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An Environmental, Economical and Feasibility Study of Green Roofs and Rainwater Harvesting Systems in Ireland.

Author

Sarah Petersen

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School of Engineering

Galway Mayo Institute of Technology (GMIT), Ireland

Supervisor

Dr. Aurora Dimache

Department of Engineering

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DECLARATION OF ORIGINALITY

September, 2011.

The substance of this thesis is the original work of the author and due reference and acknowledgement has been made, when necessary, to the work of others. No part of this thesis has been accepted for any degree and is not concurrently submitted for any other award. I declare that this thesis is my original work except where otherwise stated.

Sarah Petersen
Name of Candidate

Sarah Petersen

19 - 9 - 2011
Date

Name of Supervisor

Dr. Aurora Dimache

09.09.2011
Date

Abstract

This minor thesis is a comparative study of the environmental and economical impact of normal roofs versus green roofs, as well as an examination of the feasibility of integrating a rainwater harvesting system with a green roof.

Water is becoming more and more valuable as a resource in today's environment and society. Domestic water charges are also being re-introduced in Ireland in order to fund the high cost of treating water to drinking quality, as well as the cost of maintaining and upgrading sewerage and stormwater drainage systems around the country.

Green roofs have been installed in a number of international cities in order to harness the environmental and cost benefits they bring to urbanised areas. However, they are a relatively new sustainable build technique in Ireland. Rainwater harvesting systems are also quite uncommon in commercial and domestic buildings in Ireland. There are no government incentives for either technology in this country.

This study aims to outline the description, benefits, limitations and potential applications of green roofs, as well as rainwater harvesting systems, in Ireland.

An extensive literature review was carried out in order to acquire as objective a point of view on the topic as possible. The study begins with describing the problem of climate change; action that is being taken at various levels to combat climate change; sustainable building techniques – namely, green roofs and rainwater harvesting systems; different methodologies that are used to calculate the environmental and financial impacts of green roofs and rainwater harvesting systems – Life Cycle Assessment and Whole Life Costing.

A comparative LCA/LCCA analysis was then carried out in order to determine the environmental and financial impact of each system in the study. This study was carried out for the benefit of an Irish company, Bauder Ltd., who expressed an interest in the results of the LCA/LCCA. The author worked closely with the staff at Bauder, who provided all the normal roof and green roof technical information and images in this thesis without hesitation.

In order to carry out an accurate study, a hypothetical building on which each roof and rainwater harvesting system would be installed, was developed. The author used the Eco Indicator method to calculate, in millipoints (mPt), the environmental impact of each system. An NPV (Net Present Value) formula was used to calculate the cost of each system over the course of 70 years.

The results showed that the green roof had a lower environmental impact than the normal roof. However, the cost of the green roof was higher than the cost of manufacturing and maintaining a normal roof over the course of 70 years – the average lifespan of a building. Recommendations were then made as to which system would be most suitable for both a domestic and commercial building in Ireland.

Acknowledgements

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Finally, I would like to express my thanks to my family and friends for their continued support and encouragement throughout the MSc. and Minor Thesis.

Table of Contents

List of Figures & Tables

Chapter 1 – Introduction

1.0 Introduction

This chapter aims to describe this dissertation under the headings:

- Scope of study;
- Main aims and objectives;
- Summary.

1.1 Scope of the Study

This study is concerned with the environmental and financial impact of green roofs and rainwater harvesting systems. Green roofs and rainwater systems are both effective stormwater management solutions and have been used individually to reduce strains on local and regional stormwater drainage and sewerage systems. The author is of the opinion that both technologies could be used on a large scale in Ireland to help mitigate certain impacts associated with climate change: water scarcity, the urban heat island effect (UHI), rising energy demands, as well as the deterioration in sustainability and biodiversity.

To discover if green roofs and rainwater harvesting systems can be successful in Ireland the following steps were taken:

- Identify the main problem at hand – i.e. Climate change;
- Investigate the impacts associated with climate change;
- Research different sustainable technologies used to combat those impacts;
- Carry out further research on green roofs and rainwater harvesting systems (RHS);
- Research international green roof and RHS policies and incentives;
- Explore Irish companies who manufacture and supply green roofs and RHS;
- Look at Irish case studies;
- Acquire information from experts in the relevant fields;
- Calculate the environmental and financial impact of green roofs and RHS in an Irish context;
- Examine the feasibility of integrating the two systems and developing a new concept for the Irish market.

1.2 Aims and Objectives

The aims and objectives of the thesis are:

1. To examine the environmental and economical impact of green roofs and RHS in an Irish context;
2. To compare the impacts of the green roof with those of a normal roof;
3. To determine the feasibility of integrating a green roof with an RHS for the purpose of stormwater management;
4. To recommend the best possible system for a commercial and domestic building in Ireland;
5. To create awareness of the environmental and cost benefits of each technology.

1.3 Summary of the Thesis

The following section gives a brief outline of what the author covered in each chapter of the thesis.

Chapter Two

This chapter briefly describes the different types of research methodologies that were employed in order to complete the thesis. The author focuses on both quantitative and qualitative methods, in order to give the reader an objective view of how the research for this thesis was carried out.

Chapter Three

This chapter begins with describing the problem of climate change, and the action that is being taken at various levels to combat the inevitable effects of climate change. Following this, the discussion moves towards a description of different sustainable building techniques – namely, green roofs and rainwater harvesting systems. Finally, innovative methodologies that are being used to calculate the environmental and financial impacts of green roofs and rainwater harvesting systems – Life Cycle Assessment and Whole Life Costing - are discussed. Current research that has been carried out on the topics described above is identified. The author also identifies the gaps in the research, with the aim of the research in this study contributing some information towards the topic at hand.

Chapter Four

In this chapter, the author looks at green roofs, specifically a Sedum Blanket Extensive Green Roof – supplied and manufactured by Bauder Ltd. This type of roof has been used in the LCA/LCCA study in the thesis. The components of the roof are described in great detail, and the design considerations and proper maintenance of the roof after it has been installed have been examined. Applications of green roofs and the potential for green roofs in Ireland are also identified.

The concept of the integration of green roofs and an RHS is introduced briefly in this chapter. This leads to further research regarding the technology of rainwater harvesting. The applications, benefits and potential in the Irish market for this sustainable technology are discussed.

Chapter Five

This chapter looks at the methodologies that are used to calculate the environmental and financial impact of products and processes. In this case the author used the Eco Indicator method to carry out the LCA and the Net Present Value equation to calculate the cost of each system.

The author carried out an LCA/LCCA on the following:

1. Normal Roof;
2. Green Roof;
3. 35,400L Rainwater Storage Tank;
4. 20,000L Rainwater Storage Tank.

The results of the LCA/LCCA are represented by graphs and tables and the results of each study have been interpreted by the author.

Chapter Six

The thesis concludes with a final discussion of the wide range of topics that were outlined in the previous chapters of the thesis. Finally, recommendations for further study are made as part of the overall conclusion.

Chapter 2 – Research Methodology

2.0 Introduction

This chapter will show the author's chosen research strategy and technique. The reason for choosing the research topic, as well as the structure of research methods carried out in the thesis will be examined. The author will compare the primary research strategies of quantitative research and qualitative research and give reasons for their chosen strategy.

2.1 Reasons for the Study

The author chose to carry out research on green roofs and rainwater harvesting systems as well as life cycle assessment and life cycle cost analysis due to a particular interest in sustainable technologies. This interest stemmed from particular modules the author chose to study during the MSc. in Environmental Systems – namely Sustainable Building Construction and Life Cycle Engineering.

The concept of the integration of green roofs and rainwater harvesting systems came from a conversation the author had with a technical sales representative from Moy Materials Ltd., who had a particular interest in the idea. The author then chose to expand on this idea and carry out a feasibility study along with the environmental and economical analysis of green roofs and rainwater harvesting systems. The author could also benefit from readily available information on green roofs and rainwater harvesting systems, with the help of technical staff at Bauder Ltd. and JFC Ltd., respectively.

2.2 Research Question

Choosing a research question(s) is the main feature of both quantitative and qualitative research. In some cases this step may come before the construction of the theoretical structure of the study. In all cases, it makes the hypotheses in the thesis more specific, most of all it indicates what the researcher wants to know most and first (Empire State College, 2011).

The author has generated a list of research questions that are relevant to the topics being studied in this thesis. Here, the research topic is very general, covering a variety of subjects. However, the research questions are more specific and deal with individual points.

In this case, there are several research questions;

1. How are climate change and high levels of energy use in buildings linked to sustainable and renewable technologies?
2. Compared to normal roofs, are green roofs feasible and/or more effective for the Irish climate and society?
3. Have green roofs a lower environmental impact than normal roofs?
4. Is it feasible to integrate green roofs and rainwater harvesting technologies?
5. Would this concept be suitable for the Irish climate?
6. Is the green roof more cost-effective than the normal roof over the course of its lifespan?
7. What recommendations can be made to lower the cost of green roofs in comparison to normal roofs?
8. How can green roofs and rainwater harvesting systems individually mitigate the impacts of climate change?

The author generated these questions after carrying out initial research on the topics of climate change, green roofs, rainwater harvesting and life cycle engineering. Each question has been addressed accordingly throughout the thesis.

2.3 Qualitative versus Quantitative Research

Choosing the appropriate research strategy depends on the research to be carried out, the purpose for it and the availability of the information required (Naoum, 2006). There are two types of primary research strategies, which are quantitative research and qualitative research.

Quantitative research is an organised, impartial approach involving a large group, to produce quantifiable insights into behaviour, motivations and attitudes. It involves researching problems of a social nature, testing a theory through the use of variables, measured by numbers, and examined with statistics. Data collection techniques associated with quantitative research includes surveys using a structured questionnaire, experiments and structured observation (Naoum, 2006).

Qualitative research lacks in structure and is a more personal approach, involving a small group, used to produce insights into behaviour, incentives and outlooks, which cannot be measured. This type of research strategy emphasises description, goals and experience. Data collection techniques associated with qualitative research includes in-depth interviews, focus groups and case studies (Naoum, 2006), (Carson, 2001).

The following table summarises the distinguishing characteristics of quantitative and qualitative approaches (Leedy & Ormrod, 2010).

Question	**Quantitative**	**Qualitative**
What is the purpose of the research?	To explain and predict To confirm and validate To test theory	To describe and explain To explore and interpret To build theory
What is the nature of the research process?	Focused Known variables Established guidelines Predetermined methods Detached view	Holistic Unknown variables Flexible guidelines Emergent methods Context-bound Personal view
What is the nature of the data and how are they collected?	Numeric data Representative, large sample Standardised instruments	Textual and/or image based data Informative small sample Loosely structured or non-standardised observations and interviews
How are the data analysed?	Statistical analysis Stress on objectivity Deductive reasoning	Search for themes and categories Acknowledgment that analysis is subjective and potentially biased Inductive reasoning
How are the results communicated?	Numbers Statistics, aggregated data Formal voice, scientific style	Words Narratives, individual quotes Personal voice, literary style

Table 1: Quantitative versus qualitative research approaches

The author has chosen to use a mix of research methods for this thesis. Quantitative methods, in the form of software which calculates the environmental impact of products and processes, will be used as the main research method. However, in order to gather data for the quantitative part of the study, the author is required to use certain qualitative research methods – such as interviews with experts in the green roof and rainwater harvesting industries (telephone and face-to-face), email correspondence and extensive primary research (in order to complete the literature review).

2.4 Data Collection Techniques

Once the research approach has been selected, i.e. quantitative or qualitative research, the technique for collecting the data must be chosen. It is not necessary to select just one single approach or one single technique for collecting data. It can be a combination. The research question will dictate the best way of collecting information (Naoum, 2006).

The data collection techniques that will be discussed are: Interviews and Internet Research.

2.4.1 Interviews

The personal interview is a widely used technique of data collection. The information collected can be both objective and subjective. The interview is generally conducted face-to-face where the interviewer asks questions linked to their hypothesis. Interviews can be unstructured, structured or semi-structured but it is also possible to combine the three (Naoum, 2006).

The unstructured interview can make the participant feel as if they are simply engaging in a friendly, informal chat with the researcher. This is a very open-ended type of interview, perhaps addressing one or more central issues, but otherwise going in different directions for different participants (Leedy & Ormrod, 2010). The structured interview comprises of a specific list of questions, which all the interviewees are asked. The interviewer has control and usually begins with open-ended questions, then moving on to closed-ended questions (Naoum, 2006). In a semi-structured interview, the researcher may follow the standard questions with one or more individually tailored questions to clarify certain information or gain a deeper understanding of the person's reasoning and opinions (Leedy & Ormrod, 2010).

There are both advantages and disadvantages to personal interviews. The advantages include: factual information may be collected, the response rate is very high and the interviewer can gather more in-depth information by asking further questions. The body language and facial expressions of the person being interviewed can be read, which gives evidence of how they feel about a particular topic. Questions can be more detailed and the interviewer can re-phrase the question if it is not easily understood. People generally find it easier to give their own personal opinions and thoughts on a face-to-face basis.

The disadvantages of personal interviews are that interviews can take up a lot of time, as they require generating questions, interviewing, recording, analysing and reporting. The interviewer may have to travel to meet the interviewee which can be both time consuming and expensive. A specific disadvantage in relation to unstructured interviews is that insufficient information may be gathered in order to make fixed conclusions. It can also be difficult at times to find people who are willing to be interviewed (Naoum, 2006).

The author carried out numerous telephone and face-to-face unstructured interviews with a variety of people for research purposes. Telephone interviews are less time-consuming, and the researcher has ready access to a wider range of people around the world. Personal interviews, whether they are face to face or over the telephone, allow the researcher to clarify information and, when appropriate, seek follow-up information (Leedy & Ormrod, 2010).

The table below shows the name, profession and company of each interviewee in alphabetical order.

Name	Profession	Company	Location
Martin Bermingham	Area Manager (Connaught/Munster)	Bauder Ltd.	Carrickmacross, Co. Monaghan
Brian Conroy	Technical Sales Representative	Moy Materials Ltd.	Tallaght, Dublin
Michael Fitzpatrick	Rainwater Harvesting System Installer	RAINWATER	Menlough, Co. Galway
Dwayne Higgins	Architect	Oliver Higgins Consulting Engineers (OHCE)	Oranmore, Co. Galway
Derek McGrath	Technical Sales Representative	JFC Ltd.	Tuam, Co. Galway
Nick Ridout	Green Roof Product Manager	Bauder Ltd.	Ipswich, UK
Kieran Townes	Senior Technician (Green Roof Section)	Bauder Ltd.	Ipswich, UK
Judy Walsh	Office Manager	Bauder Ltd.	Carrickmacross, Co. Monaghan

Table 2: List of interviewees contacted during the research phase

Each interviewee offered advice on different aspects of the thesis. All interviews were conducted either via email, telephone or face-to-face. The author found each interviewee very helpful and co-operative. The author was able to contact each interviewee numerous times and was pleasantly surprised at the ease with which extra information and personal opinions could be provided for the author's study. In particular, the staff at Bauder were extremely helpful, and provided the majority of the images and information that can be found in this thesis.

Bauder Ltd has expressed an interest in the outcome of the author's LCA/LCCA study. The results of the LCA/LCCA study should benefit Bauder Ltd, in terms of showing the environmental impacts of their products as well as showing the cost of a Bauder Normal Roof/Green Roof over the lifetime of the roofs.

2.4.2 Internet Research

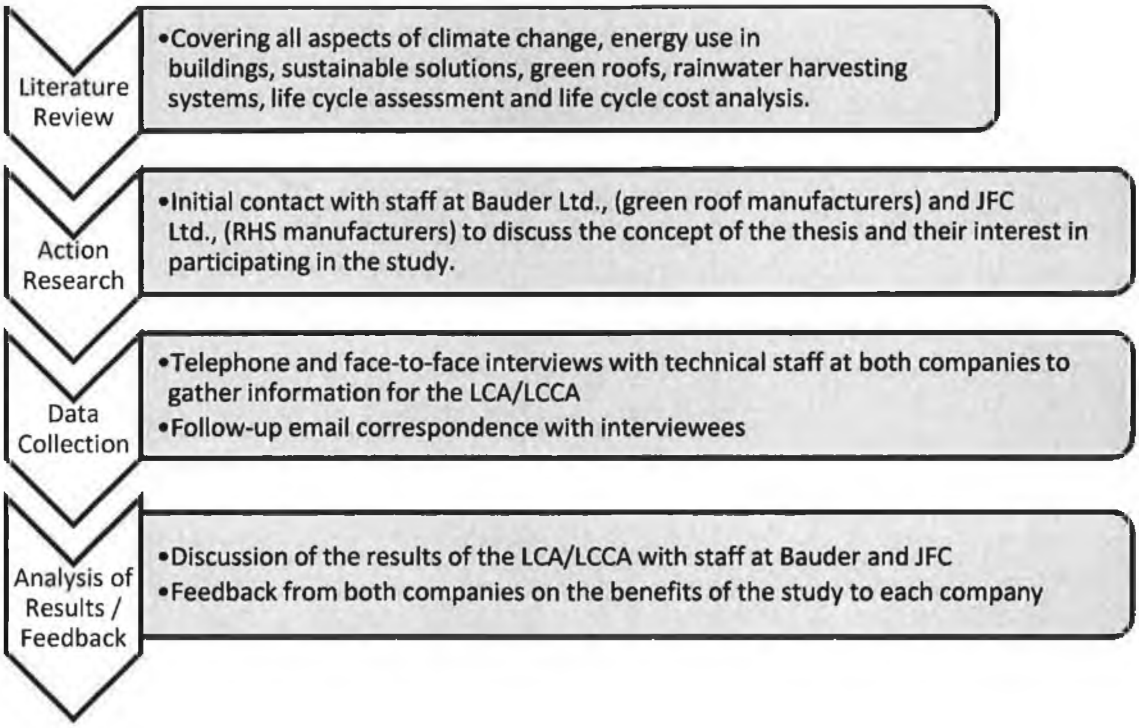
The author carried out extensive internet research at all stages of the thesis. The internet was used to source numerous scientific papers on all aspects of climate change, green construction, green roofs, rainwater harvesting systems and LCA/LCC methodologies that were necessary to carry out a full Literature Review for the thesis. The internet was also used to communicate with interviewees and other experts in the green roof and rainwater harvesting fields via email and Skype.

The author accessed databases containing reliable sources of information through the GMIT Library. A wide range of scientific journals could be accessed via the computers in the library, due to the educational license that GMIT holds. This made the research process slightly easier and more environmentally friendly for the author, as the number of scientific journals that otherwise would have needed to be photocopied or printed out was low. The internet was also used here as a research tool for the Green Roof chapter and LCA/LCC chapter in the thesis. The author used internet search engines to locate reliable sources of information (for example, from other universities in Ireland and the UK) in order to aid the research process.

All sources and websites were checked for reliability before any information was taken for research purposes. This method of data collection is very quick, efficient and beneficial for research purposes.

2.5 Structure of the Research

Figure 1 shows how the author organised the research methods that were carried out throughout the thesis. A brief summary of each section is given in each block of the table.



- Covering all aspects of climate change, energy use in buildings, sustainable solutions, green roofs, rainwater harvesting systems, life cycle assessment and life cycle cost analysis.

- Initial contact with staff at Bauder Ltd., (green roof manufacturers) and JFC Ltd., (RHS manufacturers) to discuss the concept of the thesis and their interest in participating in the study.

- Telephone and face-to-face interviews with technical staff at both companies to gather information for the LCA/LCCA
- Follow-up email correspondence with interviewees

- Discussion of the results of the LCA/LCCA with staff at Bauder and JFC
- Feedback from both companies on the benefits of the study to each company

Figure 1: Research structure

2.6 Conclusion

The author has determined the reason for choosing the research topic and identified the research question. The author has reviewed the different types of research methods available and has determined the specific research method to be used in this thesis. Several successful, semi-structured, personal interviews were carried out with a variety of professionals in the green construction industry. As well as this, extensive internet research was carried out in order to complete the literature review and subsequent chapters of this thesis.

Chapter 3 – Literature Review

3.0 Introduction

Many people have now realised that climate change is upon us. If pushed, most would probably also say that if we do not do something to change the way we live, things are likely to get worse. But few seem to have noticed firstly one of the most important points to emerge from the last few years of scientific projections; evidence suggests that the world will experience significant and potentially highly dangerous changes in climate over the next few decades, no matter what we do now (King, 2008). Secondly, whatever we do now to change our carbon and energy use habits will take several decades to have any effect (King, 2008).

Research has shown that buildings are known to consume over 50% of the overall energy used by developed countries (Roaf, 2007). As a result of this, buildings subsequently generate a huge amount of GHGs, which contribute to climate change (Roaf, 2007).

The author believes that the way in which buildings are constructed and retrofitted should be radically changed. This should be done in order to prevent future problems, in terms of pollution, water scarcity, human health and other issues. One way in which the environmental impact of buildings can be reduced is through methodologies such as green construction and green urban design. Life Cycle Assessment (LCA) can be used in co-operation with these methodologies to measure the environmental impact of buildings and their components.

The chapter continues with a brief description of climate change; one of the most significant challenges to be faced by the human race in the coming years. Measures that have been taken at international, European, national and local level will then be discussed. Following this, energy use in buildings, green construction and the use of green roofs and rainwater harvesting systems as a tool for storm water management, as well as mitigating other impacts of climate change will be examined in detail. The chapter concludes with a section describing the methodologies that can be used to measure the costs and environmental impacts of products and processes.

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The proposed outcome of this chapter is to show the above topics can be interlinked, and how, as communities and a nation as a whole, Irish people can contribute to mitigating climate change. The author will also identify potential gaps in the current research, which will be partially addressed here.

3.1 Climate Change

Climate change, in general terms, refers to any significant change in measures of climate (such as temperature, rainfall levels, or wind), which lasts for extended periods of time, (US EPA, 2009). Climate change is happening and it is mainly caused by human activity. Its impacts are beginning to be felt and will only get worse in the future unless action is taken. The solution to climate change will involve a broad array of technologies and policies—many tried and tested, and many new and innovative (Pew Center on Global Climate Change, 2011).

Climate change may result from (US EPA, 2009):

- Natural factors, such as changes in the sun's intensity or changes in the Earth's orbital path around the sun;
- Natural processes within the climate system (e.g. changes in ocean circulation);
- Human activities, which result in a change in the atmosphere's composition (e.g. burning fossil fuels) and the land surface (e.g. deforestation, reforestation, or urbanisation).

The term climate change is often used in conjunction with the term global warming, but the phrase 'climate change' is growing in preferred use to 'global warming' because it helps convey that there are changes in addition to rising temperatures (US EPA, 2009).

Global warming can be described as an average increase in the temperature of the atmosphere near the Earth's surface, which can contribute to changes in global climate patterns (US EPA, 2009). Global warming can occur as a result of a variety of causes, both from natural and human-induced activities (US EPA, 2009). GHG emissions from cars, power plants, and other human activities—rather than natural variations in climate—are the main cause of contemporary global warming. Due largely to the combustion of fossil fuels, atmospheric concentrations of carbon dioxide (CO_2), the principal human-produced GHG, are at a level that has been unmatched for at least 800,000 years (Pew Center on Global Climate Change, 2011).

The 2007 report from the Intergovernmental Panel on Climate Change (IPCC) stated that the probability of global warming being caused by human activities is greater than 90% (IPCC, 2007). The previous report, published in 2001, placed the probability at higher than 66% (Collins, 2007).

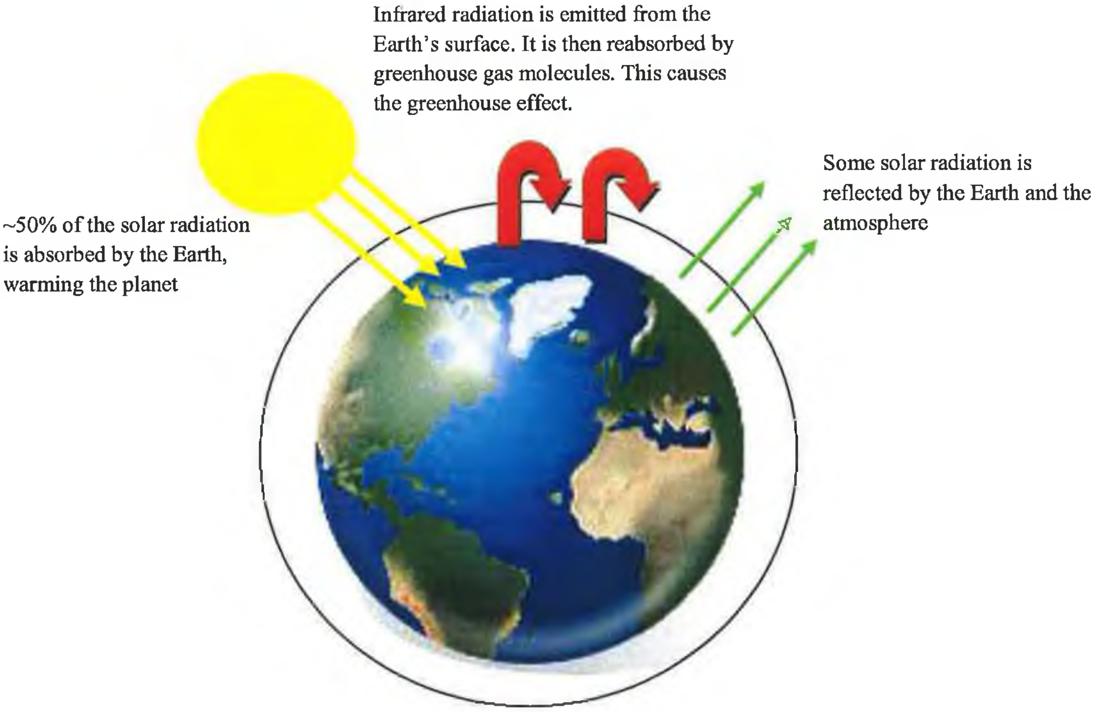


Figure 2: The Greenhouse Effect, after **(Global Greenhouse Warming, 2011).**

The greenhouse effect (Figure 2) is the natural process of the atmosphere allowing in some of the energy we receive from the sun (UV and visible light) and stopping it from being reflected back into space (as infrared radiation or heat). This makes the Earth warm enough to sustain life (Pew Center on Global Climate Change, 2011).

For several thousands of years the atmosphere has been well balanced, with quite stable levels of GHGs. Human influence has now upset that balance and, as a result, we are experiencing the negative aspects of climate change. Human activities such as burning coal, oil and gas have led to an increase in GHGs in the atmosphere. This is causing an enhanced greenhouse effect and extra warming. As a result, over the past one hundred years, there has been a steady increase in average temperatures (Pew Center on Global Climate Change, 2011). Worldwide, the ten hottest years on record have all occurred since 1997. If emissions continue to rise at current rates, CO_2 concentration in the atmosphere is likely to reach levels that are double the pre-industrial levels by the year 2050 (MET Office UK, 2009). Unless we take action to reduce emissions, global temperature could rise as much as 7°C above pre-industrial temperatures by the end of the century and push many of the world's great ecosystems (such as coral reefs and rainforests) past their "tipping point" and into irreversible decline (Pew Center on Global Climate Change, 2011).

Even if global temperatures rise by only 2°C it would mean that 20–30% of species, both flora and fauna, could face extinction (MET Office UK, 2009). We can expect detrimental effects on the global environment, food and water supplies, and health.

The main GHG responsible for recent climate change is carbon dioxide (CO_2). This has been released in huge quantities by our modern and industrial way of life. Levels have also risen as a result of the destruction of rainforests, which play an important role in absorbing CO_2 (Pew Center on Global Climate Change, 2011).

Human activities are also leading to increases in other GHGs, such as methane and nitrous oxide. Methane is produced by bacteria that are common in landfill sites, peat bogs and the guts of animals like cows and sheep. Nitrous oxide levels are raised through the use of nitrogen fertiliser in agriculture (MET Office UK, 2009).

Both of these gases have a powerful greenhouse effect. They also make a contribution towards the effects climate change. However, they have not been released in such large quantities as CO_2. The only positive aspect is that methane does not last as long as carbon dioxide does in the atmosphere. So, while they notably contribute to climate change, it is man-made CO_2 which has the greatest influence (MET Office UK, 2009).

Although further changes in the world's climate are now inevitable, the future - especially in the longer term, remains largely in our hands - the magnitude of expected change depends on what humans choose to do about GHG emissions.

The human race can respond to climate change in two ways: *adaptation* and *mitigation*. Adaptation means learning how to survive and progress in a warmer world. Mitigation means limiting the extent of future warming by taking serious action in order to reduce the net release of GHGs to the atmosphere (Pew Center on Global Climate Change, 2011). Given that temperatures have already risen, and that a continual increase would be overwhelming for the planet as a whole, a strong combination of both adaptation and mitigation measures will be essential in the fight against climate change (Collins, 2007).

3.1.1 Energy use in Buildings

Buildings are responsible for more than 40% of global energy use and one third of global GHG emissions, both in developed and developing countries (Mendler, 2005). However, the construction industry also has the largest potential for delivering long-term, significant and cost-effective solutions for reducing GHG emissions.

Buildings have a relatively long lifespan, and therefore actions that are taken now will continue to affect their levels of GHG emissions over the medium-term. Most developed countries and many developing countries have already taken steps towards reducing GHG emissions from the building sector. However, this action has had a limited impact on actual emission levels. This is due to a number of barriers which display the nature of the sector, such as the fact that there are many small reduction opportunities spread across an extensive amount of buildings.

To overcome these barriers, governments must lead the way by prioritising the building sector in their national climate change strategies and putting in place a number of hypothetical "building blocks". With these "building blocks" in place, governments would be in a good position to develop and design appropriate policies which will help to reduce emissions from the construction of new and existing buildings.

There are four main policy targets (Mendler, 2005):

- Increase the energy efficiency of buildings and appliances;
- Encourage energy companies to support emission reductions in the building sector;
- Change attitudes and behaviour towards energy consumption;
- Promote the substitution of fossil fuels with renewable sources of energy.

Reducing emissions from buildings will bring multiple benefits to both the economy and to society (Mendler, 2005).

The potential for energy savings and associated reduction in CO_2 emissions in this sector is huge. Economically feasible strategies in certain countries currently exist to reduce the amounts of energy use in new and existing buildings by approximately 50% (Mendler, 2005). Leading edge projects are even showing the potential for zero energy buildings. As well as this, building solutions for energy efficiency and CO_2 emissions reduction can provide benefits throughout the entire lifespan of the building. Building materials, products and design process tools are now available to allow a relatively smooth transition to more energy efficient buildings and communities (Mendler, 2005).

Key points that need to be recognised in relation to energy use in buildings (UNEP, 2009):

- The building sector has the highest potential for delivering significant and cost-effective GHG emission reductions;
- Countries will not be able to meet emission reduction targets without supporting energy efficiency gains in the building sector;
- Proven policies, technologies and knowledge already exist to deliver considerable reductions in building-related GHG emissions;
- Significant co-benefits including employment will be created by policies that encourage energy efficient and low-emission building activity;
- Failure to encourage energy-efficiency and low-carbon when constructing new buildings or retrofitting existing buildings will leave countries to deal with the effects of poor performing buildings for decades.

3.1.2 Climate Change Impacts

Scientists can now say, without must hesitation, that the earth is warming (Pew Center on Global Climate Change, 2011). Natural variations in climate cannot solely explain this trend. Human activities, especially the burning of coal, oil and other fossil fuels, have warmed the earth by dramatically increasing the concentrations of heat-trapping gases in the atmosphere. The greater amount of GHGs that humans emit into the atmosphere, the more the earth will warm in future decades and centuries. The impacts of warming can already be seen in many places, from rising sea levels to melting snow and ice, to changing weather patterns. Climate change is already affecting ecosystems, freshwater supplies, and human health. Although climate change cannot be avoided entirely, the most severe impacts of climate change can be avoided by substantially reducing the amount of GHGs being released into the atmosphere. However, the time available for beginning serious action to sidestep severe global consequences is growing short (Pew Center on Global Climate Change, 2011).

Extreme Weather Events

Extreme weather events have become more common in recent years, and this trend is predicted to continue in the future. Climate change has a significant effect on local weather patterns and, in turn, these changes can have serious impacts on human societies and the natural world (Pew Center on Global Climate Change, 2011).

Stronger Hurricanes

Scientists have verified that hurricanes are becoming more extreme. Since hurricanes draw their strength from the heat in ocean surface waters, hurricanes have the potential to become more powerful as the water warms (Pew Center on Global Climate Change, 2011).

Hotter, Wetter Extremes

Meteorological data has shown that average temperatures are rising, but extreme temperatures are rising even more. In recent decades, hot days and nights have grown more frequent and cold days and nights less frequent. There have been more successive heat waves and hotter high temperature extremes.

Figure 3: Flash flooding in Co. Galway, Ireland 2010 © www.nuachtchlair.com

More rain is falling in extreme events now compared to 50 years ago, resulting in more common flash flooding events. Figure 3 shows the extreme floods that occurred in Co. Galway in 2010, which resulted in extensive damage to houses and infrastructure, as well as significant costs for repair and reconstruction.

In 2003, Europe experienced a heat-wave which was so hot and so long that scientists estimated that such an extreme event had not occurred there in at least 500 years. That heat wave caused more than 30,000 deaths throughout southern and central Europe (Pew Center on Global Climate Change, 2011).

Impacts on Human Health

Climate change is expected to affect human health directly—from heat waves, floods, and storms—and indirectly—by increasing smog, pollution and ozone levels in cities, contributing to the spread of infectious diseases, and reducing the accessibility and quality of food and water (Pew Center on Global Climate Change, 2011).

Impacts on Ecosystems

Climate change is threatening ecosystems around the world, which is affecting plants and animals on land, in oceans, and in freshwater lakes and rivers. Some ecosystems are particularly at risk, including: the Arctic and sub-Arctic regions - because they are sensitive to temperature and most likely to experience the greatest level of warming; coral reefs - because they are sensitive to increased water temperatures and the acidity of the ocean, both of which are rising with increases in atmospheric CO_2 levels; and tropical rainforests - because they are sensitive to minor changes in temperature and precipitation. Evidence exists which shows that the recent warming trend is already having an effect on the planet's ecosystems. Entire ecosystems are shifting toward the north and south poles and to higher altitudes. This presents unique challenges to species that already live at the poles, like polar bears, as well as mountain-dwelling species already living at high altitudes. Spring events, like the budding of leaves and bird migrations, are taking place earlier in the year. The risks to species increase with rising temperatures; scientists say that an additional 2°C of warming will increase the risk of extinction for up to 30% of species (Pew Center on Global Climate Change, 2011).

Impacts on Global Water Resources

Water is not only necessary for biological life; it plays a major role in our cities, economy, industry, and agriculture (Droege, 2010). Water shortage is quickly becoming one of the largest problems in the world today. Freshwater resources are becoming more polluted and supplies are being exhausted around the world. This is an ongoing danger to sustainable development and human health (Li, Boyle, & Reynolds, 2010). Climate change will modify the amount and quality of fresh water supplies as well as increase the frequency and duration of floods, droughts, and heavy rainfall events. Although climate change will affect different regions in unique ways, it is generally expected that arid regions of the world will get drier and wet regions will get wetter (Pew Center on Global Climate Change, 2011). Climate change is predicted to increase the number of heavy rainfall events around the world (Intergovernmental Panel on Climate Change, 2007). Urbanising land use generally increases the amount of water-resistant surface area. As a result, the local hydrology is changed by affecting run-off, evaporation and recharge rates (Droege, 2010).

These negative effects can be mitigated through smart design which takes inspiration from nature and works with natural processes. Designing projects that use new technologies and concepts which collect and treat water, as well as reuse it, help to protect and sustain one of the world's most precious resources (Droege, 2010).

Climate change is also predicted to increase water supply problems that are already occurring around the world. Designing to increase infiltration and recharge groundwater supply as well as sufficient storm water management practices, is necessary to adapt to and mitigate the water stress caused by climate change (Droege, 2010).

Urbanisation and high consumption levels contribute to the shortage in water and energy resources. As a result, the significance of their sustainable use grows. Climate change will raise the pressure that is already being applied on these resources. As populations and temperatures continue to grow, more water and energy will be in demand (Colombo, 2003).

The challenges and effects of climate change will only result in an increasing global demand for water resources. Therefore, there will be a greater need for a type of design that creates environmental, economic, social and aesthetic value at the same time (Droege, 2010).

The author will examine the potential role of a green roof and rainwater harvesting system unit as a tool for storm water management, thus having a positive effect on climate change impacts.

3.2 Dealing with Climate Change

Climate change is a global problem, which therefore requires a global response. Discussions regarding action against climate change must move away from non-binding agreements and focus on concrete commitments. This section outlines the policies and proposed actions of international, European and national bodies.

3.2.1 International Agreements

The Kyoto Protocol

The EU has been a driving force in international conferences that led to agreements on two United Nations climate treaties, the UN Framework Convention on Climate Change (UNFCCC) in 1992 and the Kyoto Protocol in 1997 (European Commission, 2010). The UNFCCC is an international environmental treaty which has an aim to achieve "stabilisation of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system," (UNFCCC , 1992). The objective of the Kyoto Protocol is to dramatically reduce GHG emissions in order to slow down and mitigate climate change. The objective of the Kyoto climate change conference was to establish a legally binding international agreement, whereby all the participating nations would agree to tackling the issue of global warming and reducing their individual GHG emissions. The target agreed upon was an average reduction of 5.2% from 1990 levels by the year 2012. The Protocol expires at the end of 2012 (UNFCCC, 2009).

Post-Kyoto Agreements:

Two further international climate change conferences were held in Copenhagen in 2009 and Cancún in 2010. A framework for climate change mitigation beyond 2012 was to be agreed there (Flannery, 2009). In both cases, the conclusion that was reached was an agreement, though not a binding treaty. It recognises that climate change represents an urgent and potentially irreversible threat to human societies and the planet. The agreement calls on rich countries to reduce their GHG emissions as pledged in previous conferences, as well as for developing countries to plan to reduce their emissions (UNFCCC, 2010).

3.2.2 EU Action

The European Union is showing the way forward through climate change mitigation and adaptation strategies and policies that are currently being put into practice. Combating climate change is a top priority for the EU. Europe is working hard to cut its GHG emissions substantially while encouraging other nations and regions to do the same. Over the past two decades, emissions have been reduced by 16%, whereas the economy has grown by 40% over the same period. If current policies are fully implemented, the EU is on the right path to achieving its targets for 2020 of reducing emissions to 20% below 1990 levels and raising the share of renewable resources in its energy mix to 20% (European Commission, 2010).

At the same time, the EU is developing a strategy for adapting to the adverse effects of climate change that can no longer be avoided. Action against climate change carries a cost, but doing nothing will be far more expensive in the long run. Furthermore, investing in the green technologies that reduce emissions on a large scale will also create jobs and boost the European economy (European Commission, 2010).

Roadmap to 2050

If the EU makes the transition to a low-carbon society by 2050 we will live and work in low-energy and low-emission buildings, with intelligent heating and cooling systems. We will drive electric and hybrid cars and inhabit cleaner cities with lower levels of air pollution and improved public transport. The transition would give Europe's economy a boost thanks to increased investment in clean technologies and clean energy. Europe could dramatically reduce emissions and reduce consumption of key natural resources such as oil, gas, raw materials, land and water (European Commission, 2011).

A low-carbon economy would have a higher need for renewable sources of energy, energy-efficient building materials, more efficient cars, 'smart grid' equipment, low-carbon power generation, as well as carbon capture and storage technologies. To make a smooth transition to a low-carbon economy and to realise benefits such as a lower oil bill, an additional €270 billion or 1.5% of the EU GDP would need to be invested annually, on average, over the next forty years. The extra investments would stimulate growth in a broad range of manufacturing divisions and environmental services in Europe. By increasing the rate of climate action, 1.5 million additional jobs could be created across Europe by 2020 (European Commission, 2011).

The chief driver for this transition will be energy efficiency. By 2050, the energy sector, households and business could potentially reduce energy consumption levels by approximately 30% compared to 2005, while at the same time enjoying more and better energy services. Locally produced energy from renewable sources would be used more frequently. As a result, the EU would be less reliant on costly imports of oil and gas from outside the EU and European economies would be less sensitive to increasing oil prices. The EU could potentially save € 175 - 320 billion per year on fuel costs over the next forty years (European Commission, 2011).

Initiatives that have been taken to reduce GHG emissions include (European Commission, 2010):

- Constantly improving the energy efficiency of a wide range of products and processes;
- Promoting the increased use of renewable energy sources, such as wind, solar, hydro and biomass, and of renewable transport fuels, such as bio-fuels;
- Supporting the development of carbon capture and storage (CCS) technologies which trap and store CO_2 emitted by power stations and other fossil fuel burning industries.

20/20/20 by 2020 - Europe

In 2007, the European Council adopted impressive energy and climate change objectives for 2020 – to reduce GHG emissions by 20%, rising to 30% if the conditions are right, to increase the share of renewable energy to 20%, and to make a 20% improvement in energy efficiency across the continent. The European Council has also proposed a long-term commitment to decarbonisation strategies with a target for the EU and other industrialised countries of 80 - 95% reductions in emissions by 2050 (EUROPA, 2007).

Reducing energy consumption by 20% by 2020 is the objective the EU has set itself in its Action Plan for Energy Efficiency (2007-2012). Constant efforts need to be made to accomplish this objective, in relation to: energy saving measures in the transport sector; the development of minimum efficiency requirements for appliances that consume energy; creating awareness among consumers about efficient and cost-effective energy use; improving the performance of the production, transport and distribution of heating and electricity and also developing innovative energy technologies as well as improving the energy performance of buildings (EUROPA, 2007).

3.2.3 National Action - Ireland

Ireland's climate change and energy policy priorities are structured in the context of the European Union (DCENR, 2007).

Under the Kyoto Protocol Ireland agreed to a target of limiting its GHG emissions to 13% above 1990 levels by the end of the four year period between 2008 and 2012 as part of its contribution to the overall EU target. Ireland ratified the Kyoto Protocol on the 31 May 2002, along with the EU and all other Member States, and is internationally legally bound to meet the challenging GHG emissions reduction target. A National Climate Change Strategy was drawn up for Ireland for the period between 2007 and 2012. This plan sets out a variety of measures, building on those already in place under the first National Climate Change Strategy (2000) to ensure that Ireland reaches its target under the Kyoto Protocol. The Strategy provides a framework for action to reduce Ireland's national GHG emissions (Dept of Environment, Heritage and Local Government, 2007).

The purpose of this Strategy is twofold:

- To display the measures by which Ireland will meet its 2007-2012 commitment;
- To show how these measures place Ireland for the post-2012 period, and to distinguish the areas in which further measures are being researched and developed to allow for a 2020 commitment.

The Irish government released a "White Paper" in March 2007 – *"Delivering a Sustainable Energy Future for Ireland".* This paper sets out a national energy policy framework for the years 2007 to 2020. The strategic goals of the paper discuss security of supply, energy sustainability and competitiveness of energy supply (IEA, 2010).

Maximising Ireland's Energy Efficiency - The National Energy Efficiency Action Plan 2009 – 2020 was published on 8 May 2009. This Government policy document describes plans and actions to achieve a target of 20% energy efficiency savings across the Irish economy in 2020 (Department of Communications, Energy and Natural Resources , 2009).

Energy efficiency-related actions include (IEA, 2010):

- Achieving 20% savings in energy across electricity, transport and heating sectors by 2020;
- Promoting the application of the Irish Standard for Energy Management in all workplaces and encouraging its operation in small and medium sized enterprises;
- Updating national building regulations with the objective of modifying existing regulations in 2008, including a reduction in energy demand by 40% relative to the current standards;
- Extending the existing Building Energy Rating on new dwellings to non-domestic buildings from 1 July 2008;
- Setting a target of 33% for energy savings across the public sector;
- Achieving a level of green procurement by 2010 that is equal on average to that of the best performers in Europe.

3.2.4 Action at business/company level

Certain measures can be taken by businesses and companies at a local level in response to international and national mitigation measures.

Mitigation measures include:

- Energy Management Systems (EnMS);
- Design for the Environment (DfE);
- Biomimicry;
- Water Conservation/Management;
- Green construction and green urban design.

The first three measures will be briefly discussed. More focus will be placed on the use of green roofs as a form of storm water management and green construction.

One of the main subjects of the thesis to follow will concern how green roofs can be used in Ireland to contribute to climate change adaptation measures.

A brief section linking green roofs to rainwater harvesting systems, in terms of stormwater management will also be discussed.

The author is particularly interested in examining the environmental impact of green roofs and rainwater harvesting systems in an Irish context.

Energy Management Systems (EnMS)

An Energy Management System (EnMS) is an efficient process for constantly improving energy performance. It is suitable for all organisations, regardless of size or sector, but is particularly beneficial where energy-intensive processes are being carried out (SEAI, 2009) Setting up an EnMS in any company requires the following measures to be carried out, shown on the following page in Figure 4.

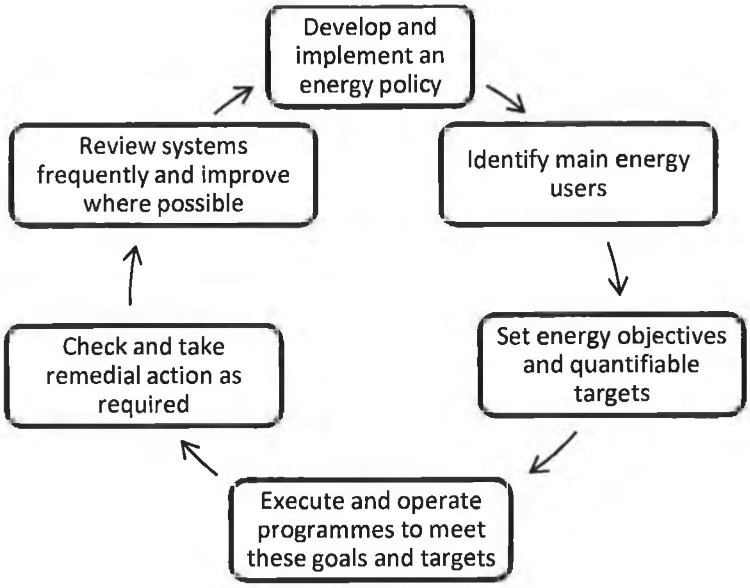


Figure 4: Setting up an EnMS, after **(SEAI, 2009)**

Constant improvement, which is a key feature of the standard, ensures that businesses and companies remain alert for new opportunities as they arise and utilise all areas where energy savings can be achieved.

The main benefits of an EnMS are that it (SEAI, 2009):

- Incorporates best-practice energy management in day-to-day operations;
- Improves performance and production;
- Reduces energy costs;
- Warrants a process of constant improvement is sustained;
- Ensures that senior managers agree with improving energy efficiency and that all staff play a part in the process;
- Helps businesses fulfil energy-efficiency and emission-reduction requirements;
- Standardises processes so that improvements are prolonged.

Design for Environment (DfE)

Design for environment (DfE) acts as a base for the integration of environmental aspects in design, and development processes of products and product systems.

DfE is based on life cycle assessment data. It allows for the environmental study of design alterations and further development of products at an early stage.

DfE can also be referred to as Ecodesign (Fraunhofer Institute for Building Physics, 2009).

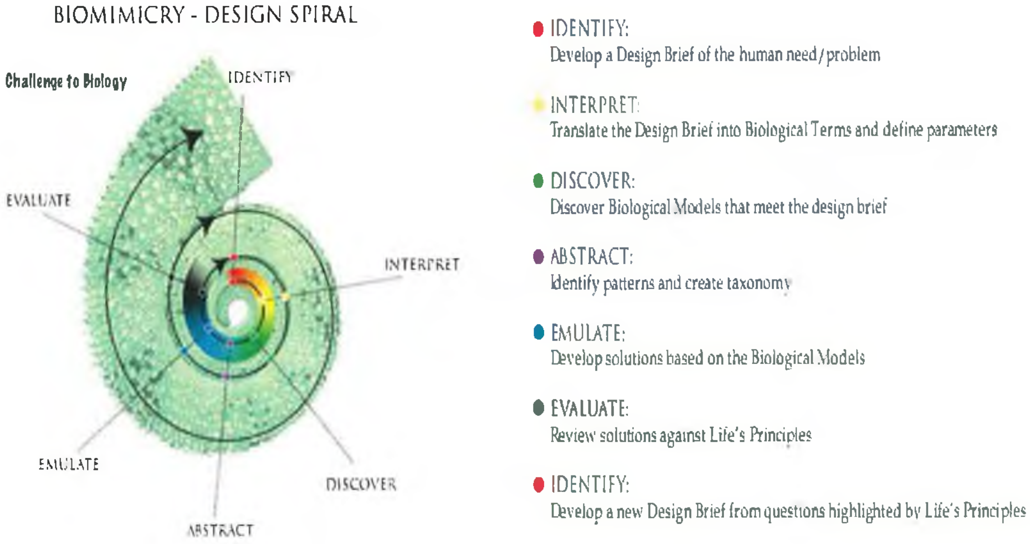
Figure 5: DfE/EcoDesign concepts, after **(European Commission - JRC, 2010)**

DfE/Ecodesign is the method of integrating various environmental considerations at the early stages of the design of products (or services). The aim is to examine different innovative design methodologies and alternatives in order to lessen the environmental impacts of products and services throughout their life cycle. This can be seen in Figure 5.

In terms of technical, economical and ecological needs (e.g. material selection and feasibility), the most suitable design choices are looked at (Fraunhofer Institute for Building Physics, 2009).

Biomimicry

Biomimicry entails looking at nature in new ways to fully realise and understand how it can be used to help solve problems. This is shown in Figure 6 below.



● IDENTIFY:
Develop a Design Brief of the human need/problem

● INTERPRET:
Translate the Design Brief into Biological Terms and define parameters

● DISCOVER:
Discover Biological Models that meet the design brief

● ABSTRACT:
Identify patterns and create taxonomy

● EMULATE:
Develop solutions based on the Biological Models

● EVALUATE:
Review solutions against Life's Principles

● IDENTIFY:
Develop a new Design Brief from questions highlighted by Life's Principles

Figure 6: Biomimicry Design Spiral **(Wikid, 2011)**

This is achieved by looking at nature as a model, measure and mentor (DesignBoom, 2010):

- *Nature as a model* means imitating nature's forms, processes and systems to solve human problems; this is the act of biomimicry.
- *Nature as a measure* means weighing up our designs and solutions against those of nature. This involves asking whether current methods are as efficient, simple and sustainable as those found in nature.
- *Nature as a mentor* implies a change in our relationship to nature. Instead of acting like there is a separation of humans from nature, humans need to accept that they are part of it and should be caring for nature in a proper way.

Application of biomimicry in design can be carried out in two ways, progressing from design to nature or going from nature to design. The design to nature approach works by identifying a design problem and turning to nature for a similar problem and solution. This approach is valuable to designers who might be looking for inspiration for new designs (DesignBoom, 2010).

Water Conservation/Management

On a global scale, climate change will alter the quantity and quality of available fresh water and increase the number and length of floods, droughts, and heavy rainfall events. Warmer temperatures threaten the water supplies of millions of people who depend on water from the seasonal snowmelt in several ways. In the long term, the loss of these frozen water reserves will significantly reduce the water available for humans, agriculture, and energy production. Climate change will affect the quality of drinking water and affect public health. As sea level rises, saltwater will infiltrate coastal freshwater resources. Flooding and heavy rainfall may overwhelm local water infrastructure and increase the level of sediment and contaminants in the water supply. Increased rainfall could also wash more agricultural fertiliser and municipal sewage into coastal waters (Pew Center on Global Climate Change, 2011).

On a more national and local scale, Ireland has plenty of available water resources due to high rainfall levels. Most of the eastern half of the country receives between 750-1000mm of annual rainfall, while the amounts generally average between 1000-1250mm in the west (Met Eireann, 2011). However, water scarcity will be one of the main problems that will need to be dealt with in Ireland in the near future. Water demand has been constantly on the rise due to population growth, higher standard of living and climate change. As a result, water shortages are predicted to occur in Ireland within the next decade. The quality of water in many Irish water resources has declined in recent decades due to climate change and human activities (Li, Boyle, & Reynolds, 2010).

Projects that use technologies which collect, treat and reuse water will minimise flooding risk, help manage and prevent droughts, advocate biodiversity, provide recreational spaces, sequester carbon and save energy (Droege, 2010).

Rainwater harvesting is an example of a concept that can contribute to the solutions listed above. Rainwater offers a sustainable, environmental alternative to purified drinking water for non-potable applications. Collecting rain from a catchment area, such as a roof, also lessens the amount of surface water run-off from domestic and commercial buildings and offers an efficient storm water solution (Bord na Mona, 2010).

The use of rainwater harvesting systems can considerably lower the levels of demand for water from the public water supply. These systems can be part of the solution for tackling water shortage issues in Ireland, as well as playing a major role in sustainable development (Li, Boyle, & Reynolds, 2010). Figure 7 below shows some of the benefits that can be associated with the installation of a rainwater harvesting system on either a commercial or domestic building.

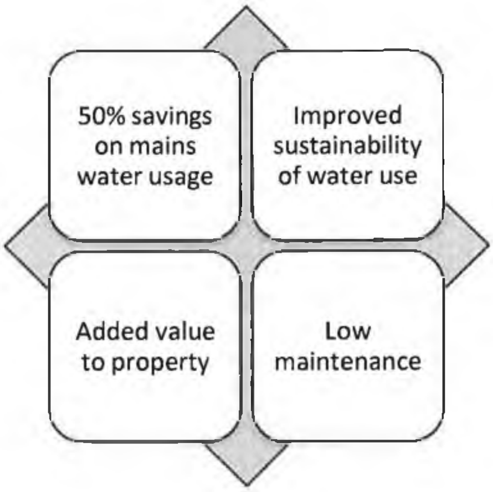


Figure 7: Advantages of Rainwater Harvesting, after **(Bord na Mona, 2010)**

There is talk of the re-introduction of domestic water charges in Ireland by 2014. This could have a considerable impact on the adoption of domestic water systems in Ireland. Reducing the use of mains water through rainwater harvesting systems will also lower the cost of providing a mains water supply by the Irish government. Therefore, it is necessary to draw up plans for financial incentives and government support which will encourage Irish businesses and householders to install these water systems (Li, Boyle, & Reynolds, 2010).

Irish communities and businesses face future uncertainties in water supplies, caused by a combination of higher levels of demand for water, population growth and climate change. There is also a possibility that commercial water charges could increase in price in the future. By preserving the water environment and sustainably managing water resources, this will have environmental, social and economic benefits (Droege, 2010).

Green Construction

Green construction is the method of creating structures and using processes that are environmentally friendly and resource-efficient throughout a building's life-cycle from choosing the site to design, construction, operation, maintenance, refurbishment and disassembly.

This procedure develops and matches the classical building design concerns of economy, value, resilience, and comfort. Green construction can also be described as a sustainable or high-performance construction (US EPA, 2010).

Green buildings are designed to lower the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources;
- Protecting the health of the occupants and improving employee productivity;
- Reducing waste, pollution and environmental deterioration.

For example, green buildings may include sustainable materials in their construction (e.g., reused, recycled-content, or materials that are made from renewable resources); create healthy indoor environments with very low levels of pollutants (e.g., low-emission products, low-toxicity materials); and/or landscape features that reduce the need for excessive water usage (e.g., by using native plants that can survive without extra watering) (US EPA, 2010).

The built environment has a large impact on the natural environment, human health, and the economy. Green construction methods can be incorporated into buildings at any stage, from design and construction, to renovation and deconstruction. However, the most significant benefits can be obtained if the design and construction team takes a combined approach from the earliest stages of a building project.

Potential benefits of green building are shown in Table 3.

Environmental	**Economic**	**Social**
Improve and preserve biodiversity and ecosystems	Reduced operating costs	Raise comfort and health levels of occupants
Increase the quality of air and water	Create, build up, and influence markets for green products and services	Accentuate visual qualities
Lower waste stream levels	Improve productivity levels of occupants	Reduce pressure on local infrastructure
Protect and sustain natural resources	Optimise life-cycle financial performance	Improve overall quality of life

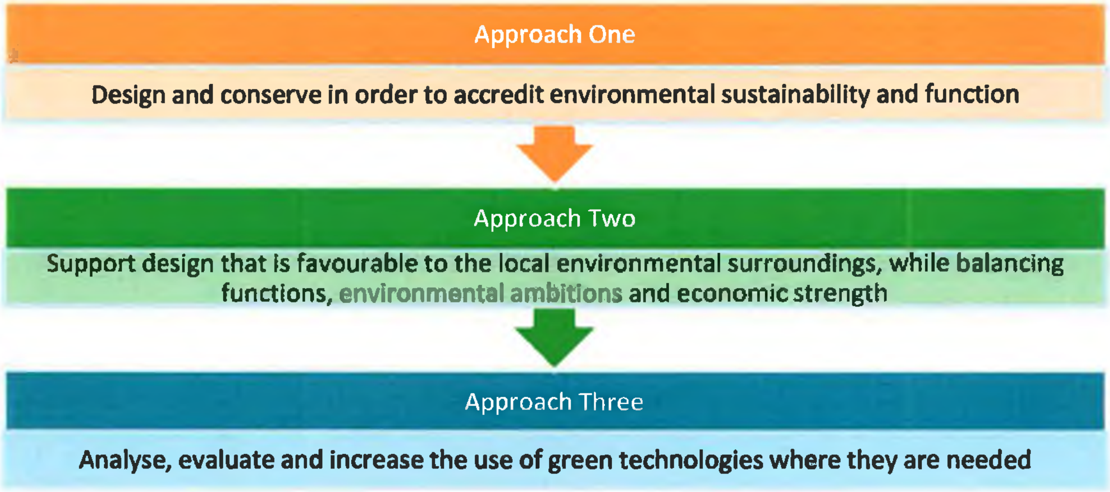
Table 3: Benefits of green building practices, after (US EPA, 2010)

Green Urban Design

Green Urban Design (GUD) includes all the external elements of a building from the building envelope, or skin, to the street, including roofs, facades, landscapes, open spaces, parkways, driveways, footpaths, alleys and roadways. It is described as those elements that are exposed to the environment and that have an effect on the environment.

Green urban design is a powerful tool, used to influence and improve cities, while at the same time, reducing their impact on the environment.

Figure 8 shows three approaches that the government can take to encourage sustainability:



Approach One

Design and conserve in order to accredit environmental sustainability and function

Approach Two

Support design that is favourable to the local environmental surroundings, while balancing functions, environmental ambitions and economic strength

Approach Three

Analyse, evaluate and increase the use of green technologies where they are needed

Figure 8: Potential government measures to encourage sustainability, after (City of Chicago, 2008)

A design methodology which has been put into action in countries around Europe for the last few decades is the green roof: a type of green construction and urban design. The author has a particular interest in the area of green roofs. Other green construction methodologies have been extensively researched, developed and applied, but green roof construction is a relatively new concept, particularly in Ireland. This area will be further explored in the author's research, which will be described later in this paper.

3.3 Green Roofs

A green roof is basically a vegetative layer grown on a rooftop. In the same way as trees and other plant act by providing shade for surfaces and removing heat from the air through a process called evapotranspiration so does vegetation act on a green roof. These two procedures reduce temperatures of roof surfaces as well that of the surrounding air. The surface of a vegetated rooftop can be cooler than the ambient air, whereas conventional roof surfaces can exceed ambient air temperatures by up to 50°C (US EPA, 2010).

Green roofs can be installed on a variety of buildings, including industrial, educational, and government facilities; office buildings; other commercial property; and even domestic houses (US EPA, 2010).

The performance of green roofs can make a significant contribution towards meeting the challenge of sustainable development by (CIRIA, 2009):

- Offering engineered solutions to stormwater management;
- Contributing to climate change mitigation and adaptation;
- Demonstrating a landscape which expresses the biodiversity and individuality of the area.

Extensive environmental and social benefits also result from the operation of green roofs, including probable improvements in amenity and health (psychological and physiological) (CIRIA, 2009).

The use of green roofs could potentially play an important role in mitigating the effects of buildings on the climate, and also helping to adapt buildings to the oncoming impacts of climate change.

Green roofs can contribute in the following ways (CIRIA, 2009):

- *Green roofs and energy transfer* – the insulating effect of a green roof can help to reduce the transfer of heat between the external and internal environment or vice versa. This can reduce interior heating and cooling costs;
- *The urban heat island effect* – the reduction in roof surface temperatures can help to reduce the impacts of the urban heat island effect, which is likely to be increasingly more common in a warming climate.

The positive impacts of green roofs on the environment will be further discussed in a later section of the thesis.

3.3.1 Green Roof Types

There are four types of green roof, which will be discussed briefly in this section of the thesis. A more detailed description of the various types of green roofs will be discussed in Chapter Four of the thesis.

Extensive Green Roof

For the more basic, light-weight extensive green roof system, the plants that are usually chosen include sedums—succulent, sturdy plants—and other vegetation generally suitable for an alpine environment. The idea is to design an unrefined green roof that needs little maintenance or human interference once it is installed. Plants that have acclimatised to extreme climates are often a good choice and may not require constant watering systems. Due to the fact that extensive roofs are quite light-weight, they will only need the lowest level of added structural support, which improves their cost-effectiveness when retrofitting an existing structure (US EPA, 2010).

Biodiverse Roof

A biodiverse roof is similar in build-up to an extensive roof. However, it is designed specifically to create a habitat that will attract certain types of flora and fauna; whether imitating the original footprint of the building or enhancing the previous habitat. Biodiverse roofs can include a type of roof called a brown roof, which is a non-vegetated version. The growing medium is selected with the objective that native species of flora and fauna will inhabit the roof and thrive over a period of time. This enhances and increases the local biodiversity (NFRC, 2011).

Semi-Intensive Green Roof

This is an "in-between" type of green roof that can be made up of features of both extensive and intensive roofs. Typically needing a depth of substrate between 100-200 mm, a wider range of plants can be used, compared to extensive roofs, including shrubs and woody plants. The need for irrigation and maintenance depends on the plant species that have been chosen (NFRC, 2011).

Intensive Green Roof

An intensive green roof can be likened to a conventional garden, or park. There is almost an unlimited choice on type of available plants, including large trees and shrubs. Building owners or managers often install these roofs to save energy and offer a garden environment for the enjoyment of the occupants of the building, as well as the general public. In comparison to extensive green roofs, intensive green roofs are much heavier and require a higher initial investment and higher levels of maintenance over the long term. They generally require greater structural support in order to comply with the weight of the additional growing medium and public use. Intensive systems also require a watering system and routine, which can use rainwater captured from the roof or another source (US EPA, 2010).

3.3.2 Benefits of Green Roofs

Green roofs are one of the most easily available sustainable technologies to the construction industry. They can be included as part of new construction projects and (subject to structural testing), retro-fitted to existing buildings to provide the following benefits to the occupants of buildings, as well as the local environment (NFRC, 2011).

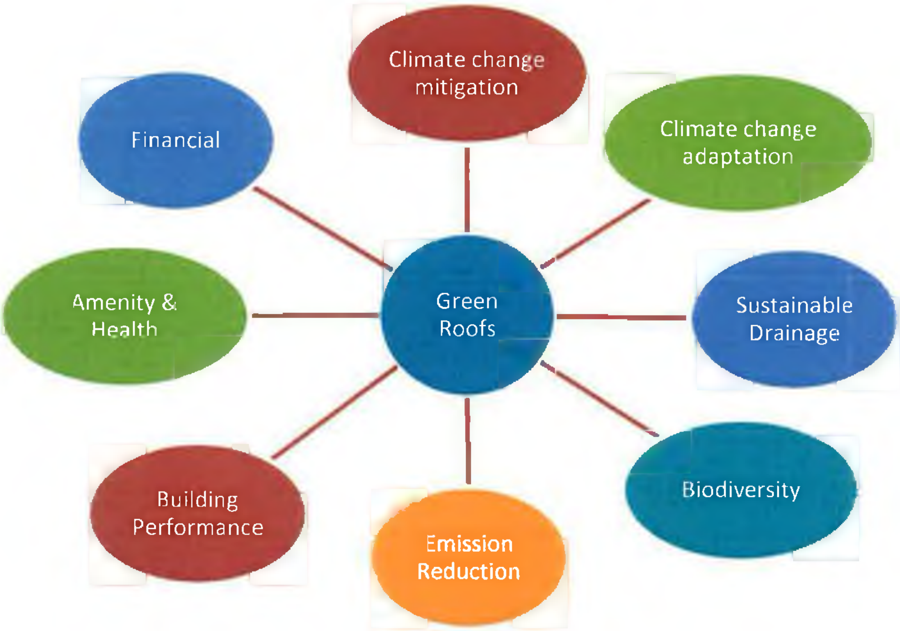


***Figure 9: Green roof benefit schematic – after* (Dublin County Council, 2008).**

Figure 9 shows the various benefits that can be attributed to the use of green roofs in the construction industry. These benefits will now be described in greater detail below.

Climate change mitigation and adaptation

As the impacts of human activities on the global climate are becoming better understood, more attention is being paid to the need to mitigate climate change by taking actions to reduce GHG emissions, and to adapt to accommodate the consequences of a warming climate.

The use of green roofs has the potential to contribute to both of these objectives, by improving the thermal performance of buildings – resulting in a reduction in energy demand - and by acting as a form of stormwater management, thus reducing the overall impact of buildings on the local environment.

These contributions can be summarised as follows (CIRIA, 2009):

- ***Thermal insulation*** - The insulating properties of a green roof should be taken into account in the context of the overall insulation plan for the building. For new buildings which meet the energy efficiency requirements of the current Building Regulations, it is unlikely that green roofs will contribute significantly to energy savings. This is due to the fact that the insulation layer is required to be completely separate from the environmental conditions outside the building. However, for older, lightweight, and poorly insulated buildings green roofs can be very efficient at resolving insulation and thermal mass problems.
- ***Reduction of daily temperature fluctuations*** - The daily temperature range of a conventional roof can vary greatly e.g. 25°C on a summer's day. In contrast, the daily temperature range at the waterproof layer of an extensive green roof during summer is generally less than 10°C. Numerous factors contribute to this, including evapotranspiration from plants, the increased thermal mass of the green roof and the higher equivalent albedo (reflective power) of plants. The reduction in daily temperature ranges can reduce impacts on the interior environment of the building and reduce the impact of the roof on the surrounding environment and climate.
- ***Mitigation of the urban heat island effect*** – If green roofs were installed on a large scale, the higher reflective ability of a green roof, compared to a normal roof, and the effect of the evaporative cooling from a green roof, could contribute towards reducing the urban heat island effect. In a warming climate this impact could become increasingly important.

Storm water Management

Green roofs are a productive storm water management solution which can simultaneously improve the energy performance of buildings, air quality and biodiversity in the surrounding environment (Scholz-Barth, 2001). Large areas of water-resistant surfaces (i.e. roofs, carparks etc.) have been linked to negative effects on the quality of surrounding water bodies. Green roofs can help mitigate this problem. Green roofs can absorb and recycle rainwater (Scholz-Barth, 2001). Extensive green roofs are a very effective solution to storm water management. Vegetation layers are installed over waterproof roof surfaces, while no extra space is being used. They are economical and widely adaptable (Scholz-Barth, 2001).

Thanks to their water storing capacity, green roofs may significantly reduce the run-off peak of most rainfall events.

This is done by: (Mentens, 2006)

- Prolonging the initial time of run-off due to the absorption of water;
- Reducing the total run-off by retaining a certain amount of the rainfall;
- Dispersing the run-off over a long time period through a relatively slow release of excess water that is stored in the substrate layer of the green roof.

Biodiversity

Green roofs can replace habitat that has been lost as a result of urban development. They can also result in the creation of habitats for enhanced biodiversity to encourage flora and fauna into the area, for example, by providing food, habitat, nesting opportunities or resting places for creatures, birds and other invertebrates (NFRC, 2011).

Different types of green roofs support different habitats and species according to the type of vegetation and substrate in the build-up of the roof. Roofs designed to either imitate the habitat for a single or limited number of plant or animal species are often referred to as biodiverse roofs. This type of roof has already previously been described. Green roof designs should be altered regionally to meet the objectives of Local Biodiversity Action Plans. Green roofs can also be used to regenerate habitats for some endangered species (The Green Roof Centre, 2010).

Reduced Air Pollution and GHG emissions

Vegetation removes air pollutants and GHG emissions through the process of carbon sequestration and storage. The reduced energy demand from green roofs also reduces air pollution and GHG emissions associated with the production of energy (US EPA, 2010). Vegetation absorbs carbon during photosynthesis, which removes emissions and helps to lessen the impacts of climate change. The evaporative cooling properties of green roof vegetation also cancel out the heat-reflecting effect associated with normal roofs and other impermeable surfaces that are a component of higher urban temperatures (known as the urban heat island effect) (NFRC, 2011).

Building Performance Enhancements

The evaporative cooling effect of green roofs, in combination with the enhanced thermal mass of the build-up of the roof, can reduce the need for interior summer cooling in a building (i.e. air conditioning), with an overall reduction in carbon emissions as a result. This additional mass also has a sound-proofing function, providing additional noise reduction benefits (NFRC, 2011).

Amenity, health & wellbeing

Green roofs can benefit the occupants of the building by providing valuable outdoor recreational areas, for a variety of uses, including recreation, activity and leisure. Research suggests that green spaces within a building can improve the productivity of employees, as well as reducing the recovery periods of hospital patients (NFRC, 2011).

Financial

Though future government policy may further increase the financial benefit to owners of buildings with green roof installations, green roofs can pay back the initial investment.

This can be seen by (NFRC, 2011):

- Increasing the life of the waterproof layer of the roof due to the vegetation cover protecting the membrane, which in turn lowers thermal stresses caused by UV rays;
- Reduced energy costs due to the lower levels of energy consumption in relation to the insulating effects of the substrate, vegetation & drainage layer.

3.3.3 Costs and other considerations

The costs of green roofs alternate depending on the components, such as the growing medium, type of roofing membrane, drainage system, use of fencing or boundaries, as well as the type and number of plants. Initial green roof costs are higher than most normal roof types. However, green roofs have a longer lifespan than most roofing products, so the total annual costs of a green roof may actually be nearer to normal roof types. As well as the initial construction costs, a building owner also gains maintenance costs to care for the plants on a green roof. Although the level of maintenance depends on the type of vegetation that is planted on the green roof, most of the costs appear in the first years after installation, as the plants stabilise and develop themselves (US EPA, 2010).

Benefit – Cost considerations

Although a green roof might have higher initial costs than most normal roofs, a full life-cycle analysis can show how the roof benefits the building owner. Quite often, these benefits advocate the cost of green roofs in densely populated areas. As well as that, the owner of a building which has a green roof can directly benefit from reduced energy consumption, reduced stormwater management fees, and enhanced roof life. Finally, the widespread application of green roofs may provide considerable, indirect net benefits to the community (US EPA, 2010).

Installation and maintenance

All materials used in a green roof system should be tested following the suitable testing protocols. The green roof components should also be considered to be fit for purpose by meeting the relevant performance standards.

A green roof requires suitable levels of each of the following in order to succeed and blossom (NFRC, 2011):

- Sunlight;
- Moisture;
- Drainage;
- Aeration to the plants root systems;
- Nutrients.

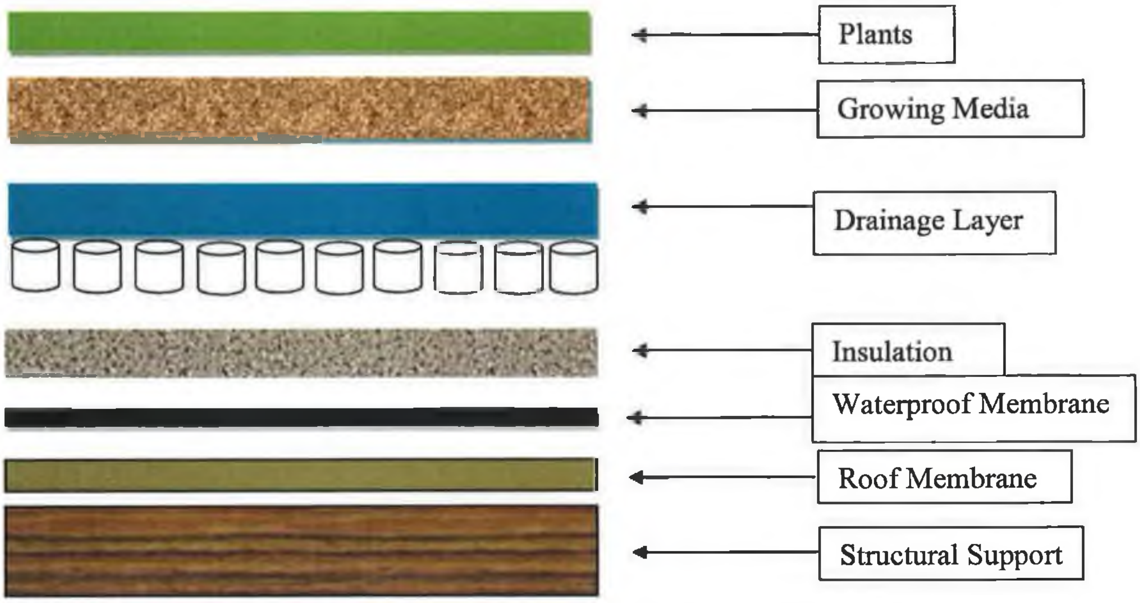


Figure 10: Green Roof Schematic – after **(Charleston Green Roofs, 2010).**

Whether extensive or intensive, green roofs generally consist of the same basic elements. Figure 10 shows a basic build-up of the components of a green roof. These include (US EPA, 2010):

- **Vegetation** - The choice of vegetation depends on the type of roof (extensive or intensive), building design, local climate, available levels of sunlight, irrigation needs and the predicted roof use;
- A lightweight, engineered **growing medium** may or may not include soil as the primary organic matter. A growing medium should last as long as the roof on which it is installed. Usually, the growing medium mainly consists of lightweight inorganic mineral materials (at least 80%) and up to 20% organic materials, such as topsoil;
- A **filter membrane** is commonly made up of a geo-textile that allows excess amounts of water from the growing medium to be released, while preventing the finer particles from being washed away and blocking up the roof drain;
- A **drainage layer** helps excess water from the growing medium to flow towards the roof drain, which prevents too much strain being put on the roof. This layer also provides a good air-moisture balance in the growing medium;

- A **root barrier** can protect the roof membrane from invasive plant roots, which may break through the waterproofing layer and cause leaks to the roof;
- A **waterproofing/roofing membrane** protects the building from water infiltration;
- A **cover board** is a thin, semi-rigid board that provides protection, separation, and support for a roofing membrane;
- **Thermal insulation** can be installed either above or below the membrane of a green roof. However, as it has previously been explained, green roofs cannot be used as a substitute for conventional insulation. It is important to adhere to, and install the recommended insulation levels as outlined in the building regulations;
- A **vapour barrier** is typically a plastic or foil sheet that prevents moisture from building up on the ceiling;
- **Building and roof structural support;** The components of a green roof weigh more than normal roofing materials. Therefore, the roof requires extra support panels. Building owners must make sure that the structure can support the green roof even when it is fully saturated with water, as well as meeting building regulations. Reinforcing roof supports on existing buildings adds to the cost of the project but can usually be incorporated into building renovation plans.

As with any structure that incorporates living elements, green roofs will need some continuous maintenance. Extensive green roofs that are designed for limited public access have fewer maintenance needs. For an intensive roof, maintenance can be ongoing, similar to a traditional garden, because the aesthetic quality of the roof will be more significant.

Maintenance measures include: fertiliser; irrigation; plant management; general clearance/removal of debris and replanting (US EPA, 2010).

3.3.4 European Green Roof Policies

Air quality, climate change, water supply, soil protection, biodiversity, and the natural landscape are subject to public protection. These natural resources are irreplaceable in terms of improving the quality of life, and common urban architecture does not always address these issues appropriately. Local authorities and city councils in European countries have realised this problem and, as a result, promote green roof projects in compensation for the increasing mismanagement of our natural resources.

Direct financial incentives, decreased stormwater taxes and administritive measures, are some of the many green roof policies which can be used to encourage green roofs and promote the development and expansion of the green roof market. In particular, Germany has done a lot of work in supporting the green roof technology with a number of innovations over the last 20 years (IGRA, 2011).

Direct Financial Incentives

Certain city councils and local authorities offer direct financial support for green roof projects. In many cases the financial allowances vary between 10€ and 20€ per m^2. Other communities pay a fixed sum for the entire green roof, which varies between 25% and 100% of the material and installation costs.The support programmes usually outline certain quality criteria for the build-up of the green roof. This guarantees that the installed green roofs achieve all of their ecological functions (IGRA, 2011).

Reduced Stormwater Taxes

Many towns in Germany have introduced special stormwater taxes. The separation of stormwater and sewage taxes, effectively promotes natural rainwater harvesting and management. For example, large water-resistant surfaces like car parks of large shopping centres or industrial areas often put a huge strain on the local sewerage systems with very high rainwater run-off. Therefore, based on the causation principle, stormwater taxes make the responsible parties accountable for the disposal costs. On the other hand, green roof areas with high water retention capacity levels are compensated with fee reductions of up to

50%. If it is a case that no stormwater is drained-off from the property into the sewerage system, the bonus has the potential to reach 100% (IGRA, 2011).

Compensation Measures for the Destruction of the Environment

Green roofs can mitigate damage to nature and landscape caused by impervious areas. This mitigation corresponds to an act in Germany known as the Federal Nature Protection Act, which requires that development should avoid any unnecessary damage to nature and that any inescapable damage should be compensated for on site. Without a doubt, green roofs can offset damages to the natural balance of water, soil, air, climate, flora and fauna (IGRA, 2011).

Regulatory Measures within Local Development Plans

Some local authorities make green roofs compulsory within new development areas. The positive effects, for both the community and the occupants of the modern estates, are impressive. Besides the broad range of private and public benefits, the sewerage system and water reservoirs within the area can be designed on a smaller scale due to the evaporation and high water retention abilities of green roofs. This results in lower public costs for the construction and maintenance phases of the sewerage system and, therefore, lower stormwater taxes for the general public (IGRA, 2011)

3.3.5 Green Roofs in Ireland

There are lessons to be learned from European policies on green roofs that have already been briefly discussed. These lessons can then be integrated into Irish policy and implemented across the Irish construction industry.

It is important to establish the idea of green roofs as being beneficial to Ireland as a whole. From the previous section, outlining the benefits of green roofs, it can be seen that if there was adequate government incentive in Ireland for the development and installation of green roofs, steps could be taken towards reducing Ireland's CO_2 emissions.

If public awareness has been developed and green roofs are then presented as solutions to issues which affect everyone, then a broad base of support can be built. It is essential to have the support of building professionals, as well as taking advantage of their skills and creativity. They have the potential to suggest innovative solutions to barriers that are specific to green roofs in an Irish context. One of the best ways to roll out a green roof programme in a local context is to begin with the main city's own buildings. There are many ways in which cities can either directly invest or help to generate outside investment in the development of local green roofing professionals. These include paid positions for green roof officers within the local council, public exhibition and education projects, training for up-skilling designers, builders and maintenance professionals, and financial support for green roof business start-ups (Dublin County Council, 2008).

After reviewing the main advantages of green roofs and examples of their application in other cities, the next step is to look at how a green roof policy in Ireland would integrate with current policy documents, both at local and national level. This policy could then be incorporated into the National Climate Change Strategy for Ireland.

This section explores how a new combined green roof policy would help to achieve some of the objectives in current government policies.

The main policy documents focused on are (Dublin County Council, 2008):

National Climate Change Strategy 2007-2012;

Green roofs can aid Ireland in reaching its carbon emission reduction targets.

Water Framework Directive (2000/60/EC);

One main requirement of the WFD is to manage surface run-off so that its impact on the surrounding environment is significantly reduced. This may mean that SUDS (Sustainable Urban Drainage System) techniques will have to be used as the method of reducing the rate and volume of run-off as well as removing pollution. A Green Roof policy would help to meet these requirements.

National Biodiversity Plan;

Biodiversity advantages of green roofs as follows:

- Helping to counteract areas that have been neglected, by providing new habitat in areas which are currently lacking in wildlife habitat;
- Creating new links in an intermittent network of habitats thereby facilitating movement and dispersal of wildlife;
- Providing additional habitat for rare, protected or otherwise important species.

From previous sections of the thesis, it can be seen that green roofs can provide a wide range of benefits; the main drivers from Ireland's perspective are climate change response, stormwater management, support for urban biodiversity, creating extra green open spaces, and reducing the consumption levels of different types of energy in buildings. The technologies involved in green roofs have been established for close to fifty years in some countries, such as Germany. So, while the idea may be somewhat new to Ireland, there are many cities in other countries which have fully embraced Green Roofing (Dublin County Council, 2008).

The following section of the chapter looks at a different form of technology that the author also believes would benefit the Irish economy, environment and society in terms of a more sustainable form of stormwater management. The author believes that rainwater harvesting can be linked in some way to decreasing the energy and water use in buildings – a major contributor to climate change.

3.4 Rainwater Harvesting Systems (RHS)

Rainwater harvesting is a technology used to collect, transport and store rainwater for later use from relatively clean catchment areas, such as roofs. This is water that would otherwise have gushed into the drainage system or discharged into the ground. The water is generally stored in a rainwater storage tank or directed towards different mechanisms which recharge the surrounding groundwater supply. Rainwater harvesting can provide water for human consumption (with high levels of water treatment), reduce water bills and lower the need to build reservoirs which may require the use of valuable land (JR Smith, 2010).

Rainwater harvesting has been practiced for over 4,000 years around the world. It has provided drinking water and water for animals, domestic water, water for irrigation and a means of replenishing ground water levels. Commonly, rainwater harvesting has been practiced in arid and semiarid regions. It has become an essential part of societies in remote places where relying on pipes and wells for clean water is not an option (JR Smith, 2010).

Rainwater harvesting in urban areas and cities can have numerous benefits. Providing extra water for the city's needs, increasing soil-moisture levels for green urban areas, raising the ground water table through artificial rejuvenation, mitigating urban flooding and improving the quality of groundwater, are only a few of the many advantages. In domestic homes and commercial buildings, collected rainwater can be used for irrigation, flushing toilets and washing clothes. In areas with hard water, rainwater is superior to the mains water supply for non-potable applications. With proper filtration and treatment methods, harvested rainwater can also be used for showering, bathing, and even drinking (JR Smith, 2010).

Rainwater harvesting is also capable of reducing the levels of storm water run-off pollution into the water catchment. When rain falls, initially it is clean, but it picks up pollutants from surfaces such as rooftops and pavements. This pollution is then carried into storm drains and subsequently into streams and rivers. Collecting storm water from rooftops and directing it to storage tanks so it can be used in and around a building decreases the volume and rate of storm water run-off. As a result local water bodies are protected from pollution (JR Smith, 2010).

Advantages of Rainwater Harvesting

Rainwater harvesting systems are easy to install, operate, and maintain. It is beneficial in the way that it provides water at the point of consumption. As well as this, operating costs are minimal. Water that is collected from the roof catchment is available for use, mostly for non-potable applications such as toilet and/or urinal flushing, laundries, mechanical systems, landscaping and site irrigation. The fact that rainwater is collected using existing structures, i.e., the roof, results in very few negative environmental impacts overall (JR Smith, 2010).

Benefits of Using Rainwater

1. It is essentially "free"; the only cost is for collection and use of the water;
2. It reduces demand on the municipal water supply;
3. Water bills are lower as a result;
4. Efficient use is made of a valuable resource;
5. It lowers the levels of flooding, erosion, and the flow to storm water drains;
6. It reduces the contamination of surface water with sediments, fertilisers and pesticides from rainwater run-off. The results are cleaner lakes, rivers, oceans and other receivers of storm water;
7. It can be used to recharge groundwater supplies;
8. It is beneficial for irrigation uses. Plants thrive due to the fact that stored rainwater is free from pollutants as well as salts, minerals, and other natural and man-made contaminants;
9. The softness of the rainwater is good for washing clothes as it reduces the need for excessive amounts of washing detergents;
10. It adds life to the equipment that depends on water to operate, due to the fact that rainwater does not produce corrosion or scale like hard water (JR Smith, 2010);
11. RHS will significantly contribute towards off-setting domestic/commercial water charges that are proposed to be in place in Ireland by 2014 (Li, Boyle, & Reynolds, 2010).

In order to realise the full benefits of installing this sustainable technology across Ireland, it is important to look at the Irish climate in terms of the amounts of rainfall the country receives on an annual basis. Based on these figures, the average amount of water that will fall on each square meter of catchment area can be estimated, therefore allowing for the rainwater storage tank to be sized accordingly.

The Irish Climate

The most prominent influence on Ireland's climate is the Atlantic Ocean. As a result, Ireland does not suffer from temperature extremes that are experienced by many other countries at similar latitude. Strong winds tend to be more common during the winter months than in summer. Sunshine periods are highest and longest in the southeast of the country.

Average rainfall varies between about 800 and 2,800mm. The East will receive between 750mm – 1000mm whereas the West can receive anything from 1000mm to 2000mm, with some levels known to reach extreme amounts of approximately 2,800mm (mostly in mountainous areas). With south-westerly winds from the Atlantic prevailing, rainfall figures are highest in the northwest, west and southwest of the country, especially over the higher ground. Rainfall accumulation is generally at its highest in winter and lowest in early summer.

The annual number of days with more than 1 mm of rain varies between about 150 in the drier parts and over 200 in the wetter parts of the country (MET Eireann, 2011).

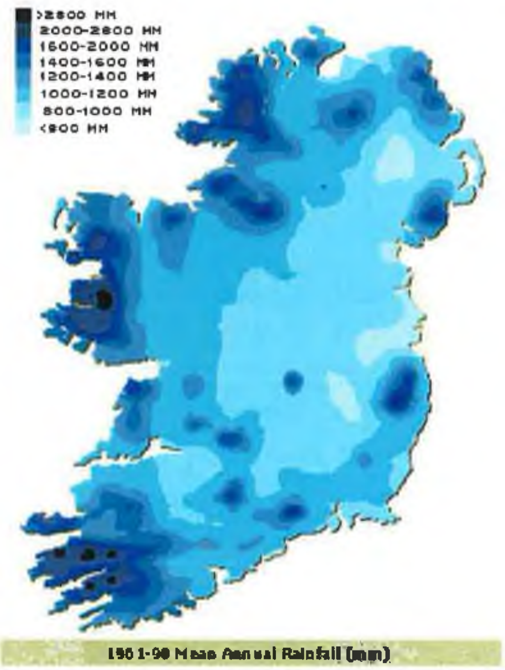


Figure 11: Mean Annual Rainfall in Ireland, © MET Eireann

Figure 11 shows the mean annual rainfall amounts in Ireland from 1961-1990. Those amounts have since increased, due to climate change and global warming. MET Eireann have been monitoring the amounts of rainfall each year and have noticed an increase in average national rainfall of about 70mm over the last few decades (MET Eireann, 2011).

The author believes that as the rainfall levels in Ireland are increasing, more strain is being put on the Irish sewer systems and stormwater drainage systems. There are greater needs for sustainable solutions such as rainwater harvesting and green roofs which can help to mitigate the risk of flooding and the deterioration of the quality and quantity of our national water supplies.The author believes that rainwater harvesting technologies would benefit buildings in Ireland due to the fact that there are high levels of annual rainfall, an increasing demand for water, the likely re-introduction of domestic water charges, as well as the increase in commercial charges in the next few years.

Components of a Rainwater Harvesting System

Typically a RHS consists of three components; a catchment area, a run-off delivery system and a storage tank. Figure 12 below shows a schematic of a domestic rainwater harvesting system.

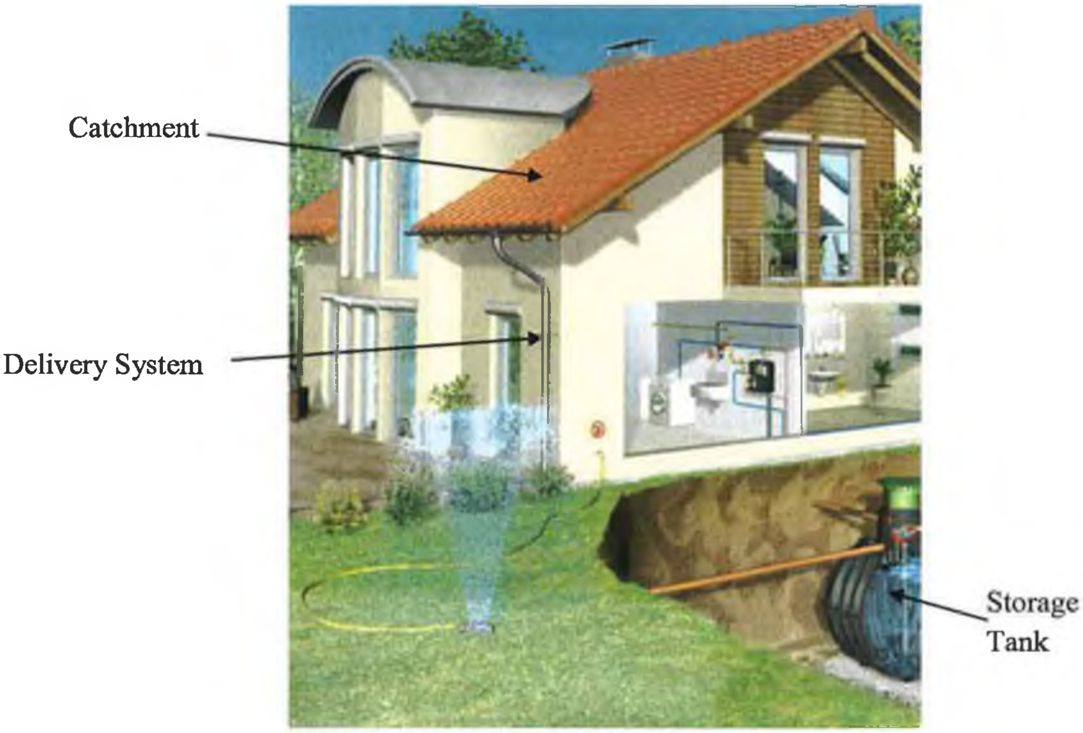


Figure 12: Rainwater Harvesting System ©JFC

Catchment

The catchment has to be installed properly, completely sealed, airtight and must not seriously contaminate the rainwater. Roofs are the most common type of catchment used for harvesting water. The material used in constructing the roof and the effective roof area play an important role in the efficiency of collection and the quality of the water running into the storage tank (Li, Boyle, & Reynolds, 2010).

Run-off Delivery System

The run-off delivery system is usually made up of gutters and downpipes which then transfer rainwater from the roof down to the storage tank. The gutter must be designed to an appropriate size so that a certain amount of water can be directed into the storage tank without any overflow. Cleaning devices, such as a self-cleaning screen or a filter basket are often needed in order to prevent leaves and other debris from flowing into the storage tank. A well-designed and maintained run-off delivery system has the ability to re-direct over 90% of all rainwater run-off into the storage tank. In reality, collection efficiencies are usually between 80-90% (Li, Boyle, & Reynolds, 2010).

Storage Tank

Harvested rainwater is ultimately stored in a storage tank. The storage tank is generally the most expensive part of the system. It can account for between 50-70% of the total cost. As a result, it is necessary to design, construct and size the storage tank carefully and accurately.

There are two types: above-ground tanks and under-ground tanks (Li, Boyle, & Reynolds, 2010):

- An above-ground tank allows for easy detection of cracks and leaks. Water can also be extracted via gravity in an above-ground tank, saving on the cost of installing and running a pump. This type of tank is generally cheaper than the underground tank. However, this type of tank takes up quite a lot of space and requires anchoring to the ground.
- An underground tank is beneficial in terms of the prevention of UV penetration, keeping stored water constantly cool and also saving on space. The main downside to having an underground tank is the difficulty in extracting the stored water and directing it towards a domestic house/commercial building for non-potable uses. A pump is required for this. It is also difficult to notice or fix any cracks or leaks in the tank when it is buried underground. There is also the possibility of contamination of the stored water in the tank from groundwater and floodwater.

3.4.1 Rainwater Quality

Good quality rainwater is more likely to be harvested and stored if the RHS is designed properly and operated/maintained efficiently. The quality of the harvested rainwater depends on local air quality and the cleanliness of the roof surface. Increasing levels of emissions and pollutants from the transport sector could be the greatest threat to the quality of harvested rainwater in Irish cities.

To help prevent a reduction in water quality, the following measures can be taken (Li, Boyle, & Reynolds, 2010):

- Storage tanks should be cleaned on a regular basis, as well as being covered to prevent insects and debris from gathering in the water;
- The catchment area (roof) should be cleaned regularly to avoid any contamination;
- The first few millimetres of rainfall run-off should be diverted away from the storage tank to also avoid contamination.

3.4.2 Cost of RHS

The cost of RHS varies greatly. It is mainly dependent on the volume of storage tank required. The size of the roof area, rainfall level and number of occupants in the building are the parameters for choosing the volume of a storage tank. An underground system is also generally more expensive than an aboveground system for the same storage tank size. This would be due to excavation and labour costs (Li, Boyle, & Reynolds, 2010). The cost of an RHS is still relatively expensive in Ireland. This is due to the fact that there still is currently no government grant available for the installation of a domestic RHS. The average payback period of 7-20 years could be further reduced if an incentive grant was provided by the Irish government (Li, Boyle, & Reynolds, 2010).

3.4.3 Domestic Water Charges

Water charges are already imposed by local authorities around Ireland. Commercial water charges are imposed on all businesses in the country and must be paid to the local authority. Water charges are payable if water is being supplied for use by business, trade or manufacture. This includes hospitals, institutions, and homes for people with mental or physical disabilities, maternity homes, convalescent homes, laboratories, clinics, health centres, schools or clubs. There are two types of commercial water charges – flat rate, or metered rate (Citizens Information, 2009).

Flat Rate

This is a flat rate charge that is to be paid to the local authority. The flat rate is calculated by estimating, on average, how much water a business uses. The volume of water will vary, depending on the type of business and how many employees are working there. There is no minimum charge set down in legislation for water charges. Each local authority can decide its own rates, which are reviewed every year (Citizens Information, 2009).

Metered Rate

A metered account involves a meter being fitted to monitor the amount of water used in a building. Metered accounts are accountable for a minimum charge per year as well as a rental charge for the meter itself. The minimum charge can differ, depending on the local authority. Meters are generally used to observe the amount of water used by large premises, e.g., factories and breweries. An upcoming EU directive will make it necessary for all commercial premises to have a meter. This is in cooperation with the "polluter pays principle", which states that you must pay for the waste you create. Local authorities will be obliged to install water meters in all commercial premises when this directive comes into effect (Citizens Information, 2009).

Since the abolition of domestic water charges on 1 January 1997, all water supplied from the public mains is free of charge. These public water schemes are managed and controlled by the local authority. However, Budget 2010, which was announced on 9 December 2009, indicated that a system of water metering for homes will be introduced in Ireland (Citizens Information, 2009). Householders could expect yearly water bills in the next two years under Government plans to install domestic water meters in all homes. Environment Minister John Gormley revealed that €1 billion will have to be raised through water charges, which will be imposed on 1.1 million homes, in order to meet the cost of treating the water system. Chambers Ireland, which has called for water charges to be extended from businesses to home-owners, estimate that the new charges would amount to between €300 and €400 per home per year. In Ireland, it costs €1.2bn to treat water on an annual basis and businesses pay an estimated €250m towards this. The Chambers Ireland figures are based on splitting the €1bn charge between all domestic households. The assumption that consumers will reduce the amount of water they use once charges are introduced has also been taken into account in this case. (Regan, 2010). Water charges will be based on the amount consumed above a free allocation level. Water charges will be used specifically to maintain and improve the water and waste water systems in Ireland (Citizens Information, 2009). Water charges are a crucial step forward, according to the Organisation for Economic Co-operation and Development (OECD). They argue that "the absence of household water charges impedes the development of an economically, environmentally and socially efficient water services sector" (Eolas Magazine, 2010).

The author believes that if rainwater harvesting systems were installed on a large scale across the domestic and commercial sectors in Ireland, with the help of government incentives, the amount of money that would need to be spent on treating water could be cut dramatically across the board. This would result in lower water bills for both domestic and commercial buildings, lower water treatment bills for the government, an effective form of stormwater management – reducing the strain on drainage and sewerage systems, as well as a clean and sustainable way of conserving water.

3.5 Measuring Environmental Impacts

In order to calculate the environmental benefits of such green technologies as green roofs and rainwater harvesting systems, different methodologies have been developed which can be applied at different stages of the life cycle of a product or process in order to measure the environmental impact of that product or process. This can be done manually or by computer software programmes.

The author has chosen to carry out a Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) on a normal roof, green roof and rainwater harvesting system.

Along with the concept of Life Cycle Thinking (LCT), LCA and LCCA will be discussed in detail in this section of the chapter.

3.5.1 Life Cycle Thinking (LCT)

"The concept of Life Cycle Thinking integrates existing consumption and production strategies towards more rational policy making and in industry, employing a wide range of life cycle based approaches and tools. By considering the whole life cycle, the shifting of problems from one life cycle stage to another, from one geographic area to another and from one environmental medium or protection target to another is avoided." (European Commission - JRC - Environment, 2010).

Businesses do not always consider their supply chains or the 'use' and 'end-of-life' processes related to their products. Government actions also often concentrate on a specific country or region, and not on the impacts or benefits that can occur in other regions.

In both cases, without considering the full life cycle of goods and services (supply/use/end-of-life), the environment suffers – resulting in a reduction in financial performance and a higher potential for damage to corporate image and status.

Life Cycle Thinking provides a broader point of view. As well as considering the direct environmental impacts of the processes, attention is also paid to the raw materials that are used, supply chains, product use, the effects of disposal of the products and the potential for re-use and recycling, (see Figure 13).

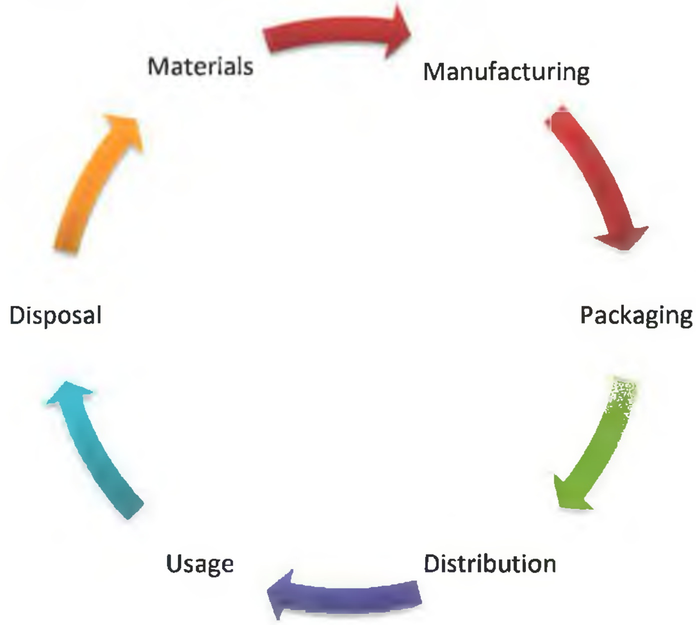


Figure 13: Life Cycle Thinking/Assessment – after **(Glass for Europe, 2010).**

The key aim of Life Cycle Thinking is to avoid "burden shifting". This means minimising impacts at one stage of the life cycle, while helping to avoid increases elsewhere. A good example is saving energy during the use phase of a product, while avoiding an increase in the amount of materials needed to provide it (European Commission - JRC, 2010).

Life Cycle Thinking can help reveal opportunities which lead to decisions which help to improve environmental performance, image, and economic benefits. This approach shows the responsibility for reducing environmental impacts is being taken at many levels (European Commission - JRC, 2010).

3.5.2 Life Cycle Assessment (LCA)

"Life-cycle assessment (LCA) is a process of compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle." (European Commission - JRC, 2010).

LCA Phases

The main phases of an LCA are shown in Figure 14 below.

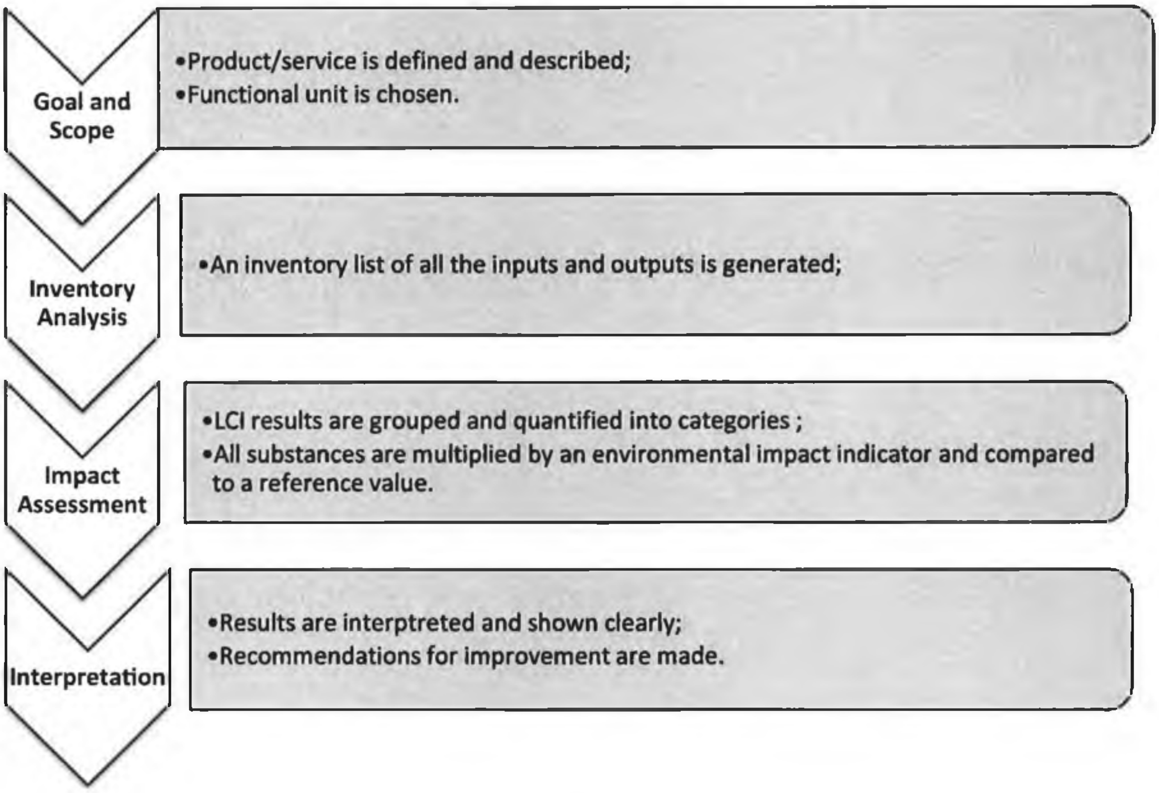


Figure 14: Main phases of an LCA, after (Pré - Product Ecology Consultants, 2010)

3.5.4 Life Cycle Costing (LCC)

Life cycle cost is the sum of all the costs related to a product. This includes costs for manufacturing, installation, operation, maintenance, restoration and disposal (Ravemark D. , 2003).

Life cycle costing (LCC) gives the total life cycle cost of the system/product and allows for comparisons of alternatives. LCC includes calculating the costs and timing over a particular analysis period and conversion of those costs to financially similar values, taking into account the time-value of money (Ravemark D. , 2003).

Like most concepts, LCC has developed and improved over time. Today, LCC serves four main principles (Emblemsvåg, 2003):

- LCC can be an efficient engineering tool for providing decision support in the design and acquisition stages of major systems, such as infrastructure. This was the original function of LCC;
- LCC defeats many of the deficiencies of traditional cost accounting and can therefore give useful insights into cost accounting and management;
- LCC has re-emerged as a design and engineering tool for environmental uses;
- Recently, LCC has become an important tool to support new environmental legislation and policy.

LCC and LCA

LCC and LCA are two influential tools which can be used separately or in combination. Used together, they can figure out the impact on the environment and the cost over an entire product life cycle. A combined LCA-LCC tool is useful for designers as it offers a clear picture of all the effects a product design change would have on the environment and on the life cycle cost. Unfortunately, such a tool does not currently exist. This is due to the fact that it is very time-consuming and difficult to build up LCA and LCC databases which are essential for determining the environmental and life cycle cost of a product or a process.

3.5.5 Current Research

Some research has already been carried out on green roofs in the USA and UK. A life cycle cost-benefit analysis of extensive vegetated roof systems was carried out by (Carter, 2008). The results of that study showed that, in the USA, the net present value of this type of green roof ranged from 10-14% more expensive than conventional roofs. A comparative life cycle assessment of green roofs was carried out by (Kosareo, 2007) in Pittsburgh, Pennsylvania. The paper describes the life cycle environmental cost characteristics of intensive and extensive green roofs versus conventional roofs. The results of the study showed that green roofs have a significant positive impact on the environmental quality of buildings compared to conventional roofs. In the UK, the potential that green roofs can offer in terms of saving energy in buildings was looked at by (Castleton, 2010). A feasibility study was also carried out to test the potential of using green roofs in the retrofitting of buildings. The results showed that older buildings would hugely benefit from the installation of a green roof in terms of energy saving and insulating properties.

In terms of rainwater harvesting systems in Ireland, the variation in Ireland's climate due to the effects of climate change is not fully known (Li, Boyle, & Reynolds, 2010). It is predicted that climate change will lead to warmer and drier summer months and wetter winter months. As a result of this, it is vital that new water sources are found and new technologies are developed in order to produce water on a large scale in order to meet demands from the public for clean water. A potential cost-savings study for the use of domestic water systems in Irish homes was also carried out (Li, Boyle, & Reynolds, 2010). It showed that only 6% of domestic water is used for potable use in Ireland. The potential water saving is estimated to be between 30-90% in an Irish house, with the possibility of obtaining all of the 94% of domestic water used for non-potable applications from rainwater harvesting and grey water recycling systems.

The author believes that methodologies such as LCA and LCC are very innovative and useful, and would be suitable in this case to measure the environmental impact and cost effectiveness of green roofs and rainwater harvesting systems in Ireland.

3.5.6 Gaps in the Research

There are potential gaps in the research that has already been carried out. We have yet to see an abundance of green roofs in Ireland. There are no government incentives for green roofs in Ireland. Also, there are no incentives for rainwater harvesting systems in Ireland. Without government aid, Ireland is facing huge carbon and water taxes in the very near future.

The author was unable to locate any scientific papers outlining a life cycle assessment that had been carried out on a green roof in Ireland. When the author discussed the topic of carrying out an LCA/LCCA study on a green roof in Ireland, the Senior Technician and Head of the Green Roof section at Bauder Ltd, Mr. Kieran Townes, was very interested and expressed an interest in the results of the studies the author would be carrying out. Mr. Townes explained that the company had not carried out its own LCA/LCCA due to the fact that these studies take time and money to complete. He also explained that there was a potential to generate results that might be subjective rather than objective. With this in mind, the author proposed to carry out a comparative LCA on two Bauder products – a normal roof and green roof – with the intention of showing the environmental benefits of green roofs in Ireland. Mr. Townes was very happy to help the author in any way and immediately provided all the relevant product information the author needed to carry out the Life Cycle Assessment.

Out of curiosity, the author asked Mr. Townes if he had ever come across a green roof integrated with a rainwater harvesting system. He had never considered the concept, but was intrigued to know how the system would work. The author then decided to include an LCA/LCCA study of a rainwater harvesting system as part of the thesis in the hopes of researching the concept further and looking at the feasibility of introducing a similar idea to the Irish market on a large scale. In order to find out more about rainwater harvesting systems, the author contacted a local company, JFC Ltd, who manufacture rainwater storage tanks. The author set up a meeting with a technical sales representative, Mr. Derek McGrath, to discuss the topic further. Mr McGrath expressed a keen interest in green roofs, as he did not have much knowledge of the technology. He was also interested in the concept of combining the two technologies. Mr McGrath provided the author with all the relevant information needed to carry out an LCA/LCCA study on rainwater storage tanks.

The two meetings the author had with staff members at Bauder Ltd and JFC Ltd helped the author to decide on the final topic for this thesis. The author believes that the studies carried out here will benefit the staff at Bauder Ltd and JFC Ltd in terms of developing technologies, improving the environmental standard of products and for marketing purposes. The author is of the opinion that there should be more extensive research carried out on the potential benefits of green roofs and rainwater harvesting systems in Ireland, in order to help reduce GHG emissions and act as a sustainable form of stormwater management. The purpose of this thesis is to contribute towards creating awareness for a potential new concept that could be potentially developed to have beneficial impacts on Ireland in terms of the environment, economy and society.

Accomplishing the extensive reduction in GHG emissions that scientists say is needed to avoid the worst effects of climate change will not be a simple task. It will demand action across all sectors of the economy; from energy, electricity, transportation and agriculture. A wide range of technologies exist today for achieving cost effective emission reductions, and emerging technologies have the potential to deliver even more emission reductions in the future. The successful development of these technologies will require research, incentives for producers and consumers, and emission reduction specifications that encourage innovation and direct investments. Governments at all levels need to encourage short-term action to abate emissions while laying the groundwork for a longer-term technology transformation (Pew Center on Global Climate Change, 2011). The author believes that green roofs and rainwater harvesting systems can play a role in mitigating oncoming climate change impacts and reducing Ireland's GHG emissions.

The author will look at the possibility and feasibility of integrating a rainwater harvesting system with a green roof for optimal storm water management and water conservation. The feasibility for a potential Irish market for this concept will also be looked at. The author intends to use methodologies such as life cycle assessment (LCA) and life cycle cost analyses (LCCA) in order to study the environmental impact and cost-effectiveness of green roofs and rainwater harvesting systems in an Irish context.

3.6 Conclusion

The aim of the literature review chapter in the thesis was to give the reader an overview of the research carried out on an expansive range of topics, ranging from climate change – in terms of impacts and international, European, national and local initiatives, to green construction and green roofs, to rainwater harvesting systems as well as the methodologies used to measure the environmental impact of different products and services. The author has determined the purpose of the thesis and has identified gaps in the current research in relation to green roofs and rainwater harvesting systems.

In the following chapter, the author will discuss green roofs and rainwater harvesting systems in greater detail, in order to investigate the potential for integration of the two technologies.

Chapter 4 – Green Roofs

4.0 Introduction

In this chapter, the author will discuss the concept of green roofs in greater detail, in particular, extensive sedum blanket green roofs. The reason the author has chosen to focus on extensive green roofs is because of the versatility of extensive green roofs, as well as the benefits they provide particularly to industrial, commercial buildings. Also, extensive green roofs seem to be the most cost-effective type of green roof for commercial buildings. Studies have shown that extensive green roofs can help lower the cost of heating and cooling commercial buildings in a city as well as reducing the strain on urban drainage systems (The Green Roof Centre, 2007). The Irish climate is influenced by the Atlantic Ocean. Average rainfall varies between about 800 and 2,800mm. Most of the eastern half of the country gets between 750 and 1000mm of rainfall in the year. Rainfall in the west generally averages between 1000 and 1400mm. In many mountainous districts rainfall exceeds 2000mm per year. The wettest months, in almost all areas are December and January. (MET Eireann, 2011). The author believes that green roofs and rainwater harvesting systems can contribute in a positive way in all areas of the country towards storm water management and the prevention of floods.

In this chapter the author will mention two leading green roof suppliers in Ireland and the UK – Bauder and Moy Materials, stating the types of roofs they manufacture, and how their products contribute towards Ireland in terms of the environment, economy and climate change. The author has chosen to work specifically with Bauder – as they expressed an interest in the LCA and LCCA studies that will be carried out as part of this study. A detailed description of the components of a typical Bauder extensive green roof will follow as well as a description of a Bauder "normal" or conventional flat roof, along with a list of design considerations and maintenance practices that should be taken into account when designing an extensive green roof. Rainwater harvesting will also be looked at in this chapter. The author believes that rainwater harvesting and other water conservation methods will become very prominent in the Irish market in the next few years. This is due to the nature of the Irish climate, and more specifically to the upcoming re-introduction of water charges in Ireland. An Irish company, JFC Ltd., which specialises in manufacturing rainwater harvesting tanks, will also be looked at. The author has chosen to use a rainwater harvesting tank, manufactured by JFC, as part of the LCA and LCCA study that will be carried out in the next chapter.

Bauder Ltd. has expressed a keen interest in the results of the LCA/LCCA studies in this thesis. The author is carrying out these studies for the benefit of the company. Due to the fact that a full LCA is expensive for any company to carry out, the results of the author's LCA/LCCA study will be very useful for marketing and other purposes.

The author believes that there is a viable link between climate change, storm water management, green roofs and rainwater harvesting systems. This link has yet to be fully explored and developed.

In order to carry out a comparative lifecycle assessment and life cycle cost analysis on conventional roofs, rainwater harvesting systems and green roofs a scenario that can be applied to each concept was developed. This will be described in more detail at the end of the chapter.

4.1 Green Roofs

Bauder is a leading flat roof and green roof manufacturer and supplier throughout Ireland, the UK and Europe. Bauder has been a producer of green roofs for over 25 years across Europe. The aim of the company is to manufacture high quality products with a long life, in order to lower whole life costs. Bauder also provides products with a high recycled content - allowing them to supply and set up green roof systems with up to 81% recycled content by volume. The thermal performance of their green roofs also plays a part in lowering the amounts of energy required for heating and cooling systems in buildings – a huge contributor to climate change, as already discussed in the literature review chapter (Bauder, 2011).

Moy Materials Ltd was founded in 1978 and has become one of Ireland's and the UK's leading supplier of high performance waterproofing systems for the construction and roofing industry. Moy Materials also provide green roofs and have completed a number of projects in Ireland and the UK. Moy Materials Extensive Green Roofs are designed to be light-weight and offer a sustainable environment for hardy, drought tolerant, low maintenance plants, (Moy Materials, 2009).

For the purpose of this thesis, the author has chosen to work with green roofs and conventional roofs supplied by Bauder Ltd. Bauder has expressed an interest in the author's work and has co-operated willingly and supplied information, photographs and other diagrams for the thesis.

4.1.1 Types of Green Roofs

Currently, Bauder is manufacturing and supplying four types of green roof. A brief description of each type will be given below. More focus will be placed on the extensive sedum blanket roof, as this is the green roof the author has chosen to include in the LCA/LCCA study for this thesis.

4.1.1.1 Biodiversity Roofs

A biodiversity roof provides a natural living habitat which can encourage birds, insects and plant species into the area (see Figure 15). The purpose of the biodiversity roof is to reflect and reproduce the surrounding ecological environment.

Figure 15: Biodiversity Roof Case Study, London, UK. ©Bauder

Key features of biodiversity roofs include:

- There is considerable scope for creating a natural habitat which will encourage plants and small wildlife to remain. As a result, the biodiversity of the area increases;
- This type of roof offers a greater benefit to wildlife than other types of green roofs and can be designed especially to sustain specific types of flora and fauna;
- Biodiversity roofs help in the planning permission process, as they help to meet local authority policies that are aiming towards creating a more sustainable local environment;
- Developing another aspect of a building, as well as boosting the potential of the building to support the local environment.

4.1.1.2 Intensive Green Roofs

Intensive green roofs provide recreational gardens at roof level, with all the benefits that usually related to traditional garden landscaping (see Figure 16). Generally, they feature landscapes combining shrubs, perennial and herbaceous plants as well as grassy areas and sometimes even trees. The plants can be a burden on the green roof and will need maintenance, watering and management throughout the year to ensure the preservation of the landscape and to allow the vegetation to blossom.

Figure 16: Intensive Green Roof Case Study – Hornton Court, UK ©Bauder

Semi-Intensive Green Roofs

This is an "in-between" green roof type that can be made up of features of both extensive and intensive roofs. Typically requiring a depth of substrate between 100-200 mm, a wider variety of plants can be used compared to extensive roofs, including shrubs and woody plants. Watering and maintenance requirements depend on the plant species that have been chosen (NFRC, 2011).

4.1.1.3 Extensive Green Roofs

Extensive green roofs are designed to be lightweight and to sustain low maintenance vegetation which is resistant to wind, frost and drought (see Figure 17). Extensive roofs are not designed for general access by the public or for leisure purposes. They are mainly used for their ecological benefits and visual appearance. There are two types of extensive green roof, offering different substrate depths.

Figure 17: Extensive Green Roof Case Study – Bishop Justus School, UK ©Bauder

The author intends on focusing on the Extensive Sedum Blanket throughout this investigation, in terms of its benefits to the Irish climate, its life cycle cost and the impact the green roof has on the environment.

Sedum Blanket

The sedum blanket is the most light-weight green roof option, with robust, pre-cultivated sedum vegetation for instant greening of the roof. Sedum blankets are a very fitting and cost effective feature in refurbishment and retrofit projects. The sedum blanket can feature up to 10 or 11 species of sedum, along with some mosses and grasses. This ensures plant diversity regardless of location of the green roof. The author has chosen this type of roof to be included in the study for the thesis (see Figure 18 & 19). This roof will be applied to the hypothetical building, which will be fully described at the end of the chapter, and a comparative LCA/LCCA will be carried out of a green roof versus a normal roof.

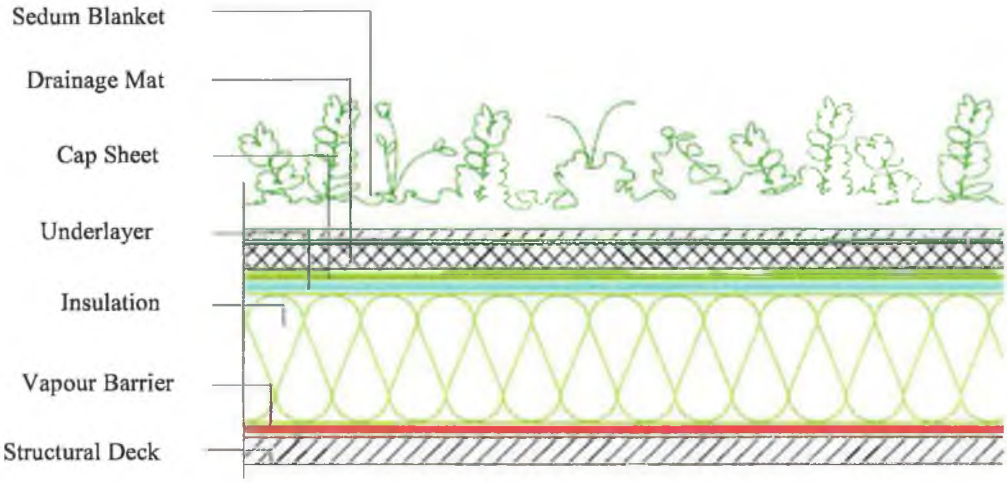
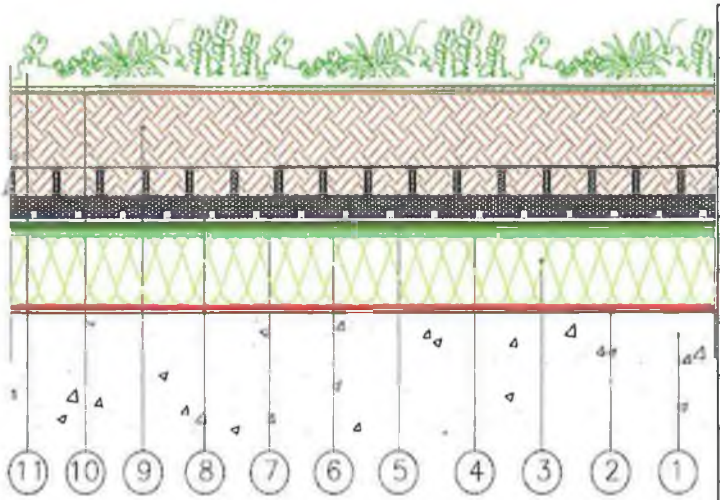


Figure 18: Typical build up – Extensive Sedum Blanket ©Bauder

Figure 19: Sedum mat being installed onto roof in large rolls ©Bauder

Substrate-based Systems

Substrate-based systems differ in the way that a greater depth of growing medium is incorporated into the build-up (see Figure 20). As a result, a wider variety of species can be used. Plants can be installed by different methods, including plug planting, vegetation mats and hydroplanting.



1. Concrete deck
2. Vapour barrier
3. Insulation
4. Underlayer
5. Cap Sheet
6. PE Foil separation layer
7. Eco Mat protection fleece
8. Reservoir board 75mm
9. Extensive soil 50mm
10. Filter Fleece
11. Vegetation Blanket

Figure 20: Typical build up of extensive substrate system ©Bauder

4.1.2 Green Roof Components

For this section, technical product information of all the components used in an extensive sedum blanket, from a leading green roof supplier, Bauder, is used (see Figure 21). The author will use this information, and further details, in the LCA and LCC analyses in the following chapter.

Extensive Sedum Blanket

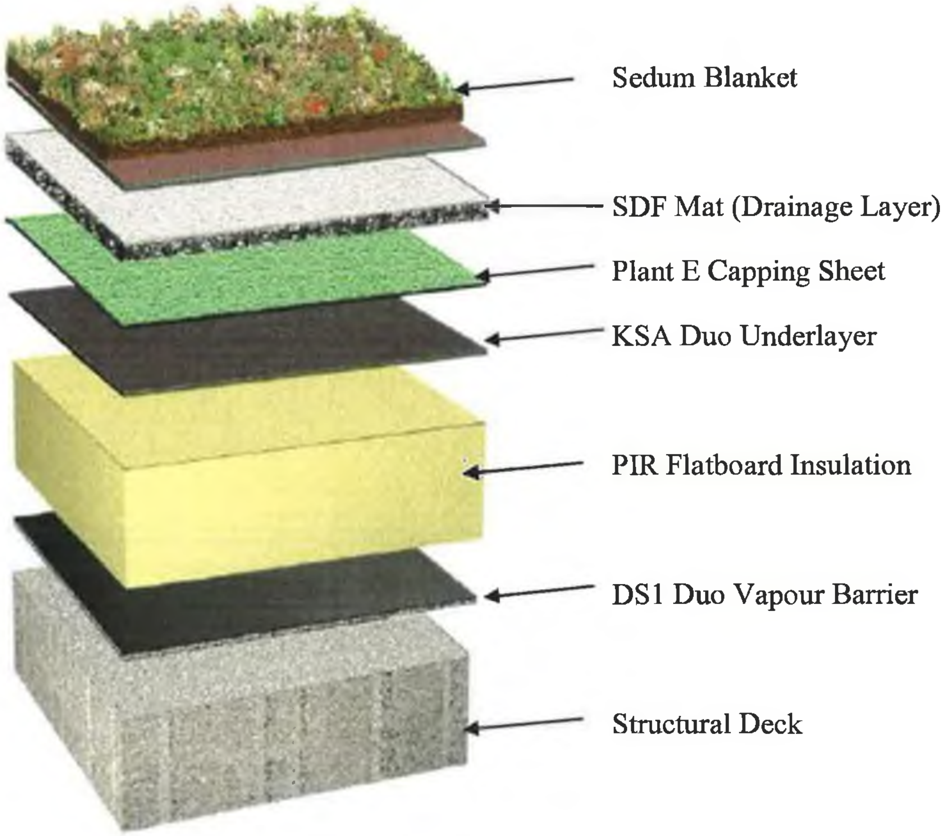


Figure 21: Extensive sedum blanket product build-up ©Bauder

Figure 22: Sedum blanket and SDF drainage mat © Bauder

This pre-cultivated sedum blanket sits on a nylon loop and geo-textile base carrier with substrate growing medium (see Figure 22). The moisture retention fleece is pre-attached, and provides a certain level of water storage. The substrate is made up of recycled crushed brick and expanded clay shale, as well as incorporating an organic component of pine bark that has been composted. The moisture retention fleece contains recycled fibres (80% man-made, 20% organic).

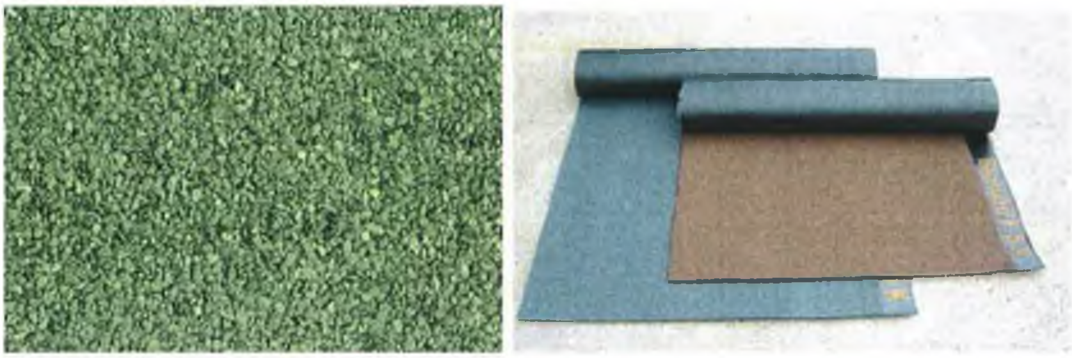


Figure 23: Plant E Cap Sheet (Green Roof) and K5K Cap Sheet (Normal Roof) ©Bauder

The Bauder Plant E Capping Sheet is used on Green Roofs (see Figure 23 – image on the left). It is a heavy duty, torch-applied, elastomeric bitumen capping sheet. Chemically treated bitumen is incorporated into the sheet when it is manufactured. This provides the necessary root resistance that is required when the roof will be supporting a layer of vegetation. The membrane is reinforced with 250g/m^2 spun-bond polyester fleece, which allows the structure to move comfortably without cracking. Expandable graphite fire-retardant is also used to inhibit the spread of flames. The capping sheet is made up of green slate mineral chippings on the surface and a foil underside. On Normal Roofs, the K5K Capping Sheet is used (see Figure 23 – image on the right). It is made up of essentially the same materials as the green roof capping sheet, except there is no need for the root barrier chemical layer, as there is no vegetation layer present.

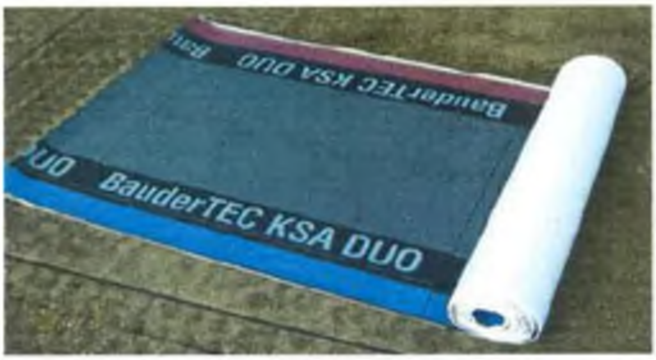


Figure 24: KSA Duo Underlayer, ©Bauder

BauderTEC KSA Duo Underlayer is a self-adhesive elastomeric bitumen underlayer with strong woven glass acting as a reinforcement layer, which provides a very high flexible strength (see Figure 24). The underlayer is finished with a foil top surface and a release film (covering the adhesive) bottom layer.

Figure 25: PIR Insulation (160mm), ©Bauder

Bauder PIR Flatboard Insulation is an insulation board with a mineralised glass fibre facing on both sides (see Figure 25). The insulation has rigid urethane foam in the centre and is manufactured using cyclopentane gas as the blowing agent. It is light-weight with a high compressive strength and has zero ozone depletion potential. It is also CFC and HCFC free.

This product can help in the reduction of GHG emissions through lower energy consumption levels for the purpose of heating and cooling in buildings.

Figure 26: DS1 Duo Vapour Barrier, ©Bauder

Bauder Therm DS1 Duo Vapour Barrier is a self-adhesive elastomeric bitumen vapour barrier (see Figure 26). It features a tear-resistant aluminium foil lining which prevents any water getting in.

4.2.2.1 Normal Roof Components

The build-up for the Bauder "Normal" roof is essentially the same as a green roof, except the sedum blanket and drainage layer are absent, and the root barrier cap sheet is replaced with a chemical-free cap sheet. The plywood deck is also replaced with a steel deck (see Figure 27).

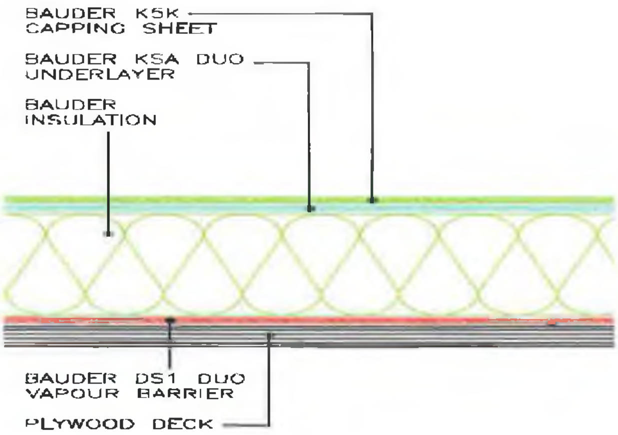


Figure 27: Normal Roof Build-up, ©Bauder

4.1.3 Design Considerations

There are certain principles that apply to the design of a green roof, regardless of the suggested landscaping, location or climate. These design considerations can also be applied to the Irish climate. The finished product must resemble the local natural environment within its build-up and incorporate the following components;

Roof Construction

- **Roofs without thermal insulation**

  On roofs without thermal insulation, above non-heated rooms (e.g. garage, porch etc.) all types of green roof system build-ups are possible;
- **Roofs with thermal insulation**

  Depending on the roof construction, specific foundations are to be considered when planning and installing a roof with thermal insulation. Generally, the installed thermal insulation must show a sufficient compression resistance to bear the load of the green roof system build-up.
    - **Non-ventilated roof ("warm roof"):** Depending on the design load, different types of green roofs are possible. A high-quality vapour barrier layer should be a main feature right from the design/planning stage;
    - **Ventilated roof ("cold-roof"):** The low load-bearing capacity of the upper layer of a ventilated roof allows for the installation of light-weight green roof constructions. The cooling effect of the green roof system build-up enhances the aeration between the layers of the roof construction;
    - **Inverted Roof:** The thermal insulation for inverted roofs is installed above the waterproofing layer, and is therefore in an area with changing moisture levels. The sheets and layers used for the green roof build-up must not prevent vapour from spreading from the insulation layer;
    - **DUO roofs:** DUO roofs are a type of roof which has supplementary thermal layers which act as a drainage element. These are accepted as a form of thermal insulation. This build-up combines the advantages of the "warm roof" with those of the inverted roof (IGRA, 2011).

Landscape Finish

The first decision that is made when designing a green roof is looking at the type of landscape needed to best suit the reason behind the development, whether it is an intensive, simple-intensive, extensive or biodiversity roof. Whatever type of landscape is chosen, the plants will have some basic needs to nourish them; nutrients, moisture and drainage balances, as well as sufficient air flow to the root systems (Bauder, 2011).

Structural Loading

Most roof deck constructions are suitable for green roof construction, provided that they can support the imposed load of the green roof. The saturated weight of the system should be determined at an early stage as a caution and a preliminary measure. The base structure can subsequently be designed (Bauder, 2011). Simple extensive green roofs weigh between 60-150 kg/m^2 depending on the thickness of the green roof system build-up. On most common gravel roofs, once the gravel has been removed, extensive green roof system build-ups can be installed without increasing the level of required structural support (IGRA, 2011).

Waterproofing/Insulation

Within the build-up of a green roof, it is vital that the waterproofing section is sturdy and proven to deliver long-term root resistance. Insulation can then be integrated into the waterproofing layer. The thickness of the insulation is pre-calculated to meet the required U-value of the roof (Bauder, 2011).

Drainage

Extensive green roofs will considerably lessen the levels of peak intensity rain water run-off and overall flow rates. For this reason it is often possible to design a green roof with less rainwater outlets than would be needed on a standard flat roof. However, as a minimum, all roof surfaces should have two rainwater outlets. This provides a fall-back option in the event of an un-detected blockage (Moy Materials, 2009).

Growing Medium

Growing medium is usually called substrate. Substrate must be suitable enough to provide the nutrients that are needed, as well as good anchorage for the plants, together with aeration of the roots, even in wet conditions. Most substrates contain a mineral component and an organic component (Bauder, 2011).

Vegetation Barriers

These provide several important functions in a green roof (Bauder, 2011);

- Protection of the vegetation layer from any water running down vertical surfaces or from higher level rainwater downpipes;
- Provide rapid surface drainage during heavy rainfall;
- Reduce and ease routine maintenance works;
- Protection of the waterproofing layer from mechanical damage during maintenance;
- Fire break.

Pebble or paving slab vegetation barriers should be provided at all perimeters and around all other roof details (roof-lights etc.).

Irrigation

The extensive green roof is quite immune to drought, which we rarely experience in the Irish temperate climate. However, if an extended period of dry weather should occur (+14 dry days) , regular checks should be made of the roof in order to examine the reservoir and drainage board, as well as to determine if all the water contained in the layers has been used by the plants. If no moisture is available, a sprinkler system should be set up and the plants should be watered until they are fully saturated (Moy Materials, 2009). The likelihood of this happening is quite rare, which keeps maintenance costs for extensive roofs quite low.

Maintenance

All roofs require at least two maintenance inspections per year to make sure that the outlets and all other elements of the roof are kept in good condition, despite the type of green roof. An intensive green roof will need the regular work, associated with the planting scheme and landscape design, whereas an extensive green roof will only need low levels of maintenance to make sure unwanted species do not become established (Bauder, 2011).

Safe Access

Safe access to the roof for routine maintenance should always be provided – as all green roofs will need to be accessed and inspected at least twice a year. It is important that the maintenance workers plus their equipment have full and safe access to each roof (Bauder, 2011).

Additional functions

Green roof system build-ups can improve the environmental and energy stability of the roof (IGRA, 2011):

- Green roof system-build ups with thermal insulating properties can be used for energy saving purposes;
- The combination of green roofs and solar power leads to a higher efficiency of the solar module;
- Rainwater run-off from green roofs can be stored in reservoirs for additional use. In cases where the water is used within the building, the colouring of the water, due to the organic component of the substrate, has to be taken into account;
- Green roofs can also be used for other functions if the roof withstands structural engineering and accident prevention measures. The roofs can be used for crop growing, recreational gardens, roof cafés or leisure and sporting facilities.

4.1.4 Maintenance

Annual maintenance is usually carried out in spring and autumn. It is important that all appropriate health and safety procedures are followed during maintenance works (Bauder, 2011).

Fertilising

A granular, organic low release fertiliser should be applied during spring, but no later than the beginning of May. It is an essential part of the maintenance routine, providing all the plants with nutrients. This allows them to become strong enough to resist extreme levels of cold, heat and drought (Bauder, 2011).

Debris

All debris and leaves should be removed from the roof surface, rainwater outlets and gutters. All rainwater pipes should be free of blockages to make sure a uniform stream of water can flow freely through them (Bauder, 2011).

Weeds/Encroachment

Any undesirable vegetation such as weeds, grass or saplings can be removed manually or mechanically. Large areas of weeds commonly occur after a warm and rainy summer and do not cause any damage to the waterproofing layer or roof structure.

Any plants that have invaded areas surrounding rainwater outlets, walkways, pebble vegetation barriers, gutters etc. must be removed in order to prevent blockage or adverse effects on the drainage (Bauder, 2011).

Plant Repair

Any bare patches that remain after the removal of large weeds or grass will need to be covered over by some of the surrounding vegetation. This process can be speeded up by taking cuttings or small clumps from surrounding plants and placing them on the bare patch, covering them with substrate or compost, and then sufficiently watering them in. After 3-4 weeks the cuttings will become fully rooted (Bauder, 2011).

4.1.5 Applications of Green Roofs

The applications and benefits of green roofs have been discussed at length in the literature review chapter of the thesis. However, the author has chosen to describe in detail two particular applications of green roofs below, as these can be directly related to the thesis.

CO_2 Sequestration/Pollution Abatement

As previously described, burning fossil fuel releases CO_2 as a by-product of combustion. It is one of the atmospheric gases that contribute greatly to the greenhouse effect and global warming (Rowe, 2011). High levels of GHG emissions and air pollutants are becoming a major environmental problem in many cities. Due to this, the CO_2 capturing and air purification abilities of urban vegetation on green roofs have been gaining more and more attention (Jian-feng Li, 2010).

Plants can reduce the build-up of heat on roof surfaces by increasing the reflection of radiation. They also remove heat from the roof through the process of transpiration. This can result in a reduction of indoor and outdoor temperatures. Vegetation can enhance the quality of urban air by removing air pollutants and trapping particulates in their leaves (Jian-feng Li, 2010).

Green roofs can play a small part in lowering the levels of CO_2 in the atmosphere in two ways. Firstly, carbon is one of the main components of the structure of a plant and is naturally sequestered in plant tissues (Rowe, 2011). Plants absorb CO_2 from the atmosphere during photosynthesis and discharge CO_2 to the atmosphere during respiration. The rate of photosynthesis depends on light intensity in the area. During the day, photosynthesis rates are high and vegetation can act as a kind of carbon sink. This results in a lower CO_2 concentration in the area surrounding the green roof. At night, plants respire, therefore releasing CO_2 to the atmosphere. As a result of the respiration process, the concentration of CO_2 rises slightly. The magnitude of the green roof effect is related to the quality and condition of the plants, the position of the green roof and the surrounding airflow conditions (Jian-feng Li, 2010). Secondly, green roofs reduce energy needs by insulating individual buildings and by alleviating the urban heat island effect (Rowe, 2011).

Storm water Management

Urban expansion has led to large areas of impervious surfaces such as car-parks, building roofs etc. being developed. Run-off from these areas is causing problems for many communities. Application of traditional stormwater practices in urban areas may not be realistic in all situations due to limited available surface area as well as other factors. Green roofs have been suggested as a means to reduce the stormwater impacts of development because they have been shown to both withhold and absorb stormwater (US EPA, 2009).

Green roofs retain rainwater by storing it in the vegetation and substrate layers, which then dissipates back into the atmosphere. By slowing down and lowering the levels of rainwater that are entering the drainage system, less strain is put on the often inadequate Irish sewage systems. This also helps to prevent the occurrence flooding incidents. A green roof has the potential to retain 40-100% of average rainfall, over the course of a calendar year (Bauder, 2011). Figure 28 illustrates this in graph form.

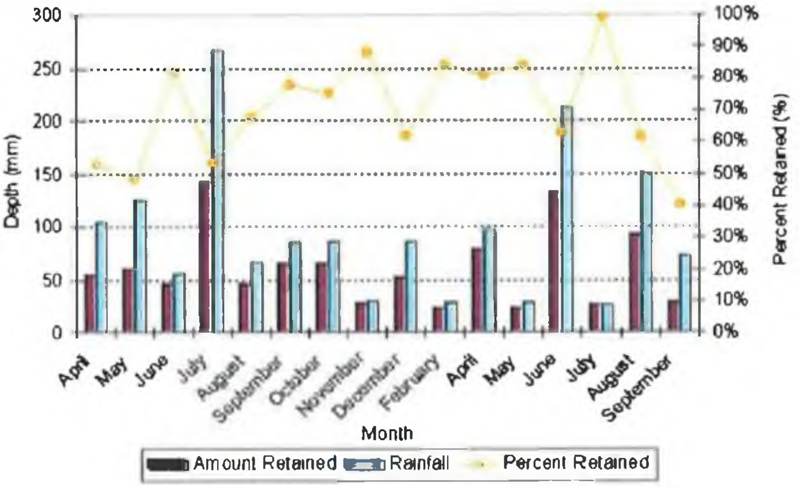


Figure 28: Monthly retention rates from a green roof over 16 months (www.greenroofs.org)

4.2 Green Roofs and Rainwater Harvesting Systems

The author has discussed and considered the idea of combining a rainwater harvesting system with a green roof in order to maximise the storm water management potential of a building with the staff at both Bauder Ltd and Moy Materials Ltd. This concept has not been fully developed. The author could only locate one company – GoGreenRoof, who have attempted to integrate green roofs with a simple rainwater harvesting system. The author discussed this idea further with the technical staff at Bauder, who expressed their interest in the feasibility of the integrated technologies. The potential for improving their green roof technology and creating new business relationships with rainwater harvesting companies in Ireland was an appealing prospect.

Rainwater harvesting systems and green roofs are elaborate constructions. Their integration could offer advantages and benefits for the environment. Rainwater harvesting systems save potable water, therefore contributing to the conservation of precious water resources, which can be very expensive to treat to the standard required for drinking. Green roofs improve the microclimate, protect the sealing of the roof, and make a significant contribution to rainwater retention (Aquality, 2010). Due to the fact that the green roof absorbs a certain percentage of water, a rainwater harvesting system would have to be sized accordingly to suit the average amounts of water running off the roof per year.

For a synthesised use with rainwater harvesting systems, extensive green roofs with layers of thicknesses between 6 and 12cm are most suitable. However, only very little rainwater will run off green roofs. The rainwater that does run off is collected in a tank, and extracted by a pump. The rainwater is then distributed via an independent distribution network which is strictly separated from the mains water network, to the points of consumption (Aquality, 2010).

Water quality and rainwater yield

Green roofs are vegetated soil filters which break down and retain pollutants. Rainwater from these roofs is very well suited for storage and use; however it can be stained by humus substances. Therefore, it should not be used for washing machines. For toilet flushing the staining is irrelevant, but it should be pointed out to users and building occupants/visitors that the water could be slightly discoloured due to the green roof installed on the building. The colour of the water can be minimised by using soil/substrates with very little organic matter. Vegetation base layers with a high mineral share are very suitable. The run-off from extensively planted roofs is 40-60%, i.e. the usable rainwater output is lessened depending on the corresponding roof system and local evaporation rate. This has to be taken into account when designing the rainwater harvesting system (Aquality, 2010).

Benefits of rainwater harvesting and roof greening

Conservation of the water cycle and ecological balance (Aquality, 2010):

- <u>Reduction and slowdown of rainwater run-off</u>: Roof greening and rainwater harvesting considerably decreases and delays the rainwater run-off share in the case of a heavy rainfall event through the detainment and evaporation of rainwater. This relieves the pressure on the sewage system and the operation of the nearest sewage treatment plant. A likeness to the natural water cycle conditions in the surrounding area is achieved;

- Improvement of living conditions in cities: Humidification improves the microclimate. Green roofs become habitats for fauna and flora, their sight improves the visual quality of developed urban areas, and they reduce noise in buildings;
- Saving mains water: The rainwater run-off from the green roof collected in a rainwater storage tank can be used for toilet flushing, watering the garden and industrial cleaning. There are also many commercial and industrial application possibilities for green roofs and rainwater harvesting systems. Rainwater harvesting therefore makes a contribution towards saving water resources.

There are both possibilities and limitations to this idea. If a rainwater harvesting system could be incorporated into a green roof on a building, any rainwater that would be collected could be used for non-potable uses such as toilet flushing or landscaping. This would benefit in terms of offsetting a portion of the commercial water charges, as well as lowering the water footprint and carbon footprint of the building.

Due to the fact that the full amount of water coming off the roof would not be directed into the rainwater storage tank (due to absorption by the green roof), the system would not be able to provide enough water to offset the mains water fully.

Also, designing the integrated system could pose some problems. Through carrying out extensive research, the author came across a very proactive company in the USA, called GoGreenRoof. They have designed a fully integrated green roof and rainwater harvesting system (see Figure 29 on the following page). As far as the author is aware, this concept is still in the very early stages of development.

Figure 29: GoGreenRoof schematic ©GoGreenRoof

This technology incorporates a hidden gutter and a parapet system which retains the growing medium (vegetation mat) while allowing for collection of the rainwater run-off from the roof (see Figure 30).

Figure 30: Hidden gutter and parapet ©GoGreenRoof

The water can then be directed towards a water storage tank, where the water can be used for irrigation of the green roof and other purposes such as gardening etc.

If the author had more time to carry out further extensive research, the feasibility of incorporating this hidden gutter and parapet system into an extensive green roof would have been examined in greater detail, with the possibility of connecting the water storage tank to pipes in a commercial/domestic building. The water could then be used for non-potable applications such as flushing toilets etc. This would benefit the economy and environment in terms of water conservation, reducing commercial/domestic water charges, storm water management, reducing flooding risk in urban areas as well as the other benefits of green roofs and rainwater harvesting systems as already described.

4.2.1 Rainwater Harvesting

It has been shown above, that green roof technology can be linked with rainwater harvesting, as both can be used as a sustainable tool for stormwater management.

Over the last few years, the issue of water supply and security has become a growing concern in Ireland. According to research commissioned by the National Rural Water Monitoring Committee, water demand resulting from urban development is typically met by importing large volumes of water across long distances – and at significant expense – from surrounding catchments. This water then needs to be treated to drinking water quality standards. It has been calculated that less than 1% of urban water consumption is used for drinking (NRWMC, 2008). For businesses, the costs of water look likely to increase. A recent report showed that the average water costs in Ireland were €1.67 per m^3 whilst in Europe the average is €3.24/m^3 (Forfas, 2008). It is likely that in time these costs will increase towards the European average. This will be done in order to pay for the expensive water treatment process. Therefore, it makes sense for businesses to start harvesting the rainwater falling on their roofs. Currently, there is not only a charge for the water supply; businesses are also being charged for water they discharge, including considerable volumes of rainwater which they are currently not using.

Ireland's domestic water use per person per day is one of the highest in Europe. The figure on the following page (Figure 31) shows the average water consumption per capita per day in selected European countries.

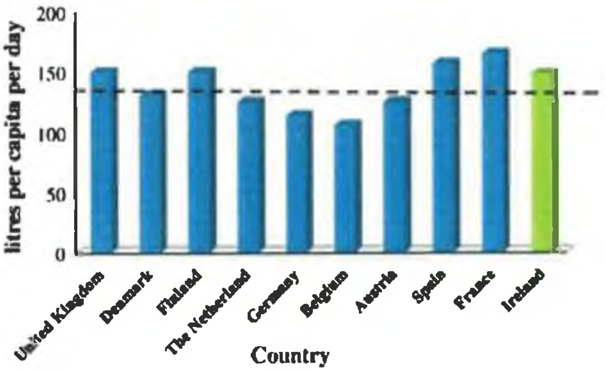


Figure 31: Average European water consumption per person per day

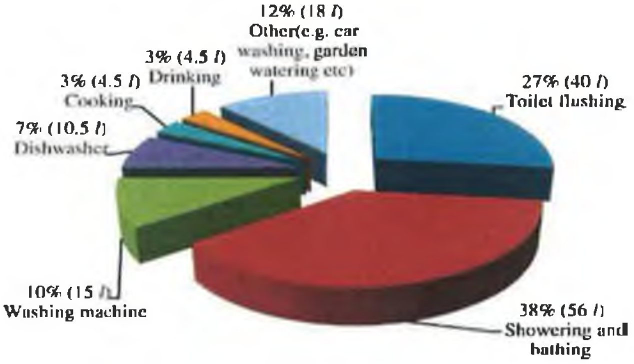


***Figure 32: Breakdown of domestic water use in an Irish household (* **(Li Z. B., 2010).**

Figure 32 shows the breakdown of domestic water use in a typical Irish household. It can be seen that only 3% of the water use in a household is used for drinking. All other water is used for non-potable applications.

Rainwater harvesting is one of the most influential alternative options for supplying water with looming prospects of increasing water scarcity and rising demand. The pressures on water supplies, environmental impact related to new projects as well as deteriorating water quality in reservoirs that have already been built, restrict the ability of local communities to meet the need for good quality freshwater from traditional sources. Rainwater harvesting raises an opportunity for the improvement of water supplies, therefore allowing for self-sufficiency and sustainability. Preserving the environment supports the overall conservation of this valuable natural resource (JR Smith, 2010). Looking at the figures above, if a rainwater harvesting system was installed on a house with a normal roof it would offset up to 60% of the water coming from the mains supply, which is all treated to drinking quality. However, the percentage would drop to approximately 30% if the house had a green roof – due to the absorption qualities of the vegetation. Harvested rainwater can be used for toilet flushing, washing machines and other uses (car washing, garden watering etc.).

Since the dissolution of domestic water charges in Ireland on 1 January 1997, all water supplied from the public mains is free. These public water schemes are organised and supported by the local authority. However, Budget 2010, which was announced on 9 December 2009, indicated that a system of water metering for homes will be introduced in Ireland (Citizens Information, 2009). The potential re-introduction of a domestic water charge may have a large impact on the support of sustainable water systems in Ireland. Householders and businesses may be willing to use RHS in order to avoid costly water charges. This has already been discussed in greater detail in the literature review chapter.

There are many businesses in Ireland who are manufacturing rainwater harvesting systems and developing the technology to suit the Irish climate. One such company is JFC, in Co. Galway. JFC is a global organisation, which is acclaimed for the manufacture and supply of a variety of innovative quality plastic products in the environmental, recycling, civil, agriculture, marine and materials-handling industries (JFC, 2010). JFC produce a number of rainwater harvesting systems – underground/above ground tanks and large water tanks, which have the ability to hold up to 250,0001 (see Figure 33).

Figure 33: Large water tank, aboveground tank, underground tank ©JFC

The tanks from JFC could be seen as an example of "Design for Environment" – a concept which has been previously defined and mentioned in the literature review chapter. The aboveground and underground tanks are sized to meet particular client requirements. Other tank systems with over-designed features in terms of storage, cost more to install and result in more stale and stagnant water, which has the potential to cause health risks. The tanks are easy to assemble, due to their modular framework. As well as this, the composite plastic used to produce the tanks contains recycled content. It is a light-weight material, but is still very substantial and strong. This makes installation easier – compared to the traditional concrete tanks (JFC, 2010). In particular, the underground tanks have a low visual impact, therefore preserving the visual qualities of the surrounding landscape (see Figure 34).

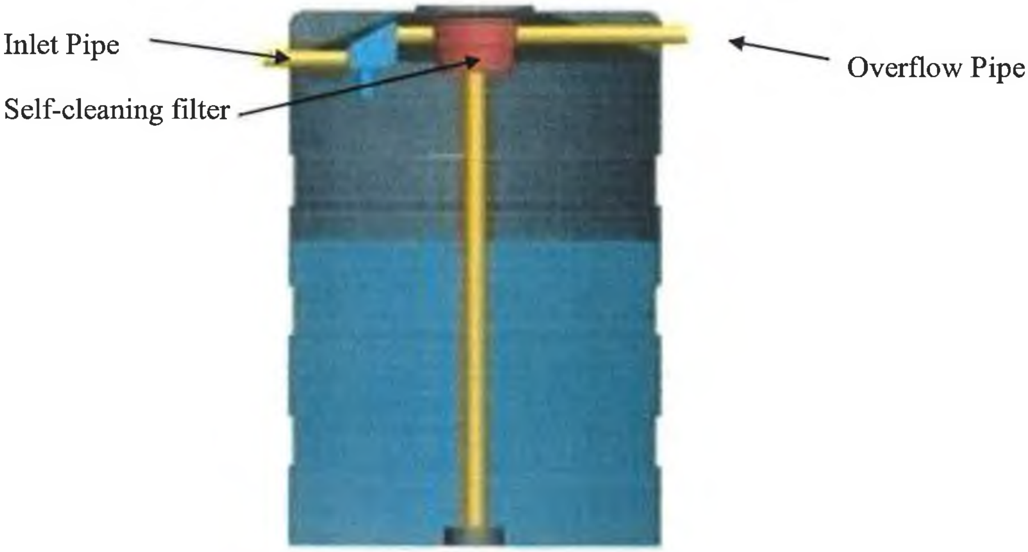


Figure 34: Commercial Rainwater Storage Tank ©JFC

The rainwater harvesting system that will be considered for life cycle assessment in the following chapter is a commercial system, sized appropriately to accommodate the functional unit of the study. The author visited JFC in order to gain a better insight into the rainwater harvesting industry. A technical sales representative at JFC calculated the size of the tank in order to suit the size of the roof to be used in the author's LCA study. Details of the size and type of rainwater harvesting system that was chosen will be discussed in the following chapter.

4.3 Control Building for the Study

In order to carry out a detailed environmental impact analysis of each product, a hypothetical control building on which the products would be installed, was developed. This was done with the help of Mr. Dwayne Higgins, a local architect, and personal friend of the author, Mr. Kieran Townes, a senior technician at Bauder Ltd., as well as Mr. Michael Fitzpatrick, RHS Installer. Figures for water use and heat use in the building have been gathered from the Internet, and confirmed by Mr. Higgins. Figures for the sizing of the rainwater storage tanks have been calculated and confirmed by Mr. Fitzpatrick. Figures regarding both roofs have been estimated and confirmed by Mr. Townes at Bauder Ltd.

- The building is a commercial industrial office building, with a roof area of 600m^2 and a floor area of 1200m^2. The area was calculated by Mr. Higgins, who has had experience in designing commercial office buildings;
- The location of this building is Dublin city. This location was chosen due to the fact that Dublin is a densely built-up area, where the benefits of a green roof will be realised more effectively than in a rural area;
- The average occupancy of the building is 50 people. After subtracting space for reception, hallways, stairs, elevator, mail room, conference rooms and toilets, each occupant has an area of approximately 20m^2. This is an accurate figure for a "spacious office building". This figure was also calculated by Mr. Higgins;
- Information from an EPA report shows that the average water consumption per person per day in office buildings is 30 litres/person/day. If the office building contained a canteen, the figure would increase to 60 litres/person/day. However, the author has chosen to design this building without a canteen. This is due to the hypothetical location of the building, as well as the abundance of amenities and restaurants etc., that would surround the building (EPA, 1999);
- Assuming each occupant uses approximately 30 litres per day, this amounts to a total water use of approximately 36,750,000 litres of water over the lifetime (70 years) of the building;
- On a roof this size, approximately 1480 litres of rain will land on the roof per day. Allowing for a 21 day reserve of rainwater (31,080 litres), the size of the tanks has

been calculated for the normal roof and green roof. These figures have been calculated by Michael Fitzpatrick (RHS Installer);

- The average heat load is 50W/m^2. This figure was extracted from the Dimplex website, which had a heat calculator for different types of buildings. The details of the calculations will be discussed later on in the thesis;
- Taking into account the figure of 50W/m^2, this amounts to approximately 5.04MW of electricity being used over the lifetime (70 years) of the building;
- The lifespan of the building is assumed to be approximately 70 years. This figure was estimated by Mr. Townes, a senior technician at Bauder Ltd.
- The mechanical lifespan of a typical conventional roof is approximately 40 years, whereas the green roof is estimated to have a lifespan of 70 years, the same lifespan as the building. The author received information regarding these figures from Mr. Townes;
- The reason that the lifespan of the green roofs is longer than that of a normal roof is due to the fact that in a green roof the bituminous membranes are protected, by the vegetation layer, from UV radiation and weather conditions (Rowe, 2011).

4.4 Conclusion

The aim of this chapter was to give the reader a more detailed insight into green roofs, in particular, extensive sedum blanket green roofs. The technology of rainwater harvesting was explained. The potential link between green roofs and rainwater harvesting systems was looked at. However, further research needs to be carried out on the successful integration of the two technologies. The author was fortunate enough to collaborate with a leading green roof manufacturer and supplier, Bauder Ltd., as well as a rainwater storage tank manufacturer, JFC Ltd., for research purposes in this thesis.

The chapter ends with a description of the hypothetical control building that was designed with the help of construction industry experts. The normal roof, green roof and two rainwater storage tanks will be analysed in the context of their installation on this control building.

The following chapter will show the entire LCA and LCC processes which were carried out by the author using the Eco Indicator method and Net Present Value equation. The results of the following LCA/LCC chapter will benefit both companies in terms of showing the environmental impacts of their respective products.

Chapter 5 – LCA/LCC Study

5.0 Introduction

Taking into account life cycles in relation to thinking and acting is the foundation of sustainable building. The more energy-efficient a building is and the less energy it uses within its useful life, the more important are the construction methods and the selection and processing of different materials (PE International, 2011).

Planners and architects who want to create buildings in a sustainable way are presented with the following questions:

- Can the materials that are used during the process of construction be recycled?
- How much primary energy is spent in the building?
- What is the size of the carbon footprint?
- Have the environmental impacts been considered in the planning throughout the whole life cycle of the building?
- What is the payback period for a more ecologically friendly building?

Every building is unique and requires an exclusive analysis to be carried out, in order to illustrate the environmental impact and sustainability performance of the building, as well as to identify potential opportunities for improvement. A life cycle assessment of a building does not only supply the required information, but is a vital component of the sustainability certification of a building (PE International, 2011).

In this chapter, the author will describe the LCA and LCC processes in greater detail. A comparative LCA will then be carried out between two types of roof; a conventional roof and an extensive green roof. A comparative LCCA (life cycle cost analysis) will also be carried out on the two roofs. The environmental impact and cost of two different sizes of rainwater storage tanks will also be examined using the same methods. The author aims to achieve an understanding of the difference between the environmental impact of the two roofs and their respective rainwater storage tanks, as well as the cost-effectiveness of the products over their lifetime.

5.1 Life Cycle Assessment

An LCA involves the analysis of the entire life cycle of different products and services, with regard to their environmental impacts and the display of these analyses in a transparent way (PE International, 2011). Every LCA is set on the same basic principle with different areas of application extending from carbon footprints, water balances, examinations of material flows and processes to studies of social and economic factors. By taking into account the whole life cycle of a product or service, environmental impacts can, not only be partially prevented, but also be presented for analysis. This allows for the identification of which phase of life (from production of raw materials to disposal) causes the most extensive damage to the environment. Therefore, specific actions can be selected and adapted to increase the environmental performance of the product or service where it is most constructive (PE International, 2011).

The main phases of an LCA are (Pré - Product Ecology Consultants, 2010):

- Goal & Scope definition;
- Inventory analysis;
- Impact assessment;
- Interpretation.

These phases have previously been described in more detail in the literature review chapter.

The LCA that is being carried out in this case is an *abridged* or *streamlined* LCA.

An abridged LCA can be carried out for various reasons:

- Full LCA is expensive;
- Full LCA takes a lot of time;
- In a full LCA, a lot of problems to gather sufficient data can be experienced.

Streamlined LCA studies are used when:

- Decisions have to be made at the design stage i.e. identifying differences between alternatives;
- The product's environmental profile needs to be understood;
- A quick calculation of the environmental impact of a product is needed in order to decide if the cost is justified for a more extensive LCA.

5.1.1 Goal & Scope of the Study

The goal of this study is to determine which system out of the following four is most suitable for a commercial building in the Irish climate and Irish market;

1. Normal Roof;
2. Normal Roof + Rainwater Harvesting System
3. Green Roof;
4. Green Roof + Rainwater Harvesting System.

This study is being carried out for the benefit of Bauder Ltd. and JFC Ltd., leading green roof and rainwater storage tank suppliers, respectively, in Ireland and the UK. Should the concept of integrating green roofs and rainwater harvesting systems be a success, this could help to improve green roof technology, while forming new business relationships between Irish companies. Also, a new niche in the green roof/rainwater storage tank market could be created.

During the scoping process, a comparative LCA of the three technologies/systems will be carried out. The manufacturing phase and use phase will be looked at. The functional unit of the study is the hypothetical building, which has already been described in the previous chapter.

- The building is a commercial industrial office building, with a roof area of 600m^2 and floor area of 1200m^2;
- The location of this building is Dublin city;
- The average occupancy of the building is 50 people. Each person is allowed 20m^2 – "spacious office building";
- The lifespan of the building is 70 years;
- It is assumed that the building is a new building, with minimum insulation standards, and that any work being carried out on the building (laying roofs, installing rainwater harvesting systems etc.) will be done during the overall construction phase of the building;

- The lifespan of the Normal Roof is 40 years, therefore needing replacing once during the lifetime of the building. The lifespan of the Green Roof is approximately the same as the lifespan of the building (70 years), with no replacement required;
- The lifespan of the Rainwater Storage Tanks is approximately 25 years, with two replacements needed during the lifetime of the building. These figures will be taken into account during the Impact Assessment stage of the LCA.
- As mentioned previously, all figures have been confirmed by Mr. Dwayne Higgins (Architect) and Mr. Michael Fitzpatrick (RHS Installer).

System Boundaries

For the life cycle of the Normal Roof, Green Roof and the Rainwater Harvesting System, only the manufacturing and use phases were considered. The author experienced considerable difficulty in obtaining information regarding the manufacturing processes of some of the materials that make up each product. All of the information for the roofs in this LCA study was obtained from the technical staff at Bauder in the UK. The author worked closely with the staff at Bauder and found them very knowledgeable and efficient in delivering any extra information required. The information about the rainwater storage tanks was obtained from the design engineers and technical sales staff at JFC Ltd. in Tuam, Co.Galway.

The first two images (Figures 35 & 36) are the author's first attempt at developing the system boundaries for the Normal Roof and the Green Roof. It can be seen that the diagrams are very detailed, with complex processes, which in turn, could not be located in the LCA software database, or in the Eco Indicator list. The following two images (Figures 37, 38 & 39) show more simplified versions of the system boundaries diagrams for the Normal and Green Roof, as well as the Rainwater Storage Tanks.

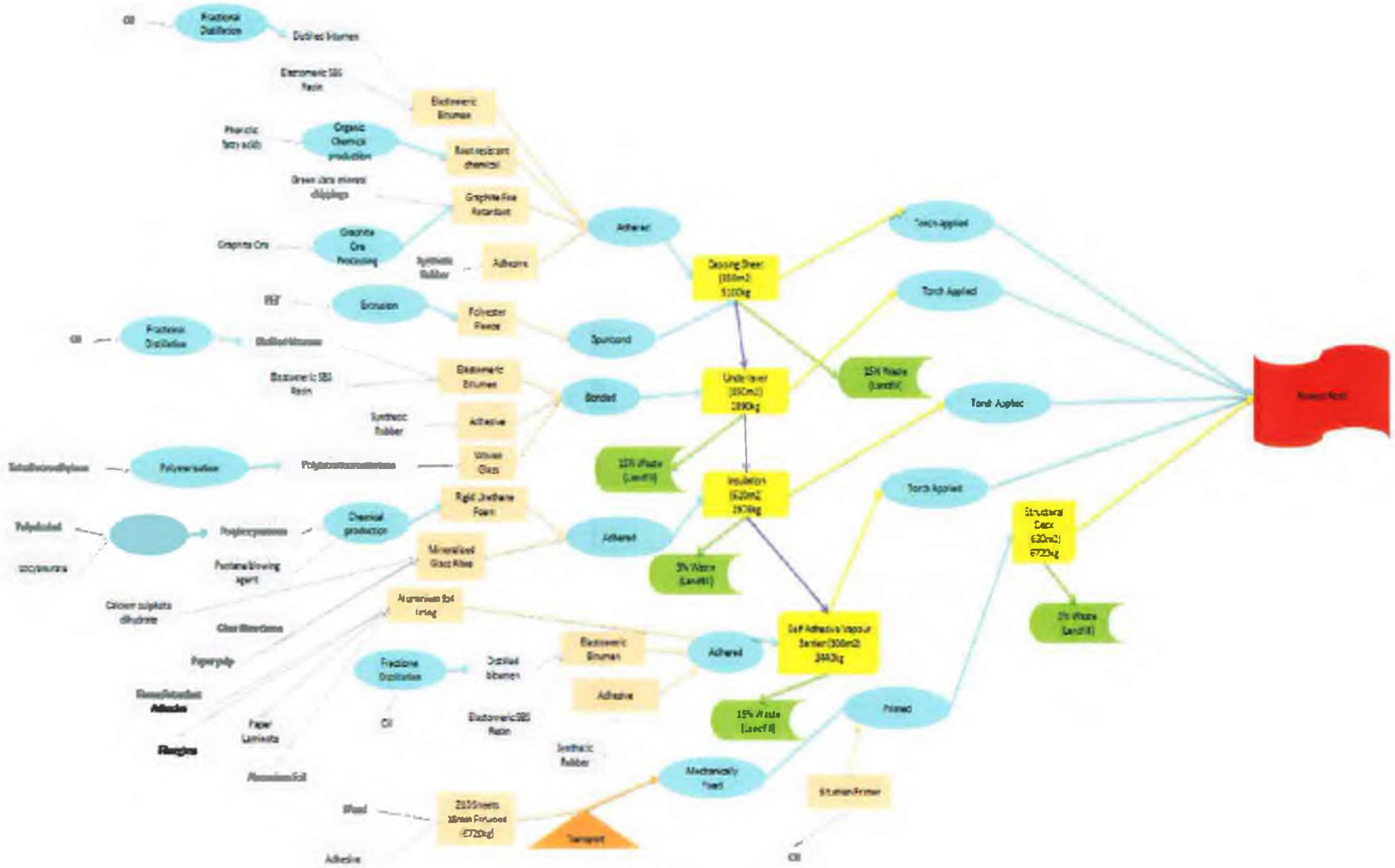


Figure 35: Normal Roof system boundaries diagram – first attempt

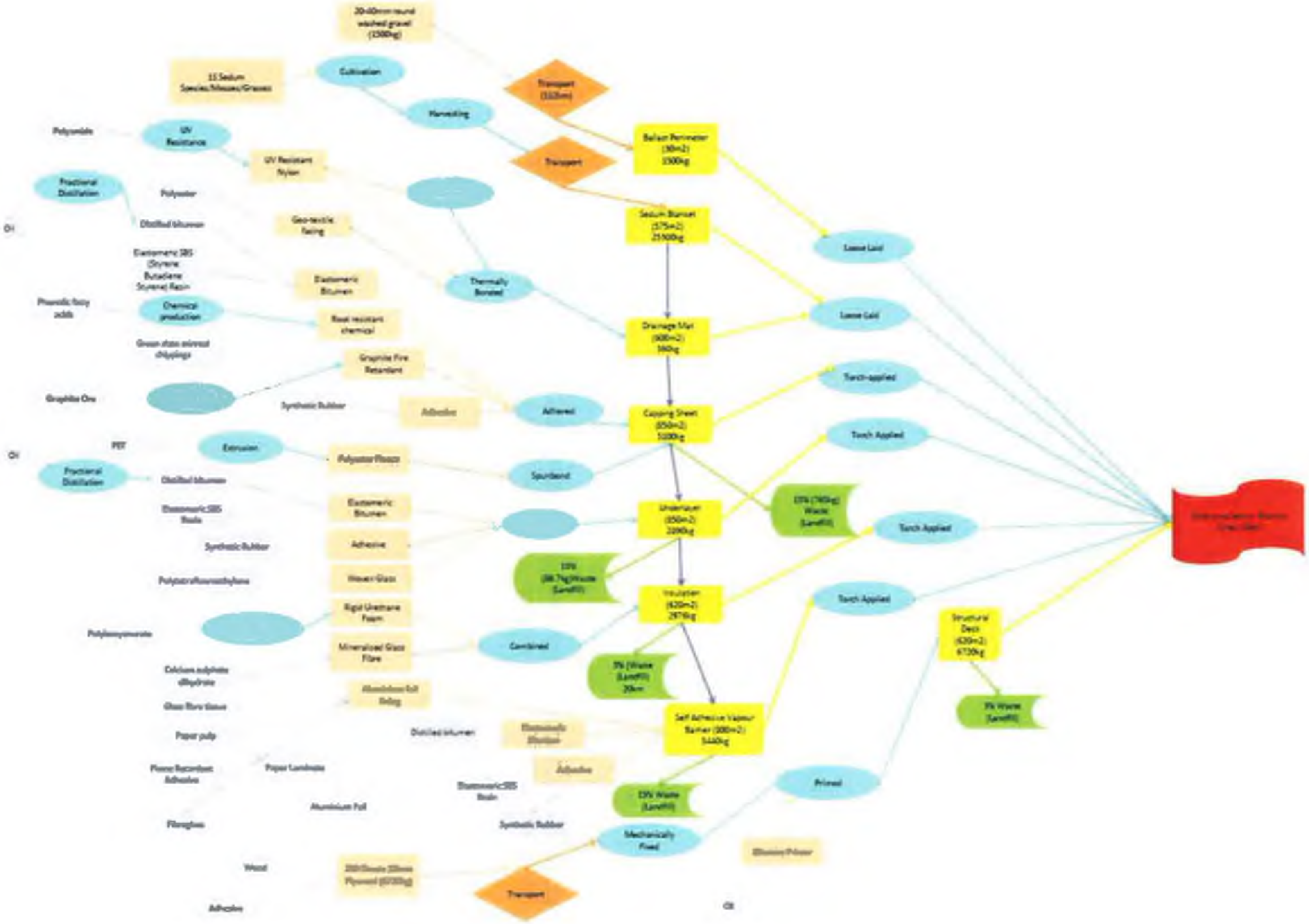


Figure 36: Green Roof system boundaries diagram - first attempt

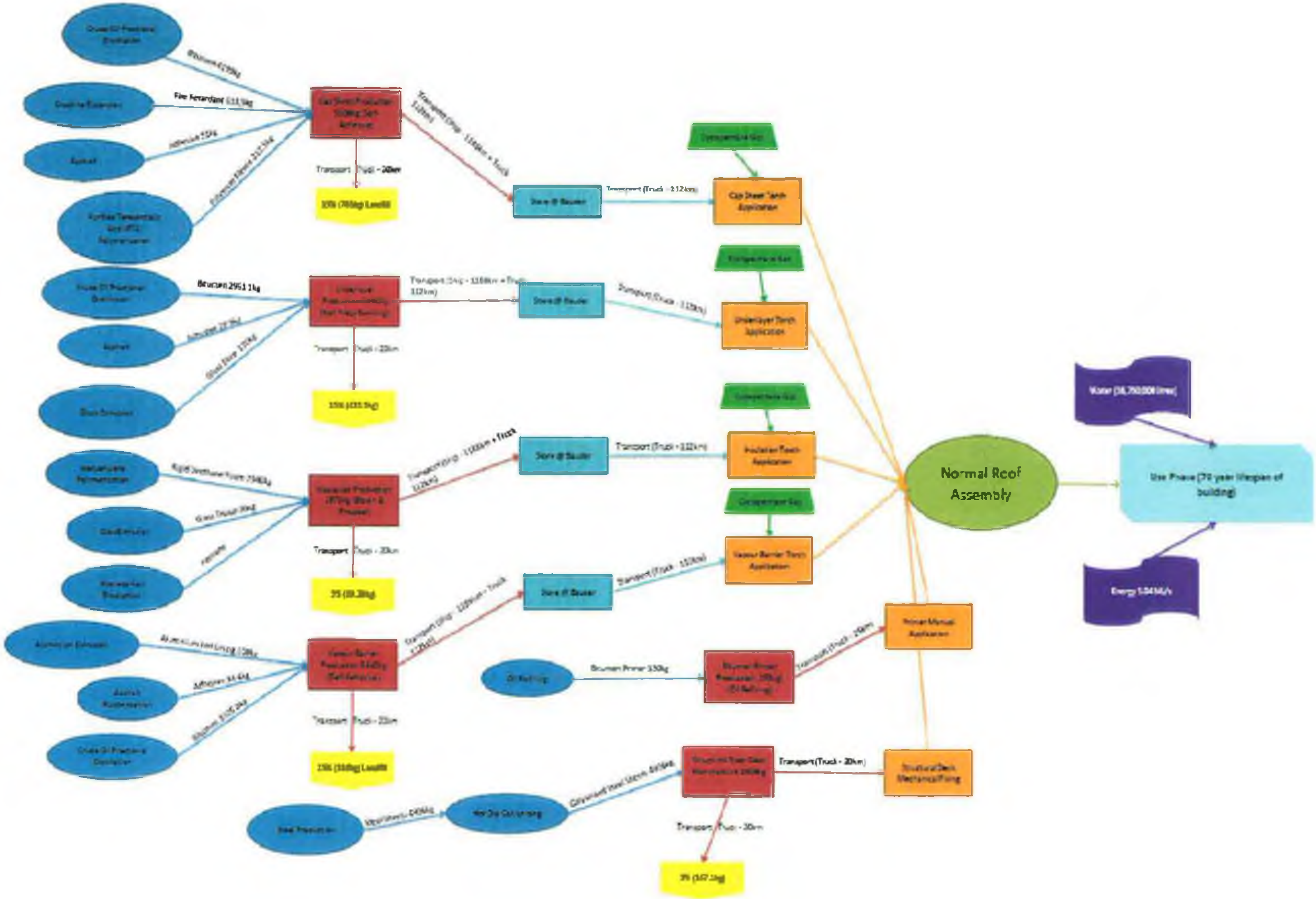


Figure 37: System Boundaries - Normal Roof

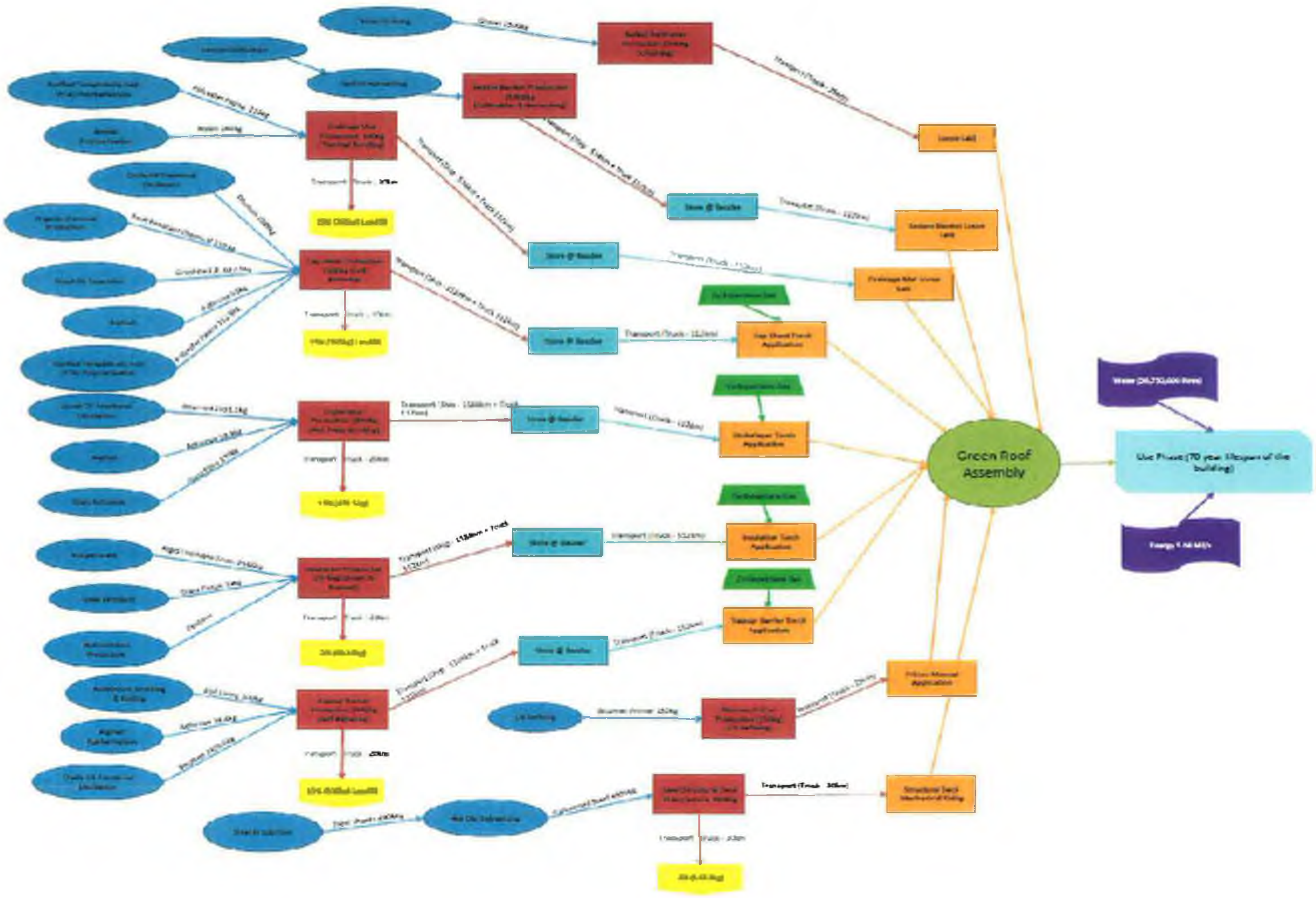


Figure 38: System Boundaries - Green Roof

As it can be seen above, the modified diagrams are more structured, containing only the relevant information needed for the LCA. Material weights and transport distances are also included in each system boundary diagram.

A system boundaries diagram for the rainwater storage tanks was also drawn up. This shows the manufacturing and use phase of the storage tanks. The estimated lifespan of each tank is approximately 25 years. The assumption is made that the rainwater harvesting system will be replaced once during the lifetime of the building. This will be taken into account in the life cycle analysis.

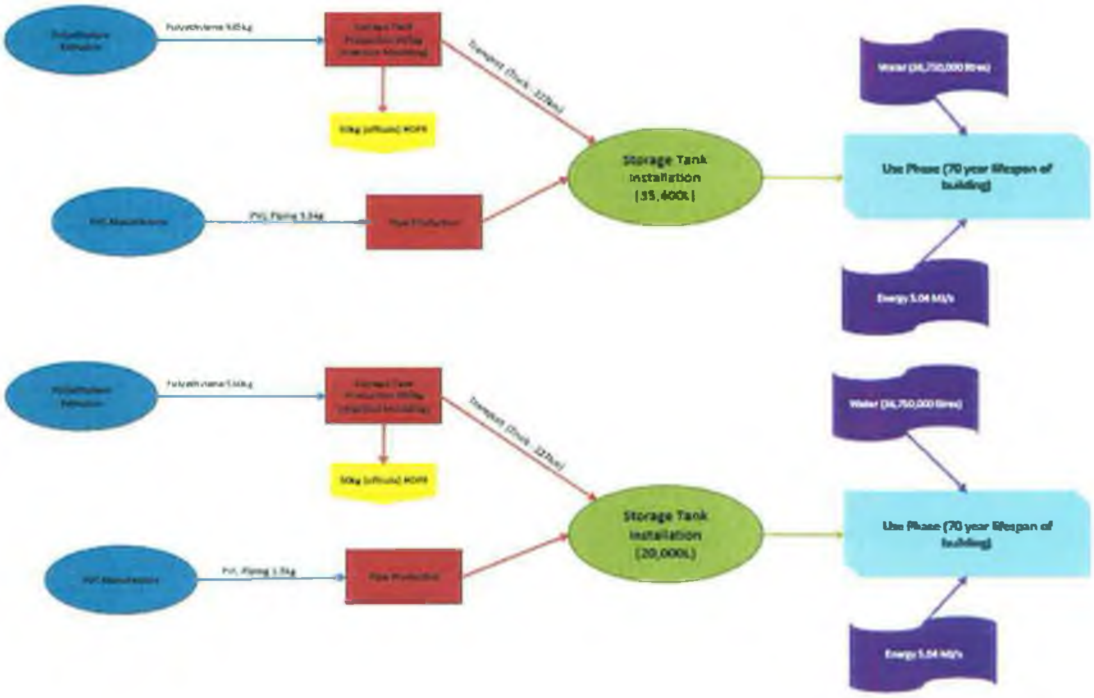


Figure 39: System Boundaries – Rainwater Storage Tanks (20,000L & 35,400L)

It can be seen from Figure 39, that the material and process flows for the rainwater storage tanks are a lot less complex than those of the green roof and normal roof. This is due to the fact that the tanks are only made from one material – Polyethylene. The processes in the manufacture of the tank are also much simpler than those for the roofs. The only extra material needed is PVC. These are required during the installation process to connect the storage tank to water pipes in the building.

5.1.2 Inventory Analysis

The Inventory Analysis stage of an LCA can be carried out manually – using such tools as the Eco Indicator – or with computer software – for example, GaBi.

The inventory analysis section proved to be quite difficult in this particular case. Gathering very specific data for each product was time-consuming and very difficult to obtain. The author was in contact with staff from roof suppliers, product manufacturers, roofing contractors, roof maintenance companies and rainwater harvesting tanks suppliers in order to gather all the necessary data for the study. As well as this, considerable internet research was carried out in situations where information gaps needed to be filled. The author did not go from "cradle to grave" in this study, covering all stages of the life cycle of the products/systems due to time restrictions. Therefore, only the manufacturing and use phases have been considered.

A generic scenario of a "typical" sized commercial building will be applied to all three systems. This building has been already described in the previous chapter.

Assumptions

Some assumptions and changes have been made in relation to certain products/materials.

- It can be assumed that the sedum blanket has no impact on the environment, as the plants actually absorb CO_2. Some energy would be used in harvesting the sedum blanket - however, this was not taken into account in this particular case;
- "Inorganic Chemical Production" has replaced Asphalt Rubberisation in the process of manufacturing adhesive;
- The production of Organic Chemicals (99mPt) has been used for "Bitumen Manufacture" as bitumen is a by-product of organic decomposed materials.
- The production of "Carbon black" (180mPt) has been used instead of "Graphite Expansion" as graphite is a form of carbon. There were the closest processes in the EcoIndicator tables that could be used.
- The process of "Pressure Forming" has been used for the cap sheet, underlayer and insulation layers of the roof - this is due to the fact that the original processes in the manufacture of these products could not be located in the EcoIndicator tables.

- The EcoIndicator for Aluminium Extrusion (72mPt) was used in place of Glass Extrusion, as there were no figures for this process in the table.
- The figure for PUR Hardofam was used instead of PIR Insulation in this case, as there were no available figures for PIR.
- The processes of Aluminium Smelting and Rolling have been excluded in the study, as there were no figures available in the EcoIndicator table.
- The indicator for the production of demineralised water (0.026) has been used for the use phase of the building.
- The indicator for the landfill of PET (3.1) has been used for Bitumen Landfill, as some of the bitumen products have been bonded to polyester fleece. Also, there was no indicator specific to bitumen.
- It is assumed that the steel deck has been hot dip galvanized (3300mPt), with a zinc coating. The steel deck is a 1mm sheet, measuring 2.5m x 1.25m per sheet, weighing 24.5kg per sheet. Approximately 200 sheets are required for 620m^2 of roof.
- It is assumed that 1 litre of water requires 0.025kg of HDPE;
- It is assumed that 50kg (in offcuts) of HPDE will be sent for recycling after the production process;
- The rainwater storage tanks will travel from Tuam to Dublin (227km);
- It has been calculated that approximately 15m (in total) of piping will be required for this product. It is assumed that 150m of piping weighs 15kg, 1m will weigh 0.1kg and 15m will weigh 1.5kg.
- It is also assumed that the Normal Roof will be replaced after 40 years, and the Rainwater storage tanks will be replaced after 25 and 50 years, while the Green Roof does not need to be replaced.
- Due to the fact that JFC do not currently manufacture a plastic rainwater storage tank that can hold a volume of either 35,000l or 18,000l, it is assumed that each tank is made up of a number of smaller tanks, making up the nearest volume to the volume required for this study. (35,400L = 3 x 10,000L + 1 x 5400L) and (20,000L = 2 x 10,000L).

Water Use

The average water consumption per person per day in office buildings is 30 litres/person/day (EPA, 1999).

The following calculations were made in order to determine the amount of water used during the lifetime of the building.

30 litres x 50 people = 1500 litres/day

1500 litres x 350 days = 525,000 litres/year

525,000 litres x 70 years = **36,750,000 litres/70 years**.

Rainwater Calculation

The author contacted an RHS installer in order to calculate the size of tank required for the size of the hypothetical building in this thesis.

Assuming that the average annual rainfall is 1000mm, Mr. Fitzpatrick carried out a simple calculation to determine the average amount of water that would fall on a 600m^2 roof per day.

600m^2 x 1000 litres x 0.9 (90% accuracy) = 540,000 litres/year.

540,000 litres / 365 days = **1,479.45 litres/day/600m^2**.

The author was advised that a 21 day reserve of rainwater was needed for every building in order to ensure an adequate supply of water to the building. Based on this, the average size of the tank needed is:

1480 x 21 = **31,080 litres**.

Allowing for extreme weather, the author has decided to use a 35,000 litre tank for the normal roof, and an 18,000 litre tank for the green roof (assuming that the green roof absorbs approximately 50% of the annual rainfall). However, JFC do not currently manufacture plastic rainwater storage tanks of this size/volume. Based on a recommendation from Mr. Fitzpatrick, the author will connect a number of smaller tanks together in order to make up the correct rainwater harvesting system for each building. For the normal roof, a volume of approximately 35,000L is required. This RHS will be made up of 3 x 10,000L tanks and one 5,400L tank. The RHS for the green roof requires a volume of 18,000L. For this system, 2 x 10,000L tanks will be used. All tanks will come with all relevant attachments, connections and a pump. The environmental impact of the pump will not be considered in the LCA. However, the pump will be included in the cost analysis section of the thesis.

Based on this calculation, as well as accounting for the fact that the building requires the use of approximately 1500 litres per day, the rainwater harvesting system for the normal roof should be able to account for 100% of the non-potable water use in the building. Due to the fact that the green roof absorbs approximately 50% of the water falling on the roof, only 50% of the building's non-potable water use can be offset by harvested rainwater.

Heat Use

To estimate the amount of heat used in this building over its lifespan of 70 years, the following information was taken from a Dimplex website, which has a heat load calculation tool. For sixty years, Dimplex have been producing a broad range of products, from electric space and water heating, to innovative renewable solutions such as heat pumps and solar water heaters (Dimplex, 2011).

A rough estimate of heat consumption can be made on the basis of the specific heat consumption (Dimplex, 2011).

- Lowest-energy house, approx. 30 W/m^2
- Minimum insulation standard acc. to the German EnEV, approx. 50 W/m^2
- Buildings with normal thermal insulation, approx. 80 W/m^2
- Older buildings with no special thermal insulation, approx. 120 W/m^2.

Taking into account the information above, the author is using a heat load of $50W/m^2$ in this study. The following assumptions have been made:

- Heating is used for 10 hours per day;
- Heating is used for 120 days a year (November-March).

Therefore, using the heat calculation tool, the following calculations were made:

$1200m^2 \times 50W/m^2 = 60kW$

60kW x 10 hours = 600kWh/day

600kWh x 120 days = 72,000kWh/year

72,000kWh x 70 years = **5.04MW/70 years**.

Over the lifetime of the building, approximately 5.04MW is used to heat the building. This corresponds to 5.04 MJ/s.

Material Requirements – Green Roof/Normal Roof

Each steel sheet measures 2.5m x 1.25m. For an area of 620m^2, approximately 200 sheets of steel are required. With each sheet weighing 24.5kg, an overall weight of 4906kg of steel is required for the normal roof and green roof construction.

Approximately 600m^2 of adhesive is required for 4 layers of the roof. The adhesive weighs 0.3 kg/m^2. Each layer will therefore require approximately 180kg. As a result, each roof will require 720kg of adhesive.

For the vapour barrier, 800m^2 would be required for 600m^2 of roof – allowing for 15% waste. The material weighs 4.3kg/m^2. For each roof, approximately 3,440kg of vapour barrier would be required.

The density of the insulation in each roof is 30kg/m^3. The thickness of the insulation is 160mm. To find out the amount of insulation required, the following is calculated - 0.16m x 620 = 99.2m^3(Depth x Area). 99.2m^3 x 30kg/m^3 = 2976kg. Therefore, 2976kg of insulation is required for each roof.

The underlayer weighs 3.4kg/m^2. To allow for waste, approximately 850m^2 of underlayer is required per roof. This amounts to a weight of 2,890kg.

Each cap sheet weighs 6kg/m^2. Allowing for waste, 850m^2 is required for a 600m^2 roof. This amounts to 5,100kg per roof.

On the green roof, a drainage mat is required. The SDF mat weighs 0.6kg/m^2. 600m^2 of drainage mat is required, resulting in 360kg of drainage mat per green roof.

The sedum blanket on a green roof is the heaviest layer. Each m^2 weighs approximately 44kg. To allow for perimeters, only 575m^2 of sedum blanket is required on a 600m^2 roof. This amounts to 25,300kg.

Every green roof should have a perimeter, to act as a vegetation barrier and a fire break. Round washed stones are ideal for this purpose. To cover a 300mm perimeter around a 600m^2 roof (~29.64m^2) approximately 1500kg of stones is required.

The information outlined above has been gathered into a table, shown below.

Material	**Weight/m^2 (kg)**	**Weight/roof (kg)**
Steel Deck	24.5kg per sheet	4906
Primer	N/A	150
Adhesive	0.3	720
Vapour Barrier	4.3	3440
Insulation	3.3	2976
Underlayer	3.4	2890
Cap Sheet	6	5100
Drainage Mat	0.6kg	360
Sedum Blanket	44kg	25300
Ballast Perimeter	N/A	1500
Normal Roof – Total Weight		**20,182kg**
Green Roof – Total Weight		**47,342kg**

Table 5: Material weight requirements per roof

Material Component Weights – Green Roof/Normal Roof

With the help of a Senior Technical Representative at Bauder, the author could calculate the approximate weights of each component that is present in each product which makes up both the normal roof and the green roof that are supplied by Bauder.

The following table represents the information that was gathered:

Product	**Total Weight**	**Components**	**Component Weight**
SDF Mat	360kg	Polyester	216kg
		Nylon	144kg
Plant E Cap Sheet (Green Roof)	5100kg	Bitumen	3989kg
		Polyester Fleece	212.5kg
		Root Resistance Chemical	210
		Adhesive	51kg
		Mineral Chippings	637.5kg
K5K Cap Sheet (Normal Roof)	5100kg	Bitumen	4199kg
		Polyester Fleece	212.5kg
		Adhesive	51kg
		Slate chippings	637.5kg
KSA Duo Underlayer	2890kg	Bitumen	2691.1kg
		Adhesive	28.9kg
		Mineralised Glass	170kg
Insulation	2976kg	Rigid Urethane Foam	2946kg
		Glass Tissue	30kg
DS1 Vapour Barrier	3440kg	Bitumen	3305.6kg
		Adhesive	34.4kg
		Aluminium Foil	100kg

Table 6: Material Component Weights - Normal Roof + Green Roof

Material Requirements – Rainwater Storage Tank

For the 35,400 litre system, approximately 935kg of Polyethylene is required. For the 20,000 litre tank, approximately 550kg of Polyethylene is required. These amounts were calculated assuming that 1 litre of water would require approximately 0.025kg of PE. This figure was obtained from Michael Fitzpatrick, who estimated the weight of a 10,000 litre tank to be 250kg. It was then assumed that by dividing 250 by 10,000 a figure of 0.025kg was obtained. This figure was then multiplied by the volume of each system required for this thesis – namely, 35,400 litres and 20,000 litres. A waste amount of 50kg has been considered in both cases. This amount of PE would ideally be sent for recycling. The HDPE makes up the entire weight of each rainwater storage tank. Small amounts of extra materials – mainly PVC – are used for piping and connecting the tank to the building's water system. Minor materials such as brass fittings and the filter basket have not been considered in the LCA study.

5.1.3 Impact Assessment

Environmental life cycle inventories produce large amounts of complicated information on natural resource use and emissions to the environment. However, these data can be difficult to understand. Impact Assessment offers a way of integrating elaborate inventory data outputs into a small number of impact categories through a conversion procedure. Numerical scores can also be developed, which weight the various impact categories. This demands the capability to compare and contrast, as well as to accurately weight the impacts of various emissions and impact categories on human health, ecological quality and natural resources (Curran, 1996).

GaBi Software & Eco Indicator 99

PE International have developed a software called GaBi, which is a life cycle assessment software used to analyse products and processes. Development of the life cycle databases in GaBi began over two decades ago and still progresses today. More than 60 life cycle experts support the development of GaBi databases. This makes PE International the largest life cycle data provider across the globe.

All LCI profiles within the database are generated in compliance with the ISO 14044, ISO 14064 and ISO 14025 standards and include all criteria appropriate for application in Life

Cycle Assessment, Design for Environment, Carbon footprinting, Water footprinting, Environmental Product Declarations, Energy Using Product analysis as well as standard material and energy flow analyses (PE International, 2011).

The author had originally chosen to work with the GaBi software for the LCA/LCCA study. An educational license containing the GaBi software was ordered and installed and was going to be used in the Impact Assessment section of this thesis. However, this version of the software is quite limited compared to the full version – which could not be purchased due to the price. Therefore, the author has had to use the Eco Indicator method to carry out an assessment of the environmental impact of a normal roof and green roof. Eco-indicator 99 is both a science based impact assessment method for LCA and a pragmatic eco-design method. It offers a way to measure various environmental impacts, and shows the final result in a single score (Pre Consultants, 2011).
This method is simpler than using the software, and the results are also not as accurate. However, with the time and resources available to the author, this was the only option.

Eco Indicator 99

Eco-indicator 99 is not only a science based impact assessment method for LCA but also acts as a pragmatic ecodesign method. It offers a way to measure various environmental impacts, and shows the final result in a single score (Pre Consultants, 2011). With Eco-Indicators, designers and product managers can analyse the environmental load of a product over its lifetime. Next to this, different design alternatives can be compared.

In Eco-indicator 99, the LCA process has been expanded and enhanced to include a weighting method. Data have also been collected, in advance, for the most common materials and processes. The Eco-indicator has been calculated from this. The materials and processes have been defined in such a way that they fit together in a series. For example, there is an indicator for the production of one kilo polyethylene, an indicator for the injection moulding process of one kilo of polyethylene and an indicator for the incineration of one kilo of polyethylene (PRe Consultants, 2000).

The Eco-indicator describes the "environment" in terms of three categories;

1. Damage to human health;
2. Damage to ecosystem quality;
3. Damage to resources.

The following section shows the Eco-indicator forms that the author has generated for each product.

Eco Indicator Forms

The author filled out Eco Indicator forms for each product – a normal roof, a green roof, a 35,400 litre rainwater storage tank and finally a 20,000 litre rainwater storage tank. The reason two rainwater storage tanks of varying sizes have been studied is due to the fact that a green roof absorbs approximately 50% of the rainwater that falls on the roof. This has been discussed in a previous section. Therefore, a smaller tank would be required for a building with a green roof.

The following Eco Indicator forms (Tables 7-10) show the environmental impact of each product in millipoints, during the manufacturing and use phase of the product over a lifetime of 70 years.

Product or component Normal Roof	**Project** MSc. Thesis
Date	**Author** Sarah Petersen

Notes and conclusions

Some assumptions and changes have been made in relation to certain products/materials.

- It can be assumed that the sedum blanket has no impact on the environment, as the plants actually absorb CO2. Some energy would be used in harvesting the sedum blanket - however, this was not taken into account in this particular case;
- "Inorganic Chemical Production" has replaced Asphalt Rubberisation in the process of manufacturing adhesive;
- The production of Organic Chemicals (99mPt) has been used for "Bitumen Manufacture" as bitumen is a by-product of organic decomposed materials.
- The production of "Carbon black" (180mPt) has been used instead of "Graphite Expansion" as graphite is a form of carbon. There were the closest processes in the EcoIndicator tables that could be used.
- The process of "Pressure Forming" has been used for the cap sheet, underlayer and insulation layers of the roof - this is due to the fact that the original processes in the manufacture of these products could not be located in the EcoIndicator tables.
- The EcoIndicator for Aluminium Extrusion (72mPt) was used in place of Glass Extrusion, as there were no figures for this process in the table.
- The figure for PUR Hardfoam was used instead of PIR Insulation in this case, as there were no available figures for PIR. However, most properties of the products are very similar.
- The processes of Aluminium Smelting and Rolling have been excluded in the study, as there were no figures available in the EcoIndicator table.
- The indicator for the production of demineralised water (0.026) has been used for the use phase of the building.
- The indicator for the landfill of PET (3.1) has been used for Bitumen Landfill, as some of the bitumen products have been bonded to polyester fleece. Also, there was no indicator specific to bitumen.
- It is assumed that the steel deck has been hot dip galvanized (3300mPt), with a zinc coating. The steel deck is a 1mm sheet, measuring 2.5m x 1.25m per sheet, weighing 24.5kg per sheet. Approximately 200 sheets are required for 620m2 of roof.

It is also assumed that the Normal Roof will be replaced once (after its 40 year lifespan) over the course of the 70 year lifespan of the building. This has been calculated in the Eco Indicator form.

Materials, treatments, transport and extra energy				
Material or process	**Amount**	**Measure unit**	**Indicator**	**Result**
CAP SHEET MANUFACTURE				
Organic Chemical Production (Bitumen)	4199	kg	99	415701
Carbon Production (Graphite)	637.5	kg	180	114750
Inorganic Chemical Production (Adhesive)	51	kg	53	2703
PET Production	212.5	kg	380	80750
Pressure Forming	5100	kg	6.4	32640
Freighter Oceanic	6063.3	tkm	1.1	6669.63
28t Truck	1146.9	tkm	22	25231.8
Total [mPt] Cap Sheet				**678445.43**
UNDERLAYER MANUFACTURE				
Organic Chemical Production (Bitumen)	2691.1	kg	99	266418.9
Extrusion (Glass)	170	kg	72	12240
Inorganic Chemical Production (Adhesive)	28.9	kg	53	1531.7
Pressure Forming	2890	kg	6.4	18496
Freighter Oceanic	3437.82	tkm	1.1	3781.602
28t Truck	651.86	tkm	22	14340.92
Total [mPt] Underlayer				**316809.122**
INSULATION MANUFACTURE				
PUR Hardfoam Production	2946	kg	420	1237320
Extrusion (Glass)	30	kg	72	2160
Injection Moulding (PUR)	2946	kg	12	35352
Pressure Forming	2976	kg	6.4	19046.4
Freighter Oceanic	3528.36	tkm	1.1	3881.196
28t Truck	665.28	tkm	22	14636.16
Total [mPt] Insulation				**1312395.756**

VAPOUR BARRIER MANUFACTURE				
Aluminium Production	100	kg	780	78000
Aluminium Extrusion	100	kg	72	7200
Inorganic Chemical Production (Adhesive)	34.4	kg	53	1823.2
Organic Chemical Production (Bitumen)	3305.6	kg	99	327254.4
Pressure Forming	3440	kg	6.4	22016
Freighter Oceanic	4091.22	tkm	1.1	4500.342
28t Truck	775.56	tkm	22	17062.32
Total [mPt] Vapour Barrier				**457856.262**
BITUMEN PRIMER MANUFACTURE				
Organic Chemical Production (Bitumen)	150	kg	99	14850
28t Truck	3.75	tkm	22	82.5
Total [mPt] Bitumen Primer				**14932.5**
STRUCTURAL DECK MANUFACTURE				
Steel Production	4906.000	kg	86	421916
Hot Galvanising	4906.000	kg	3300	16189800
28t Truck	98.100	tkm	22	2158.2
Total [mPt] Structural Deck				**16613874.2**
Total [mPt]				**19394313.270**
Use **Transport, energy and possible auxiliary materials**				

Process	**Amount**	**Measure unit**	**Indicator**	**Result**
Water	36,750,000	Litres	0.026	955500
Electricity	5040000.00	kWh	22.000	110880000
Total [mPt]				**111835500**

Disposal processes for each material type

Material and type of processing	Amount	Measure unit	Indicator	Result
PUR Landfill	86.400	kg	9.7	838.080
28t Truck	1.720	tkm	22.0	37.840
PET Landfill	64.270	kg	3.1	199.237
28t Truck	1.280	tkm	22.0	28.160
Bitumen Landfill	1569.76	kg	3.100	4866.256
28t Truck	31.40	tkm	22.000	690.800
Aluminium Landfill	15.00	kg	1.400	21.000
28t Truck	0.30	tkm	22.000	6.600
Steel Recycling	147.00	kg	-70.000	-10290.000
28t Truck	2.94	tkm	22.000	64.680
Total [mPt]				**-3537.347**
Total (mPt) 1 Roof				**1[illegible]775.923**
Total (mPt) after 70 years (assuming 1 replacement)				**150617051.846**

Table 7: Eco Indicator Form – Normal Roof

In Table 7, the red box represents the environmental impact of the manufacture of one roof. The green box represents the total environmental impact of the roof over the course of 70 years (assuming that after 40 years the roof will need to be completely replaced).

Product or component Green Roof	**Project** MSc. Thesis
Date	**Author** Sarah Petersen

Notes and conclusions

Some assumptions and changes have been made in relation to certain products/materials.

- It can be assumed that the sedum blanket has no impact on the environment, as the plants actually absorb CO2. Some energy would be used in harvesting the sedum blanket - however, this was not taken into account in this particular case;
- "Inorganic Chemical Production" has replaced Asphalt Rubberisation in the process of manufacturing adhesive;
- The production of Organic Chemicals (99mPt) has been used for "Bitumen Manufacture" as bitumen is a by-product of organic decomposed materials.
- The production of "Carbon black" (180mPt) has been used instead of "Graphite Expansion" as graphite is a form of carbon. There were the closest processes in the EcoIndicator tables that could be used.
- The process of "Pressure Forming" has been used for the cap sheet, underlayer and insulation layers of the roof - this is due to the fact that the original processes in the manufacture of these products could not be located in the EcoIndicator tables.
- The EcoIndicator for Aluminium Extrusion (72mPt) was used in place of Glass Extrusion, as there were no figures for this process in the table.
- The figure for PUR Hardofam was used instead of PIR Insulation in this case, as there were no available figures for PIR. However, most properties of the products are very similar.
- The processes of Aluminium Smelting and Rolling have been excluded in the study, as there were no figures available in the EcoIndicator table.
- The indicator for the production of demineralised water (0.026) has been used for the use phase of the building.
- The indicator for the landfill of PET (3.1) has been used for Bitumen Landfill, as some of the bitumen products have been bonded to polyester fleece. Also, there was no indicator specific to bitumen.
- It is assumed that the steel deck has been hot dip galvanized (3300mPt), with a zinc coating. The steel deck is a 1mm sheet, measuring 2.5m x 1.25m per sheet, weighing 24.5kg per sheet. Approximately 200 sheets are required for 620m2 of roof.

It is also assumed that the Green Roof will not need to be replaced over the course of the lifespan of the building.

Production

Materials, treatments, transport and extra energy

Material or process	Amount	Measure unit	Indicator	Result
BALLAST MANUFACTURE				
Gravel Production	1500	kg	0.84	1260
28t Truck	37.5	tkm	22	825
Total [mPt] Ballast				**2085**
SEDUM BLANKET				
Sedum Cultivation	25,300	kg	0	0
Sedum Harvesting	25,300	kg	0	0
Freighter Oceanic	12,954	tkm	1.1	14248.96
28t Truck	5,667	tkm	22	124678.4
Total [mPt] Sedum Blanket				**138927.36**
DRAINAGE MAT MANUFACTURE				
PET Production (Polyester)	216	kg	380	82080
PA 6.6 (Nylon Production)	144	kg	630	90720
Pressure Forming	360	kg	6.4	2304
Freighter Oceanic	184.32	tkm	1.1	202.752
28t Truck	80.64	tkm	22	1774.08
Total [mPt] Drainage Mat				**177080.832**
CAP SHEET MANUFACTURE				
Organic Chemical Production (Bitumen)	3989	kg	99	394911
Organic Chemical Production (Root Resistance)	210	kg	99	20790
Carbon Production (Graphite)	637.5	kg	180	114750
Inorganic Chemical Production (Adhesive)	51	kg	53	2703
PET Production (Polyester)	212.5	kg	380	80750

Pressure Forming	5100	kg	6.4	32640
Freighter Oceanic	6063.3	tkm	1.1	6669.63
28t Truck	1146.9	tkm	22	25231.8
Total [mPt] Cap Sheet				**678445.43**
UNDERLAYER MANUFACTURE				
Organic Chemical Production (Bitumen)	2691.1	kg	99	266418.9
Inorganic Chemical Production (Adhesive)	28.9	kg	53	1531.7
Extrusion (Glass)	170	kg	72	12240
Pressure Forming	2890	kg	6.4	18496
Freighter Oceanic	3437.82	tkm	1.1	3781.602
28t Truck	651.86	tkm	22	14340.92
Total [mPt] Underlayer				**316809.122**
INSULATION MANUFACTURE				
PUR Hardfoam Production	2946	kg	420	1237320
Extrusion (Glass)	30	kg	72	2160
Injection Moulding (PUR)	2946	kg	12	35352
Pressure Forming	2976	kg	6.4	19046.4
Freighter Oceanic	3528.36	tkm	1.1	3881.196
28t Truck	665.28	tkm	22	14636.16
Total [mPt] Insulation				**1312395.756**
VAPOUR BARRIER MANUFACTURE				
Aluminium Production	100	kg	780	78000
Aluminium Extrusion	100	kg	72	7200
Inorganic Chemical Production (Adhesive)	34.4	kg	53	1823.2
Organic Chemical Production (Bitumen)	3305.6	kg	99	327254.4
Pressure Forming	3440	kg	6.4	22016

Freighter Oceanic	4091.22	tkm	1.1	4500.342
28t Truck	775.56	tkm	22	17062.32
Total [mPt] Vapour Barrier				**457856.262**
BITUMEN PRIMER MANUFACTURE				
Organic Chemical Production (Bitumen)	150	kg	99	14850
28t Truck	3.75	tkm	22	82.5
Total [mPt] Bitumen Primer				**14932.5**
STRUCTURAL DECK MANUFACTURE				
Steel Production	4906.000	kg	86	421916
Hot Galvanising	4906.000	kg	3300	16189800
28t Truck	98.100	tkm	22	2158.2
Total [mPt] Structural Deck				**16613874.200**
Total [mPt] All Products				**19712406.462**
Use **Transport, energy and possible auxiliary materials**				
Process	Amount	Measure unit	Indicator	Result
Water	36,750,000	Litres	0.026	955500
Electricity	5040000.00	kWh	22.000	110880000
Total [mPt]				**111835500**
Disposal processes for each material type				
Material and type of processing	Amount	Measure unit	Indicator	Result
PUR Landfill	86.400	kg	9.7	838.080
28t Truck	1.720	tkm	22.0	37.840
PET Landfill	64.270	kg	3.1	199.237
28t Truck	1.280	tkm	22.0	28.160

Nylon Landfill	15.00	kg	3.600	54.000
28t Truck	0.30	tkm	22.000	6.600
Bitumen Landfill	1569.76	kg	3.100	4866.256
28t Truck	31.40	tkm	22.000	690.800
Aluminium Landfill	15.00	kg	1.400	21.000
28t Truck	0.30	tkm	22.000	6.600
Steel Recycling	147.00	kg	-70.000	-10290.000
28t Truck	2.94	tkm	22.000	64.680
Total [mPt]				**-3476.747**
Total (mPt) 1 Roof				[illegible]
Total [mPt] after 70 years (assuming no replacements)				**131544429.715**

Table 8: Eco Indicator Form – Green Roof

In Table 8, the red box represents the environmental impact of the manufacture of one roof. The green box represents the total environmental impact of the roof over the course of 70 years (assuming that the roof will not need to be replaced during this time).

Product or component Rainwater Storage Tank 35,400 L	**Project** MSc. Minor Thesis
Date	**Author** Sarah Petersen

Notes and conclusions

It is assumed that 1litre of water requires 0.025kg of HDPE.

It is assumed that 50kg (in offcuts) of HPDE will be sent for recycling after the production process.

The product will travel from Tuam to Dublin (227km).

It has been calculated that approximately 15m (in total) of piping will be required for this product. It is assumed that 150m of piping weighs 15kg, 1m will weigh 0.1kg and 15m will weigh 1.5kg.

It is assumed that over the lifespan of the building, the rainwater tank will be replaced after 25 years and 50 years. This has been incorporated into the calculations below.

If this rainwater storage tank (which would be installed on the normal roof) offsets approximately 80% of all the water used in the building over 70 years, this amounts to 2,940,000 litres of harvested water. This will be a negative number due to the fact that the water is coming from a sustainable and renewable source, and not the main water supply. The electricity and water usage of the building have thus been removed from this part of the LCA Analysis.

Due to the fact that JFC do not currently manufacture a plastic rainwater storage tank that can hold a volume of either 35,000l or 18,000l, it is assumed that each tank is made up of a number of smaller tanks, making up the nearest volume to the volume required for this study.

35,400L = 3 x 10,000L + 1 x 5400L
20,000L = 2 x 10,000L

Production

Materials, treatments, transport and extra energy

Material or process	Amount	Measure unit	Indicator	Result
HDPE Production	935.000	kg	330	308550.000
Injection Moulding HDPE	935.000	kg	21	19635.000
28t Truck	212.245	tkm	22	4669.390
Rigid PVC Production	1.500	kg	270.0	405.000
Injection Moulding PVC	1.500	kg	44	66.000
28t Truck	0.04	tkm	22.000	0.825
Total [mPt]				**333326.215**

Use **Transport, energy and possible auxiliary materials**				
Process	**Amount**	**Measure unit**	**Indicator**	**Result**
Harvested Water	2940000.00	litres	-0.026	-76440
Total [mPt]				-76440
Disposal processes for each material type				
Material and type of processing	**Amount**	**Measure unit**	**Indicator**	**Result**
Recycling HDPE	50.000	kg	-330.0	-16500.000
28t Truck	1.000	tkm	22.0	22.000
Total [mPt]				-16478.000
Total (mPt) 1 Tank				316848.215
Total [mPt] (Assuming 2 replacements in 70 years)				874104.645

Table 9: Eco Indicator Form – 35,400 litre rainwater storage tank

In Table 9, the red box shows the total millipoints for the manufacture and disposal of off-cuts for one 35,400L system. The use phase of the RHS has been taken into account in these calculations. It is assumed that this RHS will be installed on the normal roof and will offset approximately 80% of all the water used throughout the lifespan of the building. This will ultimately lower the environmental impact of the RHS. The use phase of the building has not been accounted for here as the RHS will be installed alongside the normal roof, in which the eco-indicator for the water and electricity usage has already been calculated.

The green box in Table 9 shows the total millipoints for the system after 70 years – assuming the tanks have been replaced twice and also includes the use phase.

Product or component Rainwater Storage Tank 20,000 L	**Project** MSc. Minor Thesis
Date	**Author** Sarah Petersen

Notes and conclusions

It is assumed that 1litre of water requires 0.025kg of HDPE.

It is assumed that 50kg (in offcuts) of HPDE will be sent for recycling after the production process.

The product will travel from Tuam to Dublin (227km).

It has been calculated that approximately 15m (in total) of piping will be required for this product. It is assumed that 150m of piping weighs 15kg, 1m will weigh 0.1kg and 15m will weigh 1.5kg.

It is assumed that over the lifespan of the building, the rainwater tank will be replaced after 25 years and 50 years. This has been incorporated into the calculations below.

If this rainwater storage tank (which would be installed on the normal roof) offsets approximately 80% of all the water used in the building over 70 years, this amounts to 2,940,000 litres of harvested water.

This will be a negative number due to the fact that the water is coming from a sustainable and renewable source, and not the main water supply. The electricity and water usage of the building have thus been removed from this part of the LCA Analysis.

Due to the fact that JFC do not currently manufacture a plastic rainwater storage tank that can hold a volume of either 35,000l or 18,000l, it is assumed that each tank is made up of a number of smaller tanks, making up the nearest volume to the volume required for this study.

35,400L = 3 x 10,000L + 1 x 5400L

20,000L = 2 x 10,000L

Production

Materials, treatments, transport and extra energy

Material or process	Amount	Measure unit	Indicator	Result
HDPE Production	550.000	kg	330	181500.000
Injection Moulding HDPE	550.000	kg	21	11550.000
28t Truck	124.850	tkm	22	2746.700
Rigid PVC Production	1.500	kg	270	405.000
Injection Moulding PVC	1.500	kg	44.0	66.000
28t Truck	0.038	tkm	22.0	0.825
Total [mPt]				**196268.525**

Use **Transport, energy and possible auxiliary materials**				
Process	**Amount**	**Measure unit**	**Indicator**	**Result**
Harvested Water	1470000.00	litres	-0.026	-38220
Total [mPt]				**-38220**
Disposal processes for each material type				
Material and type of processing	**Amount**	**Measure unit**	**Indicator**	**Result**
Recycling HDPE	50.000	kg	-330.0	-16500.000
28t Truck	1.000	tkm	22.0	22.000
Total [mPt]				**-16478.000**
Total (mPt) 1 Tank				**179790.525**
Total [mPt] (Assuming 2 replacements in 70 years)				**501151.575**

Table 10: Eco Indicator Form –20,000 litre rainwater storage tank

In Table 10, the red box shows the total millipoints for the manufacture and disposal of off-cuts for one 20,000L RHS. This system has been sized to be installed on the green roof of the control building. The use phase of the RHS has been taken into account, with an estimated 40% of the total water usage being offset by the RHS. The use phase of the building has not been accounted for here as the RHS will be installed alongside the green roof, in which the eco-indicator for the water and electricity usage has already been calculated. It has been assumed that only 40% will be offset, due to the fact that the green roof will absorb approximately 50% of the rainwater falling on the roof. The other 10% is assumed to be supplied by the mains water system.

The green box shows the total millipoints for the system after 70 years – assuming the tanks have been replaced twice and also includes the use phase.

It can be seen from the tables on the previous pages, that the environmental impact of the Normal Roof is significantly higher than that of the Green Roof. One can also see the difference in millipoints between the large rainwater storage tank and the small storage water tank. The following graphs (Figures 40 & 41) will show a clear comparison between all systems.

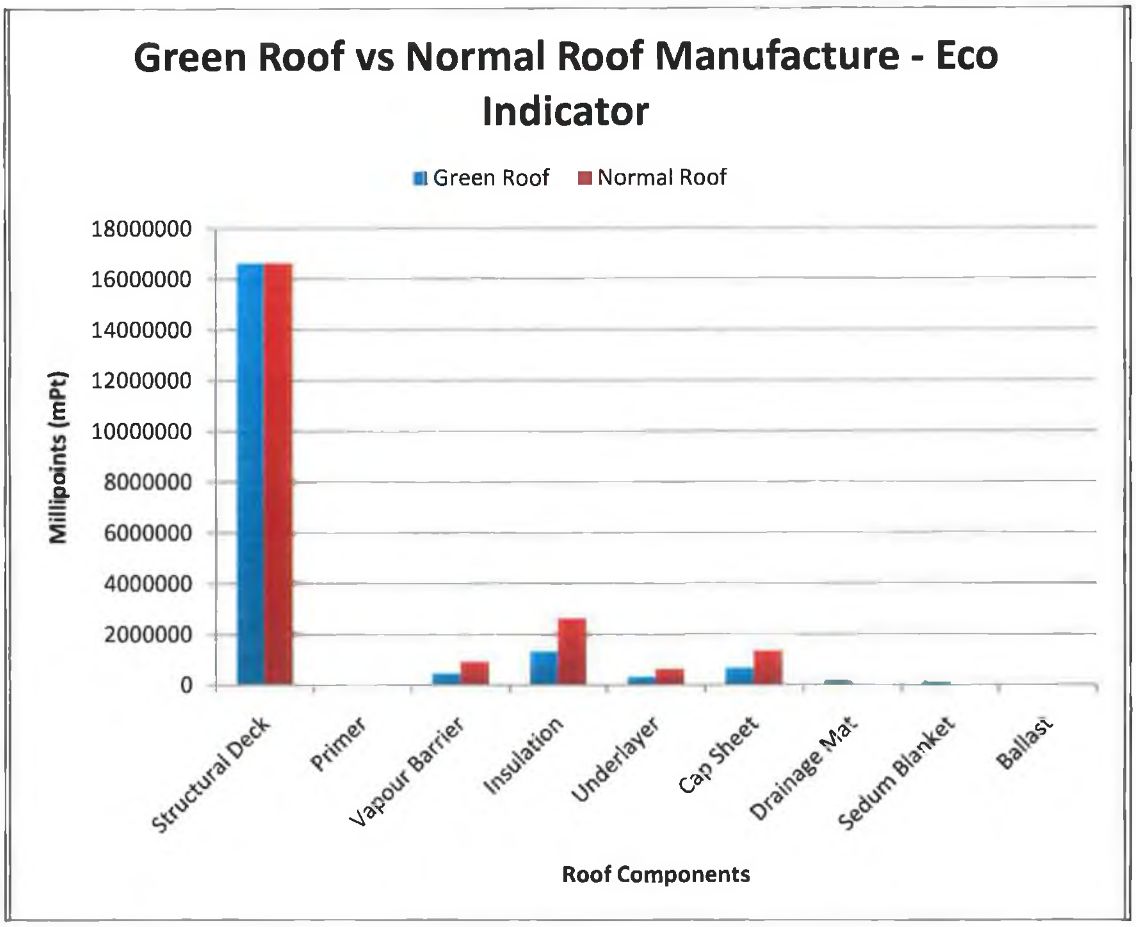


Figure 40: Environmental impact of green roof versus normal roof – manufacturing phase

Figure 40 shows the difference in environmental impact between the normal roof and green roof in this study. The millipoints for the structural deck remain the same throughout the entire lifespan of the building, as it is assumed that this component of the roof will not need replacing. The figures for the primer and ballast components are very low and do not appear on the graph in bar form.

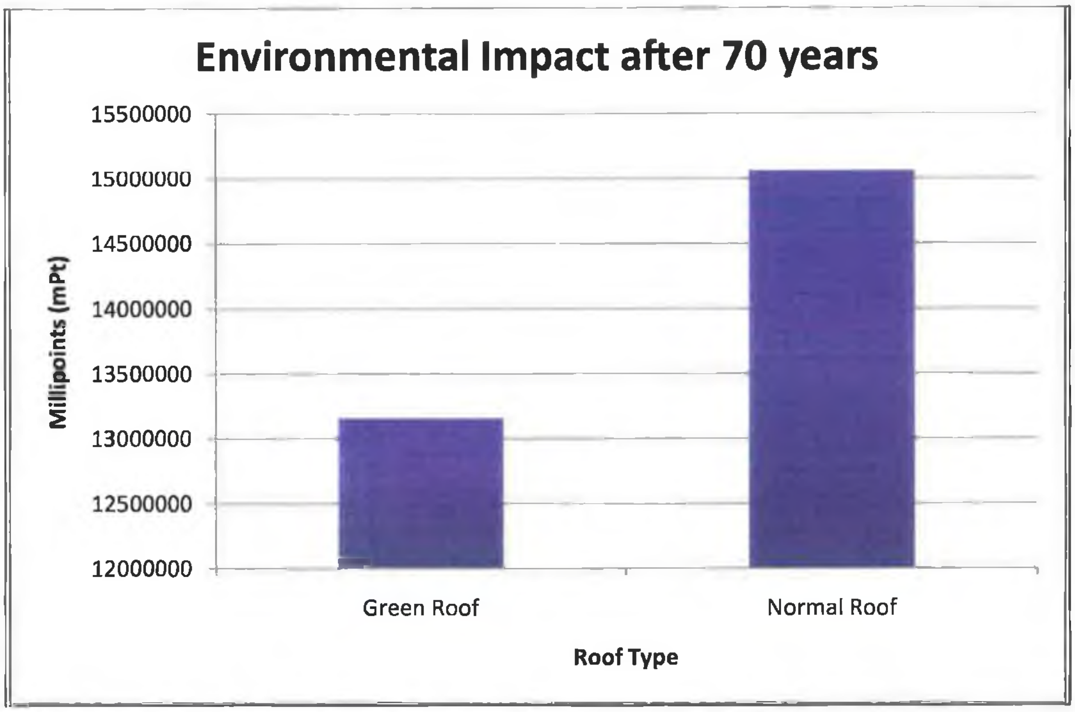


Figure 41: Total environmental impact of each roof type after 70 years

Figure 41 shows the total environmental impact in millipoints of each roof over the entire lifespan of the building. These figures take into account the manufacturing phase, use phase, disposal of any materials and the replacement of the normal roof after 40 years. It can be seen that the normal roof has a significantly higher impact on the environment than the green roof.

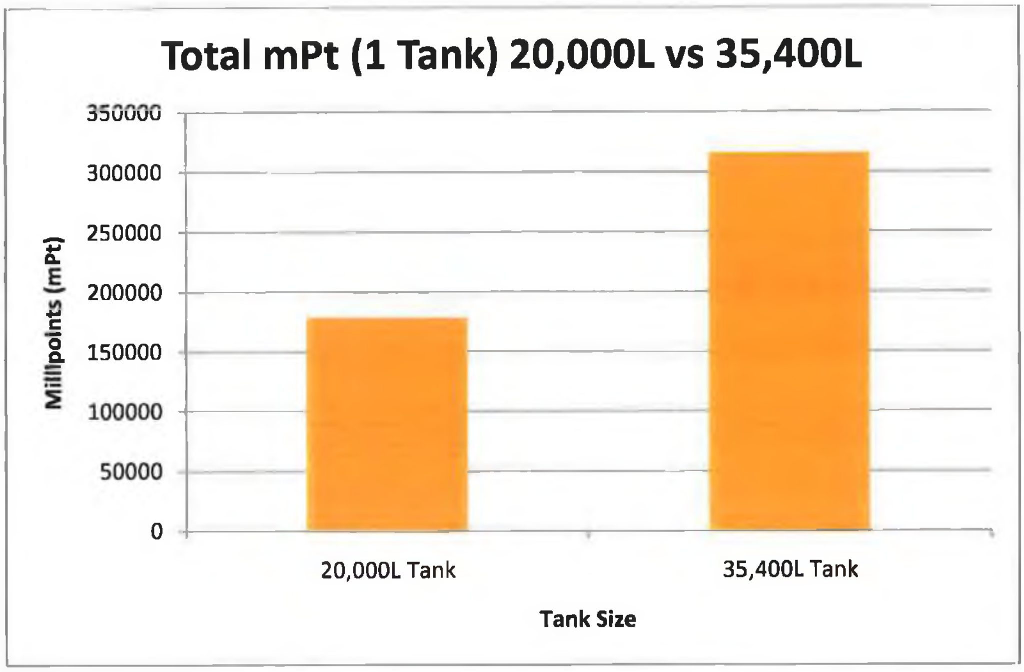


Figure 42: Environmental impact of 20,000l system versus 35,400l system – manufacturing phase

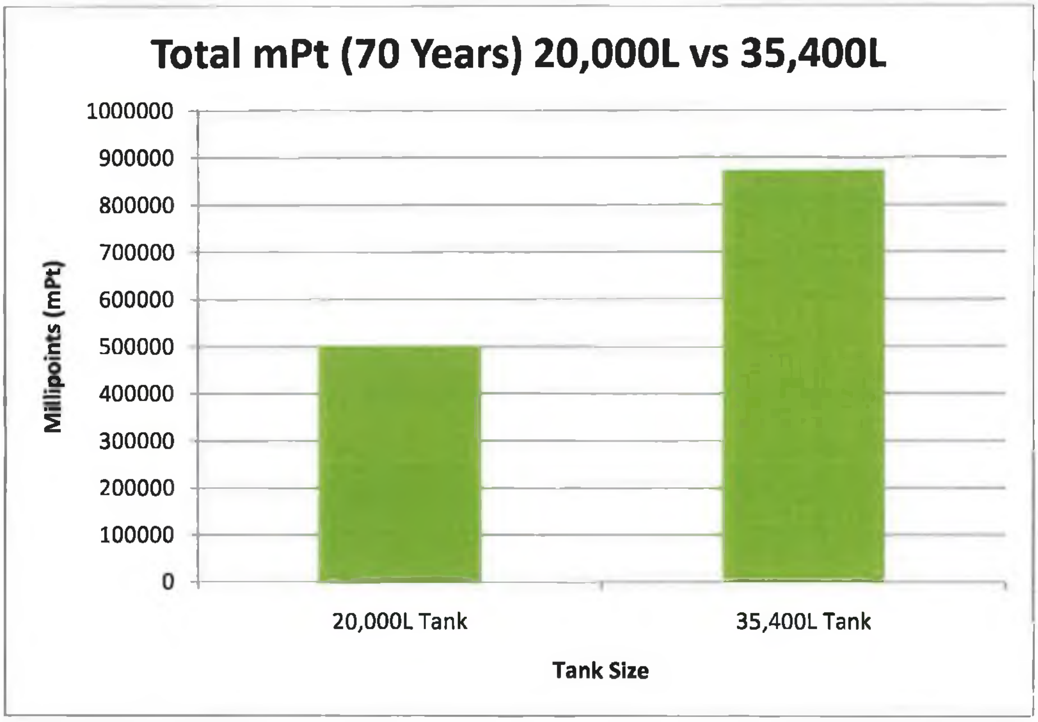


Figure 43: Total environmental impact of each rainwater harvesting system after 70 years

On the previous page, Figure 42 shows the comparison in millipoints between the two rainwater harvesting systems that have been used in this study. This shows the environmental impact of manufacturing one 35,400L system and one 20,000L system. The use phase has also been incorporated into this calculation.

However, in Figure 43, the total environmental impact of the two rainwater harvesting systems has been calculated over the lifespan of the building – assuming that the systems have been replaced twice over the course of 70 years. The negative impact of the use phase of the RHS has also been taken into account. This will lower the overall environmental impact of the combined systems, which will be shown in Figure 44.

As it can be seen in both Figure 42 and 43, the environmental impact of the 35,400L system is significantly higher than the 20,000L system. This is simply due to the obvious fact that more materials are needed for the larger rainwater harvesting system.

5.1.4 Interpretation

Looking at the Eco Indicator forms and graphs above, one can see that the Normal Roof scores significantly higher than the Green Roof in millipoints. This is due to the fact that the Normal Roof requires a complete replacement after 40 years. The waterproofing membrane and other layers of the Green Roof are protected by the drainage mat and sedum blanket, therefore prolonging the life of the Green Roof.

In terms of environmental impact, the smaller rainwater storage tank would be best suited to the Green Roof. However, in reality, the amount of water that would be harvested from a Green Roof (due to the fact that approximately 50% of the water is absorbed by the sedum blanket) would not be enough to cater for the needs of the occupants in the building. The larger rainwater storage tank would be able to cater for the number of occupants using water in the hypothetical building. However, due to the fact that the lifespan of the rainwater storage tank is significantly shorter than the lifespan of the building, this technology would need to be replaced twice over the course of 70 years. Adding to this, the environmental impact of the larger tank is significantly more than the smaller tank. However, in terms of stormwater management and offsetting domestic and commercial water charges, the Normal Roof + RHS system would be an excellent system to install on both domestic households and commercial buildings. A Green Roof on a commercial or domestic building could potentially prevent 50% of rainwater from entering stormwater drains, thus allowing for more efficient stormwater management in cities and urban areas. The author would recommend the integration of a rainwater harvesting system and a Green Roof on a domestic or commercial building, if the sole purpose of the harvested rainwater was for landscaping purposes, or to offset a small amount of other non-potable water uses. The author is of the opinion that a rainwater harvesting system operating at approximately 50% of its capacity could not offset the use of mains water for all non-potable uses within the building/household.

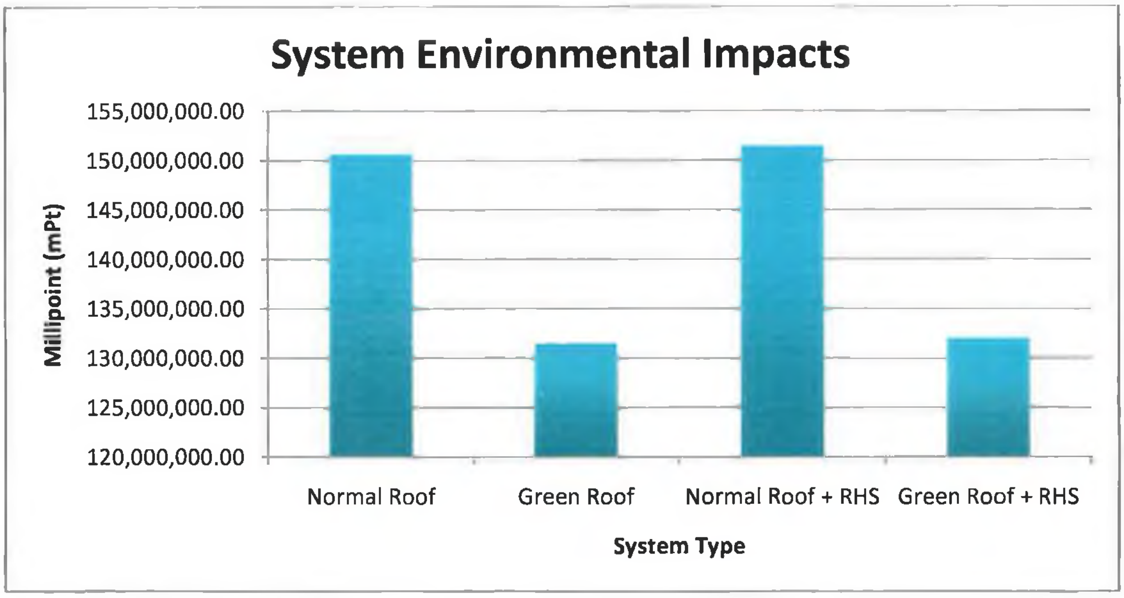


Figure 44: Total environmental impact of all systems

Figure 44 shows the environmental impact, in millipoints, of each system that was proposed at the beginning of the thesis. From the graph, it is clear to see that the green roof has a significantly lower environmental impact than a normal roof. The system with the largest environmental impact is the Normal Roof + RHS. However, in terms of the effect of this system on the environment in relation to stormwater management, this system would be an excellent choice on a commercial building. The Green Roof +RHS system has a lower impact on the environment. This system would be ideal in a commercial building with low water consumption levels, as the green roof would act as an effective stormwater management tool, and a portion of the rainwater could be harvested and recycled for non-potable use in the building.

With further research and development, the author is of the opinion that there would be a way to improve the integrated technologies (green roof + rainwater harvesting system) so that a higher volume of rainwater could be harvested from the green roof, and used to offset a higher percentage of mains usage. Within the Green Roof/RHS system, there also lies an underlying problem of water discolouration (from the crushed brick component of the substrate), which can be off-putting, especially in a commercial building situation. Discoloured water being used for toilet flushing may make visitors to the building uneasy, questioning the hygienic standard of the building. However, with adequate signage and marketing of the environmental benefits of the Green Roof/RHS system on the building, the author believes that this problem could be significantly reduced.

5.2 Life Cycle Cost Analysis

Life cycle cost analysis (LCCA) is a method that gives the total life cycle cost of the system/product and allows for comparisons of alternatives. LCCA includes calculating the costs and timing connected to alternative over a particular analysis period and conversion of those costs to economically similar values, taking into account the time-value of money, (Ravemark D. , 2003).

There are two categories of costs involved in the LCCA: initial costs and future costs (State of Alaska - DEED, 1999). Initial costs are the costs at the start of a project/product, such as land, equipment, administration. Future costs are all the costs incurred over the life cycle of the project/product. To accurately combine initial costs with future costs, the present value of all costs must be determined. The present value is defined as 'the time-equivalent value of past, present or future cash flows as of the beginning of the base year' (State of Alaska - DEED, 1999).

Present value:

$$PV = \sum_{i=0}^{T} C_i \times \frac{1}{(1+X)^i}$$

PV = Present Value; **C_i** = Cost in year i; **X** = Discount rate, which is the rate of interest that reflects the organisation's time-value of money or opportunity cost. It may include inflation (nominal discount rate) or exclude it (real discount rate); **T** = time period (expressed as number of years).

The present value method is the most recognised way of assessing overall life cycle costs in terms of the present time period. Costs calculation includes: energy cost, maintenance cost, operation cost, repair cost, downtime cost, etc. as well as unique project-related costs.

In the thesis, the author calculated the Net Present Value (NPV) with a discount rate of 5% for each system; the normal roof, green roof, and two rainwater storage tanks. The manufacturing phase and use phase of each system was taken into account over 70 years. Replacement of any components was also incorporated into each calculation.

All figures for the normal roof and green roof calculations were obtained from the technical staff at Bauder Ltd. All figures for the rainwater storage tanks were obtained from Michael Fitzpatrick, local rainwater harvesting system installer.

5.3 Net Present Value Calculations

Normal Roof NPV

According to the calculations of the technical staff at Bauder, the cost of supplying and installing a normal roof is approximately €115/m^2. For a roof size of 600m^2, this amounts to €69,000. The cost of the structural steel deck for a roof size of is approximately €15,000. In total, the normal roof initially costs €84,000. To this, maintenance costs must be added. The author consulted with the staff at Bauder as well as a roofing contractor and calculated that an average maintenance fee of €200 for the first year and every following five years until the end of the roof life. The roof would then need to be replaced after 40 years, thus costing another €69,000. The structural steel deck would not need to be replaced in this case. After the replacement of the roof, the maintenance fee of €200 would be in place every 5 years until the end of the lifespan of the building. The author has not considered the cost of decommissioning the roof in this particular case.

As with any component of a building, unforeseen events due to natural disaster, poor workmanship etc., could lead to higher costs being incurred throughout the lifetime of the roof. However, such a wide range of factors could not be taken into account in this case.

Using the NPV formula, a table of costs, including the total cost, was drawn up. This is represented in Table 11 below.

Normal Roof	
Year	**Cost**
0	€ 84,000.00
1	€ 190.48
5	€ 156.71
10	€ 122.78
15	€ 96.20
20	€ 75.38
25	€ 59.06
30	€ 46.28
35	€ 36.26
40	€ 9,801.15
45	€ 22.26
50	€ 17.44
55	€ 13.67
60	€ 10.71
65	€ 8.39
70	€ 6.57
Total	**€ 94,663.33**

Table 11: NPV Calculation – Normal Roof

Green Roof NPV

According to the calculations of the technical staff at Bauder, the cost of supplying and installing a green roof is approximately €183/m^2. This is significantly more expensive than the normal roof. This is due to the extra components in a green roof. For a roof size of 600m^2, this amounts to €109,800. The cost of the structural steel deck for a roof size is approximately €15,000. In total, the normal roof initially costs €124,800. To this, maintenance costs must be added.

The author consulted with the staff at Bauder as well as a roofing contractor and calculated that an average maintenance fee of €200 for the first 5 years (in order to make sure the vegetation on the green roof is established) and every 2 years following this until the end of the life of the roof and building.

The author has not considered the cost of decommissioning the roof in this particular case. The author has assumed that the roof will not need to be replaced at any point during its lifespan.

Using the same NPV formula as was used on the normal roof, the author calculated the whole life cost of the green roof over its lifespan. This can be seen in Table 12 below.

Green Roof			
Year	**Cost**	**Year**	**Cost**
0	**€ 124,800.00**	33	€ 39.97
1	€ 190.48	35	€ 36.26
2	€ 181.41	37	€ 32.89
3	€ 172.77	39	€ 29.83
4	€ 164.54	41	€ 27.06
5	€ 156.71	43	€ 24.54
7	€ 142.14	45	€ 22.26

9	€ 128.92	47	€ 20.19
11	€ 116.94	49	€ 18.31
13	€ 106.06	51	€ 16.61
15	€ 96.20	53	€ 15.07
17	€ 87.26	55	€ 13.67
19	€ 79.15	57	€ 12.39
21	€ 71.79	59	€ 11.24
23	€ 65.11	61	€10.20
25	€ 59.06	63	€ 9.25
27	€ 53.57	65	€ 8.39
29	€ 48.59	67	€ 7.61
31	€ 44.07	69	€ 6.90
	Total	**€ 127,127.39**	

Table 12: NPV Calculation – Green Roof

It can be seen from Tables 11 & 12 that there is a significant cost difference between the normal roof and the green roof in this study. The green roof costs approximately €32,464.06 more than a normal roof. This is a considerable extra amount of money to spend on one element of a building. However, the benefits surrounding the green roof, in terms of contributing to the reduction of heating/cooling bills, as well as sustainable stormwater management could justify the extra cost in the long run.

Rainwater Storage Tank – NPV

The following table (Table 13) represents the Net Present Value of each storage tank after 70 years (the lifespan of the building).

Year	**Cost**	**Year**	**Cost**
0	€ 9,142.76	0	€ 5,249.27
1	€ 285.71	1	€ 285.71
5	€ 235.06	5	€ 235.06
10	€ 184.17	10	€ 184.17
15	€ 144.31	15	€ 144.31
20	€ 113.07	20	€ 113.07
25	€ 2,699.88	25	€ 1,550.12
26	€ 84.37	26	€ 84.37
30	€ 69.41	30	€ 69.41
35	€ 54.39	35	€ 54.39
40	€ 42.61	40	€ 42.61
45	€ 33.39	45	€ 33.39
50	€ 797.28	50	€ 457.76
51	€ 24.92	51	€ 24.92
55	€ 20.50	55	€ 20.50
60	€ 16.06	60	€ 16.06
65	€ 12.58	65	€ 12.58
Total – 35,000 L	**€ 13,960.48**	**Total – 18,000 L**	**€ 8,577.70**

Table 13: NPV Calculation – 35,000l tank & 18,000l tank

All figures for the NPV calculation of both rainwater storage tanks were obtained from Mr. Michael Fitzpatrick, who has been previously mentioned. The following table (Table 14) shows a breakdown of the cost of each component which makes up the rainwater storage tanks used in this study. The external pump kit comprises a surface pump, floating water extraction unit, pimp control kit, expansion vessel and automatic mains switch kit. The advantage of having an external pump kit instead of an internal kit (which is housed within the tank) is that the external tank can be easily accessed for maintenance and/or replacement.

Component	**Cost (including VAT @ 21%)**
10,000 L Tank	€ 2026.75
5,400 L Tank	€ 1568.16
Universal Filter	€ 401.72
Tank Connection Kit	€ 59.29
External Pump Kit	€ 914.76

Table 14: Cost of each rainwater storage tank component

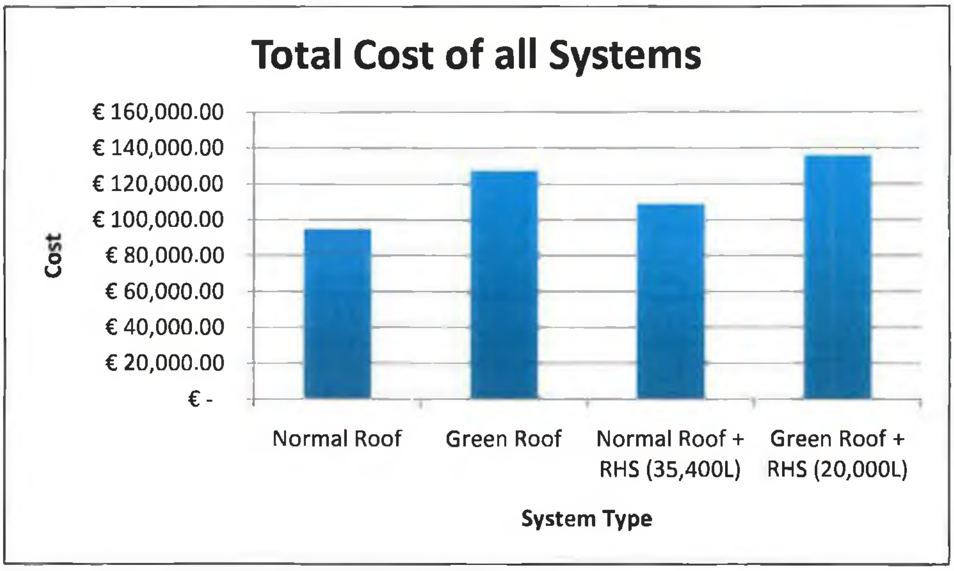


Figure 45: Total cost for all system types

From the graph shown on the previous page in Figure 45, it can be seen that the most cost effective integrated option is the Normal Roof + RHS. This option would be best suited to a commercial building which has an average usage of 1500 litres of water per day. The Green Roof + RHS system would be best suited to a commercial building with very low water consumption levels and high heating/cooling bills. The RHS would be able to offset a percentage of the non-potable water use and the Green Roof could contribute to lowering heating/cooling bills, as well as acting as an efficient stormwater management tool. The following section describes recommendations that can be made in order to improve the financial impact of green roofs, as well as rainwater harvesting systems.

5.4 Recommendations

Recommendations can be made by the author, with the aim of improving the future Irish market for green roofs and rainwater harvesting systems. It can be seen from the previous section that, in terms of cost, green roofs are the most expensive option in comparison to a conventional or normal roof. There is however, a potential alternative situation for the future, which could make the green roof a cheaper option in the long run.

As previously described, in Germany, stormwater taxes have been introduced which force building owners to pay for the amount of water which runs off the roof of the building. It was also mentioned that there are government incentives in place in Germany, which fund a certain percentage (up to 100%) of the cost of installing a green roof on a building.

If the Irish government recognised the long-term benefits and put in place a financial incentive for both green roofs and rainwater harvesting systems, savings could be made by the government on water treatment charges, stormwater drainage system design and construction, and savings on domestic/commercial water charges and heating/cooling bills for buildings could be made by householders and businesses alike. Even if the government offered to fund 40% of the cost of a green roof, it would ultimately be cheaper than the construction of a normal roof over the lifespan of the building, with all the added benefits.

Table 15 shows the various cost savings associated with different levels of government funding, if it were applied to the roofs in this study. These figures can be compared to the manufacturing cost of the normal roof in this study - €~84,000 – or the cost of a normal roof over the lifespan of the hypothetical building - ~€94,663.33.

% Government Funded	Cost of Funding (per 600m2)	Green Roof Cost (Manufacture 600m2)	Green Roof Cost (70 Years)
10	€ 12,500.00	€ 112,500.00	€ 114,627.39
20	€ 25,000.00	€ 100,000.00	€ 102,127.39
25	€ 31,250.00	€ 93,750.00	€ 95,877.39
30	€ 37,500.00	€ 87,500.00	€ 89,627.39
40	€ 50,000.00	€ 75,000.00	€ 77,127.39
50	€ 62,500.00	€ 62,500.00	€ 64,627.39

Table 15: Potential savings on green roofs with government funding

In terms of rainwater harvesting systems in Ireland, the most beneficial option for government funding would be to provide a domestic grant for householders to install an RHS, in order to offset the costs of the future domestic water charges, estimated to be in place in the coming years in Ireland. There is also the option for commercial building owners to benefit from having a rainwater harvesting system installed in order to lower commercial water charges, which are proposed to rise to match European prices in the coming years. With a large scale implementation of RHS across Ireland, the government could save money by having lower water treatment bills and a reduced need for the upgrading and maintenance of stormwater drainage systems and sewerage systems in Ireland.

With regards to the energy saving properties of green roofs, it is difficult to put a definitive amount or number on the percentage of the heating/cooling bills in a building that could be offset with the additional insulating properties of a green roof. The author has drawn up a table (Table 16) with an estimate of the cost savings that could be made over the entire life cycle of the green roof (70 years) on the hypothetical building in this study.

% Reduction	**Potential Savings in Energy (Electricity kWh)**	**Potential Cost Savings over 70 years**
1	50,400	€ 6,048.00
2	100,800	€ 12,096.00
3	151,200	€ 18,144.00
4	201,600	€ 24,192.00
5	252,000	€ 30,240.00
6	302,000	€ 36,240.00
7	352,800	€ 42,336.00
8	403,200	€ 48,384.00
9	453,600	€ 54,432.00
10	504,000	€ 60,480.00

Table 16: Potential cost savings in electricity bills over 70 years

In terms of cost savings associated with reduced mains water usage, it is difficult to calculate the amount of money that could be saved by installing a rainwater harvesting system on the roof. The calculations are dependent on the rate at which the water is charged, as well as the type of water charge which is incurred in Ireland – flat rate or meter rate. The rate of commercial charges also affects the savings that can be made in Ireland with the help of an RHS.

Table 17, on the following page shows an estimation of the cost savings that could be achieved by installing an RHS in conjunction with the normal roof and green roof on the control building in the study.

Some assumptions have been made in order to estimate these figures;

- The future Irish domestic water charge is a flat rate of approximately €300;
- The cost of water in Ireland/Europe will not increase or decrease over 70 years;
- The RHS on the normal roof will offset approximately 80% of the mains water used in a commercial building;
- The RHS on the normal roof will offset approximately 60% of the mains water used in a domestic building;
- The RHS on the green roof will offset approximately 40% (half the amount of the normal roof) of the mains water used in a commercial building – this is due to the absorption qualities of the green roof, as described previously;
- The RHS on the green roof will offset approximately 30% (half the amount of the normal roof) of the mains water used in a domestic building – this is due to the absorption qualities of the green roof, as described previously.

Water Charge	**Irish Commercial Charge**	**European Commercial Charge**	**Potential Irish Domestic Flat Rate**
Cost	1.67/m3	3.24/m3	€ 300
Cost over 70 years	€ 61,372.50	€ 119,070.00	€ 21,000.00
% saved by RHS (Normal Roof)	80%	80%	60%
Potential Cost Saving	**€ 49,098.00**	**€ 95,256.00**	**€ 12,600.00**
% saved by RHS (Green Roof)	40%	40%	30%
Potential Cost Saving	**€ 24,549.00**	**€ 47,628.00**	**€ 6,300.00**

Table 17: Potential cost savings (domestic/commercial) using an RHS

5.5 Conclusion

The purpose of this chapter was to investigate and analyse the environmental and financial impact of each system being studied. Results from the Eco Indicator method show that the best system, in terms of its effect on the environment is the green roof, followed by the normal roof, green roof + RHS and finally the normal roof + RHS. However, in terms of cost, the normal roof has the lowest cost over its lifetime. The author used the NPV equation to calculate the economical impact of each system, with the most expensive options being the green roof +RHS system, followed by the normal roof + RHS, green roof and finally the normal roof.

However, as described in the previous section, with government aid, the cost of green roofs could be reduced greatly, to ultimately become far less expensive than normal roofs, with the added benefits of stormwater management, reduced energy bills, mitigation of the urban heat island effect, increased biodiversity in urban areas and many more factors which have already been described in detail throughout the thesis.

The cost of water treatment and stormwater drainage/sewerage systems could be greatly reduced with the installation of rainwater harvesting systems across the country, in both domestic and commercial situations. There are savings to be made across the country in terms of the environment and economy with the application of more sustainable and renewable technologies.

The author has estimated the potential cost savings to be made by installing green roofs and rainwater harvesting systems in terms of energy savings and water savings. These savings would benefit Ireland in terms of its environment, economy and society.

Chapter 6 – Discussion & Conclusions

The main issue affecting the future of global resources, energy supplies and other factors is climate change. The impacts of climate change have been described throughout the thesis, from rising GHG emissions, to water scarcity and depletion of all natural resources on the planet. It is evident that drastic measures need to be taken at all levels, from international to individual, in order to slow down the inevitable effects of global warming and climate change (Pew Center on Global Climate Change, 2011).

Buildings are responsible for more than 40% of global energy use and one third of global GHG emissions, both in developed and developing countries (Mendler, 2005). However, the construction industry also has the largest potential for delivering long-term, significant and cost-effective solutions for reducing GHG emissions. The author has chosen to focus on sustainable building techniques and technologies such as Green Roofs and Rainwater Harvesting Systems in order to mitigate some of the effects of climate change associated with the environmental impact of buildings.

An extensive literature review was carried out, covering all aspects of the relevant topics surrounding climate change, energy use, sustainable building, green roofs, rainwater harvesting and the methodologies used to calculate the environmental and economical impact of products and processes. Following this, green roofs and rainwater harvesting systems, as well as their potential integration to form a single sustainable unit, was explored in more detail. Finally, a comparative Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) was carried out on: a normal roof, green roof, normal roof + RHS and finally a green roof + RHS. In order to carry out an objective study, the author designed and developed a hypothetical building, on which each roof/RHS would be installed.

The aim of the LCA/LCCA study was to show the environmental benefits associated with green roofs and rainwater harvesting systems in comparison to a conventional roof. Results of the LCA showed that the green roof had the least environmental impact out of all the systems. This was due to the fact that the normal roof required one full replacement during the 70 year lifespan of the hypothetical building that was developed for this study. In terms of cost, the most cost-effective solution was the normal roof + RHS. However, this system had the highest environmental impact over the other systems. This was due to the fact the roof requires replacement after 40 years and the RHS requires replacement after 25 and 50 years.

In terms of stormwater management, the green roof and the normal roof + RHS both performed quite well. The water conservation benefits of the RHS installed on the normal roof meant that up to 90% of the water falling on the roof could be diverted from stormwater drains and recycled within the building for non-potable uses. In terms of the green roof, it has already been shown that green roofs can retain between 40-90% of the water that falls on the roof. In this way, the green roof is a very effective form of stormwater management. However, the disadvantage of the green roof +RHS system is that because of the retention capacity of green roofs, the amount of water being diverted to the RHS is drastically lower than that of the normal roof + RHS. This means that a much lower percentage of mains water could be offset in a building which has a green roof +RHS. This is a disadvantage, if rising commercial water charges are taken into account.

In order to promote the use of green roofs in Ireland, the author proposed a number of recommendations, which could be directed towards the public sector and/or the Irish government. These recommendations included the introduction of financial incentives for green roofs and rainwater harvesting systems in order to encourage and promote the technologies in Ireland, particularly in urban areas, where the benefits are most obvious.

If more studies could be carried out in order to show the environmental and financial benefits of sustainable technologies such as green roofs and RHS, the author believes that the government, as well as the public sector could benefit.

Every year the government are forced to spend millions on water treatment, stormwater management measures and energy. The public are facing domestic water charges, increased commercial water charges, increased taxes and higher levels of energy consumption in buildings. The author agrees that there is a high initial cost associated with large scale green roof and RHS installations, however, over the long term; the environmental and financial benefits outweigh the capital investment. If stormwater could be managed more efficiently and sustainably by green roofs and rainwater harvesting systems, the quantities of water that would need to be treated to drinking standard would be significantly reduced. There would also be less strain placed on the stormwater and sewerage drains in Ireland. This would result in significant savings for the government.

If green roofs and RHS could be installed on a greater number of commercial and domestic buildings, occupants are facing lower energy bills, considerably reduced water bills and, should an incentive be introduced for either technology, an ultimately lower capital investment.

The author feels strongly about the environmental benefits that can be seen with the large scale implementation of sustainable technologies. However, in reality, it is cost benefits that often decide whether a new technology will be adopted and promoted.

The main purpose of this thesis was to carry out an environmental and economical analysis of green roofs in order to discover the true benefits associated with the technology. This was done for the benefit of a leading green roof supplier, Bauder Ltd. In order to complete the thesis, the author carried out a final telephone interview with Mr. Nick Ridout, the Green Roof Product Manager at Bauder Ltd. The purpose of this interview was to relay the findings and results in the thesis to Mr. Ridout, with the aim of receiving feedback from him regarding the usefulness of the LCA/LCCA study that was carried out.

The author received very positive feedback from Mr. Ridout. Mr. Ridout commented on how thorough, realistic and objective the study was. He commented that the author's line of thinking "matched my own thoughts". Mr. Ridout felt that this study could benefit the company in terms of marketing and improved environmental credentials for Bauder. The main point he made was that it is vital to show that it is possible to achieve enormous ecological benefits for a marginal investment. He noted that research that is usually carried out on products is done by "someone who has a point to prove, and will prove it no matter what". The author felt that there was a genuine interest from Mr. Ridout in the thesis.

Mr Ridout also agreed with the author's concept of directing the study towards the public and governmental sectors in Ireland. He made the point that climate change is inevitable, the impacts are going to happen no matter what we do. He described a "tipping point" – when the global climate tips from a stable state into another state, which may not be as stable. Identifying actions which push back the climate change tipping point are crucial in mitigating the inevitable impacts. The idea is to ensure that all decisions and actions are considered from a sustainable and long-term point of view. Mr. Ridout finished by saying that green roofs, rainwater harvesting systems and other sustainable technologies are an "integrated solution, factoring in numerous elements, which will slow down the speed with which climate change is attacking the planet". The author would like to thank Mr. Ridout for his valuable insight and opinion, as well as the interest he has shown in this study.

In conclusion, the author believes that there is huge potential for a nationwide adoption of sustainable technologies such as green roofs and rainwater harvesting systems. The benefits, limitations, applications and environmental/financial impacts of both technologies have been described in great detail in this study. The results have been displayed in a clear and concise way in order to give the reader a clear indication of the positive and negative aspects of normal roofs, green roofs and rainwater harvesting systems.

In the future, the author would like to see an abundance of green roofs and RHS installed on commercial and domestic buildings in Ireland. The benefits of these technologies greatly outweigh any associated limitations. Immediate action is needed, particularly in the construction industry, to push Ireland towards lowering its GHG emissions, meeting Kyoto requirements, conserving resources such as energy and water and towards lowering costs associated with the negative impacts of climate change across the country.

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