were modelled to have a marginally higher carbon cost per unit of water saved than communal systems. The results for rainwater systems were similar, with marginally improved water savings and carbon cost performance.

- Rainwater systems are expected to result in a 40 mega litre (ML) per year water saving with net carbon emissions of 2,400-4,800 tCO_{2eq}.

  (Equating to 1 $kgCO_{2eq}/m^3$ of water saved in communal applications and 2 $kgCO_{2eq}/m^3$ (over a 60 year life) for individual domestic applications (over a 60 year life).)

- Greywater systems are expected to result in a 25ML per year water saving with net carbon emissions of 3,000-5,400 tCO_{2eq}.

  (Equating to 1 $kgCO_{2eq}/m^3$ of water saved in communal and 3.6 $kgCO_{2eq}/m^3$ for individual domestic applications (over a 60 year life).)

This study follows and builds on the previous EA 2008 study and makes frequent reference to this earlier work and the methodology used.

Other life cycle assessments observe the following trends for rainwater and greywater systems:

- Larger scale developments have a smaller lifetime carbon footprint per delivered unit of water than individual domestic installations.
- Domestic systems usually have higher life cycle carbon emissions per unit of water delivered than mains water.
- No clear trend can be identified for the life cycle carbon emissions of water delivered from communal reuse systems. They have been modelled to be both more (Beal C, et al. 2008) and less (Bronchi V, et al. 1999 & Tarantini et al., undated) carbon intensive than mains potable supplies, although the studies are not based in the UK context.

Studies investigating rainwater systems have identified that:

- Combinations of demand management options, even those including rainwater harvesting in new homes, offer larger water savings compared to individual water efficiency options and still compare favourably to supply side options [for new supply infrastructure] in terms of overall lower carbon emissions (EA 2008).
- The component of the life cycle carbon impact associated with embodied energy of the water storage was dominant in the domestic context. In commercial buildings, the operation of the pumps is the key component (Bronchi V, et al.1999).
- The roof area and consumption patterns of commercial buildings allow for a smaller total storage volume per unit of delivered water than is possible for systems installed in individual dwellings (Bronchi V, et al. 1999).
- The energy savings made by reducing water consumption through low flush WCs are more significant than from installation of a rainwater harvesting system (Crettaz et al. 1999).

Studies investigating greywater systems have identified that:

- Natural treatment processes can have lower impacts than membrane based technologies (Memon F., et al. 2007).
- For natural treatment process, life cycle impacts are mostly attributable to construction. The impact of mechanical systems is predominantly caused by the operational phase (Memon F., et al. 2007).
- Water saving appliances result in a smaller volume of available greywater with a higher concentration of pollutants and a smaller demand for non-potable water (Memon F., et al. 2005).
- For individual domestic systems, smaller WC flushing volumes decrease the amount of greywater utilised and increases lifetime costs (Memon F., et al. 2005).

3 Carbon footprinting approach and methodology

3.1 Approach

The general approach to carbon footprinting in this study is to provide a broad quantitative understanding of the carbon implications of rainwater and greywater systems, making reasonable use of the most reliable information available. System carbon footprints are influenced by factors including system type and scale, building type, size, location and water demand. The analysis aims to calculate the range of carbon footprint results for rainwater and greywater systems and to identify the key factors that produce variability in the results.

The analysis approach was strongly influenced by the choice of the main metric to be used for presenting final results. Results are presented as net carbon footprints. Previous related studies (see section 3.1.1) presented their results as average incremental carbon costs, and marginal abatement costs, which were also considered for this study. The relative merits of these alternative metrics are discussed below.

3.1.1 Previous EA and Energy Saving Trust studies

EA Science Report – water supply and demand management options

The *Greenhouse Gas Emissions of Water Supply and Demand Management Options* (EA 2008) study considered the carbon impacts of a range of options for supplying water or reducing water demand. It established a basis for presenting results on the carbon impacts of water supply and saving options as follows:

- The AISC [Average Incremental Social Cost] is the standard term used for options appraisal in water resources planning.
- The AISC is the ratio of total capital and operating costs for a scheme, including one off and annual social and environmental costs, per volume of additional water supplied or reduced demand, discounted over a defined period of time. The unit of measure is pence per metre cubed (p/m3). The ratio represents the net present value of social costs over the net present value of additional water supplied or reduced demand. A low value represents a low social cost.
- For this study [EA 2008] the average incremental ratio is referred to as the average incremental carbon cost (AICC), in the same way as AISC used in water resources planning but based only on carbon costs (calculated using SPC [Shadow Price of Carbon]) and excluding other social costs. Thus AICC is the ratio of total capital and operating carbon costs for a scheme, calculated based on net present value (NPV) as follows:

$$\text{AICC} = \frac{\text{CAPEX} + \text{OPEX} - \text{Saving}}{\text{Water x 10}}$$

Where

CAPEX: NPV capital expenditure as carbon cost (£)

OPEX: NPV operating expenditure as carbon cost (£)

Saving: NPV water saving as carbon cost if demand management (£)

Water: NPV water delivered or saved (mega-litres, ML)

The AICC provides a succinct summary of the required calculation approach (embodied + operational – savings) for a lifetime carbon study, and a similar format is adopted for calculations in this study.

EA / EST Report – energy and carbon effects of water saving

The *Quantifying the energy and carbon effects of water saving* (EA/EST 2009) study was more focused on total net carbon emissions than on carbon valuation. In addition it used Marginal Abatement Cost (MAC) curves to explore the relationship between:

- The cost of water efficiency measures,
- Their potential to save water (particularly hot water) and hence reduce carbon emissions.

The summary MAC from the study is shown below.

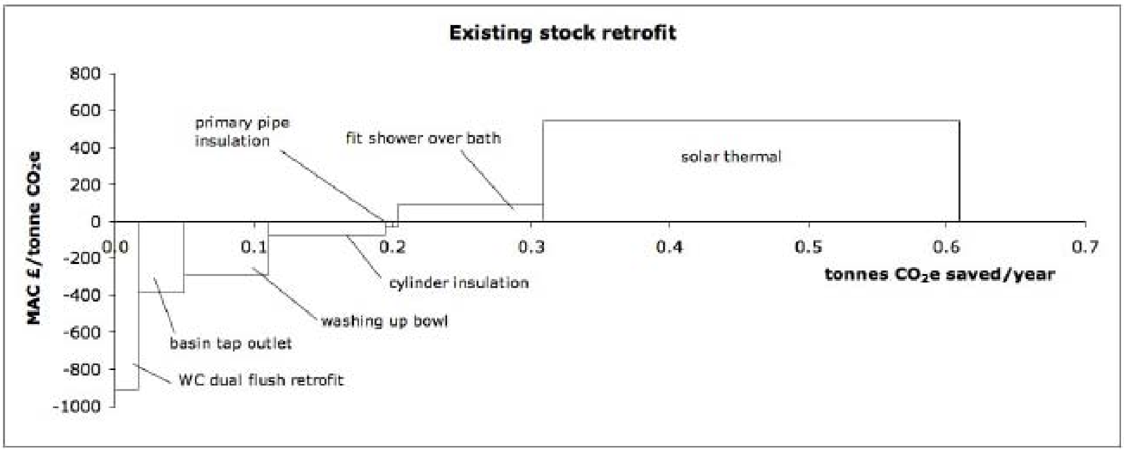


Figure 4. Marginal Abatement Cost Curve used to demonstrate the cost effectiveness of measures that save CO_2 for a single dwelling. Measures that save CO_2 as well as money are below the x axis.

Figure 7. MAC curve for home water efficiency measures (EA/EST 2009)

3.1.2 Approach and target outputs in this study

The net carbon footprint of rainwater and greywater systems were of most interest, alongside results that relate carbon and water saving quantities. This study presented the following outputs:

• Lifetime carbon footprints	Total net lifetime carbon emissions (embodied carbon + operational carbon – mains water supply carbon savings – foul water transportation carbon savings) per property. Where systems are applied to multi-residential buildings the footprint is divided equally among the properties (the study assumed such buildings are made up of identically sized homes). Footprints were calculated over 15, 30 and 60 years. The 60 year lifetime was selected to maintain comparability with the previous EA study (2008), representing a standard timeframe for water resources planning. The 15 and 30 year lifetimes are multiples of the assumed 15 year service life of generic pumps (CIBSE 2008). System may not remain in operation for the theoretical maximum time period (i.e. the assumed storage tank life) if owners choose not to replace critical parts at the end of their lives. Analysis over the 15 and 30 year periods reflects this.
• Annualised carbon footprints	The cumulative carbon footprint over 15, 30 and 60 years divided by the number of years. This measure helps to understand the relative impacts of initial embodied carbon, operational emissions, and the embodied carbon in replacement components.
• Normalised carbon footprints	The annualised carbon footprint divided by the quantity of water saved in the period. This is a simple ‘efficiency’ type measure that can be used to compare different applications of rainwater and greywater systems.
• Average Incremental Carbon Cost	The discounted value of net carbon emissions over time divided by the discounted quantity of water saved, in units of pence per mega litre, is calculated as an additional useful comparator. AICC is described in more detail in section 3.1.1.

Other quantities of interest are:

- Initial embodied carbon + breakdown;
- Energy and carbon intensity of rainwater and greywater systems and of mains water supply and wastewater treatment;
- Other energy and emissions rates and footprints as comparators, such as the baseline annual mains carbon emissions for buildings to which rainwater and greywater systems are being applied, and (for homes) the annual household carbon footprint.

Together these quantities should enable a better understanding of the energy and carbon implications of these systems.

AICC results are presented in section 4.8 for continuity and to enable future comparisons with other studies. AICC is also used as a convenient single indicator for comparing carbon impacts under future scenarios.

3.1.3 Selecting a representative carbon footprint

A carbon footprint may be a more accessible concept than AICC but there is no method for footprinting that combines the relative simplicity of AICC with its implied acceptability as a standard metric. The difficulties with undertaking lifetime footprint calculations in this study relate to dealing with the future, which is important when studying systems that are expected to operate for 30 years or more. Two approaches for calculating lifetime footprints are used. Each has its own advantages and drawbacks.

Steady state (Baseline)

The analysis method adopted to produce interim study results assumed that all the main variables represent the current status quo and remain constant for the analysis period, similar to the approach in previous studies. The variables include, in rough order of their impact on carbon footprint results:

- Carbon intensity of the electricity grid, which affects rainwater and greywater system carbon intensity and the carbon intensity of mains water supply;
- Rainfall;
- Occupant demand;
- Carbon intensity of mains water supply (and foul water pumping for greywater systems) which can be affected independently of mains electricity carbon intensity, e.g. by leakage and water company use of renewable energy systems installed on their own sites (although it is largely, (~80%) dependent on mains electricity).

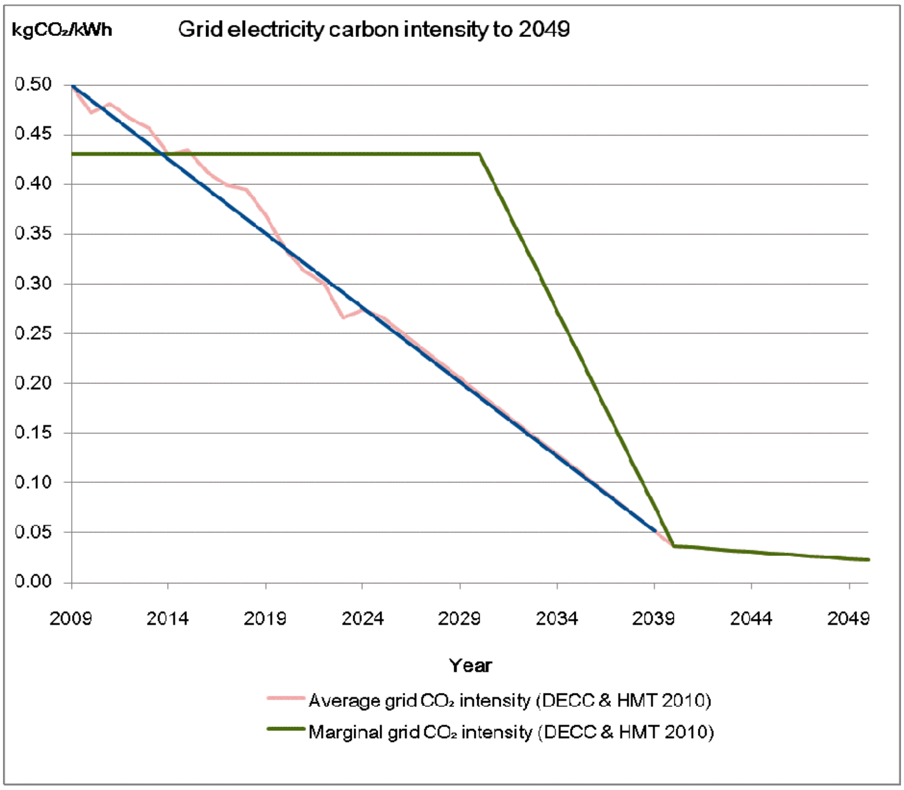


Figure 8. DECC projection of the carbon intensity of grid electricity to 2049.

DECC guidance on carbon valuation, which reflects national policy on the transition to a low carbon economy, projects that the grid will decarbonise by 90% over the next 30 years, i.e. over the main analysis period adopted for this study, as illustrated in Figure 8, above. That will have a big impact on the carbon footprint results, suggesting that a baseline, steady state analysis that assumes constant grid emissions factors over 30 years will not produce a realistic representation of the carbon footprint of rainwater and greywater systems.

The baseline results remain useful, e.g. for sensitivity analysis, and as the basis for comparison with previous studies.

Scenario results

The second analysis approach adopted attempts to deal explicitly with future change, which means also dealing with uncertainty. This has been tackled using four future scenarios, previously developed by the EA, which is explained further in section 3.2.7. In terms of selecting a footprint to present, the difficulty is that the scenarios adopted do not include one scenario that is intended to represent the most likely future. Rather, they are a tool for exploring different outcomes in different types of future.

For pragmatic reasons the ‘Uncontrolled Demand’ scenario was adopted as the reference scenario that is used as the basis for reporting representative study results. This is a ‘pessimistic’ scenario in terms of water demand (which increases) and grid carbon intensity (which falls more slowly than in the other three scenarios used). However, it produces lower carbon footprints than the steady state baseline and is considered by the study team to come closest to the sort of ‘business as usual’ case that is often used as a baseline.

3.2 Outline methodology

The analytical work of the study involved the following steps:

- Clarifying the scope and limitations of the analysis (see section 3.2.1);
- Quantifying the key locational factors – rainfall and the carbon intensity of mains water supply – and establishing how the values relate to different regions of the UK (see section 3.2.2);
- Selecting ‘system – building applications’, i.e. the generic types of rainwater and greywater systems to be studied, and the types and relevant characteristics (roof area, occupancy / water demand etc.) of buildings to which they would be applied (see section 3.2.3);
- Producing system inventories of components & materials to enable calculation of the embodied energy of rainwater and greywater systems and rainwater tanks (see section 3.2.4);
- Calculating water savings for system – building applications (see section 3.2.5);
- Calculating and presenting baseline carbon footprints for the system – building applications. The footprint components are illustrated in Figure 9 and the calculation method for each component is explained in more detail in section 3.2.6.
- Looking at ways to reflect important changes from current conditions that will affect the carbon footprint of rainwater and greywater systems, discussed in section 3.2.7

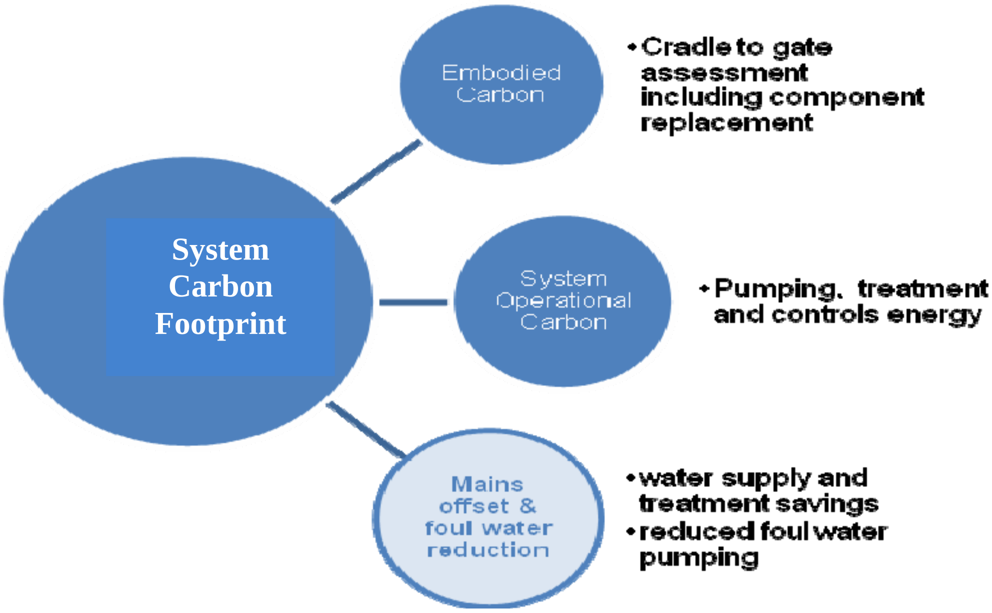


Figure 9. Carbon footprint components

3.2.1 Scope and limitations of the analysis

Carbon footprinting analysis boundaries

Figure 10 illustrates the boundaries of the carbon footprint adopted for the study (green) and the corresponding, comparative footprint for mains water (blue). These broadly include the embodied energy of the system components and the operational energy of the system with savings as a result of reduced treated mains water and waste water distribution.

Water company emissions		System emissions	
Source: June Returns (UKWIR 2009): Adopts Defra reporting guidelines and reports greenhouse gas emissions as CO_2 equivalent		Source: system inventory and Bath ICE database (University of Bath, 2009) for components, operational energy data from manufactures and previous studies carbon equivalent emissions factors for electricity and transport for distribution and delivery from Defra reporting guidelines	
Waste water treatment	Water distribution	System parts embodied energy. Includes manufacturing, materials distribution and delivery	End use disposal and materials recycling
	Leakage	Replacement part embodied energy (see above)	Maintenance transport
	Waste water pumping	Operational energy: - Pumping - Treatment	System assembly, site installation and construction

Figure 10. Carbon footprint analysis boundaries.

Study limitations

The key data required for the study are embodied carbon data for the components in rainwater and greywater systems and measured data on the operational energy use of pumps and other electrical components used for supply, treatment and controls. The study confirmed the expectation that there is a lack of good quality data in both areas. The study found limited reported embodied carbon data for system components, and no reports of systematic measurement of operational energy and carbon for these systems in the UK.

The results of the literature review and evidence gathering stage confirm that quantitative information about the energy and carbon implications of rainwater and greywater systems is scarce. The previous studies, reports, submissions from suppliers, and responses to data requests contain a variety of interesting but disparate information. Few published reports containing measured data on operational energy use and water savings were found. No manufacturers' information on embodied carbon was found. In many cases it was difficult to establish a mass and material inventory of system components from product literature and communications with suppliers. The analysis of energy and carbon implications of rainwater and greywater systems therefore relies on assumptions and judgements based on weak evidence in some key areas, particularly operational energy use. It was not possible to remedy this situation as measurement of operational energy use and the collection of accurate mass and material inventories for particular systems (e.g. by system inspection or disassembly) were beyond the scope of this study.

The analysis aims to include in the footprints all **additional** carbon emissions that arise as a result of installing and operating each of the rainwater or greywater systems considered. As such, it excludes the embodied energy of components that are physically part of a system, but which would be required anyway if the system were not present (e.g. the downpipes in a rainwater system and the cistern in a short retention greywater system).

The initial proposals for this study were to look at retrofit and new build systems independently. Potential differences in carbon footprint were considered when planning the analysis. Some differences between retrofit and new build are construction-related:

- the carbon emissions for excavation are estimated to be relatively small as illustrated in Figure 24; and
- increased emissions from the use of hand tools are assumed to be insignificantly small.

For a particular type and size of building, whether new build or retrofit there are:

- the same range of system options and basic size of each;
- no major differences in systems inventory and embodied carbon; and
- no difference in operational footprint (same pumps, treatment and water savings).

Under these assumptions there is virtually no difference between new build and retrofit footprints. It was decided that there is no benefit in presenting separate results for retrofit and new build systems.

There is evidence that a significant impact in the life cycle of a WC is the heat losses from the cistern when the cold water used to fill the cistern absorbs ambient heat. (EA & EST 2009) This heat is subsequently flushed away when the WC is used. Similar heat losses can be experienced in uninsulated pipework and tanks. The impact of this effect could be reduced or increased as a result of greywater and rainwater systems:

- Treated greywater stored in internal tanks, pipes and cisterns may be warmer than mains cold water supply reducing the ambient heat absorbed.
- Additional internal uninsulated (dual) pipework may result in additional internal heat losses.
- Internal (within heated areas) water storage and/or treatment tanks may result in additional internal heat losses.

The heat losses and gains resulting from this effect are difficult to quantify especially given the complexity of possible configurations of pipe work and water storage. Neither, the potential internal heat (and resulting CO_2 emission) gains, or losses have been included in our analysis.

Excluded types of rainwater and greywater system

The study did not model the following system variations:

- Combined rainwater and greywater systems – The carbon implications of these systems can be largely inferred from the footprint component results of this study by adding a rainwater tank footprint to the appropriate greywater system footprint. The efficiency of the solution (carbon emissions per unit of water saving) will depend on the assumption about the increased proportion of non-potable water demand saving
- Combined rainwater and/or greywater systems with stormwater attenuation – Solutions are highly variable, context dependent and may involve custom designed civil engineering, additional storage capacity and drainage and green infrastructure elements. This is in contrast to the more generic, component-based system designs considered in this study.

The study did not investigate emerging, gravity rainwater systems with small storage volumes, and no pumping requirement for supplying ground floor WCs. These systems are currently being prototyped in the UK and based on their concept designs would have smaller embodied footprints and achieve net operational savings, with lower water saving potential.

3.2.2 Location factors

The location of a building determines the rainfall used for rainwater calculations and the carbon intensity of mains water supply. The analysis in this study took account of regional differences in rainfall and differences in mains carbon intensity between different water companies. As water companies serve particular areas, differences in the carbon intensity of mains water supply are also essentially dependent on location.

There are also distinct differences in water demand between different regions of the UK. However the study adopted standardised water use benchmarks of water demand in different building types, and so did not consider regional variation in water demand.

Rainfall

Rainfall influences the sizing of rainwater tanks and the potential water savings from applying rainwater systems with tanks of any given size. Rainfall also influences water demand in some cases, with demand tending to rise in hot dry periods due to garden watering and irrigation.

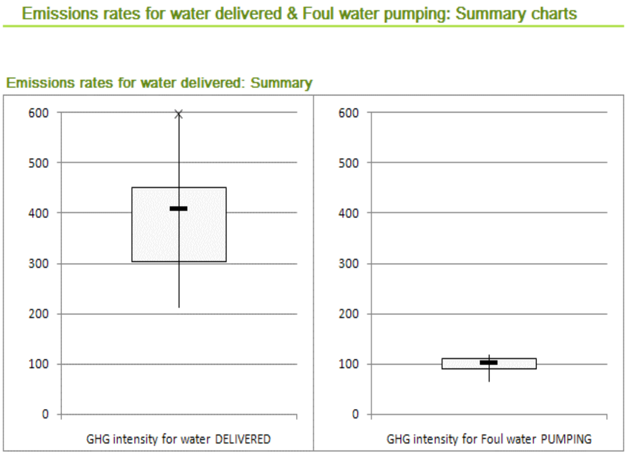
Carbon intensity of the mains water supply and treatment system

New requirements for water company reporting on carbon emissions mean that more data is available to support quantification and apportionment of emissions than at the time of previous studies. Companies report to the industry regulator, Ofwat, on the carbon emissions arising from their operations as part of their annual ‘June returns’. They report separate figures for mains water supply and wastewater treatment based on guidelines developed by UKWIR (2009) and trialled on a voluntary basis before the introduction of regulatory reporting in 2007/8. In principle, the reported footprints cover direct company emissions, e.g. from energy use in buildings and treatment plants, and non-energy emissions from sludge decomposition, and indirect supply chain emissions. Companies include indications of data quality as part of their reporting.

This study used company data published on the Ofwat website as part of water company June 2008/9 returns as the basis for deriving a median and quartile bands for carbon intensity of mains water supply. Two modifications were made to the reported data:

- Companies report mains water carbon intensity based on water distribution, i.e. the quantity of water put into the mains from reservoirs, abstraction, etc. This does not account for leakage. Each company’s carbon intensity was modified to account for its leakage rate, taken from the same June returns.
- The reported emissions for wastewater treatment cover both the pumping of foul water to treatment works and the treatment process. Some companies provide further emissions breakdowns including separate figures for wastewater treatment and foul water pumping. These figures were used to apportion carbon emissions for foul water pumping.

The range, median, upper and lower quartile values for carbon intensities for delivered mains water and the estimated foul water pumping component of wastewater treatment of UK water companies in 2008/9 (Water UK 2009) are shown in Figure 111.



	Mains water CI kgCO₂e/ML		Foul water pumping CI kgCO₂e/ML
Max	597.6		118.1
Third quartile (75th percentile)	450.5		110.1
Median value (50th percentile)	409.3		104.3
Mean	382.3	not shown	98.0
First quartile (25th percentile)	302.9		89.4
Min	212.9		67.4

Figure 11. Carbon intensity for mains water delivered and sewage pumping

The analysis considers the carbon impacts of rainwater and greywater systems in areas with medium, low and high mains carbon intensity (corresponding respectively to the median, third and first quartile values in Figure 11). The median carbon intensity for foul water pumping is used for all calculations.

3.2.3 Selected system – building applications

The analysis considered rainwater and greywater systems applied to a selection of representative types of homes and non-domestic buildings in different locations. Many other system – building applications are possible. Those presented here are not intended to be comprehensive, nor optimal cases but to be reasonably representative of common building forms for new buildings and for the existing stock.

System types

Inventories were developed for the rainwater and greywater systems, shown arranged by application scale in Table 5.

Application scale	System ID	System description
Single home	H1DF	RW 1-Home Direct Feed
	H1HT	RW 1-Home Header Tank
	SmMBR	GW 1-Home, Small-scale MBR
	ShrtRtntn2	GW Short retention, 2 WCs
Single home & other*	ShrtRtntn1	GW Short retention, 1 WC
	SmBio	GW Small-scale biological
Multi-residential	H10DF	RW 10 Flats Direct Feed
	H10iHT	RW 10 Flats Individual Header Tanks
Larger buildings	ND2_4DF	RW 2 to 4-storey ND Direct Feed
	ND2_4HT	RW 2 to 4-storey ND Header Tank
	ND5_8DF	RW 5 to 8-storey ND Direct Feed
	LgMltiMdia	GW Larger scale, Multi media
	LgMBR	GW Larger scale, MBR

*e.g. results are calculated for this system applied to hotels

Table 5. System types studied

Building types

The buildings types to which rainwater and greywater systems were applied are shown in Table 6.

Building type	Building description
Multi-residential	70m² Flat with 2 occupants in a 4-storey block of 10 flats
Homes	90m² e.g. Semi-detached house with 3 occupants
	120m² e.g. Detached house with 4 occupants
Non-domestic	Budget Hotel, 80 rooms over 3 storeys
	City centre office refurbishment, 10,000m² over 6 storeys
	Small 11 - 18 Secondary school (585 pupils)

Table 6. Building types studied

Water demand benchmarks

An extensive set of water use benchmarks and end use splits for different building types was collected and reviewed. In some cases a standardised benchmark for use in the analysis has been derived from the published benchmark. This and the end use splits used to derive the non-potable demands and greywater yields can be seen in the detailed benchmark table in the technical annex.

The benchmarks used in the analysis were as follows:

Building detail (benchmark type)	Standardised benchmark water use		Daily non potable water demand	Potential GW yield	GW demand, WCs only	GW demand, WCs & laundry	GW demand, WCs, laundry & other
Household, average E&W (Typical)[1]	148.0	L/person /day	51.9	91.9	29.2	47.1	51.9
Household, Code 3 (Target)[2]	105.0	L/person /day	27.7	61.3	12.0	27.7	27.7
Hotel, 2-3 star, no pool (Typical)[3]	54.8	L/bedspace /day	18.1	18.7	11.4	18.1	18.1
School, secondary, no pool (Typical)[4]	10.5	L/pupil/day	8.2	1.1	8.2	8.2	8.2
Office, 1 BREEAM credit (Typical)[5]	15.1	L/employee /day	9.5	4.1	9.5	9.5	9.5

1 Source: EA (2009); end use split: MTP (2008) BMWAT 28. Note: End use demand % taken from the sample of new build homes.

2 Source and end use split: CLG (2009. Note: End use demand % calculated from the Code For Sustainable Homes water Calculator for a representative Code Level 3 home.

3 Source and end use split: CIRIA (2006) C657. Note: Guest room use split by WC, washing and basin tap use for residential. Locker room/public toilet use split by WC, urinal and 'washing' use for offices.

4 Source: DCSF (2004) Maintained Schools benchmarks. End use split: MTP(2007) BNWAT 22.

5 Source: CIRIA C657 (2006). End use split: IoP (2002)- plumbing services design. Note: Washing is a category used in typical office water use. Assumed to contain hand basin and occasional shower use.

Table 7. Water use benchmarks by building type

The resulting building demands and yields for the system – building applications can be seen in the rainwater tank sizing calculations and the greywater savings calculations in later sections.

3.2.4 System components & materials inventories

Data collection

UK Rainwater Harvesting Association members were approached with a request for information for the study. Initial discussions took place to catalogue rainwater and greywater systems supplied by each organisation along with information on the installation procedure and cost for each system. A breakdown of system components was obtained through follow-up communication with suppliers. The information gathered for each system was recorded in a systems database.

The data collection process adopted the following hierarchy:

- Technical literature The preferred sources of data were technical datasheets or specification document and these were reviewed to obtain as much referenced data as possible.

Manufacturer or supplier estimates	Information gaps in the technical literature were identified. Suppliers and manufactures with established experience and expertise were asked to give their best professional estimation of missing information.
Rules of thumb	There were occasions where manufacturer sources did not yield the required information. In these instances standard industry practices including design guide estimates, in most cases generic rather than system specific, were used.

Throughout the process the project team’s consultants and engineers used their professional judgment to sense check the data collected.

Once sufficient information had been gathered to group together comparable systems, “generic” system profiles were produced. The generic system types were defined by characteristics such as the location and type of pump used, the number of tanks required, the tank materials, etc.

There are significantly fewer greywater than rainwater systems on the market, and a high degree of variability between systems that do exhibit similar operation principles. This resulted in single system representing several of the generic greywater system types.

During the data collection process it became apparent that several of the system components were made up of numerous materials and that the information available on each material and its mass would be limited. To account for the limitations and reduce the number of assumptions needed to fill in the information gaps, the two most significant materials in a component were identified and included in the study model. As an example, a commonly used filter for commercial rainwater systems comprises a stainless steel mesh within a polyethylene housing. The filter has a mass of 6.2 kg which was assumed to be 85% polyethylene and 15% stainless steel. Therefore the proportion factors are 0.85 and 0.15 respectively. For composite components such as pumps with multiple materials, the embodied energy calculations in this study are likely to be an underestimate of the material embodied energy, however given the available information within the project programme, this methodology adopted was considered the most suitable approach.

Rainwater systems materials inventory

Rainwater systems consist of a storage tank and the ‘balance of system’ components required to:

- collect and filter rainwater,
- pumping water to the building for use, directly or via a header / break tank
- switch to mains water when storage is not replenished with rainwater
- generally control the system.

While the balance of system inventory for direct feed and header tank systems for particular building applications are fairly standard, the rainwater tank size varies according to rainfall and water demand. It was also expected that the storage tank would account for a large proportion of the embodied carbon of rainwater systems. As such, storage tanks are considered separately from the balance of system and were subject to a focused data collection exercise to relate tank volume with mass, to enable the embodied energy to be calculated.

Storage tanks

Published mass versus volume data for RC, GRP and PE rainwater tanks was collected from supplier literature and internet research. The mass versus volume data for rainwater tanks is presented in Figure 12.

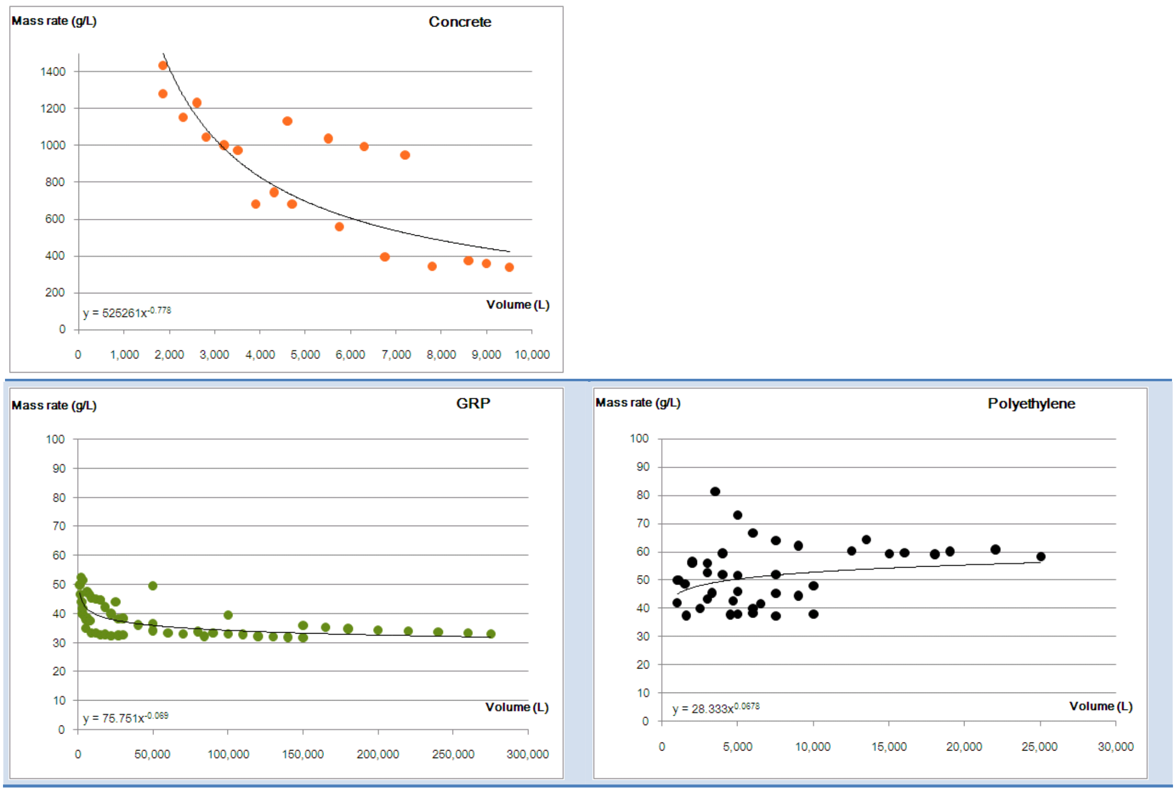


Figure 12. Collected data on mass per litre of storage volume for rainwater tanks

Variation in the mass rate (in grams per litre) of tanks of a particular material is likely to be due in part to varying tank design, but also to inaccuracy in measurement or rounding of reported data. A pragmatic approach was taken, and a best fit curve (shown on the charts above) was used to derive standardised tank masses for each material and for the range of tank volumes required.

Multiple tanks and tank access were assumed where necessary based on assumed maximum tank sizes. Only underground tanks were considered, and the following assumptions made about installation requirements:

- RC tanks – 150 kg of reinforcement bar per 100 m^3 of concrete, 30,000 L maximum tank size;
- GRP tanks – encased in a concrete shell to a 'cover' depth depending on tank diameter;
- PE tanks – sand bed and surrounding backfill. (Some PE tanks and/or installation contexts may require a concrete base, but a number of suppliers offer PE tanks targeted at home applications that do not require a concrete base or surround.)
- All tanks – one access per 30,000 L, designed for pedestrian loading above 3,000 L and for vehicle loading above 6,000 L.

Rainwater – system inventory (excluding storage tank)

A generic inventory of common components for rainwater systems and the components specific to direct feed and header tank systems is presented in Table 8.

Component	Description
Common Components:	
Storage tank	Variable size and materials (RC, GRP or PE)
Telescopic dome shaft	Used for access
Pipework	External usually PE
	Internal PVC / MDPE
Filter (options)	Stainless steel mesh, PE surround
Calmed inlet	Polyethylene part
Overflow siphon	Polyethylene part
Float switch & Flow regulator	Polyethylene ball, Brass connecting parts, stainless steel clamps
Pump (options)	Two types of pumps submersible and multistage self-priming centrifugal pump used as standard
Controls	Mains top up controls
Direct feed system:	
Pump controller	For the submersible pump
Header tank system:	
Header tank	Usually MDPE

Table 8. Outline materials inventory – generic rainwater systems excluding storage tank

Greywater systems materials inventory

The approach taken to construct the grey water system inventories was more targeted due to the reduced number of systems in the market. In this respect a generic system type might represent a single commercially available system.

The general greywater system types included in this study are:

- Bio-mechanical (MBR)
- Short-retention
- Biological
- Multi Media

A generic inventory of common components for greywater systems and the components specific to each of the system types considered is presented in Table 9.

Component	Description
Common Components:	
Collection tank	Collection of pre-treated grey water ,
Treatment tank(s)	Usually polyethylene
Clean water tank	Usually polyethylene
Diverter valve	PE part (domestic systems), Steel/brass & PE composite (commercial systems)
Isolation valve	Brass part
Solenoid valve	Brass, stainless steel and plastic part
Overflow	Polyethylene pipes
Float switch	High-level for flood protection, low-level for dry-run protection of pumps (Polyethylene, brass)
Aerator	For oxygenation (GRP, stainless steel)
UV Treatment	For sterilisation (Glass bulb, stainless steel)
Bio-mechanical System	
Biological agents	e.g. bacteria, enzymes
Filtration media	e.g. polymer membranes, coarse & fine inert materials, activated carbon
Short Retention System	
(No treatment tank or components)	System frame Miscellaneous plastic parts
Biological System	
Filtration media	e.g. bacteria, enzymes, plants
System frame and media container	Growing media

Table 9 Outline materials inventory – broad greywater system types

3.2.5 Water savings

The savings for rainwater systems depend strongly on the size of the storage tank provided. The optimum storage tank size depends on rainfall, collection area and the demand for collected rainwater, which in turn depend on the type of building to which the system is applied.

The savings for greywater systems depend on the dynamics of water use within buildings over short periods of time – a day or so. Systems are sized to treat collected water to satisfy a proportion of daily demand. The demand that can be met is determined as much by the timing of events that yield collected water (typically showering and bathing), the rate of treatment, and the timing of demand events (typically toilet flushing and laundry) as by the storage capacity of the system.

The water saving calculations used in this study are set out in the sections below, with a comparison to the approach used in the previous EA 2008 study.

Water saving calculation in this study

EA 2008 assumes that rainwater systems achieve a 30% saving on household total water demand and that greywater systems achieve a 20% saving. The calculation of water savings is an area where this study takes a significantly more detailed approach. This reflects both the specific focus of this study and the emergence of relevant British Standards since the publication of EA 2008.

The features of the modelling approach adopted in this study that differ from the approach in the previous study are:

- Application-specific tank sizing using the intermediate approach set out in BS 8515:2009;
- Applications-specific water saving calculation based on Fewkes & Warm (2000);
- Consideration of both homes and non-domestic buildings and of a variety of built forms for dwellings (e.g. houses and flats).

This approach enables investigation of variations in:

- embodied carbon with tank size, and
- operational carbon with water savings.

Rainwater tank sizing

Tank sizes for the system – building applications were selected using the Intermediate Method set out in BS 8515:2009 Rainwater harvesting systems – Code of practice.

Rainwater savings

The approach to optimum tank sizing in BS 8515 (2009) is closely related to the work of Fewkes & Warm (2000) who developed empirical formulae relating rainwater yield, storage capacity and demand. The following formula is used to calculate annual water savings on the basis of known storage tank size, collection area, rainfall, and non-potable water demand:

Annual water saving = systems x Pd x occupancy x Er x days

Where:

systems is the number of rainwater systems serving 1000 homes or a specified number of non-domestic buildings

Pd is the daily non-potable water demand per person

occupancy is the number of people served per system (2.36 per household for homes)

Er is the water saving efficiency of the rainwater harvesting system

days is 365 days per year

Greywater recycling calculation in this study

The modelling approach adopted in this study for greywater systems are:

- Average daily yield and demand per person approach used as set out in the draft BS 8525:2009;
- Savings can vary between systems depending on the end-uses served (e.g. WCs, washing machines, external);
- Consideration of both homes and non-domestic.

Greywater savings

The study adopts the approach of the draft BS 8525 with savings equal to the demand of non-potable end uses served, provided that there is sufficient greywater yield. The greywater yields and demands were based on the benchmarks and sources previously set out in Table 7.

The maximum saving from greywater systems is 95 per cent of the yield. The 5 per cent reduction in yield is to allow for e.g. filter backwash, where treated water is periodically flushed back through the filter and to waste to help keep the filter clean. This is intended to be conservative (i.e. an overestimate of the yield reduction).

3.2.6 Carbon footprint calculations

The carbon footprint of rainwater and greywater systems is made up of embodied and operational components as shown in Table 10.

Footprint component		Rainwater systems	Greywater systems
Embodied	Rainwater tank	Considered separately as size depends on rainfall and building water demand	N/A
	Initial System excl. RW tank	The collection of components that typically make up a system of a particular type (excluding the variable-size rainwater tank).	
	Component replacement & maintenance	The embodied carbon in replacement components such as filters and pumps accounting for transport emissions for deliveries and maintenance	
Operational	Supply pumping	Pumping stored water to end uses (Direct Feed) or to Header Tank	
	Treatment	(not normally required)	Pumping between treatment tanks, backwash, aeration, etc.
	Mains water offset	Energy and carbon associated with volume of mains water offset	
	Foul water reduction	N/A	Energy and carbon associated with avoided pumping of a foul water volume equal to the mains water offset

Table 10. Carbon footprint components

Embodied carbon

This study uses the updated *University of Bath Department of Mechanical Engineering, Inventory of Carbon and Energy* (University of Bath, 2009); referred to as the Bath ICE database for unit material CO_2 footprints and the latest Defra and DECC guidance on company greenhouse gas emissions reporting for vehicle carbon emissions factors to calculate the embodied carbon of rainwater and greywater systems over various lifetimes.

The embodied carbon content of systems including replacements is taken to be the ‘cradle to gate’ carbon footprint, calculated as follows:

Cradle to gate carbon footprint = sum of (material + manufacturing + distribution + delivery to site) footprints

Where:

material footprint = unit footprint (from ICE database, etc.) x mass of material

manufacturing footprint = material footprint x % manufacturing overhead distribution footprint = average distribution distance x vehicle emission rate

delivery to site footprint = average delivery distance x vehicle emission rate

The accuracy of embodied carbon calculations depends on the availability and accuracy of data on the embodied carbon content of materials and manufactured components. Bulk material data is available but data on manufactured components remains limited and of uncertain quality.

The Bath ICE database provides data on embodied CO_2 emissions – invariably on a cradle to gate basis consistent with the approach in this study – and NOT carbon dioxide equivalent emissions. As such it was used to calculate the embodied CO_2 emissions for each component. The embodied CO_2 for components was then combined to produce total embodied CO_2 figures for each system type based on an inventory of parts. (No attempt has been made to factor non-CO_2 emissions into those calculated using the Bath ICE database.)

Simple inspection and maintenance tasks required annually are assumed to undertaken by the householder in private homes, or by the facilities manager or general maintenance contractor in non-domestic and multi-residential buildings. Additional transport emissions are added in any year where a component is replaced, which in practice means at least every fifth year. The potential transport emissions related to more regular (e.g. annual) third party maintenance inspections requiring additional visits to buildings (beyond any that would be made to a building without a rainwater or greywater system) have not been included. The potential footprint related to additional maintenance travel is discussed briefly in section 4.5.4.

The components of these system types are a mix of materials and of static, mechanical and electrical operations. As such it is not appropriate to model the systems as single entities with a particular operational life. Instead the individual operational life of each component was included which resulted in a model consisting of “umbrella” systems under which individual components were replaced as and when required to maintain the system integrity.

The tanks are likely to have a useful life in excess of 60 years so because the analysis is undertaken only over a 60 year timescale it is assumed the tank will never be replaced. However the pumps have a far shorter operational life; 12 – 15 years was assumed depending on pump type and maintenance regime (i.e. 4 or 5 pumps are required over the 60 year system life). The result is that embodied carbon increases at discrete time intervals as components are replaced at the end of their operational life.

The calculations of embodied carbon were undertaken at years 0, 15, 30 and 60.

Rainwater tanks

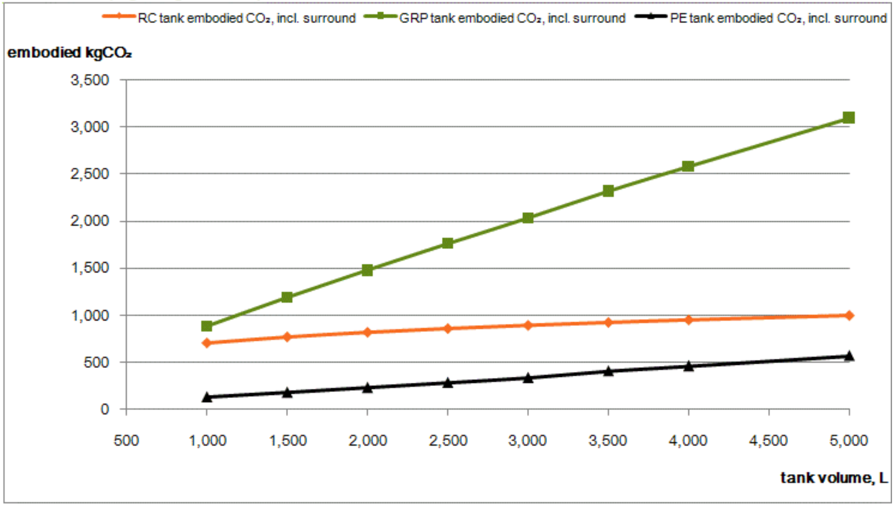
The embodied carbon of rainwater tanks was calculated separately from the ‘System excl. RW tank’ components (i.e. everything else). While tanks can be custom made, for the purposes of calculating embodied carbon it is reasonable to consider a set of representative fixed tank sizes in a similar way to the set of representative rainwater and greywater system inventories.

The embodied carbon was calculated for each of reinforced concrete, GRP and polyethylene tanks for storage volumes between 1,000 and 300,000L. (In practice, different tank materials may be suited to particular applications and required total storage volumes, which is a decision for designers.)

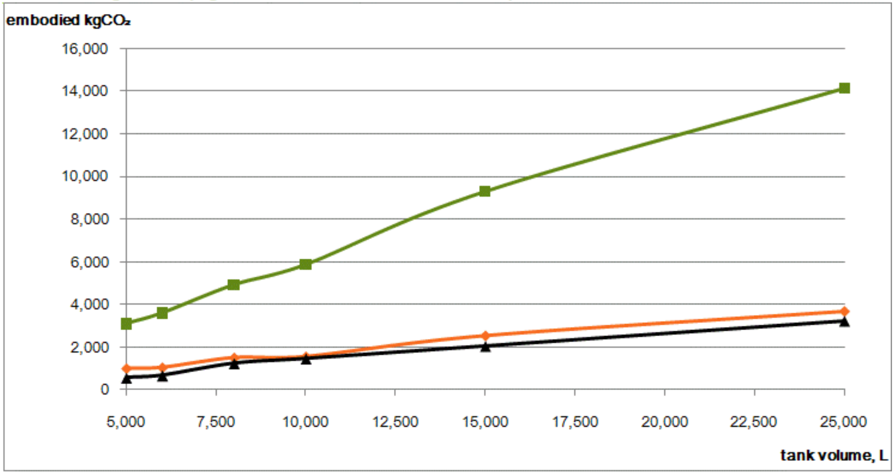
The calculated embodied carbon figures for small and medium tank sizes relevant to the selected system – building applications are presented in Figure 13. Based on the information available on the embodied energy of the three main tank materials, GRP tanks have a relatively high embodied carbon due to the high embodied carbon of GRP itself and of the concrete ‘shell’ surround required as part of installation. PE tanks have the lowest embodied carbon of the three, but the gap to RC tanks narrows with larger total storage volumes as multiple smaller PE tanks are required.

Representative tank size vs. embodied CO_2 charts

Small tanks (e.g. single homes)



Medium & large tanks (e.g. multi-residential and non-domestic)



Note: discontinuities are due to assumptions about maximum single tank size, multiple tank access, etc.

Figure 13. Volume vs. embodied carbon for small and medium rainwater tanks

For each analysis period of 15, 30 and 60 years, the storage tank fitted in year 0 is assumed to remain in place and operational.

Operational carbon emissions

Operational carbon corresponds to the carbon emissions related to system operation. The total operational energy for a system can involve some or all of the following:

- Pumping for distribution of treated water;
- Pumping energy to move the water through the treatment process and from the final storage tank to the end use;
- Pumping energy for aeration of biological treatment tanks;
- Energy for controls and electro-mechanical devices;
- Energy for (anti freeze) trace heating elements.

The pumping energy for the distribution of treated water is common to the majority of systems with the exception of short retention grey water systems or raised rainwater storage tanks (the latter of which has not been considered in detail in this study).

Rainwater harvesting systems do not normally include energy intensive treatment; however it has been observed that in some cases UV disinfectant systems are included to the system post filtration. The calculation model base assumptions do not assume the presence of UV for any of the generic rainwater systems.

In this study, operational carbon is taken to be the emissions associated with electricity use for any pumping and treatment, calculated as follows:

> Operating carbon footprint = sum of energy use for (pumping + treatment) x electricity emissions factor

The accuracy of operational calculations depends on the accuracy of assumptions made about the electricity use for pumping and treatment. (Carbon emissions associated with component replacement and system maintenance is considered as part of the cumulative embodied carbon footprint of the systems.)

EA 2008 relied on a few reported data points and manufacturer estimates to establish annual electricity use in kWh/litre. The literature review identified a range of operation energy figures for rainwater and greywater systems from previous research. The selection of operational energy and carbon intensity for this study was particularly influenced by the work of Retamal et al. (2009) outlined in section 2.2.5. This has the benefit of providing a theoretical basis for estimating pump energy use that has been validated against monitored data.

In use carbon of rainwater systems

Retamal et al. (2009) included a number of systems broadly equivalent to direct feed systems as applied in the UK and after discussion with the authors the average whole house energy intensity was used in this study. However the source study included only one header tank system (referred to in Australia as ‘trickle top-up’). The figure adopted for this study took account of the variation in pumping energy use with end use served. End uses that involve frequent pump starts and short pumping durations have higher energy intensity. The figure used for header tank systems assumes that short water use events like taps and toilet flushing are unrepresentative of header tank filling, which is more like long events with constant flow rates like showering (cf. assumed energy intensities in Table 11 with intensities by end use in Table 3).

The energy and related carbon intensity figures used in this study are shown below.

System type	**Assumed carbon intensity**	High carbon intensity	Low carbon intensity	**Assumed energy intensity**	High energy intensity	Low energy intensity
		$kgCO_2e/m^3$			kWh/m^3	
Direct feed	**0.82**	1.59	0.27	**1.5**	2.9	0.5
Header tank	**0.55**	0.82	0.22	**1.0**	1.5	0.4

Table 11. Assumed operational energy and carbon intensities for rainwater systems

For larger buildings, the assumptions made in this study is that the additional pumping (compared to a default pumped mains supply) is that required to move water from the collection/storage vessel to the point in the building that would be the origin of the default pumped mains water supply. This is assumed to be equivalent to the energy that would be used to supply end uses in a single home.

In use carbon of greywater systems

Energy and carbon intensities for greywater systems took account of the figures adopted for pumping water to end uses in rainwater systems. Information was also received from system suppliers and manufacturers. The figures adopted, and their basis, are set out in Table 12 below.

System description	**Assumed total intensity**		**Notes**
	Carbon $kgCO_2e/m^3$	energy kWh/m^3	
GW Small-scale MBR	1.9	3.5	Supplier reported energy intensity
GW Short retention, 1 WC	0.34	0.6	assumes reduced pumping due to proximity of source and end use, and accounts for no treatment energy use
GW Short retention, 2 WCs	0.34	0.6	assumes second WC at lower level than storage vessel entailing no additional energy use
GW Small-scale biological	0.82	1.5	as for direct feed RW system, assuming high level collection, filtration through filter media under gravity and direct pumping to end uses
GW Larger scale, Multi media	1.4	2.5	figure for large MBR system used (subject to receipt of further information) although system has fewer pumping stages
GW Larger scale, MBR	1.4	2.5	top of range reported, assuming some economy of scale compared to smaller MBR system

Table 12. Assumed operational energy and carbon intensities for greywater systems

Mains and sewage carbon savings

'Saving' corresponds to the avoided emissions associated with reductions in mains water demand, and where relevant sewage quantities, calculated as follow:

> Carbon saving = (reduction in mains water demand x emissions rate per unit of water delivered) + (reduction in sewage pumped for treatment x emissions rate per unit of sewage)

The accuracy of the saving calculation depends on the accuracy of data on water company carbon emissions and on the assumptions made to apportion these emissions between water supply and wastewater treatment in general, and sewage pumping in particular.

The first step in deciding the methodology to adopt for this study was a broad review of the potential benefits of rainwater and greywater systems in terms of energy and carbon from the perspective of the supply side (mains water distribution and wastewater treatment). These are set out in Table 13 below with some notes.

Impact	Rainwater systems	Greywater systems	Notes
Offset demand for mains water	Yes	Yes	
Reduce volume of foul water for pumping and treatment	No	Yes	Rainwater – except any retrofit old buildings where run-off is collected with foul water.
Change pollutant charge of foul water for treatment	No	Probably not	Greywater – depends on net result of treatment (any additional chemical charge vs. any pollutants removed at source)
Reduce sludge volumes for treatment & disposal	No	Probably not	Pollutant charge likely to be unaffected – any changes for greywater likely to be marginal
Reduces requirement for additional reservoir capacity (re drought) or emergency bowsers and tanker use.	Probably not	Possibly	Rainwater storage tanks likely to be empty before any onset of 'drought'. Greywater systems likely to make consistent savings. However, large numbers of systems required to affect supply side planning.
Impact on admin & transport	No	No	No real change in admin and transport. Customer numbers unchanged, for instance.
Impact on mains infrastructure	No	Probably not	No changes are likely to result at waste water treatment works, but at water treatment works a case might be made for smaller facilities in the future as demand for mains water reduces (not for rainwater because of intermittency of impact).

Table 13. Potential energy and carbon benefits of rainwater and greywater systems.

The carbon benefit of rainwater harvesting is limited to the reduction in demand for mains water. The additional benefits of greywater is more complex. Greywater reduces the volume of foul water being pumped to treatment centres, but is assumed not to significantly change the total pollutant charge sent for treatment, and therefore to have no impact on the treatment required and associated carbon emissions.

The approach adopted in this study was influenced by pragmatic issues of data availability as well as judgements on the proper scope of the carbon footprint. The saving calculation for greywater systems has been extended to cover reduced energy and emissions related to foul water pumping. Greywater systems are assumed to reduce the volume of sewage that needs to be pumped for treatment but not the overall strength that determines the energy required for treatment.

3.2.7 Effects of future change

This study also looks at the effect of changes that could take place over the 60 year analysis period. Variables considered are:

- Climate change – Climate change is expected to alter average monthly and seasonal rainfall in future decades. Changes in total annual average rainfall and in the distribution of rainfall over the year will directly alter the performance of rainwater systems. Projected changes are provided in UK Climate Projections.
- Decarbonisation of the power and transport sectors – The UK Low Carbon Transition Plan (DECC, 2009b) is based on rapid decarbonisation of the UK power sector. Large changes in the carbon intensity of UK grid electricity will affect:

  - The emissions arising from the operation of rainwater and greywater systems;
  - The emissions arising from the supply of mains water and the treatment of wastewater; and
  - The embedded emissions associated with system components manufactured in the UK.

  Various sources suggest emissions factors in the range 80 – 120 gCO_2/kWh in 2030 and below 50 gCO_2/kWh in 2050. DECC guidance on carbon valuation has a figure of 57 gCO_2/kWh in 2039 (i.e. at the end of a 30-year life from the start of the analysis period).

- Variability in building water demands – Water demands in buildings are inherently variable and there may also be a systematic change in water demand over time in response to e.g. more or less sustainable attitudes and behaviour, and changes in rainfall affecting irrigation demand.
- Variability in rainwater tank sizing – Not all household systems will be sized based on the British Standard intermediate approach and there is inherently greater variability in the sizing of non-domestic systems. Such variability has an effect on the water savings achieved as well as a small effect on the embodied carbon footprint.
- Risk and rate of system failure – Rainwater and greywater systems are not indispensible items of sanitaryware or water supply features. In general, because systems will be designed to ‘fail safe’, i.e. in a way that does not disrupt water supply, they may suffer periodic or complete failure either without the user becoming aware or without the user taking corrective action. The rate of both temporarily and permanently undetected and/or unrepaired failures will affect the aggregate performance of systems over time.
- Decarbonisation of direct emissions related to water supply and treatment – A proportion of water suppliers’ carbon emissions are direct, such as methane arising from the decomposition of sludge from wastewater treatment. These non-energy related emissions could be reduced in future.

Exploring variability

Two approaches are used to explore the impact of changes in these variables on the results over a 60 year period:

- Sensitivity analysis – looks independently at the impact of changes in particular variables. (For results see Section 4.5.4)
- Future scenarios – look at the results in a number of distinct possible futures in which the variables have evolved in a way consistent with the envisaged scenario. This is a useful way to explore a limited selection of possible pathways, each involving systematic changes in variables, and the resulting outputs over the analysis period. (For results see Section 4.7)

Future scenarios

This study adopted scenarios developed by the Environment Agency, as described in the Briefing Note: Demand for water in the 2050s (EA undated), and presented in Figure 14.

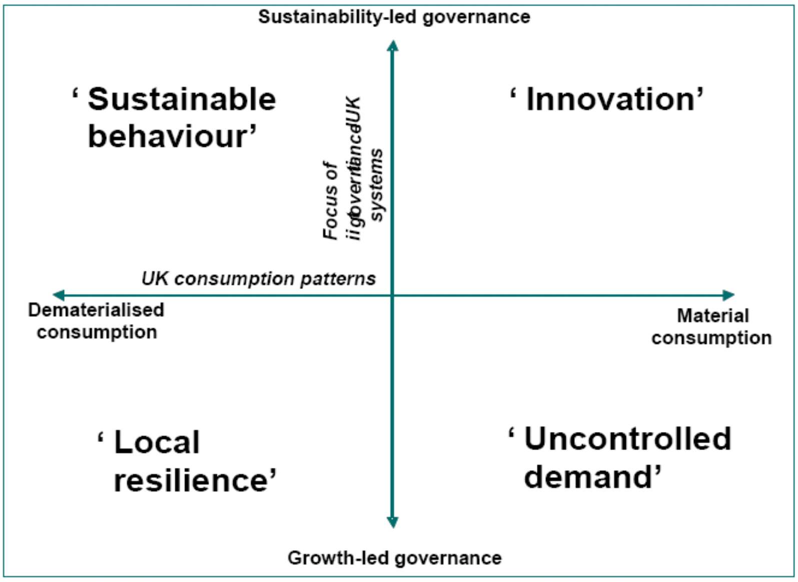
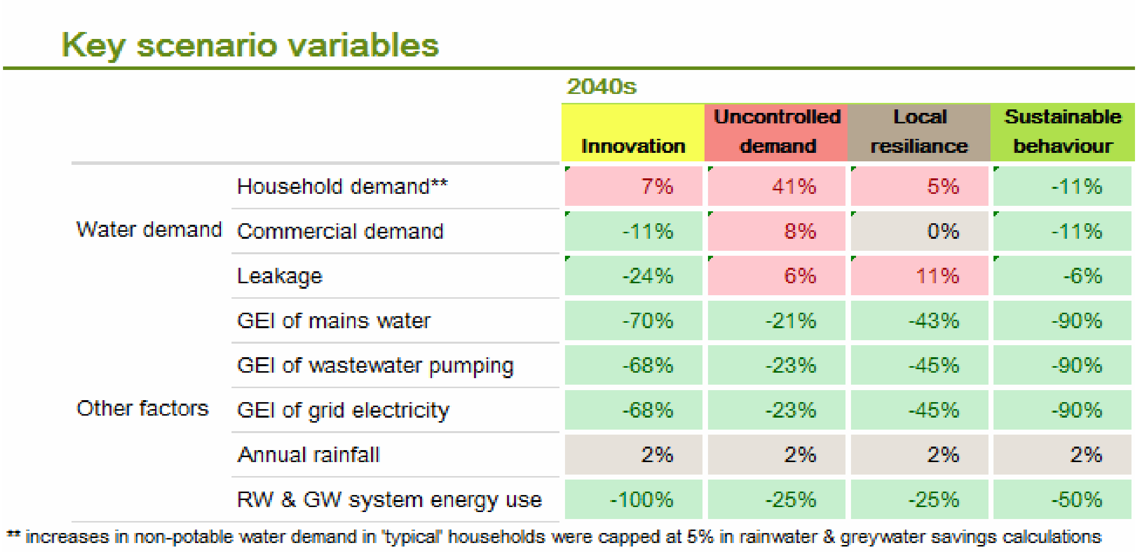


Figure 14. EA future scenarios matrix.

Based on information in the briefing note, and considering the key factors most likely to determine the carbon impacts of rainwater and greywater systems, the model inputs set out in Figure 15 were used to explore possible systematic effects of changes over time.



Key scenario variables

		2040s			
		Innovation	Uncontrolled demand	Local resiliance	Sustainable behaviour
Water demand	Household demand**	7%	41%	5%	-11%
	Commercial demand	-11%	8%	0%	-11%
	Leakage	-24%	6%	11%	-6%
Other factors	GEI of mains water	-70%	-21%	-43%	-90%
	GEI of wastewater pumping	-68%	-23%	-45%	-90%
	GEI of grid electricity	-68%	-23%	-45%	-90%
	Annual rainfall	2%	2%	2%	2%
	RW & GW system energy use	-100%	-25%	-25%	-50%

** increases in non-potable water demand in 'typical' households were capped at 5% in rainwater & greywater savings calculations

Figure 15. EA future scenarios matrix percentage changes to 2040s.

The next section sets out the key modelling inputs and the study results in terms of:

- Lifetime carbon footprints,
- Annualised carbon footprints,
- Average Incremental Carbon Cost.

4 Results and interpretation

This section sets out the results of the carbon footprint calculations for rainwater and greywater systems undertaken in this study. The carbon footprint components for the baseline (assuming constant building water demands, mains and grid electricity carbon intensity, rainfall, etc.) are presented as follows:

- Size (and embodied carbon) of rainwater tanks, as these are needed to calculate rainwater savings,
- Water savings;
- Embodied carbon of rainwater and greywater systems excluding rainwater tanks (and total system embodied carbon);
- Operational carbon footprints; and then
- Total carbon footprints.

Additional results and some sensitivity analysis are then presented for selected system building applications and scenarios.

4.1 Rainwater tank size and embodied carbon

The embodied carbon of rainwater tanks was considered separately from the remainder of the system because, for a given building type and water demand, the tank size (based on the British Standard tank sizing method) varies depending on rainfall. The suggested tank sizes and selected embodied carbon values of rainwater tanks for the system – building applications studied are shown in Table 14.

Embodied carbon results are presented for just one of the three tank materials in each case: PE tanks for homes, GRP tanks for hotels and offices and RC tanks for schools. This is reasonably reflective of typical applications with PE a common choice for home systems, GRP more common for larger installations, and RC an option for both, and illustrated here for schools. (The relative embodied carbon of the three tank materials for any given small to medium tank size can be seen in Figure 12.)

	Rainfall zone	Annual rainfall	Per system		Year 0 Embodied CO_2
			Collection area	Tank size specified	
Property type, size	txt	m	m^2	L	$kgCO_2$
Homes					
10 flats, each $70m^2$	Medium	0.890	175	5,750	65
10 flats, each $70m^2$	Low	0.650	175	4,300	49
10 flats, each $70m^2$	High	1.250	175	8,000	124
Home, $90m^2$	Medium	0.890	45	1,500	184
Home, $90m^2$	Low	0.650	45	1,100	144
Home, $90m^2$	High	1.250	45	2,300	265
Home, $120m^2$	Medium	0.890	60	2,000	234
Home, $120m^2$	Low	0.650	60	1,500	184
Home, $120m^2$	High	1.250	60	2,700	307
Hotels					
Budget Hotel, 80 rooms	Medium	0.890	690	25,000	14,140
Budget Hotel, 80 rooms	Low	0.650	690	18,000	10,783
Budget Hotel, 80 rooms	High	1.250	690	40,000	23,908
Offices					
City Refurb, 10,000 m^2 GIA	Medium	0.890	1,667	60,000	33,487
City Refurb, 10,000 m^2 GIA	Low	0.650	1,667	40,000	23,908
City Refurb, 10,000 m^2 GIA	High	1.250	1,667	80,000	43,076
Schools					
11 - 18 Secondary, 585 pupils	Medium	0.890	3,173	90,000	11,581
11 - 18 Secondary, 585 pupils	Low	0.650	3,173	80,000	10,428
11 - 18 Secondary, 585 pupils	High	1.250	3,173	90,000	11,581

Table 14 Rainwater system tank sizes by building application

4.2 Water savings

4.2.1 Rainwater system water savings

Rainwater savings for each system – building application, calculated using the Fewkes and Warm (2000) method, are presented in Table 15. The saving calculation is based on the total non-potable water demands in each building type. As would be expected, rainwater systems supply more water in areas with high rainfall and serve a greater proportion of demand in buildings where non-potable demand is a higher proportion of overall demand.

Application summary	Rainfall zone	Per property Tank size specified	Per property annual non-potable demand met by collected rainwater	% demand met non-potable	% demand met total
		L	m³	%	%
70m² Flat, 4-storey block of 10, 2 occupants	Medium	550	10	27%	9%
	Low	375	7	18%	6%
	High	720	14	36%	13%
90m² 2-storey house 3 occupants	Medium	1,500	26	45%	16%
	Low	1,000	18	32%	11%
	High	1,850	32	57%	20%
120m² 2-storey house 4 occupants	Medium	1,850	34	45%	16%
	Low	1,500	25	33%	12%
	High	2,500	43	57%	20%
80-room 3-storey hotel 160 occupants	Medium	22,000	401	38%	13%
	Low	15,000	279	26%	9%
	High	30,000	524	49%	16%
10,000m² 6-storey office 900 occupants	Medium	50,000	958	31%	19%
	Low	40,000	678	22%	14%
	High	70,000	1,293	41%	26%
585-pupil 2-storey secondary school	Medium	90,000	1,369	78%	61%
	Low	70,000	1,131	65%	51%
	High	90,000	1,521	87%	68%

Table 15. Mains water offset by rainwater system applications.

4.2.2 Greywater system water savings

It is assumed that short retention systems are applied to meet WC demand only, that small biological systems are applied to WC and laundry demand, and that other systems are applied to meet all potential greywater demands. It is then assumed that greywater systems are sized to satisfy the maximum proportion of applicable non-potable demand. In design terms this notionally corresponds to sizing greenwater storage tanks to equal daily non-potable water demand. The proportion of demand met is capped by the greywater yield and the efficiency of the treatment system. Treatment efficiency is assumed to be 95 per cent of greywater yield for all systems, accounting for filter backwash in large systems, for example.

The calculated water savings for each greywater application are shown in Table 16

Application	Per property annual				Mains water offset					
Application summary	Potential GW yield	GW demand, WCs only	GW demand, WCs & laundry	GW demand, all	SmMBR	ShrtRtntn1	ShrtRtntn2	SmBio	LgMltiMdia	LgMBR
Txt	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3
70m² Flat, 4-storey block of 10, 2 occupants	67	21	34	38		21				38
90m² 2-storey house 3 occupants	101	32	52	57	57	16	32	52		
120m² 2-storey house 4 occupants	134	43	69	76	76	21	43	69		
80-room 3-storey hotel 160 occupants	1,093	667	1,059			667			1039	1039
10,000m² 6-storey office 900 occupants	1,337		3,119						1270	1270
585-pupil 2-storey secondary school	234		1,748						222	222

SmMBR = small membrane bioreactor, SrtRtntn1/2 = short retention systems with 1 or 2 WCs, SmBio = small biological system, LgMltiMdia = large multimedia filter, LgMBR = large membrane bioreactor

Table 16. Mains water offset by greywater system applications.

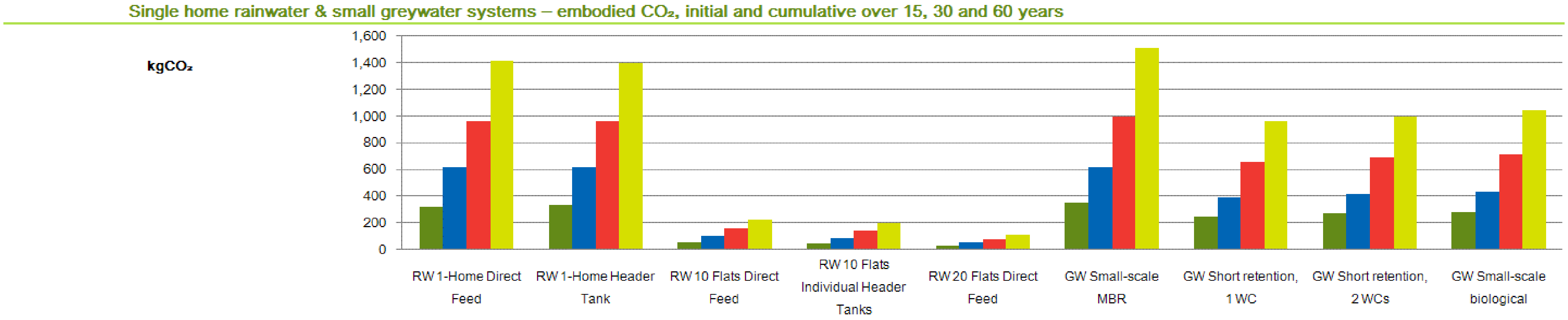
It can be seen that in general the water savings in non-domestic buildings are constrained by the available greywater yield e.g. only 12 per cent of the schools demand can be met by the system, for the office 40 per cent of demand can be met by the system and for the hotel 98 -100 per cent of demand can be met by the system. In homes all the potential end uses for water can be served from the available yield.

4.3 Embodied carbon of rainwater & greywater systems excluding RW tanks

4.3.1 Single home systems ‘System excl. RW tank’ embodied carbon

The initial year 0 embodied carbon and the cumulative and annualised carbon emissions over 15, 30 and 60 years for the systems selected for analysis are presented in Figure 16 and Figure 17. Cumulative emissions increase over time due to component replacement and maintenance. Annualised emissions decrease over time due to the fact that only a small proportion of the components are replaced over time.

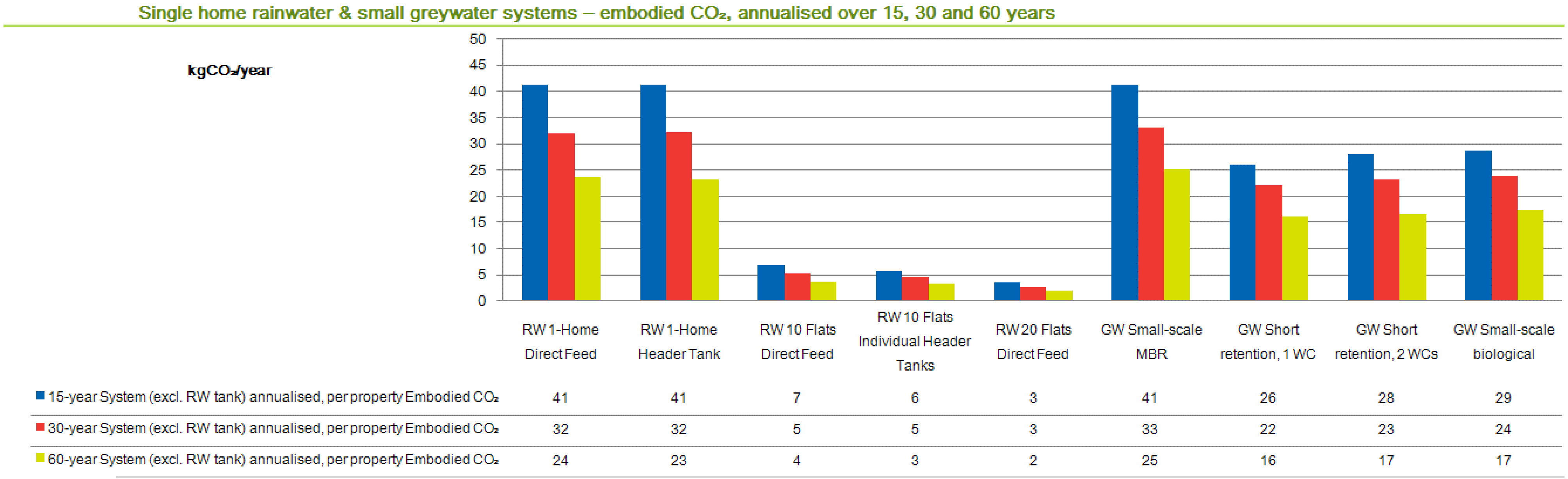
Embodied carbon for rainwater and greywater systems, excluding the rainwater tanks, was also calculated. An illustrative breakdown of the embodied carbon for a rainwater system (excluding the rainwater tank) is shown in Figure 18. In most case a few components account for the majority of the embodied footprint. This includes pumps, which often account for between a quarter to over a half of the initial footprint. Their contribution to the lifetime footprint is higher, because pumps will need to be replaced typically once every 12 to 15 years.



	RW 1-Home Direct Feed	RW 1-Home Header Tank	RW 10 Flats Direct Feed	RW 10 Flats Individual Header Tanks	RW 20 Flats Direct Feed	GW Small-scale MBR	GW Short retention, 1 WC	GW Short retention, 2 WCs	GW Small-scale biological
🟩 Year 0 System (excl. RW tank) Embodied CO₂, per property	320	337	53	49	27	351	246	274	280
🟦 15-year System (excl. RW tank) Embodied CO₂, per property	619	620	102	85	51	619	391	419	431
🟥 30-year System (excl. RW tank) Embodied CO₂, per property	958	965	155	139	78	993	660	692	713
🟨 60-year System (excl. RW tank) Embodied CO₂, per property	1,413	1,394	221	196	111	1,508	960	993	1,043

Note: The time period between the red and yellow columns (years 30 and 60, is greater than the period between other columns.

Figure 16. Cumulative embodied CO_2 for small rainwater and greywater systems over 15, 30 and 60 years



	RW 1-Home Direct Feed	RW 1-Home Header Tank	RW 10 Flats Direct Feed	RW 10 Flats Individual Header Tanks	RW 20 Flats Direct Feed	GW Small-scale MBR	GW Short retention, 1 WC	GW Short retention, 2 WCs	GW Small-scale biological
🟦 15-year System (excl. RW tank) annualised, per property Embodied CO_2	41	41	7	6	3	41	26	28	29
🟥 30-year System (excl. RW tank) annualised, per property Embodied CO_2	32	32	5	5	3	33	22	23	24
🟨 60-year System (excl. RW tank) annualised, per property Embodied CO_2	24	23	4	3	2	25	16	17	17

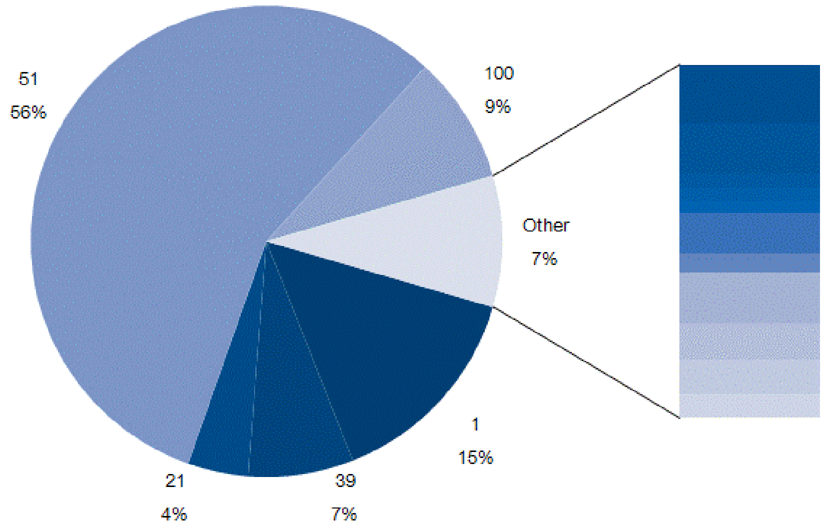
Note: The time period between the red and yellow columns (years 30 and 60, is greater than the period between other columns. Short retention systems are also applicable to non-domestic buildings.

Figure 17. Annualised embodied CO_2 for small rainwater and greywater systems over 15, 30 & 60 years

RW 1-Home Header Tank

H1HT

Installed component embodied CO$_2$



Total Mass	**65**	**kg**
Total embodied CO$_2$	**327**	**kgCO$_2$**

CID	**Component class**	**Component description**	**Quantity**	**Manufactured component mass**	**Installed component embodied CO$_2$**
#	z	txt	#	kg	kgCO$_2$
1	Plastic pipe		22.5	22.3	47.5
39	Plastic parts, <20% other	Valve - plastic (anti-surcharge)	1	5.5	23.6
21	Plastic parts, <20% other	Header tank (159L)	1	6.4	13.6
8	Plastic parts, <20% other	Filter (in-tank, domestic)	1	1.7	4.8
17	Plastic parts, <20% other	Pipework (overflow siphon with rodent barrier)	1	2.0	4.3
7	Plastic parts, <20% other	Air gap (tundish)	1	0.5	1.2
40	Plastic parts, <20% other	Valve - plastic (internal non-return)	1	0.3	1.1
14	Plastic parts, <20% other	Pipework (calmed inlet)	1	0.5	1.1
15	Plastic parts, <20% other	Pipework (pressure hose)	5	1.2	3.3
75	Metals, <20% other	Pump system (floating intake)	1	0.5	1.5
51	Electro-mechanical	Pump (generic)	1	15.0	184.4
100	Electro-mechanical	Controls (control panel)	1	6.5	28.6
41	Electro-mechanical	Valve - metal (solenoid)	1	0.5	4.3
98	Electro-mechanical	Float switch (high level, demand)	1	0.8	3.0
98	Electro-mechanical	Float switch (high level, demand)	1	0.8	3.0
99	Electro-mechanical	Float switch (dry run protection)	1	0.5	1.9

Note: These figures and charts exclude distribution and delivery emissions (~10kg of CO$_2$) which are included in the systems embodied carbon figures quoted later in this report.

Figure 18. Example embodied carbon breakdowns for home applications

4.4 Operational carbon footprints

4.4.1 Rainwater

Operational carbon for rainwater depends on the type of system (direct feed or header tank) which determines its energy and carbon intensity, the quantity of water supplied, and the electricity grid emissions factor. Carbon savings depend on the carbon intensity of the local mains water supply.

Direct feed systems give rise to much higher carbon emissions than header tank systems for two separate reasons:

1. **Pump energy intensity**. Direct feed systems are assumed to have higher energy intensity than header tank systems, i.e. on average they use more energy to supply a unit of water (kWh/m^3). This is because of detailed differences in the pumping regime. In a typical household direct feed system, the pump needs to start whenever water is drawn off by an end use served by the system. The relatively frequent pump starts and the load characteristics of some end uses contribute to pump losses and inefficiency compared to occasional steady filling of a header tank. Variations in pumping energy intensity for serving different end uses were illustrated in section 2.2.5, Table 3.

2. **Mains backup arrangement**. As outlined in section 2.3.1, mains backup water is supplied to the rainwater tank in direct feed systems whereas it is supplied to the header tank where one is present. This means that in direct feed systems the proportion of connected end use demand met by mains water has to be pumped from the rainwater tank. I.e. local pumping energy and carbon is added to the carbon footprint of delivered mains water. By contrast, in header tank systems the mains backup water is assumed to be delivered to the header tank under mains pressure and then serves connected end uses under gravity.

There may be design solutions that avoid the additional energy and carbon of the typical direct feed backup arrangement assumed in this study. Mains backup switches appear to be widely used in direct feed rainwater systems in Australia but may not incorporate an air gap, which is required to comply with UK water regulations.

Operational carbon and mains offset carbon savings for rainwater system applications are shown in Table 17.

		RW Annual mains offset carbon saving			RW Annual operational carbon	
Application summary	RF	Medium CI	Low CI	High CI	Direct Feed	Header Tank
Txt		kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e
70m² Flat, 4-storey block of 10, 2 occupants	M	4	3	5	31	6
	L	3	2	3	31	4
	H	6	5	7	31	8
90m² 2-storey house 3 occupants	M	11	8	12	47	15
	L	8	6	9	47	11
	H	14	11	16	47	19
120m² 2-storey house 4 occupants	M	15	11	16	62	20
	L	11	8	12	62	15
	H	19	14	21	62	25
80-room 3-storey hotel 160 occupants	M	177	131	195	869	236
	L	130	96	143	869	173
	H	238	176	262	869	318
10,000m² 6-storey office 900 occupants	M	431	319	474	2,557	575
	L	303	224	334	2,557	405
	H	584	432	642	2,557	779
585-pupil 2-storey secondary school	M	576	426	633	1,433	769
	L	496	367	545	1,433	662
	H	640	474	705	1,433	855

CI = carbon intensity

Table 17. Operational carbon and mains offset carbon savings for rainwater applications.

4.4.2 Greywater

Operational carbon and savings for greywater are calculated as for rainwater with the addition of savings from reduced foul water pumping. The calculated median value for foul water pumping carbon intensity of 104.3 kgCO2e/ML is used for all geographical locations. Operational carbon, mains offset carbon savings, and foul water pumping carbon savings for greywater system applications are shown in Table 18.

GW Annual operational carbon						
Application summary	SmMBR	ShrtRtntn1	ShrtRtntn2	SmBio	LgMltiMdia	LgMBR
						kgCO$_2$e
70m² Flat, 4-storey block of 10, 2 occupants	0	7.2	0	0	0	51.8
90m² 2-storey house 3 occupants	109	5.4	10.7	42.3	0	0
120m² 2-storey house 4 occupants	145	7.2	14.3	56.3	0	0
80-room 3-storey hotel 160 occupants	0	225	0	0	1,420	1,420
10,000m² 6-storey office 900 occupants	0	0	0	0	1,735	1,735
585-pupil 2-storey secondary school	0	0	0	0	303	303
GW Annual mains offset carbon saving						
70m² Flat, 4-storey block of 10, 2 occupants	0	8.7	0	0	0	15.5
90m² 2-storey house 3 occupants	23.3	6.5	13.1	21.1	0	0
120m² 2-storey house 4 occupants	31	8.7	17.4	28.1	0	0
80-room 3-storey hotel 160 occupants	0	273	0	0	425	425
10,000m² 6-storey office 900 occupants	0	0	0	0	519	519
585-pupil 2-storey secondary school	0	0	0	0	90.8	90.8
GW Annual foul water reduction carbon saving						
70m² Flat, 4-storey block of 10, 2 occupants	0	2.2	0	0	0	4
90m² 2-storey house 3 occupants	5.9	1.7	3.3	5.4	0	0
120m² 2-storey house 4 occupants	7.9	2.2	4.4	7.2	0	0
80-room 3-storey hotel 160 occupants	0	69.6	0	0	108.3	108.3
10,000m² 6-storey office 900 occupants	0	0	0	0	132.4	132.4
585-pupil 2-storey secondary school	0	0	0	0	23.1	23.1

SmMBR = small membrane bioreactor, SrtRtntn1/2 = short retention systems with 1 or 2 WCs, SmBio = small biological system, LgMltiMdia = large multimedia filter, LgMBR = large membrane bioreactor

Table 18. Operational carbon, mains offset carbon savings, and foul water pumping carbon savings for greywater system applications.

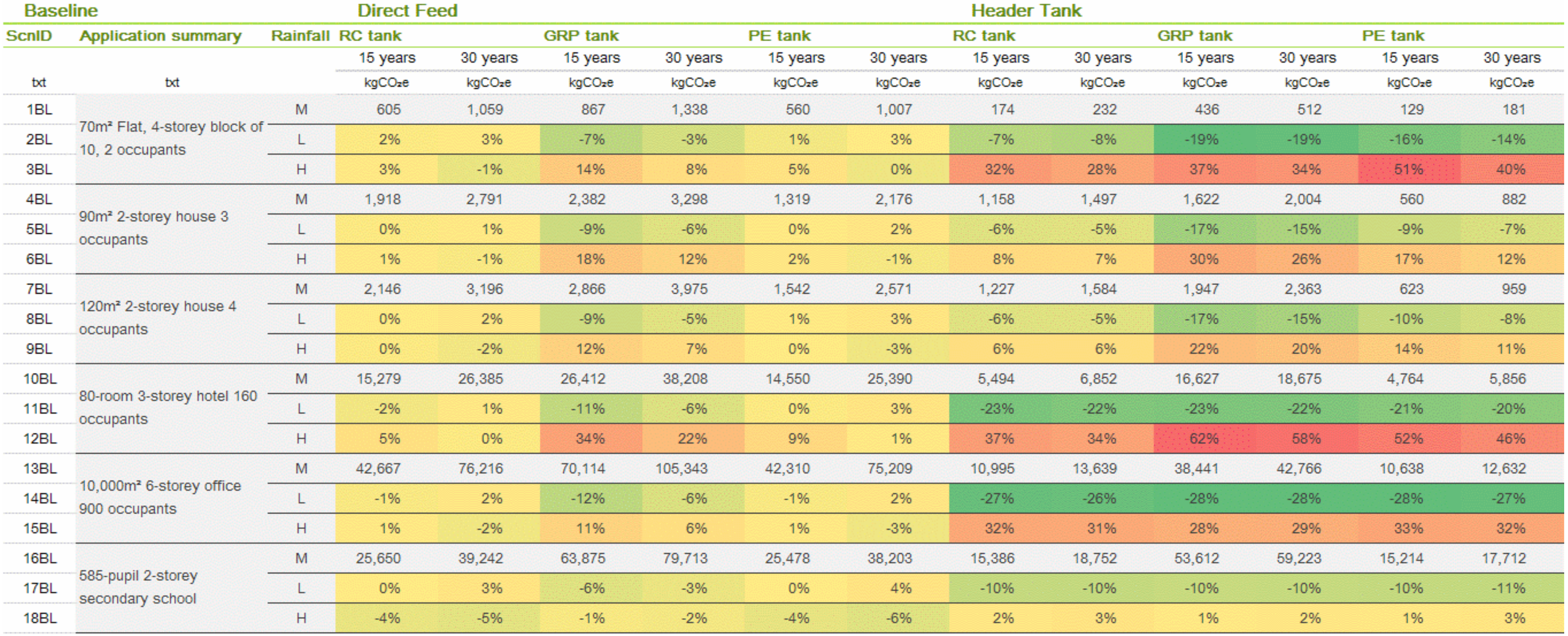
4.5 Total baseline carbon footprints

4.5.1 Total rainwater system carbon footprints

Baseline total net carbon footprints for systems applied in medium rainfall areas are shown in Figure 19. Results for low and high rainfall areas are shown on subsequent lines for each application with shading indicating the percentage difference in carbon footprint compared to the medium rainfall case.

Emissions in different rainfall bands vary more for header tank systems than for direct feed systems. This is because direct feed systems have a higher operational carbon component than header tank systems. Change in tank size and embodied carbon therefore have a greater relative effect for header tank systems. Other trends are observable, such as the impact of higher embodied carbon for GRP rainwater tank

Figure 19. Baseline total net cumulative carbon footprints for rainwater systems over 15 and 30 years



Baseline			Direct Feed						Header Tank					
ScnID	Application summary	Rainfall	RC tank		GRP tank		PE tank		RC tank		GRP tank		PE tank	
			15 years	30 years	15 years	30 years	15 years	30 years	15 years	30 years	15 years	30 years	15 years	30 years
txt	txt		kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e	kgCO$_2$e
1BL	70m² Flat, 4-storey block of 10, 2 occupants	M	605	1,059	867	1,338	560	1,007	174	232	436	512	129	181
2BL		L	2%	3%	-7%	-3%	1%	3%	-7%	-8%	-19%	-19%	-16%	-14%
3BL		H	3%	-1%	14%	8%	5%	0%	32%	28%	37%	34%	51%	40%
4BL	90m² 2-storey house 3 occupants	M	1,918	2,791	2,382	3,298	1,319	2,176	1,158	1,497	1,622	2,004	560	882
5BL		L	0%	1%	-9%	-6%	0%	2%	-6%	-5%	-17%	-15%	-9%	-7%
6BL		H	1%	-1%	18%	12%	2%	-1%	8%	7%	30%	26%	17%	12%
7BL	120m² 2-storey house 4 occupants	M	2,146	3,196	2,866	3,975	1,542	2,571	1,227	1,584	1,947	2,363	623	959
8BL		L	0%	2%	-9%	-5%	1%	3%	-6%	-5%	-17%	-15%	-10%	-8%
9BL		H	0%	-2%	12%	7%	0%	-3%	6%	6%	22%	20%	14%	11%
10BL	80-room 3-storey hotel 160 occupants	M	15,279	26,385	26,412	38,208	14,550	25,390	5,494	6,852	16,627	18,675	4,764	5,856
11BL		L	-2%	1%	-11%	-6%	0%	3%	-23%	-22%	-23%	-22%	-21%	-20%
12BL		H	5%	0%	34%	22%	9%	1%	37%	34%	62%	58%	52%	46%
13BL	10,000m² 6-storey office 900 occupants	M	42,667	76,216	70,114	105,343	42,310	75,209	10,995	13,639	38,441	42,766	10,638	12,632
14BL		L	-1%	2%	-12%	-6%	-1%	2%	-27%	-26%	-28%	-28%	-28%	-27%
15BL		H	1%	-2%	11%	6%	1%	-3%	32%	31%	28%	29%	33%	32%
16BL	585-pupil 2-storey secondary school	M	25,650	39,242	63,875	79,713	25,478	38,203	15,386	18,752	53,612	59,223	15,214	17,712
17BL		L	0%	3%	-6%	-3%	0%	4%	-10%	-10%	-10%	-10%	-10%	-11%
18BL		H	-4%	-5%	-1%	-2%	-4%	-6%	2%	3%	1%	2%	1%	3%

4.5.2 Annual carbon footprints

The total annualised net lifetime carbon emissions over 15, 30 & 60 years were calculated for:

- Homes, and
- Non-domestic buildings.

One of the aims of the analysis was to identify the relative influence of the different variables on the carbon footprints of rainwater and greywater systems. The combination of variables gives a large number of results, as shown in Table 19.

Variable	Rainwater	Greywater
System type	2, Direct feed or header tank	6
Rainfall zone	3	n/a
Rainwater tank type	3	n/a
Mains carbon intensity	3	3
Combinations	**54**	**18**

Table 19. Analysis variables and combinations (number of results).

Full results are available in the technical annex. Tables in the main body of this report present selected results for systems applied to buildings with medium rainfall and medium carbon intensity for delivered mains water.

The following relationships and trends were observed in the results:

- Carbon footprint increases with the quantity of water saved. This is to be expected as the carbon intensity of rainwater/greywater is already known to be higher than mains, so supplying more water increases net emissions. The exception is short retention systems which have negative net operation emissions.
- It follows that systems that have high footprints (because they save a lot of water) are often those with the best normalised carbon footprints (which is an efficiency measure, carbon divided by water supply).
- Rainwater footprints start generally higher than greywater because of high embodied energy, mostly in the tank. Results converge with those for greywater systems over time as rainwater operational intensities are lower than greywater. Note greywater inventories were more difficult to check for completeness due to complexity, lack of standardisation of systems and less freely available technical data.
- It is clear that the use of GRP tanks is associated with the highest carbon footprints. This is both because GRP has a high embodied carbon in itself, and because of the assumption that these tanks need to be encased in a concrete shell when installed underground.
- The differences in footprint due to mains water carbon intensity are relatively small compared to differences due to system type, rainfall and tank type.
- At the detailed level, the final pattern of results depends on interplay between the relative impacts of the variables:

i. Rainfall – Higher rainfall increases rainwater savings, and hence carbon footprint in most cases.

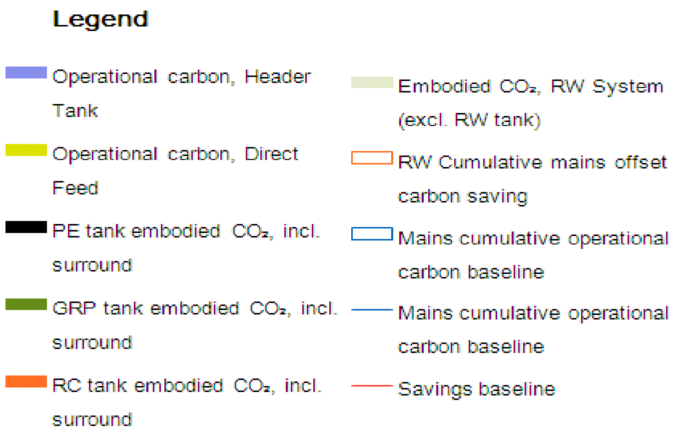
ii. Direct feed results in low mains carbon intensity locations counter this trend and cluster together because the footprint is dominated by high operational carbon from pumping mains backup water, accentuated by lower mains carbon offset as mains water carbon intensity is low.

iii. These are the situations where ‘lost’ carbon / water savings have a greater effect than initial embodied carbon and operational carbon: e.g. relatively small tank / low rainfall systems with higher cumulative footprints.

4.5.3 Build-up of carbon footprint for home water supply with rainwater and greywater

The following graphs illustrate the results of the operational and embodied energy modelling for each system type. The baseline scenario is the use of mains water with no water harvesting systems (blue bar). The carbon savings from using less mains water are indicated as a red bar which leads to a new baseline (red line) upon which the embodied and operational carbon of the rainwater harvesting and greywater recycling systems are added. The rainwater harvesting system analysis has been undertaken for high, medium and low rainfall intensities.

The charts illustrate the difference in operational emissions between direct feed and header tank systems (largely due to the mains backup issue discussed previously) and the variation in the percentage makeup of the total footprint depending mainly on tank type selected and the quantity of rainwater supplied.



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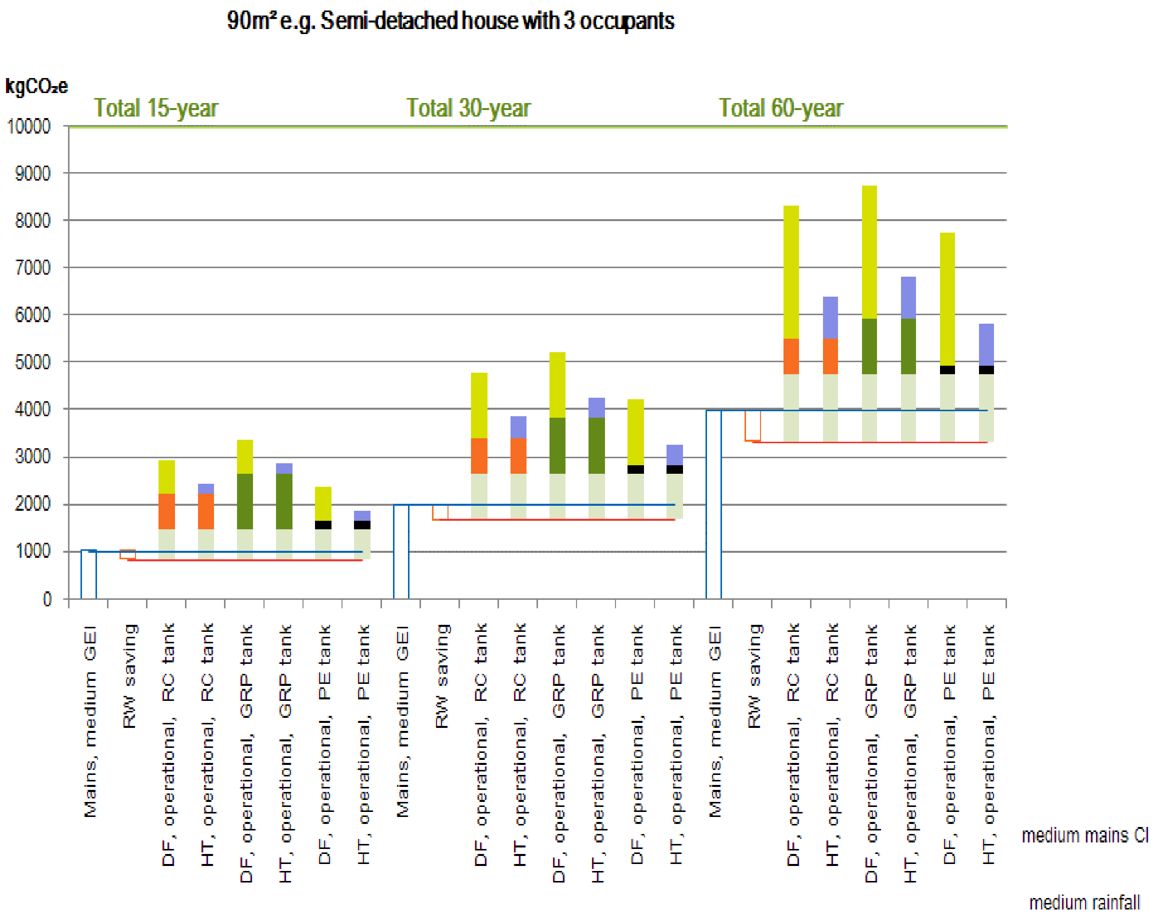


Figure 20. Relative sizes of footprint components for a typical home application.

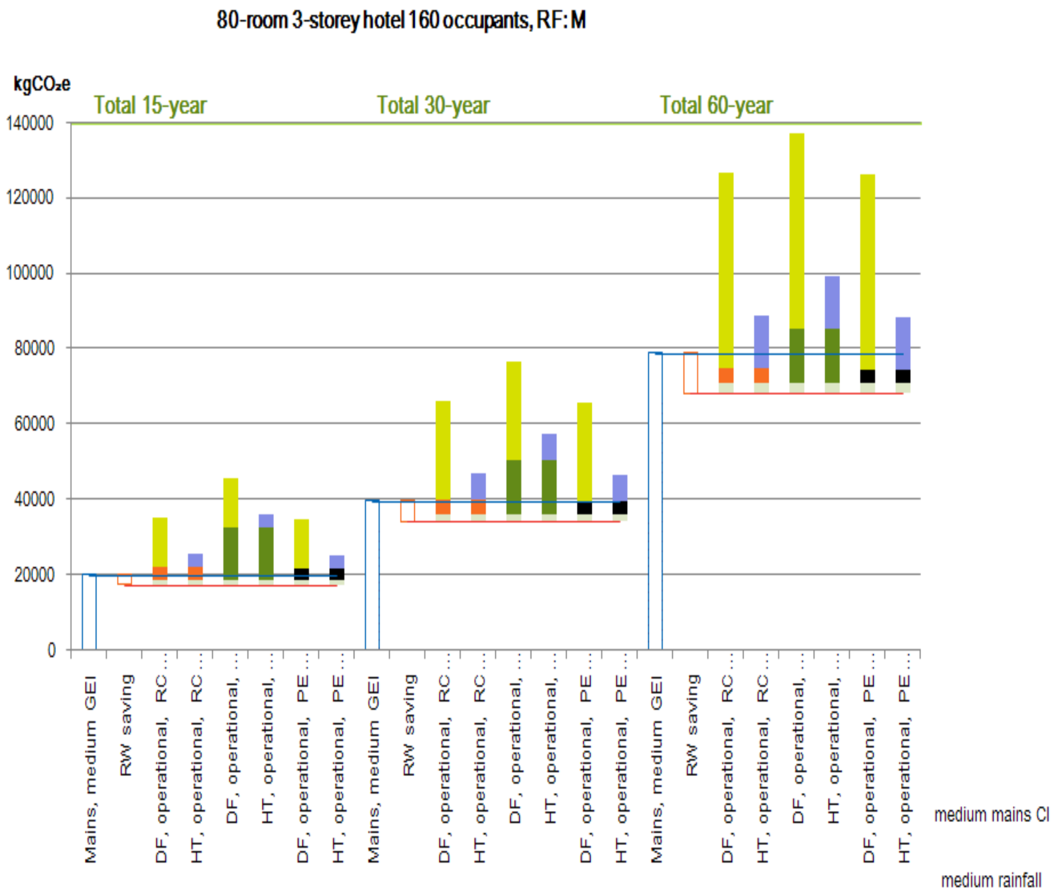


Figure 21. Relative sizes of footprint components for a hotel.

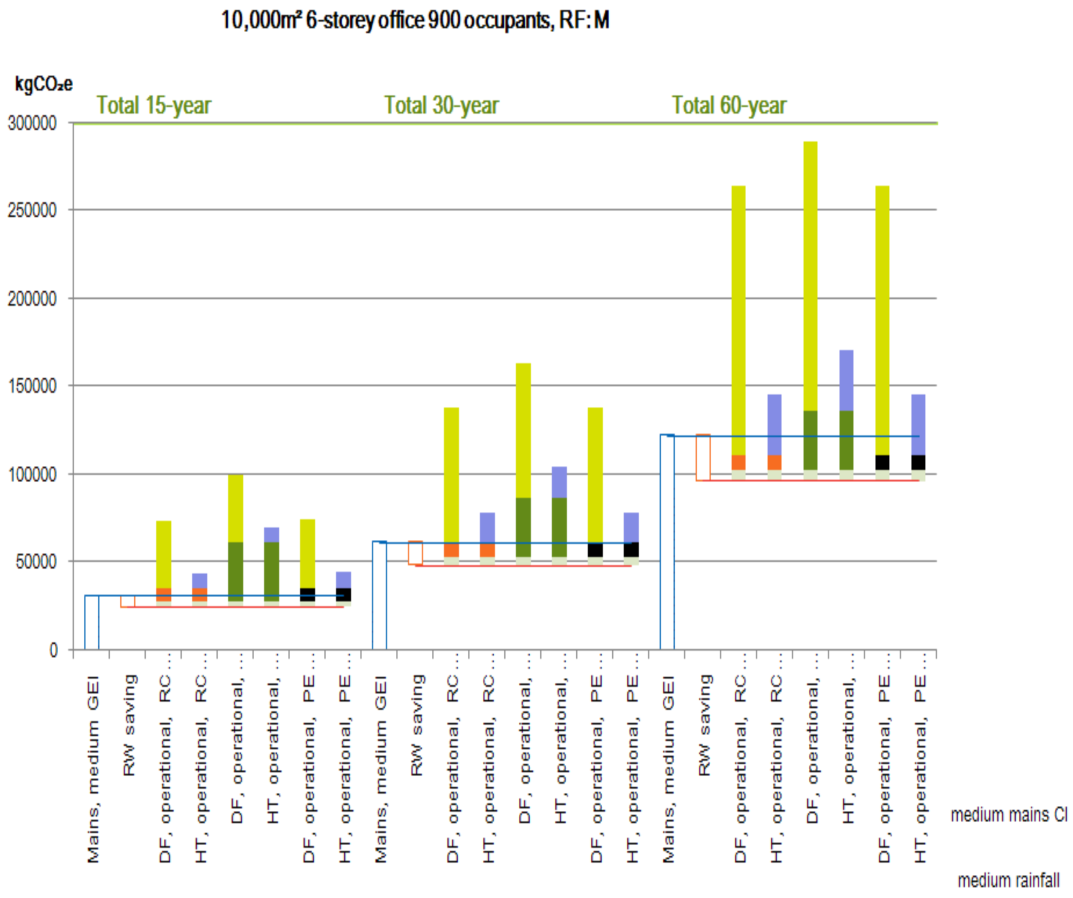


Figure 22. Relative sizes of footprint components for an office.

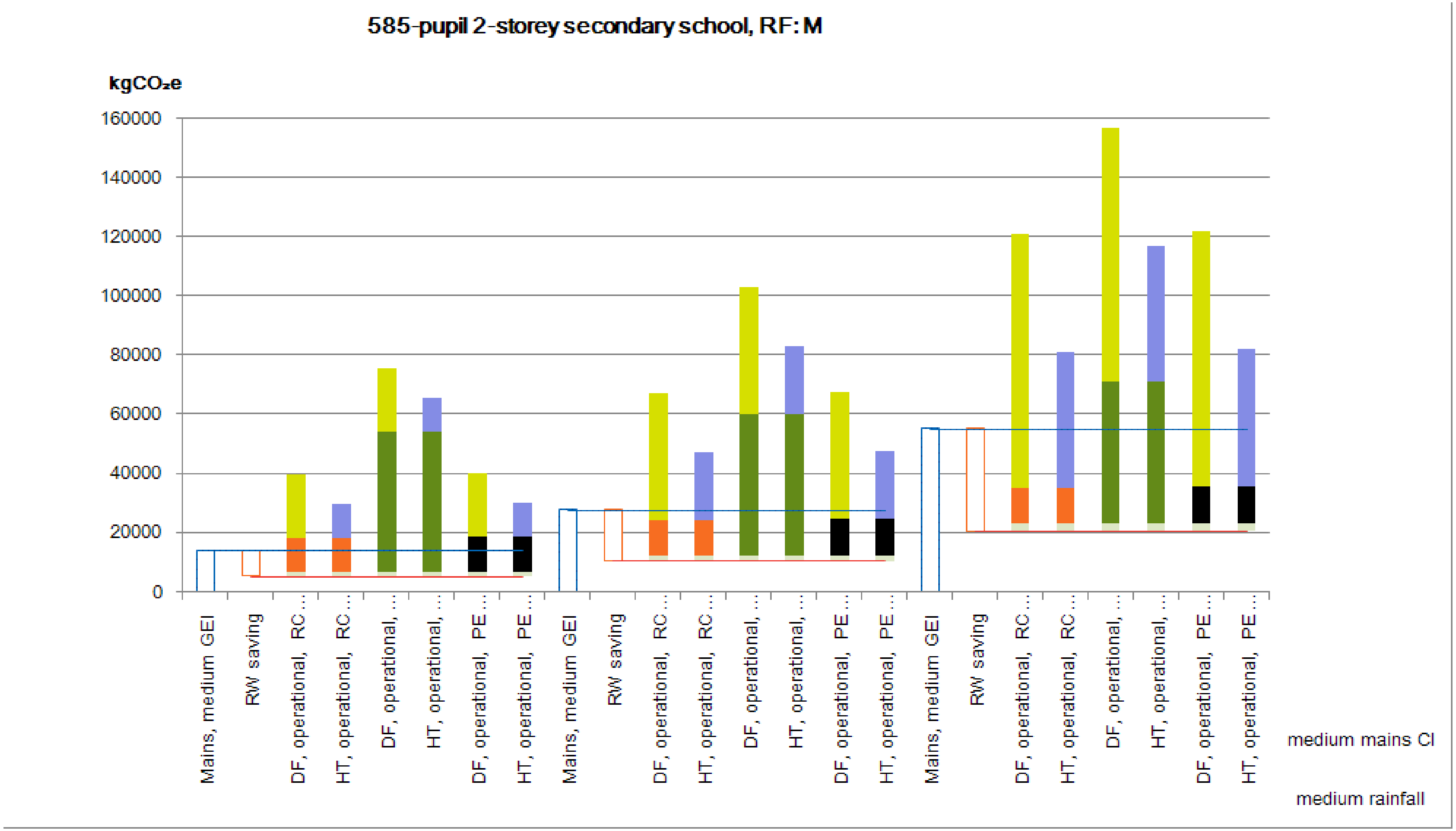


Figure 23. Relative sizes of footprint components for a school.

4.5.4 Sensitivity analysis of excluded potential footprint components

When deciding the scope of the footprint calculation the decision was taken not to include construction emissions, notably for the excavation to allow installation of an underground storage tank. This was omitted because it was not sufficiently clear that excavation should be considered additional for a new building, and there were potential trade-offs in the footprints associated with different installation options (underground, half buried, concrete base at grade) combined with each tank type. It was also assumed that the impact of excavation was small enough to ignore.

Another potential footprint component excluded were transport emissions related to maintenance. In this case, the grounds were uncertainty that maintenance would be undertaken by a third party, rather than by the householder, if at all, and uncertainty about the distance that would be travelled for maintenance visits. There is potentially more certainty on maintenance regime in non-domestic building and social housing, but in both cases, rainwater / greywater system maintenance could be combined with visits for general maintenance, avoiding additional impacts.

A representative excavation footprint, and a range of transport footprints for different assumed travel distances per year are presented in Figure 24 and set against the baseline 30-year cumulative carbon footprints for rainwater system applications to a 90m^2 house with medium rainfall.

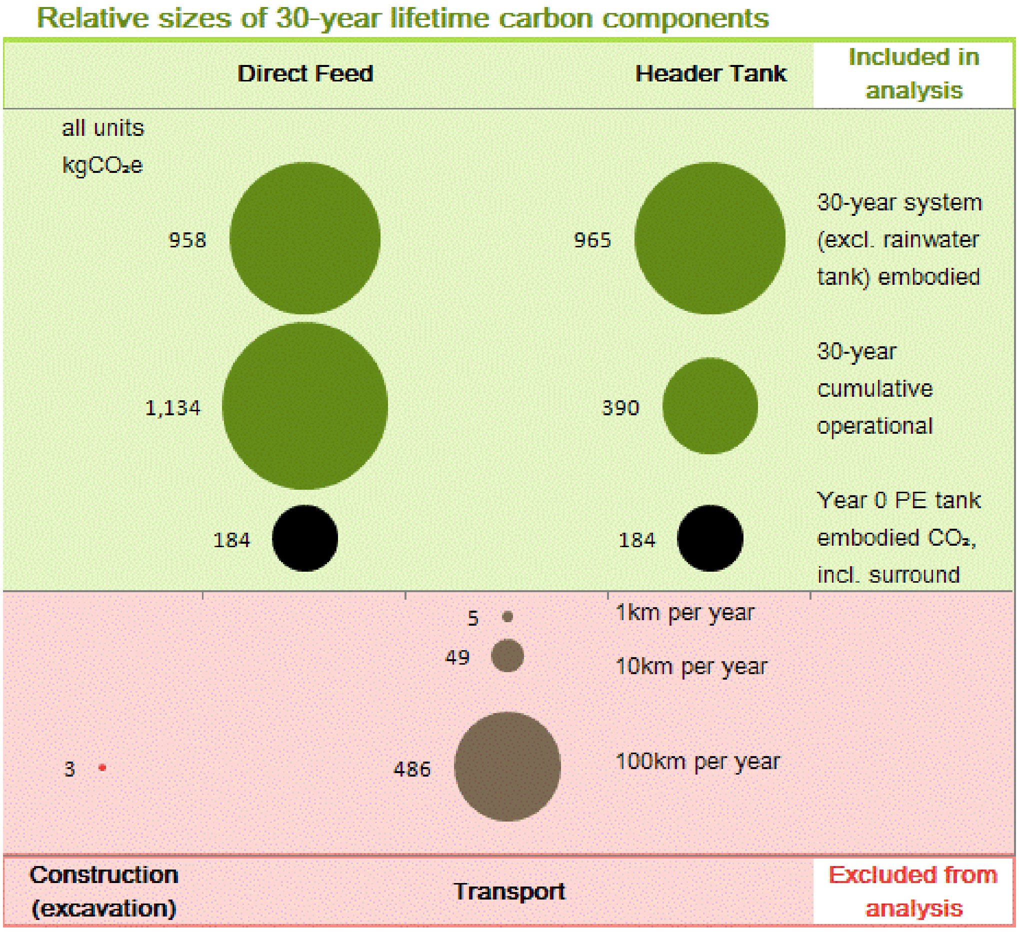


Figure 24. Potential significance of factors excluded from the analysis (using baseline figures for a 90m^2 house in a medium rainfall zone).

The comparison supports the assumption that the impact of excavation is negligible. It also shows that travel for maintenance could have a large impact if many call outs occur or if the selected contractor has to make long, exclusive trips.

4.6 Comparators

A table of useful carbon emissions comparators is shown below. These are provided to aid understanding of the relative scale of rainwater and greywater systems emissions. The carbon footprints for rainwater and greywater systems have been set in context against these values in the conclusions.

	New residential			**Existing resi. 1919-1975**	
All units kgCO_2/year	Detached	Semi	2 bed Flat	Semi	Flats / maisonettes
Building Regulations Targets					
Regulated CO_2 emissions	2,195	1,612	1,298	2,725	2,604
Unregulated CO_2 emissions	1,323	1,163	1,166	2,639	2,782
Total Building regs compliant CO_2	3,518	2,775	2,464	5,364	5,386
Code for Sustainable Homes Level 3 Targets					
Regulated CO_2 (25% less than building regs regulated emissions)	1,646	1,209	973		
Code 3 unregulated CO	1,323	1,163	1,166		
Code 3 total CO_2 emissions	2,969	2,372	2,139		

Table 20. Carbon footprint comparators.

Note: Regulated emissions = Emissions from space and water heating, pumps, fans and 30% of lighting. Unregulated emissions = Emissions from all additional electrical demand (e.g. appliances) and emissions from cooking with both gas and electric.

The carbon footprint from building energy use for hotels, offices and schools, based on CIBSE TM46 benchmarks, are as follows:

Office (10,000m^2) 750 tonnes CO_2/year;

Hotel (2,070m^2) 249 tonnes CO_2/year;

School (6,345m^2) 320 tonnes CO_2/year.

4.7 Future scenario results

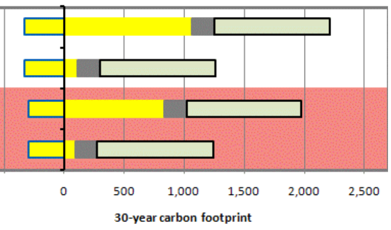
The scenario modelling showed that the carbon footprints for rainwater and greywater systems would be lower under all future scenarios, given the proposals for rapid grid decarbonisation. This was by far the dominant factor determining the absolute size of net carbon footprints. The uncontrolled demand scenario results were selected as representing the closest thing to a ‘business as usual’ scenario (but still with lower carbon footprints than the baseline).

Selected 30-year cumulative scenario results are presented in horizontal bar charts in Figure 25 and Figure 26 alongside their corresponding baseline (steady state) results. The contiguous bright yellow bars, including those portions with borders, represent the total operational carbon. The bar starts negative (to the left) of the axis by the amount of mains water carbon offset, plus foul water pumping offset for greywater systems. It generally ends on the fight hand side of the axis, indicating net carbon emissions greater than zero. The far right bar segments with a black border always represent the embodied energy of the system, excluding the rainwater tank.

Using this presentation for all of the system types studied illustrates for the first time that short retention greywater systems make a net operational carbon saving (predictable from the comparison of the operational carbon intensity of these systems with the three carbon intensity bands for mains water). In other respects the charts underline the pattern of results already seen.

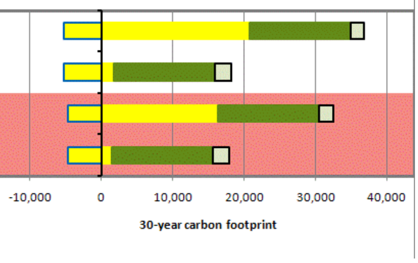
90m² e.g. Semi-detached house with 3 occupants

Year 30 mains offset carbon saving, Medium CI	Year 30 foul water reduction carbon saving	Year 30 operational carbon	Year 30 Net operational carbon	Year 30 PE tank embodied CO_2	Year 30 System (excl. RW tank) Embodied CO_2	Rainfall	System type	Scenario
					kgCO_2e			
-333	0	1,399	1,067	184	958	Medium	Direct feed	Baseline
-333	0	444	112	184	965		Header tank	
-299	0	1,134	835	184	958	Medium	Direct feed	Uncontrolled Demand
-299	0	390	91	184	965		Header tank	



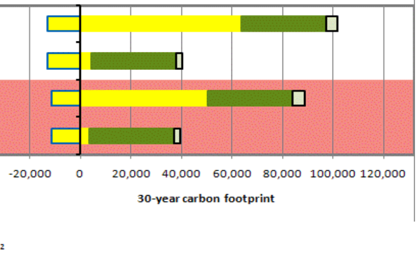
80-room Budget Hotel

Year 30 mains offset carbon saving, Medium CI	Year 30 foul water reduction carbon saving	Year 30 operational carbon	Year 30 Net operational carbon	Year 30 GRP tank embodied CO_2	Year 30 System (excl. RW tank) Embodied CO_2	Rainfall	System type	Scenario
					kgCO_2e			
-5,302	0	26,056	20,754	14,140	1,936	Medium	Direct feed	Baseline
-5,302	0	7,081	1,779	14,140	2,288		Header tank	
-4,758	0	21,119	16,361	14,140	1,936	Medium	Direct feed	Uncontrolled Demand
-4,758	0	6,207	1,449	14,140	2,288		Header tank	



10,000m² City centre office refurbishment

Year 30 mains offset carbon saving, Medium CI	Year 30 foul water reduction carbon saving	Year 30 operational carbon	Year 30 Net operational carbon	Year 30 GRP tank embodied CO_2	Year 30 System (excl. RW tank) Embodied CO_2	Rainfall	System type	Scenario
					kgCO_2e			
-12,921	0	76,716	63,794	33,487	4,701	Medium	Direct feed	Baseline
-12,921	0	17,257	4,335	33,487	2,692		Header tank	
-11,575	0	62,180	50,606	33,487	4,701	Medium	Direct feed	Uncontrolled Demand
-11,575	0	15,101	3,526	33,487	2,692		Header tank	



Small 11 - 18 Secondary school (585 pupils)

Year 30 mains offset carbon saving, Medium CI	Year 30 foul water reduction carbon saving	Year 30 operational carbon	Year 30 Net operational carbon	Year 30 RC tank embodied CO_2	Year 30 System (excl. RW tank) Embodied CO_2	Rainfall	System type	Scenario
					kgCO_2e			
-17,268	0	42,993	25,725	11,581	1,936	Medium	Direct feed	Baseline
-17,268	0	23,062	5,794	11,581	2,288		Header tank	
-15,645	0	34,847	19,202	11,581	1,936	Medium	Direct feed	Uncontrolled Demand
-15,645	0	20,405	4,760	11,581	2,288		Header tank	

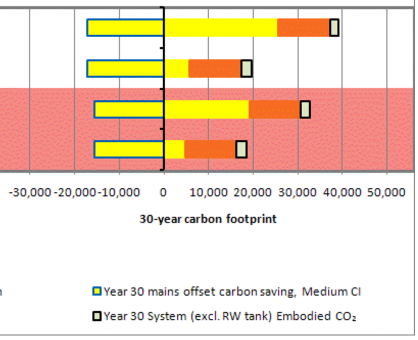


Figure 25. Rainwater system 30-year carbon footprints

90m^2 e.g. Semi-detached house with 3 occupants

Year 30 mains offset carbon saving, Medium CI	Year 30 foul water reduction carbon saving	Year 30 operational carbon	Year 30 Net operational carbon	Year 30 representative tank embodied CO_2	Year 30 System (excl. RW tank) Embodied CO_2	System type	Scenario
					kgCO_2e		
-699	-178	3,265	2,389	0	993	SmMBR	Baseline
-196	-50	161	-85	0	660	ShrtRtntn1	
-392	-100	322	-170	0	692	ShrtRtntn2	
-633	-161	1,268	474	0	713	SmBio	
-639	-161	2,646	1,846	0	993	SmMBR	Uncontrolled Demand
-179	-45	131	-94	0	660	ShrtRtntn1	
-359	-91	261	-188	0	692	ShrtRtntn2	
-579	-146	1,028	302	0	713	SmBio	

80-room Budget Hotel

Year 30 mains offset carbon saving, Medium CI	Year 30 foul water reduction carbon saving	Year 30 operational carbon	Year 30 Net operational carbon	Year 30 representative tank embodied CO_2	Year 30 System (excl. RW tank) Embodied CO_2	System type	Scenario
					kgCO_2e		
-8,197	-2,088	6,738	-3,547	0	52,773	ShrtRtntn1	Baseline
-12,756	-3,249	42,590	26,585	0	25,693	LgMltiMdia	
-12,756	-3,249	42,590	26,585	0	11,103	LgMBR	
-7,504	-1,893	5,461	-3,936	0	52,773	ShrtRtntn1	Uncontrolled demand
-11,678	-2,946	34,520	19,896	0	25,693	LgMltiMdia	
-11,678	-2,946	34,520	19,896	0	11,103	LgMBR	

10,000m^2 City centre office refurbishment

Year 30 mains offset carbon saving, Medium CI	Year 30 foul water reduction carbon saving	Year 30 operational carbon	Year 30 Net operational carbon	Year 30 representative tank embodied CO_2	Year 30 System (excl. RW tank) Embodied CO_2	Rainfall	System type	Scenario
					kgCO_2e			
-15,591	-3,971	52,057	32,495	0	25,693		LgMltiMdia	Baseline
-15,591	-3,971	52,057	32,495	0	11,103		LgMBR	
-14,274	-3,601	42,194	24,319	0	25,693		LgMltiMdia	Uncontrolled demand
-14,274	-3,601	42,194	24,319	0	11,103		LgMBR	

Small 11 - 18 Secondary school (585 pupils)

Year 30 mains offset carbon saving, Medium CI	Year 30 foul water reduction carbon saving	Year 30 operational carbon	Year 30 Net operational carbon	Year 30 representative tank embodied CO_2	Year 30 System (excl. RW tank) Embodied CO_2	System type	Scenario
					kgCO_2e		
-2,725	-694	9,097	5,678	0	25,693	LgMltiMdia	Baseline
-2,725	-694	9,097	5,678	0	11,103	LgMBR	
-2,494	-629	7,373	4,250	0	25,693	LgMltiMdia	Uncontrolled demand
-2,494	-629	7,373	4,250	0	11,103	LgMBR	

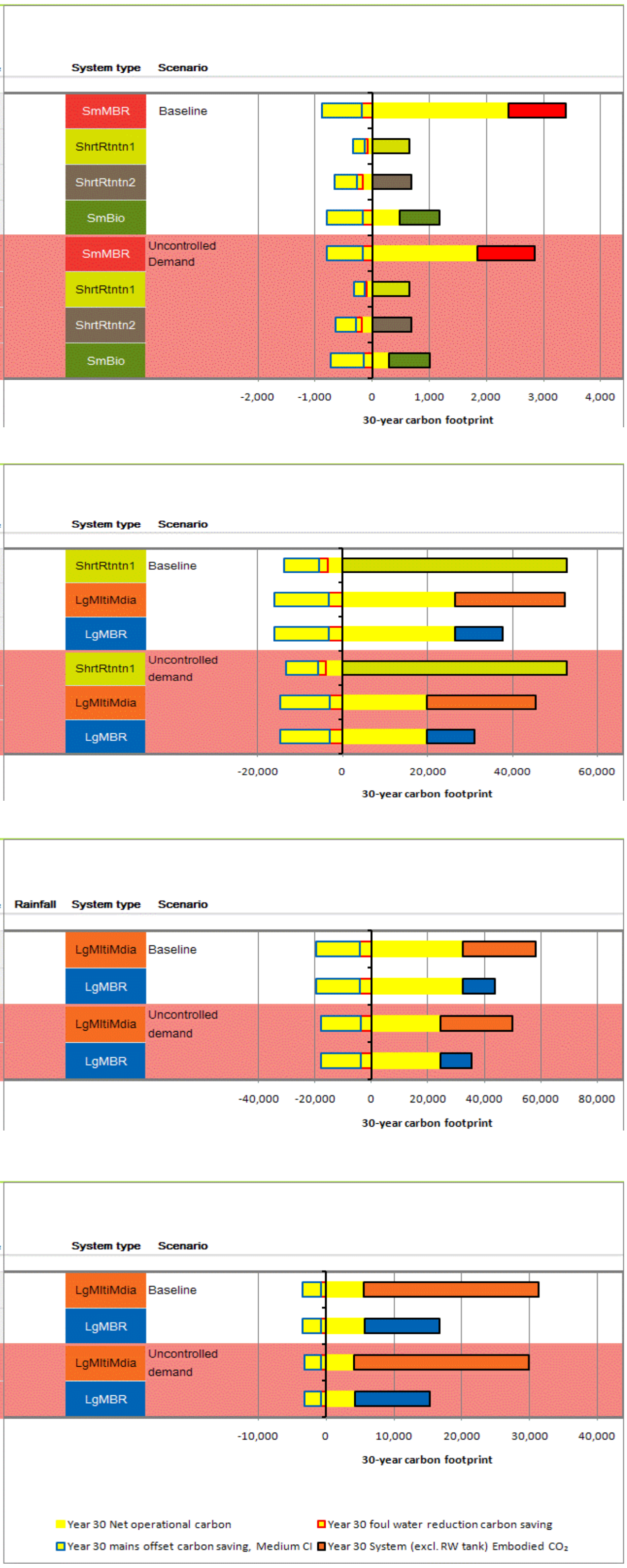


Figure 26. Greywater system 30-year carbon footprints

This set of charts, showing the footprint breakdown for the Uncontrolled Demand scenario, confirms the findings from the baseline analysis. In the other scenarios (Innovation, Local Resilience and Sustainable Behaviour), rainwater and greywater systems have lower carbon footprints than the Uncontrolled Demand scenario. The effects of the carbon intensity of mains water supply and future changes in non-potable demand on the results were marginal but the footprints for direct feed systems decrease by up to 20 per cent in the Innovation and Sustainable Behaviour scenarios because of faster grid decarbonisation, with lower impacts on header tank systems. However, none of the scenarios produced a significant change in the relative outcomes as found in the baseline case, nor altered the finding that fitting rainwater and greywater systems produces a net increase in emissions.

The total net carbon footprints for rainwater and greywater systems over 30 years, and the split between the net operational and embodied carbon contributions to the footprint are presented in Table 21. For short retention systems, which achieve net operational carbon savings, embodied carbon and net operational percentages are shown relative to the total net 30 year carbon footprint.

Building type	Rainwater or greywater system type	Total net 30-year carbon emissions ($kgCO_2e$)	Percentage split: net operational / embodied carbon
90m^2 home	RW Direct feed	1,978	42% / 58%
	RW Header tank	1,240	7% / 93%
Budget hotel	RW Direct feed	32,437	50% / 50%
	RW Header tank	17,877	8% / 92%
City office	RW Direct feed	88,794	57% / 43%
	RW Header tank	39,706	9% / 91%
Small secondary school	RW Direct feed	32,719	59% / 41%
	RW Header tank	18,629	26% / 74%
90m^2 home	GW Small MBR	2,839	65% / 35%
	GW Short retention, 1WC	566	-17% / 117%
	GW Short retention, 2 WCs	504	-37% / 137%
	GW Small biological	1,015	30% / 70%
Budget hotel	GW Short retention, 1WC	48,838	-8% / 108%
	GW Large multimedia	45,589	44% / 56%
	GW Large MBR	30,999	64% / 36%
City office	GW Large multimedia	50,012	49% / 51%
	GW Large MBR	35,422	69% / 31%
Small secondary school	GW Large multimedia	29,943	14% / 86%
	GW Large MBR	15,353	28% / 72%

Table 21. Summary of system carbon footprints (Uncontrolled Demand scenario).

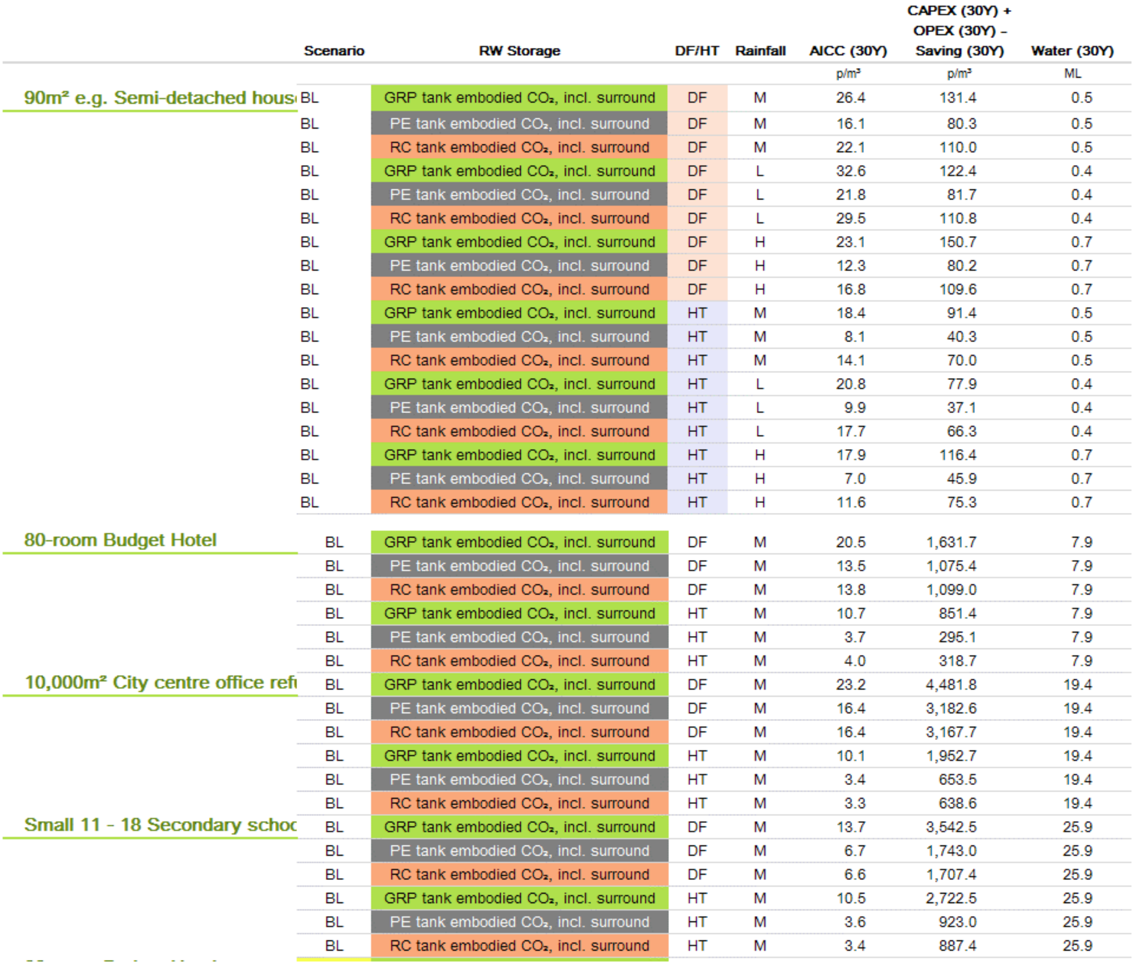
4.8 Other carbon metrics

Previous work by the EA in 2008 compared the carbon costs of a range of water supply and demand management options. It is difficult to compare directly the carbon costs of these different options as calculations must take into account different water yields or savings, asset life, total carbon emissions, and an annual rising carbon price. A common baseline can be established however using an average incremental cost approach, which was replicated in this study.

The Average Incremental Carbon Cost (AICC) is the ratio of total capital and operating costs for a scheme, based on carbon costs only (calculated using SPC) and excluding other social costs, per volume of additional water supplied or reduced demand, and discounted over a defined period of time.

AICC results for the baseline case are presented below. Major changes in carbon valuation methodology since 2008 mean that the AICC results calculated in this study are not directly comparable with those in EA 2008, or other studies that pre-date the change. These results are included to aid future comparisons.

AICCs calculated using the new carbon values are distinctly higher than those in previous studies, because the new valuations attach a much higher price to carbon emissions. In other respects, this study generally found water savings to be lower than those assumed in EA 2008, while embodied carbon of systems were broadly similar, given the large margins of error inherent in the calculations.



	Scenario	RW Storage	DF/HT	Rainfall	AICC (30Y)	CAPEX (30Y) + OPEX (30Y) – Saving (30Y)	Water (30Y)
					p/m³	p/m³	ML
90m² e.g. Semi-detached hous	BL	GRP tank embodied CO_2, incl. surround	DF	M	26.4	131.4	0.5
	BL	PE tank embodied CO_2, incl. surround	DF	M	16.1	80.3	0.5
	BL	RC tank embodied CO_2, incl. surround	DF	M	22.1	110.0	0.5
	BL	GRP tank embodied CO_2, incl. surround	DF	L	32.6	122.4	0.4
	BL	PE tank embodied CO_2, incl. surround	DF	L	21.8	81.7	0.4
	BL	RC tank embodied CO_2, incl. surround	DF	L	29.5	110.8	0.4
	BL	GRP tank embodied CO_2, incl. surround	DF	H	23.1	150.7	0.7
	BL	PE tank embodied CO_2, incl. surround	DF	H	12.3	80.2	0.7
	BL	RC tank embodied CO_2, incl. surround	DF	H	16.8	109.6	0.7
	BL	GRP tank embodied CO_2, incl. surround	HT	M	18.4	91.4	0.5
	BL	PE tank embodied CO_2, incl. surround	HT	M	8.1	40.3	0.5
	BL	RC tank embodied CO_2, incl. surround	HT	M	14.1	70.0	0.5
	BL	GRP tank embodied CO_2, incl. surround	HT	L	20.8	77.9	0.4
	BL	PE tank embodied CO_2, incl. surround	HT	L	9.9	37.1	0.4
	BL	RC tank embodied CO_2, incl. surround	HT	L	17.7	66.3	0.4
	BL	GRP tank embodied CO_2, incl. surround	HT	H	17.9	116.4	0.7
	BL	PE tank embodied CO_2, incl. surround	HT	H	7.0	45.9	0.7
	BL	RC tank embodied CO_2, incl. surround	HT	H	11.6	75.3	0.7
80-room Budget Hotel	BL	GRP tank embodied CO_2, incl. surround	DF	M	20.5	1,631.7	7.9
	BL	PE tank embodied CO_2, incl. surround	DF	M	13.5	1,075.4	7.9
	BL	RC tank embodied CO_2, incl. surround	DF	M	13.8	1,099.0	7.9
	BL	GRP tank embodied CO_2, incl. surround	HT	M	10.7	851.4	7.9
	BL	PE tank embodied CO_2, incl. surround	HT	M	3.7	295.1	7.9
	BL	RC tank embodied CO_2, incl. surround	HT	M	4.0	318.7	7.9
10,000m² City centre office ref	BL	GRP tank embodied CO_2, incl. surround	DF	M	23.2	4,481.8	19.4
	BL	PE tank embodied CO_2, incl. surround	DF	M	16.4	3,182.6	19.4
	BL	RC tank embodied CO_2, incl. surround	DF	M	16.4	3,167.7	19.4
	BL	GRP tank embodied CO_2, incl. surround	HT	M	10.1	1,952.7	19.4
	BL	PE tank embodied CO_2, incl. surround	HT	M	3.4	653.5	19.4
	BL	RC tank embodied CO_2, incl. surround	HT	M	3.3	638.6	19.4
Small 11 - 18 Secondary schoc	BL	GRP tank embodied CO_2, incl. surround	DF	M	13.7	3,542.5	25.9
	BL	PE tank embodied CO_2, incl. surround	DF	M	6.7	1,743.0	25.9
	BL	RC tank embodied CO_2, incl. surround	DF	M	6.6	1,707.4	25.9
	BL	GRP tank embodied CO_2, incl. surround	HT	M	10.5	2,722.5	25.9
	BL	PE tank embodied CO_2, incl. surround	HT	M	3.6	923.0	25.9
	BL	RC tank embodied CO_2, incl. surround	HT	M	3.4	887.4	25.9

Figure 27. Baseline AICC results

5 Conclusions and recommendations

5.1 Discussion

Scope

This study calculated the net carbon footprints of a sample of rainwater and greywater systems supplying water for non potable use in three types of residential buildings (a block of 10 x 70m^2 flats, a 90m^2 semi-detached house, and a 120m^2 house) and three types of non-domestic building (an 80-bed budget hotel, a 20,000m^2 city office, and a 585-pupil secondary school). The carbon footprints consisted of cumulative cradle to gate embodied carbon, plus operational carbon from energy use, minus emissions savings from offsetting mains water supply and foul water pumping.

The study looked at four future scenarios: Uncontrolled Demand, Innovation, Sustainable Behaviour and Local Resilience. The Uncontrolled Demand scenario is considered to be the closest to a ‘business as usual’ case, while reflecting expected electricity grid decarbonisation[8]. Grid decarbonisation produces smaller operational footprints in all the scenarios than in the steady state baseline calculations. All discussions here are based on the results for the Uncontrolled Demand scenario, and results for an ‘average’ home, corresponding to a 90 m^2 semi-detached house.

Rainwater system footprints

Over 30 years, the net cumulative embodied and operational carbon footprint of a rainwater system with a polyethylene tank applied to an ‘average’ UK home is approximately 1.25 – 2 tonnes of carbon dioxide equivalent emissions compared to annual building energy related emissions of around 2.4 tonnes. The average home was taken to be in an area with medium rainfall and median mains water carbon intensity. Footprints for systems with reinforced concrete and glass reinforced plastic tanks are higher by between 0.5 and 1.0 tonnes respectively and the footprint is around 5% lower in low rainfall areas and around 10 per cent higher in high rainfall areas due to the changes in rainwater storage tank size (with tanks sized in accordance with BS8515).

Footprints for rainwater applications to non-domestic buildings are more variable, but as examples a 30 year footprint for a system with a concrete tank serving a 10,000m^2 city office is 14 – 63 tonnes compared to benchmark annual emissions from building energy use of around 750 tonnes. A similar system for an 80-bed budget hotel has a 30-year carbon footprint of 7.5 – 22 tonnes compared to annual building energy emissions of 250 tonnes. For a 585-pupil secondary school the system has a 30-year footprint of 19 – 33 tonnes compared to annual energy-related emissions of 320 tonnes.

The main factors determining the carbon footprint of a rainwater system are the type of tank used and the pumping arrangement. Rainwater tanks, particularly GRP tanks requiring a concrete shell, have the biggest impact in terms of embodied carbon over at least the first 15 years a system is in operation. Pumping energy intensity is

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[8] Grid decarbonisation is the future variable with the greatest effect on the carbon footprints of rainwater and greywater systems. The Uncontrolled Demand scenario assumes decarbonisation happens at a quarter of the rate projected by the Department of Energy and Climate Change.

inherently slightly higher in direct feed systems, where the rainwater is pumped directly to end uses, than in systems where water is pumped to a header tank and supplied to end uses under gravity.

The large difference in operational carbon between direct feed and header tank systems is caused by the differences in mains backup arrangement. In header tank systems the mains backup water is supplied to the header tank under mains pressure. In a direct feed system, mains backup water is supplied to the rainwater storage tank and then pumped to the end uses. So in a direct feed system, 100 per cent of the water for the non-potable end uses connected to the rainwater system is pumped from the rainwater tank. In a header tank system, only 20 – 40 per cent of non-potable demands met by harvested rainwater are pumped and the rest is supplied without additional energy use and carbon emissions above those for mains supply. Innovative design could have an immediate impact on the emissions of direct feed systems by removing the need for mains backup to be pumped to end uses via the rainwater tank.

Emissions associated with rainwater systems vary with rainfall, which depends strongly on regional location. Counter intuitively the study found that header and break tank systems, where the mains top up requires no additional pumping, have lower operational energy demands in geographical areas with lower rainfall. This is as a result of the operational carbon intensity being higher than mains, so supplying more water via these systems increases the net carbon emissions. Systems that are designed with mains top up to the tank and pump all of the water supply (including mains back up) to the non-potable end uses have much higher operational footprints, but the net additional emissions reduce with higher rainfall and greater mains savings.

Greywater system footprints

There is a wide variety of distinct greywater system types and six were analysed: small membrane bioreactors, short retention systems serving one or two WCs (as a distinct type), small biological systems, multimedia filters, and larger membrane bioreactors. Footprints for smaller greywater systems, applicable to the average home, range from 0.5 – 2.8 tonnes (similar to the range for rainwater systems but, with the exception of short retention systems, with higher carbon footprints per unit of water saving). Footprints for the larger systems applicable to non-domestic and multi-residential buildings range from 13 – 47 tonnes, for the building types studied.

With the exception of short retention systems, the energy intensities assumed for greywater systems were higher than those for rainwater. Short retention greywater systems, that require less pumping, have lower emissions than other greywater systems because collected water is stored close to both source and point of use with minimal treatment. Other greywater systems have storage arrangements similar to those for rainwater and therefore similar pumping emissions. The treatment processes used in most greywater systems entail additional energy use and emissions on top of that for pumping.

There is wide variability in the main footprint components of greywater systems. While location is not a factor in sizing, the net operational footprint is affected by the variation in the carbon intensities of mains water supply and foul water pumping.

Operational carbon footprints

The operational carbon emissions associated with pumping water from the point of collection to storage and/or from storage to the point of use in buildings were found to be higher than the carbon savings from reduced mains water supply. With one exception, the net operational emissions of these systems were higher than emissions from equivalent buildings without a rainwater or greywater system. In other words, rainwater and greywater systems were generally found to be more carbon intensive than mains water. The exception is short retention greywater systems, which were found to be approximately 40 per cent less carbon intensive than mains water supply.

The relative carbon intensity of rainwater and greywater systems compared to mains water depend directly on the values established in the study for:

- The energy intensity (and hence carbon intensity) of pumping water from storage to end uses for rainwater and greywater systems;
- The carbon intensity for mains water supply, as reported by water companies to Ofwat and modified to account for leakage;
- The carbon intensity for foul water pumping, derived from water company data on the carbon intensity of the wastewater treatment cycle;

and hence

- The net operational carbon intensity of rainwater and greywater systems accounting for the offsetting of mains water supply and, for greywater systems, foul water pumping.

The assumed energy intensities for rainwater and greywater systems are based on limited measured data. However, accepting this as the most reliable information available to the study, it is clear prior to the calculation of the overall carbon footprints that rainwater and greywater systems are currently more carbon intensive than mains water. The scale of the increase in operational emissions is around 40 per cent for a typical rainwater application, and over 100 per cent for most greywater applications.

Embodied carbon footprints

Embodied carbon footprints vary greatly across the different system types. Rainwater system embodied carbon footprints generally start higher than greywater because of high embodied energy, mostly in the tank. Greywater systems with heavy components such as multi media filters housed in a steel vessel and treatment tanks in larger systems also have high embodied carbon[9].

The large and heavy storage and treatment tanks in all systems tend to be long-lasting so their initial high carbon impacts are a reducing proportion when annualised over increasing periods of time. By contrast pumps, which are typically the second largest contributors to embodied carbon in both rainwater and greywater systems, need replacing from time to time so their proportional contribution to embodied carbon increases over time. **Pumps are therefore a good candidate for improvements in design as they are also the key component determining operational impacts.**

Variation in footprints under different future scenarios

The analysis of the scenarios showed that the assumed rate of decarbonisation of the electricity grid is the biggest factor determining the carbon footprints of rainwater and greywater systems over the longer term (15 years plus). Footprints for direct feed systems decrease by up to 20 per cent in the ‘Innovation’ and ‘Sustainable Behaviour’ scenarios because of faster grid decarbonisation, with lower impacts on

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[9] NB GW inventories more difficult to check for completeness due to complexity, lack of standardisation of systems and less freely available technical data.

header tank systems. Differences in the carbon intensity of mains water supply and future changes in non-potable end use demand have only a marginal effect on footprints.

The study did not fully explore the potential effect of seasonal changes in rainfall caused by climate change. The water saving model adopted is based on average annual rainfall, which is only projected to change by a small amount (~2 per cent across the rainfall zones used in the analysis) in the 30-year future period that was studied.

Relative value of carbon, water savings and wider benefits of rainwater and greywater systems

It is important to set the study findings on the carbon footprints of rainwater and greywater systems in context by considering:

- the scale of emissions compared to other building emissions
- the corresponding water savings as a benefit in their own right, and
- the value of other benefits of these types of systems.

Over 30 years, the total net carbon footprint of rainwater and greywater systems represents in the order of up to 1 year of building energy emissions when applied to the ‘average’ home, and in the order of up to 1 month of building energy emissions when applied to the types of non-domestic buildings studied (hotels, offices, schools).

Rainwater and greywater systems are currently fitted and promoted based on their potential to save water. Having extensively discussed carbon impacts, these need to be set against water savings achieved. The water savings in megalitres over 30 years for the examples above are:

- average home, 0.8 ML
- budget hotel, 13 ML
- office, 31.6 ML
- secondary school, 42.7 ML.

This means that water savings are broadly achieved at rates of carbon arisings in the range 0.5 – 4 tCO_2e/ML, although emissions rates for most applications are in the range 1 – 2 tCO_2e/ML.

Potential conflicts between the water resource and carbon emission impacts of rainwater and greywater systems is complex. Net carbon increases need to be considered alongside other potential benefits of rainwater and greywater systems such as reduced rainwater run-off, and increased resilience to climate change from on-site collection and storage, as well as the more easily quantifiable value of reduced mains water demand and sewage volumes. Where water related drivers have been identified, the carbon impact of the systems should be considered relative to total emissions in a building and balanced against the wider sustainability benefits.

The total carbon emissions of systems over 15 to 60 years could be considered to be relatively small but still represent additional emissions over a typical home without rainwater or greywater system. Given the focus of this report on energy and carbon impacts, it is difficult to find a basis to state confidently which types of other benefits should be considered sufficiently valuable to “bridge the gap” represented by the net increase in carbon footprint over the mains baseline.

Decision makers may want to review the current situation in which rainwater and greywater systems are universally encouraged. For example, given the current additional carbon emissions and energy requirement of these systems, policies that strongly encourage these systems could be targeted in areas where the water and wider benefits are of most value. The carbon impact of systems should be considered relative to total emissions in a building and balanced against the wider sustainability benefits.

5.2 Conclusions

1) Considering cumulative cradle to gate embodied and operational carbon, all rainwater and greywater systems included in the study give rise to additional net carbon emissions over their lifetimes. For example over 30 years, the cumulative embodied and net operational carbon footprint of a rainwater system with a polyethylene tank applied to an ‘average’ home is 1.25 – 2 tonnes of carbon dioxide equivalent emissions. This is similar to one year of energy-related emissions from a house built to Code Level 3 energy efficiency standards.

2) Accepting the assumed operational energy intensities of rainwater and greywater systems are based on limited measured data but on the most reliable information available to this study, with one exception, short retention greywater systems, the net operational emissions of the systems studies were higher than emissions from equivalent buildings without a rainwater or greywater system. The scale of the increase in operational emissions is around 40 per cent for a typical rainwater application, and over 100 per cent for most greywater applications. The critical value for operating energy is the mains water intensity in the system proposed location.

3) The main factors determining the carbon footprint of a rainwater system are the type of tank used and the pumping arrangement. For greywater systems heavy components such as multi media filters housed in a steel vessel and treatment tanks have a large impact on the footprint but the main factor is the pumping and treatment operational energy.

4) Header tank systems (with no mains top up additional pumping requirement) have lower operational energy demands in geographical areas with lower rainfall as a result of the operational carbon intensity being higher than mains.

5) System configuration and pumping arrangement has a large impact on the operational energy. Systems that are designed with mains top up to the tank pumping all of the water supply (including mains back up) to the non-potable end uses have significantly higher energy demands than mains supply but the net additional emissions reduce with increased rain supply and mains savings.

6) Over a 30 year lifetime the net emissions operational and embodied energy split varies considerably. Large greywater systems and direct rainwater systems have the largest operational proportional impact. The highest operational to embodied

carbon percentage split is 69 / 31. The net carbon emissions of short retention greywater systems result entirely from the embodied energy of the system.

7) The four future scenarios reviewed showed that differences in the carbon intensity of mains water supply and future changes in non-potable demand have only a marginal effect on footprints. The most significant impacts for future scenarios are the speed of grid electricity decarbonisation.

8) System design and component specification solutions could have an immediate impact on the emissions generated by systems both in terms of embodied and operational carbon.

9) The carbon impact of the systems should be considered relative to total emissions in a building and balanced against the wider sustainability benefits.

10) Decision makers may want to review the current situation in which rainwater and greywater systems are universally encouraged.

5.3 Recommendations

For decision makers

While the conclusion that rainwater and greywater systems increase net carbon emissions is clear, the absolute quantities of carbon should be balanced against wider sustainability benefits. A proportionate response would be for policymakers to review the strength of encouragement for rainwater and greywater systems in policy and look to introduce effective checks on the system applicability in a given situation to ensure that they have wider environmental and social benefits that bridge the gap resulting from the net additional carbon emissions.

For suppliers and manufacturers

Suppliers should work quickly to reduce the embodied carbon footprints of their systems, and particularly to reduce the operational carbon emissions related to pumps and treatment.

In partnership

There is scope for suppliers and manufacturers to both improve their products and the information they have and provide about lifetime carbon impacts. Engagement and technical support from the Environment Agency, Energy Saving Trust, NHBC Foundation and others could speed up the process of producing and disseminating such information. Given the difficulty of generating accurate embodied carbon figures and gathering extensive performance data, policymakers will find it difficult to improve the evidence base reached in this report without engaging effectively with suppliers.

The project partners could engage with standard bodies to promote the incorporation of carbon considerations and improved system designs.

5.4 Further work

Lack of UK and system / component specific data posed a problem for both of the key quantitative activities underpinning this study – calculating the operational energy and the embodied carbon of rainwater and greywater systems.

The areas of work which would improve the evidence base are:

- Better quantification of operational energy and carbon intensity, which will require primary data collection. Retamal et al. (2009) provides a good process map for this work;
- Development/adaptation of a theoretical pump model specific to pumping in rainwater and greywater systems;
- Independent monitoring of installations to extend the general evidence base available and specifically to validate and tailor the pump model.

The amount of effort to put into remedying the problem of low level of available data depends in part on the future policy priorities and the interest in promoting rainwater and greywater systems for their benefits in terms of water resource efficiency, water stress, drainage, etc.

There is immediate potential to reduce the carbon impacts and refine the evidence for the operational energy of the systems but the embodied carbon impacts of systems will remain a consideration in situations where their implementation does not necessarily have wider sustainability benefits. Work to establish the relative relationship between the water saving, wider benefits of the systems and their energy impacts and a detailed cost benefit analysis would support the development of policy that considers system applicability in a given situation. Practical and theoretical research investigating the rainwater yield and water saving potential of rainwater systems on a daily or monthly basis could support further work in this area.

Practical work that could provide immediate benefit to the carbon impacts of rainwater and greywater systems would be to work with suppliers on:

- Improving treatment systems, pumps and system arrangements with a focus on reducing operational carbon impacts;
- Detailed lifecycle assessment of large storage tanks and systems to reduce the embodied carbon;

In addition, the project partners could work with suppliers to promote appropriate systems application to buildings focusing on the balance between the wider sustainability benefits and carbon impacts.

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7 List of abbreviations

AICC	Average Incremental Carbon Cost
AISC	Average Incremental Social Cost
BoS	Balance of system
BREEAM	BRE Environmental Assessment Method
CAPEX	Capital expenditure (in this study defined as a carbon cost)
CI	Carbon intensity
CO_2	Carbon dioxide
CSH	Code for Sustainable homes
CLG	Communities and Local Government
DECC	The Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
GBA	Gross building area
GEI	Greenhouse Gas Emissions Intensity
GIA	Gross internal area
GW	Greywater
ICE	(Bath University) Inventory of Carbon and Energy
ML	Megalitres
NPV	Net present value
Ofwat	The Water Services Regulation Authority
OPEX	NPV operating expenditure (in this study defined as a carbon cost)
RW	Rainwater
SAP	Standard Assessment Procedure
SDS/SuDS	Sustainable Urban Drainage Systems
SPC	Shadow Price of Carbon as defined by Defra
TFA	Treated Floor Area
WSDMO	Water Supply and Demand Management Options

8 Glossary

Aerosols	Minute particles suspended in gas.
AICC	Average Incremental Carbon Cost. The AICC is the ratio of total capital and operating costs for a scheme, based on carbon costs only (calculated using SPC) and excluding other social costs, per volume of additional water supplied or reduced demand, discounted over a defined period of time.
AISC	Average Incremental Social Cost. The AISC is the ratio of total capital and operating costs for a scheme, including one off and annual social and environmental costs, per volume of additional water supplied or reduced demand, discounted over a defined period of time.
Asset Management Plan (AMP)	A plan for managing an water companies' infrastructure and other assets in order to deliver an agreed standard of service. The Asset Management Plans are submitted to Ofwat every 5 years and forms the basis by which water rates are set. These plans identify the timescales and levels of investment required to maintain and upgrade the serviceability of the assets.
Back-wash	Reversal of the normal direction of flow of water through a filter in order to clean it.
Biochemical (BOD)	Measurement of the amount of organic oxygen demand pollution in water.
BOD	A measure of polluting potential - a measure of oxygen use, or demand, by bacteria breaking down the biodegradable load in wastewater treatment plants or environmental waters. It is used to indicate the quality of water.
Balance of System (BOS)	'Balance of system' refers to the components required to: • collect and filter rainwater, • pump water to the building for use, directly or via a header / break tank • switch to mains water when storage is not replenished with rainwater • generally control the system.
BRE Environmental Assessment Method	A voluntary environmental assessment method for buildings widely used by government departments and planning authorities to set whole-building environmental targets or as the basis of binding requirements for new building construction.
Carbon intensity	The quantity of carbon emissions arising per unit of useful delivered output. Examples of outputs of interest in this report are mains water (carbon intensity in $kgCO_2/m^3$ or $t.CO_2/ML$) and mains electricity (carbon intensity in

	$kgCO_2$/kWh)
Cistern	A fixed container for holding water at atmospheric pressure.
Code for Sustainable Homes	A national standard (in England and adopted by Wales) for sustainable design and construction of new homes. The Code measures the sustainability of a new home against a range of sustainability criteria including minimum standards for energy and water use in new properties.
Communities and Local Government (CLG)	The UK government department responsible for policy on local government, housing, urban regeneration, planning and fire and rescue.
Cradle to Gate	A life cycle assessment covering manufacture (‘cradle’) to the factory gate. Transport to the consumer, operational energy consumption and disposal are not included.
DECC	The English Department of Energy and Climate Change (DECC) was created in October 2008, to bring together: energy policy (previously with BERR, which is now BIS – the Department for Business, Innovation and Skills), and climate change mitigation policy (previously with Defra – the Department for Environment, Food and Rural Affairs).
Department for Environment, Food and Rural Affairs (Defra)	The government department that brings together the interests of farmers and the countryside; the environment and the rural economy; the food we eat, the air we breathe and the water we drink. Defra sponsors the Environment Agency and sets policy on flood risk management and water and environmental matters.
Future Water	The Government’s new water strategy for England, setting out the Government’s long-term vision for water and the framework for water management in England.
Gross building area/ gross internal area	For the purposes of this study, both terms correspond to the area of a building assumed to be covered by the roof. GIA is more commonly used for homes and offices, Areas for some non-domestic buildings are sometimes quoted as GBA. This report repeats the units used in source data.
Greywater	The wastewater from water-using domestic appliances and fittings excluding, kitchen sinks, washing machines, WCs and bidets. (i.e. Wastewater from showers, baths and hand basins only.)
Greenwater	Harvested rainwater or treated greywater.
Microbiological	To do with minute living beings such as bacteria.
Non-return valve	A pipe fitting that limits flow to one direction only.
Ofwat – The Water Services Regulation Authority	The body responsible for economic regulation of the privatised water and sewerage industry in England and Wales. Ofwat is primarily responsible for setting limits on the prices charged for water and sewerage services, taking into account proposed capital investment schemes (such as building new wastewater treatment works) and expected operational efficiency gains.
Run-off	Water falling on a surface but flowing into a downpipe,

	drainage channel or surface water rather than permeating the ground
Pathogen	A living organism which causes disease.
Particulates	Tiny particles.
Potable	Drinkable; fit for human consumption.
Retrofit	“Retrospective fitting”. The fitting of something onto or into an existing appliance or building in order to update it or change it.
Standard Assessment Procedure	The Standard Assessment Procedure (SAP) is the UK Government's recommended method for measuring the energy rating of residential dwellings
Sustainable Urban Drainage Systems (SuDS)	Sustainable drainage systems (previously referred to as sustainable urban drainage systems): a sequence of source control, management practices and control structures designed to drain surface water in a more sustainable fashion than some conventional techniques (may also be referred to as SuDS or SDS).
System excl. RW tank	The collection of components that typically make up a rainwater or greywater system of a particular type (excluding the variable-size rainwater tank in rainwater systems).
Treated floor area (TFA)	The floor area of a building corresponding to spaces that are heated.
Water Framework Directive (WFD)	A European Union directive which commits member states to making all water bodies (surface, estuarine and groundwater) of good qualitative and quantitative status by 2015.

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The Environment Agency. Out there, making your environment a better place.

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